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FORCES *of* NATURE

Assessment and Economic Valuation of Coastal Protection Services Provided by Mangroves in Jamaica

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nepa National Environment and Planning Agency

ODPEM

University of California Santa Cruz

IH cantabria Instituto de Hidraulica Ambiental Universidad de Cantabria

The Nature Conservancy

UWI

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Assessment and Economic Valuation of Coastal Protection Services Provided by Mangroves in Jamaica

Acknowledgments

The *"Forces of Nature: Assessment and Economic Valuation of Coastal Protection Services Provided by Mangroves in Jamaica"*, is the result of a World Bank analytical support funded by the Program on Forests (PROFOR), which started in 2017 at the request of the Government of Jamaica through the National Environment and Planning Agency (NEPA), and the Office of Disaster Preparedness and Emergency Management (ODPEM). Numerous entities and professionals interested in the subject participated and an important group of collaborators made possible the materialization of this study. This analytical work is linked to the World Bank Jamaica Disaster Vulnerability Reduction Project (DVRP).

The team especially wishes to thank the Program on Forests (PROFOR) for financing this product, and for the guidance and leadership provided by World Bank staff including Tahseen Sayed (Caribbean Country Director, LCC3C), Ozan Sevimli (Jamaica Country Manager, LCC3C), Sameh Naguib Wahba (Global Director, SURDR), Ming Zhang (Practice Manager, SLCUR), Valerie Hickey (Practice Manager, SLCEN), Werner Kornexl (Sr Natural Resources Mgmt. Spec, SEAE2), Garo Batmanian (Lead Environment Specialist, SENGL), Saurabh Dani (Task Team Leader DVRP and Senior DRM Specialist, SLCUR), Vanessa Velasco Bernal (co-Task Team Leader DVRP and Urban Development Specialist, SLCUR), Roland Bradshaw (Senior DRM Specialist, SLCUR), Eric Dickson (Senior Urban and DRM Specialist, SAFU2), Glenn-Marie Lange (Senior Environmental Economist, SENGL), Sylvia Michele Diez (Senior Environmental Specialist, SLCEN), Brenden Jongman (DRM Specialist, SAFU2), Alvina Elisabeth Erman (Economist, GFDRR), and Laura Ivers (Senior Communications Officer, SENGL).

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The *"Forces of Nature: Assessment and Economic Valuation of Coastal Protection Services Provided by Mangroves in Jamaica"*, was coordinated by a group of World Bank specialists in disaster risk management and natural resources led by Juliana Castaño-Isaza (Senior Consultant in Disaster Risk & Natural Resources Management, SLCUR) who provided overall leadership, and Simone Lee (Local Consultant, SLCUR), who coordinated this effort at the local level and provided invaluable technical inputs. Saurabh Dani (Task Team Leader DVRP and Sr. DRM Specialist, SLCUR) provided overall supervision and ensured alignment with the Jamaica Disaster Vulnerability Reduction Project.

The complete methodologies, data collection and analytics were led by a team of specialists that produced four technical studies, which were used for the elaboration of this report. These technical institutions and lead authors included:

The University of California Santa Cruz (UCSC), the Environmental Hydraulics Institute (IH Cantabria), and The Nature Conservancy (TNC) developed the technical study *"The Flood Protection Benefits and Restoration Costs for Mangroves in Jamaica"*. Lead authors of this study included Dr. Michael W. Beck (UCSC and TNC), Dr. Siddharth Narayan, (UCSC), Dr. Iñigo J. Losada (IHC), Dr. Antonio Espejo Hermosa (IHC), Dr. Saul Torres Ortega (IHC), and Sheila Abad Herrero (IHC). The extended team for this study was comprised of Donna Blake (TNC), Dr. Steve Schill (TNC), and Laura Flessner (TNC).

The University of the West Indies (UWI) Mona campus in Kingston Jamaica developed the technical study *"Local Scale Assessments on Mangrove Ecosystems Status and their Role in Coastal Resilience"*, and the *"Mangroves Monitoring and Evaluation Manual–Jamaica"*. The UWI Mona team was formed by Dr. Arpita Mandal, Dr. Rose-Ann Smith, Dr. Taneisha Edwards, Dr. Robert Kinlocke, Dr. Simon Mitchell from the Department of Geography and Geology; Dr. Mona Webber, Camilo Trench, and Patrice Francis, from the Centre for Marine Science; and Dr. Adrian Spence from the International Centre for Environmental and Nuclear Sciences (ICENS).

Dr. Peter E.T. Edwards, developed the technical study *"Valuation of Selected Ecosystem Service Co-Benefits Beyond Coastal Protection"*.

GOVERNMENT OF JAMAICA LEADERSHIP AND CONTRIBUTION

During the development of "Forces of Nature: Assessment and Economic Valuation of Coastal Protection Services Provided by Mangroves in Jamaica", invaluable support and leadership were provided by Andrea Donaldson, Anthony McKenzie, Ainsworth Carroll, Monique Curtis, Gabrielle-Jae Watson, and Kellie Gough, from the **National Environment and Planning Agency (NEPA);** and Anna-Kay Spaulding, and Michele Edwards from the **Office of Disaster Preparedness and Emergency Management (ODPEM).**

Technical contributions were also provided by the Technical Working Group comprised of Stacey-Anne Preston (Jamaica Social Investment Fund), Le-Anne Roper (Planning Institute of Jamaica), Johanna Richards (Water Resources Authority), and Howard Prendergast and Krystal Lyn (National Works Agency).

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Special thanks are extended to all the research assistants, and undergraduate and graduate students from UWI MONA that were involved in the data collection and analytics.

Finally, the team would like to express gratitude to Andrés Barragán, Mateo Zúñiga, Guillermo Torres, Diego Cobos, Felipe Caro, and Sebastián Calderón from PuntoAparte., for translating complex scientific data into clear illustrations and infographics.

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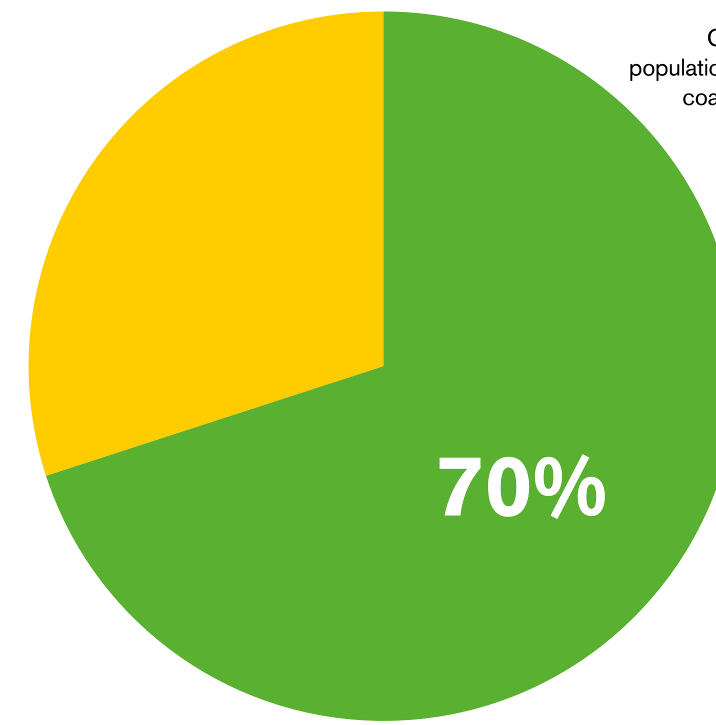
Message from the National Environment and Planning Agency of Jamaica

This World Bank study funded by the Program on Forests (PROFOR) recognizes the importance of coastal ecosystems and highlights the contribution of mangrove forests to coastal resilience and reduction of vulnerability in the context of climate change impacts. This is particularly important to the Caribbean and Small Island Nations (SIDS) like ourselves, in which the majority of industries and some 70% of the population are located well within the boundaries of what could be considered the coastal zone.

The competing interest of conservation vis a vis development, and the need for removal/clearance of these coastal resources in instances, have been challenging for government regulators and natural resources managers. Accounting for the ecological value of coastal resources in terms of disaster risk reduction is proving to be critical at this time, in light of the Country's National Vision 2030 objectives.

FIGURE 1

Caribbean population living in coastal zone.



This Report will provide further quantitative measures to inform the decision-making processes and Government Policy.

About the Project

44 females
(51%)

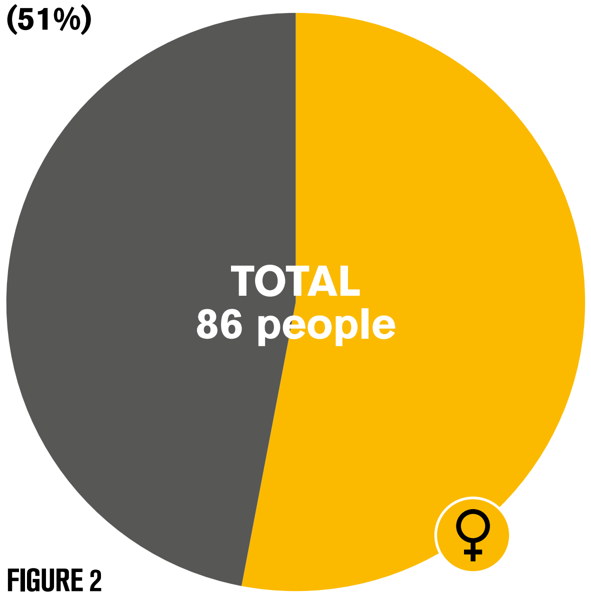


FIGURE 2
Female percentage.

62 Jamaicans
(72%)

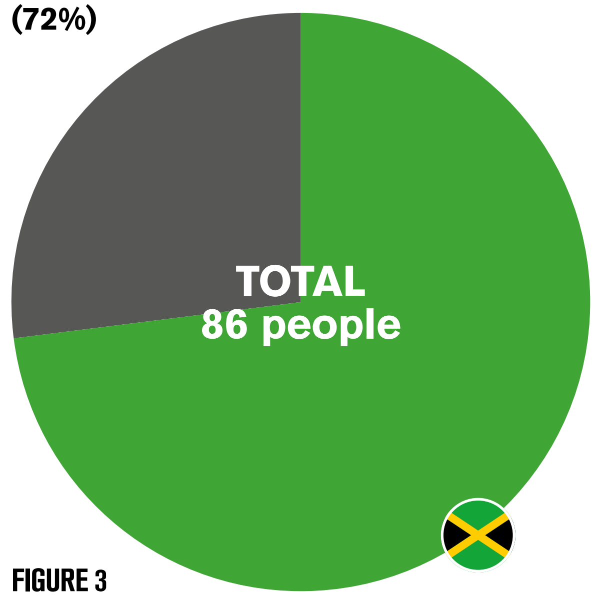


FIGURE 3
Jamaican percentage.

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4 undergraduate students

4 Research Scientists

3 research assistants

Socio-Economic

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4 field workers

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Iván Cortés (Illustrator)

Original Content and Further Reading

This report presents the results generated in four studies conducted under the PROFOR grant "Assessment and Economic Valuation of Coastal Protection Services Provided by Mangroves in Jamaica".

The studies contain the methodologies, full set of results, and specific references, and can be downloaded at the National Environment Protection Agency's website (www.nepa.gov.jm), and the World Bank's website (documents.worldbank.org).

The following reports were produced by the next agencies and lead authors:

"The Flood Protection Benefits and Restoration Costs for Mangroves in Jamaica"
Developed by The University of California Santa Cruz (UCSC), the Environmental Hydraulic Institute of Cantabria (IHC), and The Nature Conservancy (TNC).

Lead authors included: Dr. Michael W. Beck (UCSC-TNC), Dr. Siddharth Narayan (UCSC), Dr. Iñigo J. Losada (IHC), Dr. Antonio Espejo Hermosa (IHC), and Dr. Saul Torres Ortega (IHC).

"Local Scale Assessments on Mangrove Ecosystems Status and their Role in Coastal Resilience", and the "Mangroves Monitoring and Evaluation Manual- Jamaica"
Developed by the University of West Indies MONA Campus (Kingston, Jamaica).

Lead authors included: Dr. Arpita Mandal, Dr. Rose-Ann Smith, Dr. Taneisha Edwards, Dr. Robert Kinlocke, Dr. Simon Mitchell (Department of Geography and Geology); Dr. Mona Webber, Camilo Trench, and Patrice Francis (Centre for Marine Science); and Dr. Adrian Spence (International Centre for Environmental and Nuclear Sciences).

"Valuation of Selected Ecosystem Service Co-Benefits Beyond Coastal Protection"
Developed by Dr. Peter E.T. Edwards.

In addition to these reports, the University of California Santa Cruz (UCSC), the Environmental Hydraulic Institute of Cantabria (IHC), and The Nature Conservancy (TNC) produced the following online tool:

maps.coastalresilience.org/jamaica

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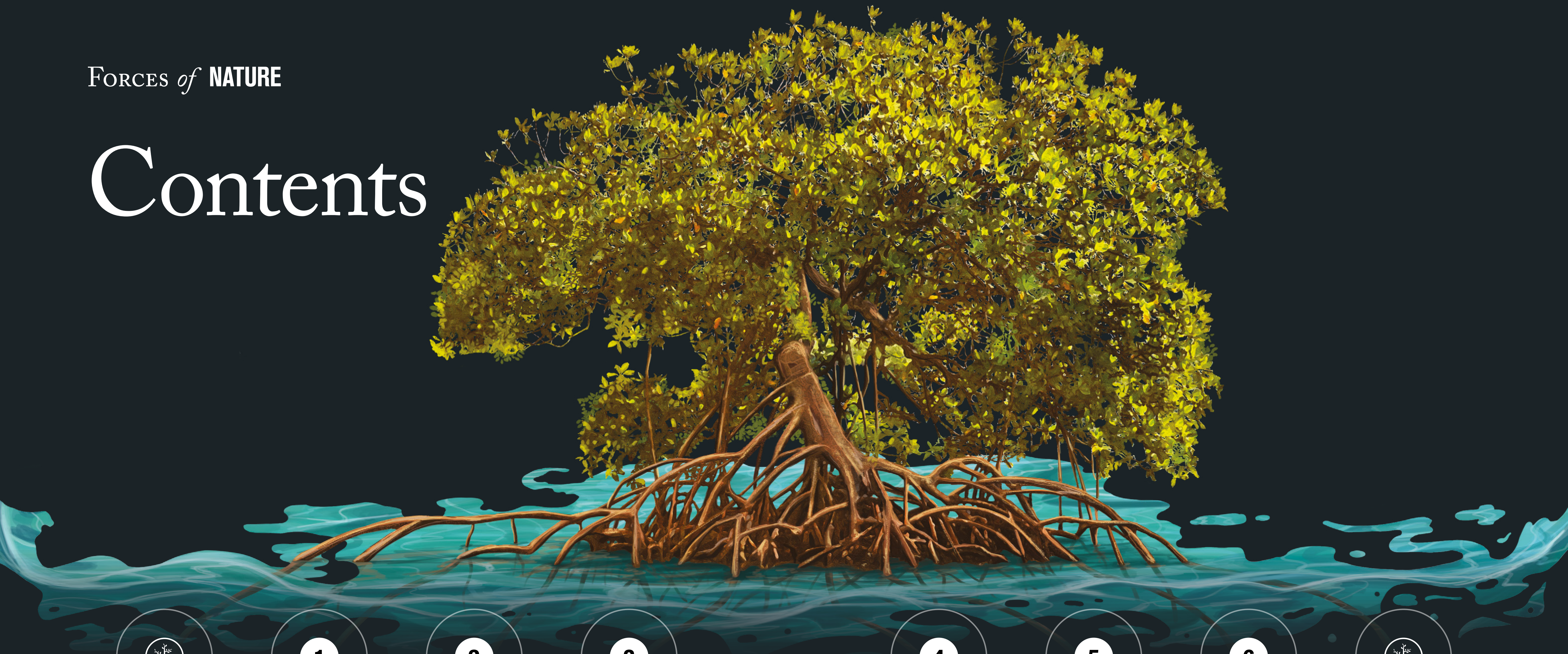
Contents



Executive Summary

INTRODUCTION

Jamaica, like many Small Island Developing States (SIDS) is at high risk from coastal hazards due to its exposure to tropical storms, high levels of coastal development, vulnerable coastal communities, degradation of coastal ecosystems and the predicted impacts of climate change.

For example, Hurricane Ivan in 2004 caused over US$0.5 billion in damages, i.e., nearly 6% of national Gross Domestic Product (GDP). Utilizing mangroves or other natural ecosystems to mitigate, prevent, or buffer against disasters - termed Nature-Based Solutions or Ecosystem-based Disaster Risk Reduction (Eco-DRR) - is becoming an increasingly popular and beneficial approach to Disaster Risk Management (DRM). Mangrove coastlines offer a first line of defense, acting as natural barriers, mitigating flooding by reducing wave energy and slowing down storm surges, and providing stabilization of soils and mudflats. They also provide numerous other co-benefits such as fisheries maintenance, carbon sequestration, ecotourism and water purification. It is important to be able to quantify the economic benefits of mangroves, to better value and conserve these ecosystems, and mitigate the impacts of climate events.

In 2013, there was 9,800 hectares of mangrove in Jamaica, mostly on the south coast. Limited data suggests that more than 770 hectares of mangroves have been lost in Jamaica over the past two decades (1996 - 2016). However more than 70% of these lost mangrove areas could be potentially restorable. Currently mangroves in Jamaica are threatened by extraction (for timber, small-scale farming and fishing uses), coastal squeeze from developments, human sources of pollution, changes in land use leading to clearing and land degradation, and climate change.

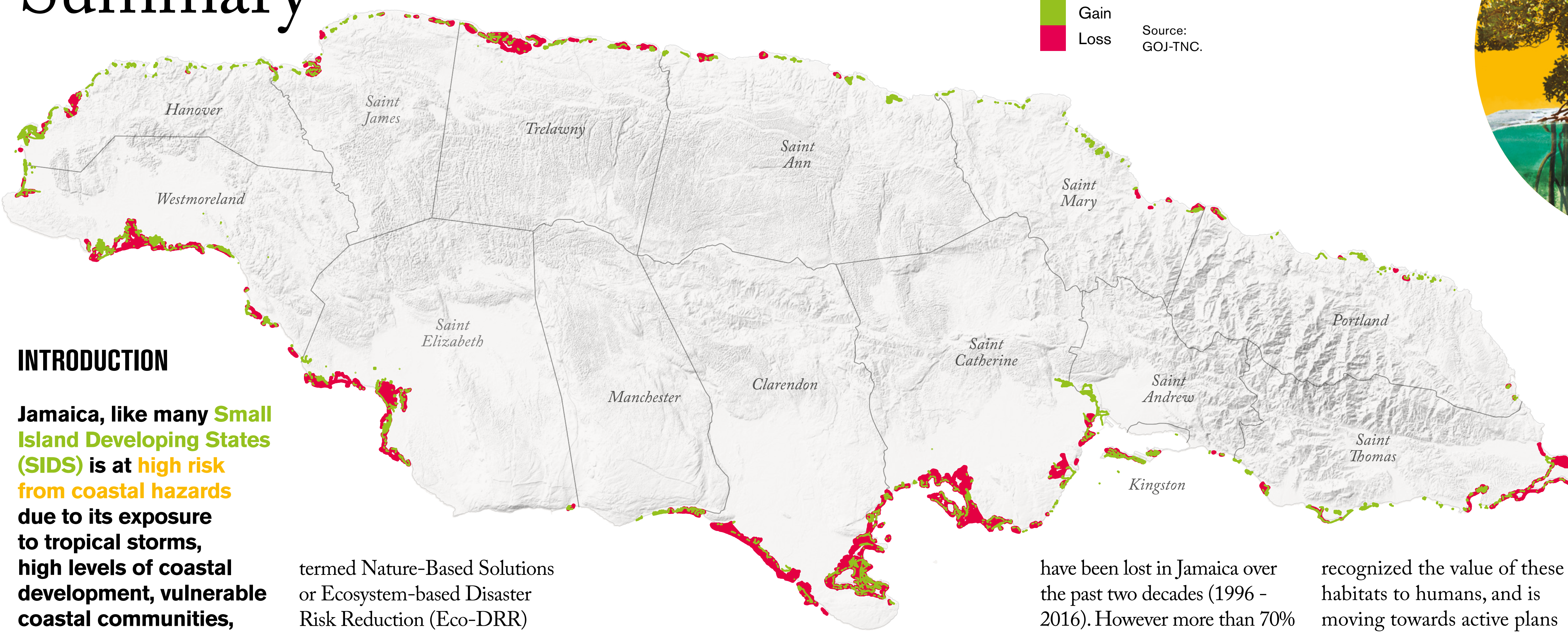
However, the Government of Jamaica (GOJ) has recognized the value of these habitats to humans, and is moving towards active plans and measures to conserve and protect Jamaica's remaining mangroves through becoming signatories to important conventions, establishing protected areas, developing several national plans or guidelines, and international partnerships supporting the conservation or sustainable use of coastal resources.

This analytical product, the 'Assessment and Economic Valuation of Coastal Protection Services Provided by Mangroves in Jamaica' is an important product that supports the GOJ's 'National Development Plan Vision 2030', through efforts to secure a healthy natural environment, reduce hazard risk and adapt to climate change. This product is linked to the ongoing World Bank Jamaica Disaster Vulnerability Reduction Project (DVRP), and will also provide value to Jamaica's Resilience Agenda.

This product examined the current status and risks of mangrove habitats in Jamaica, identified and assessed ecosystem services - especially coastal protection - and looked at the costs and benefits of mangrove conservation.

FIGURE 4

Change in Mangrove Extent in Jamaica from 2005 (baseline GOJ data) to 2013 (TNC data).



The Flood Protection Benefits of Mangroves in Jamaica

National level assessments on the coastal protection provided by mangroves in Jamaica was carried out by a team from University of California Santa Cruz (UCSC), IH Cantabria, and The Nature Conservancy (TNC).

At present, coastal flooding from storms in Jamaica is estimated to result in US$136.4 million in damages every year, in the presence of mangroves. If these mangroves were lost, the expected damages from flooding would increase to $169 million annually. Thus, mangrove forests in Jamaica provide over US$32.7 million in annual flood reduction benefits to built-capital (more than US$2,500 per hectare per year). This represents a nearly 24% annual reduction in flood risk. The loss of Jamaica's mangroves would further result in a 10% increase in the total number of people flooded every year. Mangrove benefits are most apparent for higher intensity storms events.

The risk reduction benefits against tropical cyclones from mangrove forests can be significantly higher in more populated areas. For example, in Hunts Bay, the average annual value exceeds US$5,000 per hectare per year, which translates to avoided damages of more than US$30 million in a 1 in 100-year storm. In general, mangroves reduce flooding extents and heights across all storm frequencies, but are particularly important for the areas of Black River, Falmouth and the parish of Westmoreland. In other sites where mangroves are more coast aligned, the reduction of the flood height is less evident, with an average reduction of about 0.5 to 1 meter for the 50-year return period.

Damages over built capital can be separated into different stock categories - residential, industrial and service. The annual protection offered by mangroves translates into a protection of US$16.6 million over residential stock (50% of total stock protected), US$4.5 million over industrial facilities (14% of total stock protected) and US$11.4 million protection over services stock (35% of total stock).

The costs of mangrove restoration vary greatly due to many different factors, but in the wider Caribbean range from about US$14,000 to US$45,000 per hectare. Recent mangrove restoration projects in Jamaica had an average cost of US$63,000 and US$250,000 per hectare, which included the very high cost of barriers for solid waste management that other regional estimates did not. Mangrove restoration in Jamaica, and globally, is much cheaper than coastal protection structures. In Jamaica, limited data indicate that sea-dykes and levees to protect the Kingston Harbour can cost over US$11 million per kilometer.

Old Harbour Bay

CASE STUDY

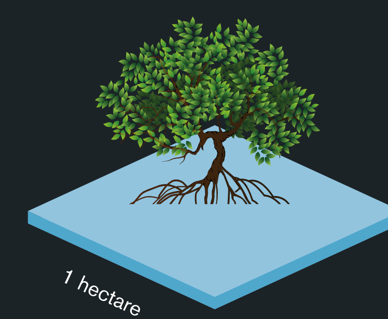
For Old Harbour Bay, the benefits from mangrove presence is most evident during more intense tropical cyclone events and are less apparent during smaller wave-driven flood events.

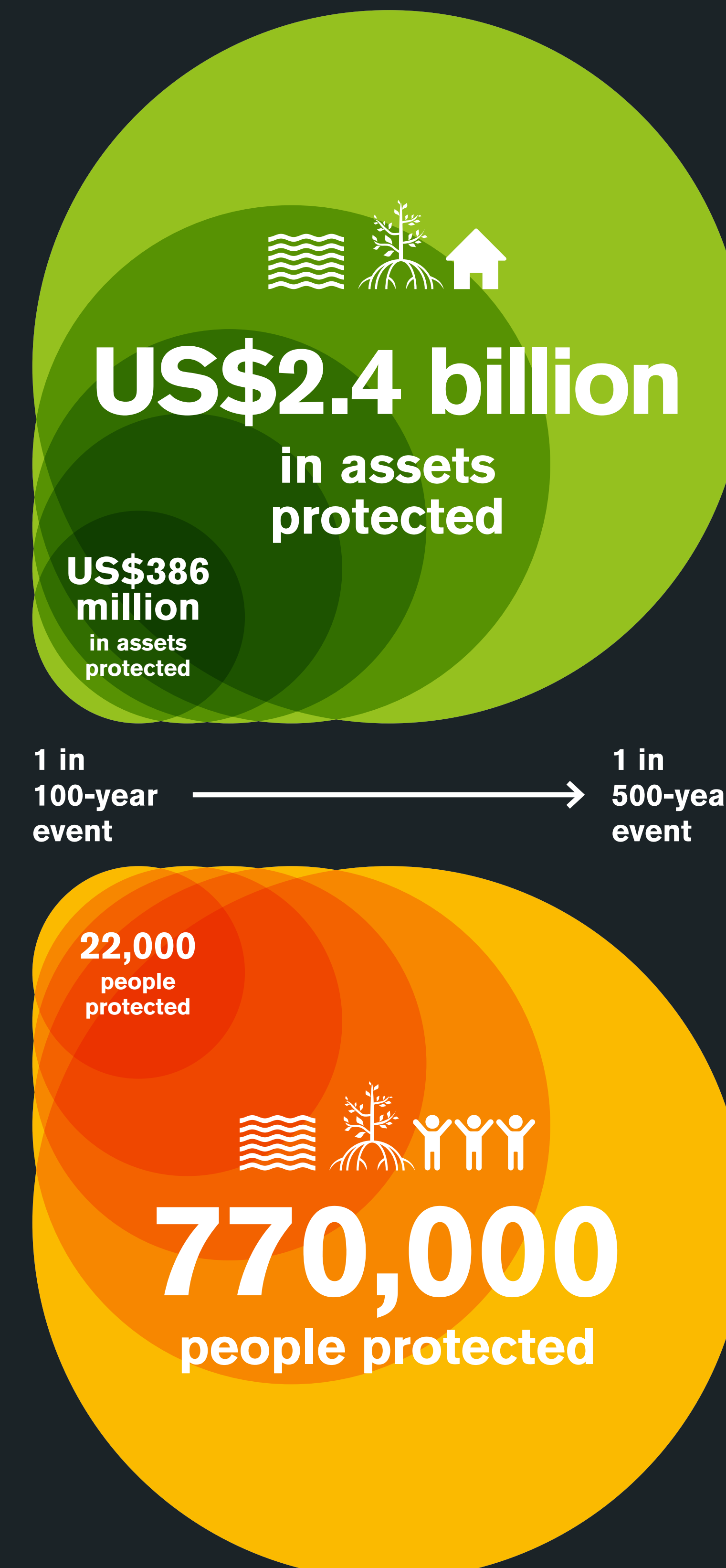
FIGURE 5

Mangrove benefits are most apparent for higher intensity storm events.

Source: UCSC-IHC-TNC.

More than US$2,500 per hectare protected annually.





Mangroves in this area protect some US$3.5 million in built stock every year. Results show that during Hurricane Dean (2007), mangroves were able to reduce water levels around 0.3 and 0.6 meters. This apparently small contribution was responsible for Mitchell Town remaining safe against the storm surge thanks to the protective role of the mangroves, otherwise, a 1 meter water layer would have covered the streets of the village.

Site Level Ecosystem Services

Three sites - Bogue Lagoon (Montego Bay, St. James), Salt Marsh (Falmouth, Trelawny), and Portland Cottage (Portland Bight, Clarendon) – were assessed by a team from the UWI Mona for ecological, physical and socio-economic factors. And Dr. Peter Edwards conducted the economic valuation.

SITE DESCRIPTIONS

1


BOGUE LAGOON

Bogue Lagoon has mixed land-use dominated by commercial and industrial activities. The area was found to have low sensitivity to coastal flooding.

2

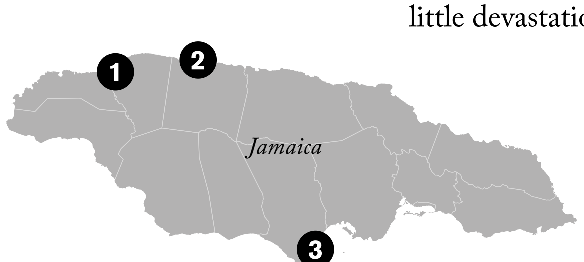

SALT MARSH

Salt Marsh is a low-lying coastal town in northern Jamaica that has moderately low levels of social and economic blight. Although exposed to numerous coastal hazards, it has had relatively little devastation.

3


PORTLAND COTTAGE

The Portland Cottage community is located along the island's southern coastline and is characterized by the highest levels of social and economic blight in the study. The area is highly exposed to the effects of coastal inundation. Portland Cottage's adaptive capacity can be considered low. The majority of respondents in all three communities have not implemented any measures to reduce future flooding event impacts.



In all communities mangroves were seen to be most important for their shoreline protection services, and least important for timber services. In Bogue Lagoon and Salt Marsh, the community mostly reported a decrease in mangroves (due to clearing of trees), whilst in Portland Cottage most respondents saw an increase (due to among other things, restoration activities). In all sites respondents showed a willingness to participate in restoration activities. Fishing was an important activity for Portland Cottage and less so for Salt Marsh, and Bogue Lagoon.

Site Comparisons

Some broad associations between sites and assessments can be made. Only red mangrove parameters as well as fish eggs and larvae were found to vary significantly between the three sites.

The changes support the theory that the Portland Cottage forest is affected by disturbance, and so the forest would be in a state of regeneration. Bogue Lagoon, while having the lowest red mangrove density is the healthiest forest, indicating a mature forest with little or no disturbance. Only Salt Marsh had all three mangrove species represented.

The physical properties of the mangroves can be considered to be 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 studies imply tectonically driven subsidence has occurred recently or is still occurring. Elevation results suggest that the forests are keeping pace with the subsidence and rise in sea level. Subsidence seems to be playing an important role within the sites and coupled with sea level rise will increase the vulnerability of communities and infrastructure associated with these systems. 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 Portland Cottage site. Lateral (horizontal) accretion was greater at Bogue Lagoon and Salt Marsh, but lateral erosion was more predominant at Portland Cottage, possibly as a result of recent hurricanes. This may result in higher disaster risks to coastal communities.

Comparisons at all 3 sites indicate that more wind was attenuated for largest trunk diameters in red mangroves and most density of trees. In some sites the tree density was considered to be most important. No clear pattern was derived for the relationship between prop root densities and wave attenuation.

It was felt that Bogue Lagoon should offer the greatest protective services followed by Salt Marsh, with Portland Cottage mangroves offering the least. Bogue Lagoon offers the most ecosystem service in protection of the coastline as it protects critical road infrastructure and contributes to the viability of mainstream and alternative tourism industries. 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.

Ecosystem Services Beyond Coastal Protection

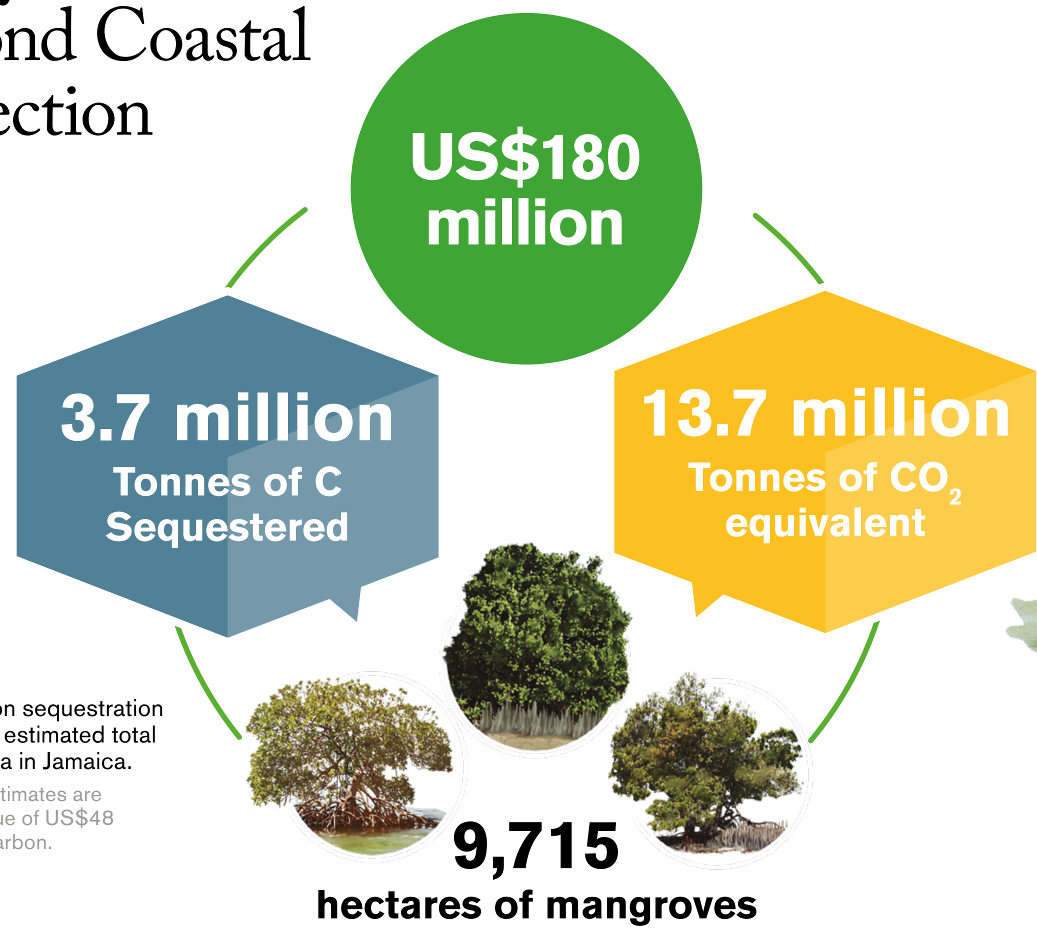


FIGURE 6

Annual Carbon sequestration values for the estimated total mangrove area in Jamaica.

Note: These estimates are based on a value of US$48 per tonne of Carbon.

Blue Carbon

On average, mangroves contain 3 to 4 times the mass of carbon typically found in boreal, temperate, or upland tropical forests. Results from the site studies show a significant positive relationship between white or red mangroves and total vegetative carbon, and a smaller positive relationship between black mangroves and total vegetative carbon.

Using global estimates, the value of annual sequestration for Jamaica is US$179.9 million with Net Present Values (NPV) calculated for a 100 year time span, showing estimated values for keeping carbon sequestered at US$17.8 billion.

The site-specific results confirm that based on the carbon stocks at these three sites there is significant carbon sequestration economic value. UWI's estimates of soil carbon stock for each location showed higher averages for carbon stock when compared to the global average. It should be noted that carbon value estimates are influenced by the choice of discount rate and represent the avoided costs to society of not releasing this stored carbon to the atmosphere.

Nearshore Fisheries

Mangroves are particularly effective as nursery grounds for juveniles of species that later move offshore or to adjacent habitats such as coral reefs.

Using a global estimate of US$213 per hectare per year for mixed species fisheries, the estimated annual economic contribution of mangroves for Portland Cottage, Bogue Lagoon and Salt Marsh was US$54,145, US$14,101 and US$5,218 respectively.

The estimates indicate that the economic contributions from these sites are relatively modest in comparison to other systems. However, these are comparatively small areas and thus limited in their ability to contribute more significantly to fishers' incomes. There are also potential economic benefits from the development of a local-based, high-end recreational fishery focused on catch and release based on species associated with mangroves.

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Limitations

The availability and quality of data was a common limitation throughout all studies. Where current, high resolution data was not available, estimates or broad scale data for analyses was obtained from secondary sources and previous related studies. The site-specific studies generated accurate, detailed data but was limited in scale and length of study. Global economic estimates were used for carbon and fisheries values which restricts the accuracy of the results. The study was able to generate a number of important data gaps that can be addressed in future studies to improve analyses of this nature.

Conclusions

Jamaica faces substantial flood risk from coastal storms and mangroves provide considerable flood risk reduction benefits. Annually, the average of Jamaica's mangrove forests for flood risk reduction to the nation's built capital is more than US$2,500 per hectare. During the 1 in 500-years storm, mangrove forests protect 177,000 people, and nearly US$2.4 billion or 50% of the total affected population and built capital. This translates to economic benefits of more than US$186 million per hectare of mangroves.

This Report supports the growing interest within the development agenda to include nature-based solutions for disaster risk management (DRM), and provides vital information for discussions on adaptation, insurance, hazard mitigation and disaster recovery decisions. It has advanced existing knowledge on current health status of Jamaican mangroves, improved understanding on how the loss of mangroves can increase coastal flood risk, and has identified potential risk reduction measures. This Report shows that mangroves offer significant benefits for flood risk reduction and overall coastal resilience, and identifies key areas affected by floods for where mangrove management (including restoration) may yield the greatest returns.

The Report also presents important data on benefits beyond coastal protection such as fisheries provision, carbon sequestration, erosion control, and ecotourism which can have significant implications on poverty reduction.

It has presented its results in economic terms which allows it to be utilized on important decision-making platforms. Incorporating ecosystem services and benefits can assist DRM and climate resilience strategies, through e.g. the re/insurance sector, or incorporating environmental degradation in risk models. The Report can be used by public agencies to inform hazard mitigation, disaster recovery, and resilience financing funding decisions, and to incorporate mangrove conservation and restoration activities as part of build-back-better strategies.

Finally, this effort funded by the Program on Forests (PROFOR) through the World Bank was able to involve sixty-two Jamaicans (two thirds of the total project workforce), ranging from government officials, to professors, and university students. This has important repercussions on capacity building at the local scale, as the country is now more capable of replicating this effort, and to explore new opportunities in which coastal ecosystems can help reduce climate risks.

1 2 3 4 5 6

1

Introduction

Coastal hazards and risk in Jamaica as a SIDS

Approximately **70%** of Jamaica's population lives in **coastal areas,** and about **56%** of its **economic assets** such as airports, harbours and tourism infrastructure are located on the coast[2].

Flooding in Jamaica is dependent on location and storm characteristics

Is less extensive in the north, than in bays on the south (due to topography)

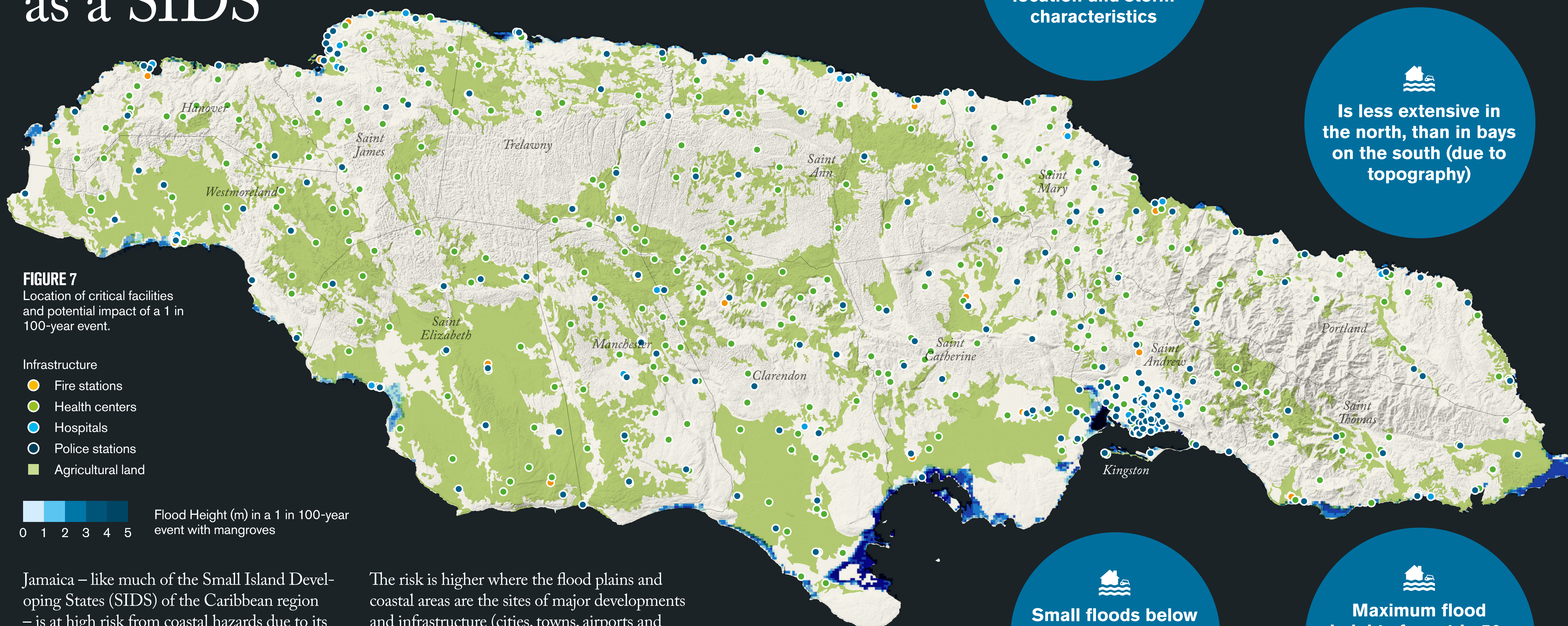

FIGURE 7
Location of critical facilities and potential impact of a 1 in 100-year event.

Small floods below 0.5 m are expected to occur throughout the Jamaican coastline.

Maximum flood heights for a 1 in 50-year storm can go up to 1.5 m in the most exposed areas of the country.

Jamaica – like much of the Small Island Developing States (SIDS) of the Caribbean region – is at high risk from coastal hazards due to its exposure to tropical storms, high levels of coastal development, vulnerable coastal communities and the predicted impacts of climate change. Hurricane and storm related hazards account for some 75% of natural hazards in the Caribbean[1].

The risk is higher where the flood plains and coastal areas are the sites of major developments and infrastructure (cities, towns, airports and seaports). The last 10-15 years has shown an increase in the demand for coastal space in Jamaica, thus showing continued growth regardless of the vulnerability to coastal natural hazards such as hurricanes and storm surges.

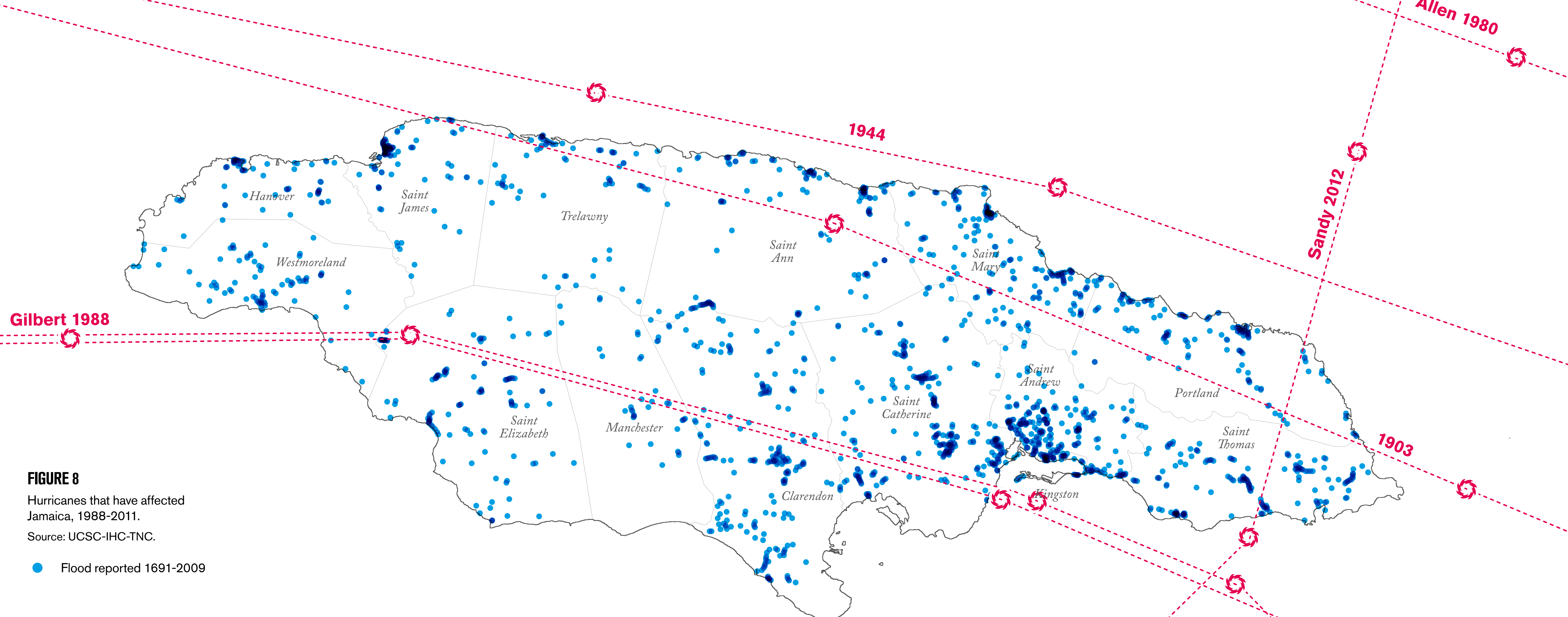

FIGURE 8

Hurricanes that have affected Jamaica, 1988-2011.

Source: UCSC-IHC-TNC.

● Flood reported 1691-2009

Some of the recent examples of hurricane-associated flooding in the Caribbean were in the years of 2016 and 2017 with 2017 recording the highest impact ones. In 2016, Hurricane Matthew caused significant flood and wind damage to Haiti, while in 2017 Hurricanes Irma and Maria -both category 5 - caused devastating impact in Puerto Rico, Dominica, US Virgin Islands, St. Thomas and Croix, St. Maarten. In 2017, insured losses from coastal storms[3] reached an all-time high with greatest impacts and damages across the Caribbean and southeast USA[4].

Between 1988 and 2011, 11 major storms made landfall in Jamaica, causing significant damages to people and property.

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.

Assessments on the impacts of select hurricane events between 1980 and 2007 revealed maximum storm surge heights of 3-6 m for areas in Kingston, and a run up range of 50-1,000 m islandwide[5]. Additionally, for the period 1971-2003 the coastline of Negril showed a 16 cm retreat as compared to the 7 cm shoreline retreat proposed by the Intergovernmental Panel on Climate Change (IPCC)[6].

The impacts of coastal hazards can be devastating to coastal SIDS economies and economic outlook with significant challenges for disaster recovery and redevelopment.

The risk of loss due to tropical cyclones, storm surge and floods is growing as the exposure of economic assets increases and the health of coastal ecosystems degrades[7].

Some reported figures for the impact of coastal hazards on economies include:

Hydrometeorological events in Latin America and the Caribbean accounted for US$31.8 billion or 54% of the total losses from natural hazards for the period 1970 to 1999[8].

In 1998, Hurricane Gilbert caused damages in St. Lucia exceeding 365% of the island's GDP. In 2004, the losses caused by Hurricane Ivan in Grenada were more than twice the nation's GDP.

Since 2004, Jamaica has experienced 10 major hurricanes, including Hurricanes Irma and Maria in 2017, that have caused over US$2 billion in losses[8].

In Jamaica, Hurricane Ivan (2004) accounts for the highest damage and loss amounting to over US$0.5 billion in damages[10].

The vulnerability of coastal communities is expected to rise with the predicted trends and impacts of climate change. Similar to other regional SIDS, the impacts of climate change will affect Jamaica's water supply, biodiversity and coastal environments[11]. According to the World Bank study (2009), *"Sea Level Rise and Storm Surges: A Comparative Analysis of Impacts on Developing Countries"*, 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 57% - with 29% of the coastal population exposed and potential losses of coastal GDP projected to exceed 27%. Furthermore, the study also reveals that the inundation risk in Jamaica from storm surges will cover 37% of the coastal wetlands, which are already squeezed between the sea and the urban developments.

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. Continued increase in extreme events will result in degradation of coastal ecosystem thus increasing the vulnerability of communities in these areas. 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[12].

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Predicted impacts of climate change to Jamaica[13]

TEMPERATURE

Warming trend with the months of June to August showing the maximum high temperatures.

An increase in the frequency of very hot days and nights with a decrease in the cold days and nights.

SEA LEVEL RISE

Range from 0.18-1.4m by 2100 relative to 1980-1999 levels.

Jamaica's north coast to be 0.43 to 0.67 m, by the end of the century with a maximum rise of 1.05m for the south coast.

A 0.5 to 3m projected rise would lead to a 30-100% loss in beach area with the maximum being at Hope Bay in Portland.

HURRICANES

Intensity of hurricanes still increases despite decreases in frequency.

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.

Mangroves for Coastal Resilience

Mangroves are tropical and sub-tropical plants that live in coastal intertidal zones, which are typically low-oxygen, slow moving waters and are also sites of sediment accumulation[14]. Mangrove forests and their associated aquatic environment provide a range of regulating and supporting, provisioning and cultural ecosystem services, many of which relate to coastal hazards and risks[15].

Supporting and regulating services

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.**

Provisioning ecosystem services

1. **Fisheries production;**
2. **Aquaculture production**
3. **Pharmaceutical generation;**
4. **Coastal protection.**

Cultural services

1. **Recreation and tourism;**
2. **Educational opportunities;**
3. **Aesthetic and cultural values**

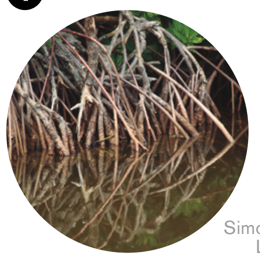
Whilst providing numerous important ecosystem services, this Report placed emphasis on their protection, food provisioning (fishery) and carbon sequestration services.

Mangrove coastlines offer a first line of defense as a transition zone from marine to terrestrial environments, playing a vital role in coastal resilience[16]. They do this through[17]:

- **A** **Acting as a sediment trap,**
- **B** **Acting as natural purifiers of the water**
- **C** **Acting as natural barriers and help mitigate flooding by reducing wave energy and slowing down storm surges**
- **D** **Supporting, preserving and balancing the ecosystem by releasing key nutrients**
- **E** **Being a nursery ground and habitat for species**
- **F** **Acting as a refuge ground for aquatic species during hurricanes and storm events.**
- **G** **They also provide exploitable resources, food and timber**

Some key elements of their defense are[18]:

1



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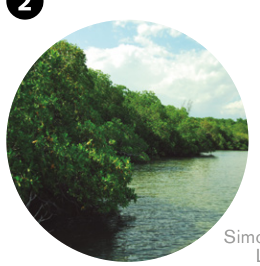
The dense roots and stems of a mangrove forest provide a drag resistance that is strongly related to wave reduction.

On average, mangrove forests can attenuate incoming wave heights by more than 30% and in some cases, almost completely. A reduction in wind speed is also related to mangrove presence.

2



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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. Mangrove forests can reduce storm surges by 26-76%. Peak water level height can be decreased by 4.2 to 9.4 cm on average across multiple mangrove forest patches. Mangroves on Florida's coastline reduced inland flooding due to the storm surge from hurricane Wilma by up to 70%.

3

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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.

These protection services are translated into benefits to people, in terms of reductions in coastal flooding during storms and hurricanes. For example, in Belize mangroves have been shown to act as buffers for coastal erosion and thus provide protection for approximately 40% of the Belize population[19]. In Florida, a reduction in wave height of 80% resulted in 800% more protection to associated coastal areas[20].

In addition to their direct effects on water levels, healthy mangrove forests have the capacity to build land elevation and keep pace with sea-level rise[21]. As ecosystem-based adaptation measures, healthy mangrove forests provide the unique advantage of self-maintenance in this respect, unlike traditional structures such as levees which will require costly upgrades to maintain current standards of protection[22].

Mangrove forests are also among the most carbon-rich ecosystems globally 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 2 to 3 times higher than those of most terrestrial forest. 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.

The economic value of the benefits of mangroves, particularly flood reduction, becomes evident in situations where coastal people and property sheltered by these ecosystems experience reduced flood damages during storms. These risk reduction benefits of mangrove forests have been demonstrated in several places around the world[23]. Importantly, the value of this risk mitigation service can be rigorously quantified to estimate the economic benefits of actions to conserve and/or restore coastal ecosystems that act as natural defenses. For example, across the Philippines mangroves protect over 613,000 people from flooding and avoid damages of US$1 billion annually[24].

The predicted impacts of climate change are important to consider both with respect to the impact on mangroves, and the role that mangroves play in mitigating climate change. The predictions are anticipated to result in an increase in 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. Utilizing mangroves or other natural ecosystems to mitigate, prevent, or buffer against disasters - termed Nature Based Solutions (NBS) or Ecosystem-based Disaster Risk Reduction (Eco-DRR) - is becoming an increasingly popular and beneficial approach to Disaster Risk Reduction (DRR). It is important to note that mangroves are not standalone solutions for coastal protection, but in combination with hard engineering and other risk reduction measures can be effective in reducing damage to coastal towns and cities.

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 and their roles in climate change adaptation 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[25].

Despite these benefits to coastal communities' economies and welfare, coastal

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ecosystems including mangrove forests continue to be lost and degraded. Often, the loss of these habitats is greatest around large populations, i.e., the places were the impacts of coastal degradation are greatest, and where the most people stand to benefit from coastal ecosystems. Globally, mangrove forests have seen area losses of about 35% to 50% since original global recordings in the early 1980s[26]. Their annual loss rate is about 2% from natural forces such as hurricanes and associated winds, and anthropogenic forces such as coastal development and aquaculture[27]. The loss of mangroves and coral reefs will result in the loss of their ecosystem services, and specific to coastal flooding, will result in an increase in flood damages to communities that are otherwise protected by these ecosystems.

2

Mangroves in Jamaica

The Jamaican Context

Jamaica, being a tropical island has its wetlands largely comprised of mangrove forests, the majority (82%) of which can be found in southern parishes with the highest distribution in the parish of St. Elizabeth.

These forests are typified by a low diversity of species with the black mangrove species dominating. 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.

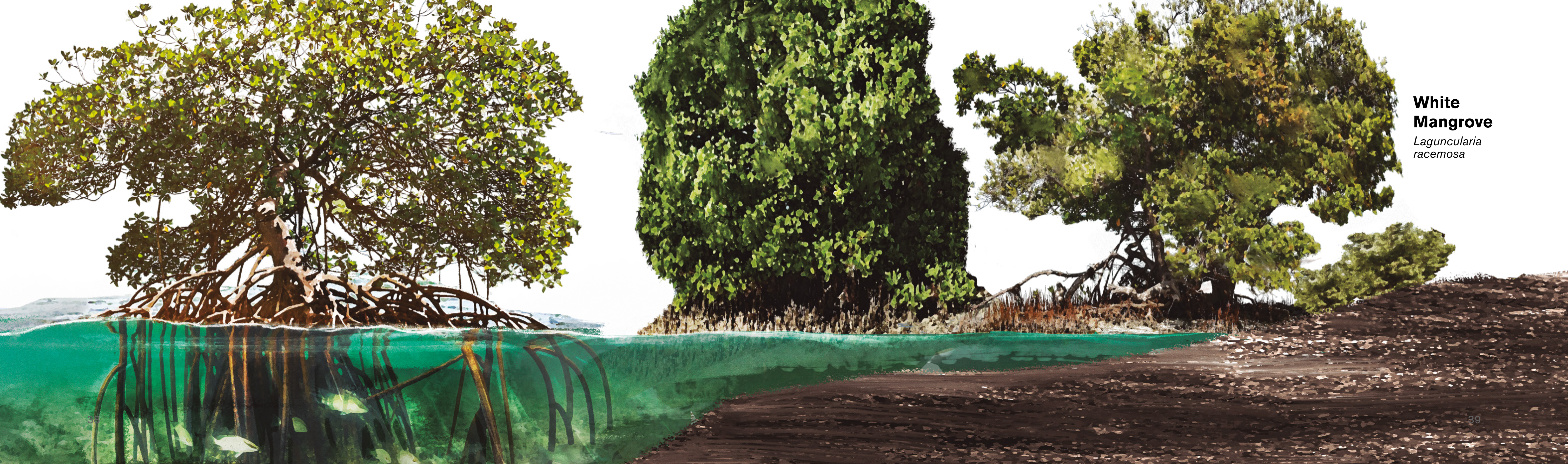
Impacts to mangroves range from direct extraction uses to those that indirectly affect them from other activities. For Jamaica in particular:

Mangrove forests have played an important historical and traditional role in many Jamaican coastal communities with services such as timber supplies for construction, daily-use and artisanal products, small-scale farming, firewood (charcoal) and subsistence fishing in canals and rivers. As a result, these forests are threatened in some areas due to over-exploitation of resources[28].

Shoreline hardening using artificial structures and developing coastlines with hard barriers can increase the vulnerability of mangroves to sea-level rise by preventing landward mangrove migration – a process commonly known as 'coastal squeeze'[29].

FIGURE 9

Mangrove species found in Jamaica.



Pollution from human activity, such as outfalls from waste-water treatment plant or waste from construction activities can cause already stressed mangrove habitats to either degrade further or be completely lost, and negatively impact their ability to recover after natural stressors such as hurricanes or drought[30].

Changes in land use, especially clearing for development (tourism, residential and commercial), and agriculture (but not shrimp aquaculture). These differences also have implications for mangrove restoration potential, that is, areas lost to aquaculture are easier to restore than those lost to development such as airports.

FIGURE 10

Species related to mangrove forests.

Green heron
Butorides virescens

Mudskipper
Periophthalmus

In addition to direct human impacts, mangrove forests in Jamaica and in the rest of the Caribbean are expected to be affected by climate change - increases in sea-level, frequency of and/or increased intensity of storms, temperature and aridity[31]. While mangroves in the Caribbean appear to be keeping pace with current sea-level rise rates of 1 to 2.5mm/year this may not remain the case with accelerated sea-level rise in the future[32]. Although damage to mangrove is expected to rise with increases in hurricanes of higher intensity or frequency, recent evidence from hurricane-impacted mangroves in the Philippines and elsewhere, indicates that these mangroves can equally recover from hurricanes over time-spans of few years to a couple of decades[33].

Great egret
Ardea alba

Brown pelican
Pelecanus occidentalis

The reasons for the loss and degradation of Jamaica's mangrove forests are multiple. The combination of current stressors means that there are present losses of mangroves in Jamaica and in other regions of the Caribbean and reduces their resilience and ability to manage and recover from the combined effect of future stressors, particularly those from climate change[34]. As the value of these habitats to humans, in terms of coastal protection and other critical ecosystem services is recognized, the Government of Jamaica is moving towards active plans and measures to conserve and protect Jamaica's remaining mangroves. Since 2005, the Government of Jamaica (GOJ) has protected multiple mangrove sites across the island. The recent National Forest Management and Conservation Plan explicitly recognizes mangrove restoration as a priority for national climate adaptation plans[35].

The GOJ and the World Bank Program on Forests (PROFOR) have worked to assess and evaluate the economic value of coastal protection provided by mangroves in Jamaica, linked to their ongoing Disaster Vulnerability Reduction Project (DVRP).

Historical Changes and Mangrove Status

It is difficult to get an accurate estimate of historical changes in mangrove extent due to different survey techniques, omissions of some forest areas etc.

Below statistics are taken from different sources regarding historical changes in mangrove extents:

- Increased from 9,700 hectares (1997) to 11,600 hectares (2010), then decreased to 9,800 hetares (2013)
- Increased from 11,674 hectares (2010) to 16,735 hectares (2012)
- Covered 14,800 hectares (2005)
- Covered 15,000 hectares (1970s)

More than 770 hectares of mangroves have been lost in Jamaica over the past two decades (1996 to 2016), with at least 20 hectares lost to informal settlement since 2010. This decadal loss represents a 95% decrease since 1998, primarily due to clearing for agriculture, buildings and infrastructure, and shifts to herbaceous wetlands.

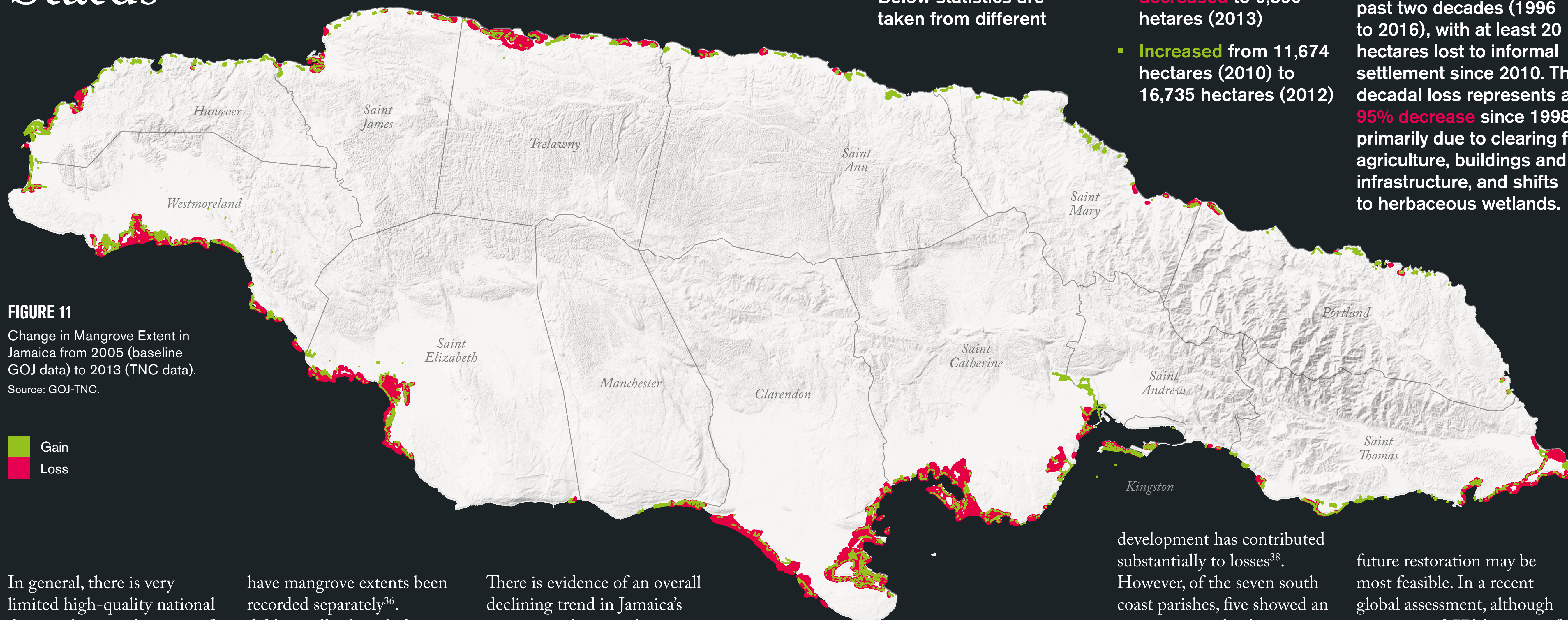


FIGURE 11

Change in Mangrove Extent in Jamaica from 2005 (baseline GOJ data) to 2013 (TNC data).

Source: GOJ-TNC.

Gain
Loss

In general, there is very limited high-quality national data on the spatial extents of mangroves, since mangroves in Jamaica are typically classified and counted together with fresh-water 'swamp' forests and only recently have mangrove extents been recorded separately[36]. Additionally, though data on individual wetlands exist, there is little documentation of long-term trends in the extent, status and health of Jamaica's mangroves[37].

There is evidence of an overall declining trend in Jamaica's mangroves, however losses and gains across the island are not spatially uniform, with some areas seeing significant losses and other coastlines witnessing gains. In the north of the country residential and tourism development have probably contributed the most to mangrove loss whereas in the south, port and industrial development has contributed substantially to losses[38]. However, of the seven south coast parishes, five showed an increase in wetland coverage between 2005 and 2011[39].

Assessing historic mangrove loss and current mangrove extents is important for understanding where future restoration may be most feasible. In a recent global assessment, although an estimated 770 hectares of mangroves have been lost in Jamaica between 1996 and 2016, more than 70% of these mangroves could be potentially restorable[40].

Socio-Economic linkages to mangroves

The contributions of mangrove ecosystems to human wellbeing are interrelated to their direct ecological benefits.

For example, their role as a wildlife habitat and nursery area including birds, shrimp, crabs and fish supports coastal communities' supply of seafood for local consumption or as part of a business.

The role of mangroves in shoreline protection and flood prevention 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. Howevert these are compromised by tropical systems such as hurricanes or coastal flooding, with their vulnerability increasing due to climate change[41]. Most of the coastal towns in Jamaica have coastal forest origins, and the removal of these for coastal development would increase the area's vulnerability[42].

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, and which are ultimately important to the Jamaican economy[43]. Mangroves are particularly important for the sustainability of the fishing industry, providing habitat for over 220 fish species including commercially important fish such as snapper, grunt, parrotfish, barracuda and mackerel, and also economically important crustaceans such as shrimps, lobsters and crab[44]. There is also much opportunity for ecotourism utilizing mangrove forests' structure and diversity for sightseeing, boating, swimming, and sport fishing. Boat excursions into wetlands, for example, is gaining increasing popularity as a tourist attraction in Jamaica, and provides additional benefit to local communities by making use of their traditional knowledge of the areas and therefore support local livelihoods[45].

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Project Significance to Jamaica

There is a serious need for preservation of Jamaica's mangrove ecosystems considering that majority of the country's economy and business is from these coastal areas. The GOJ has taken a number of steps to incorporate this into national strategies and guidelines.

Jamaica became a signatory to The Convention of Wetlands (Ramsar Convention) on February 7, 1998.

Jamaica currently has 4 sites designated as wetlands of international importance (Ramsar sites), with a total surface area of 37,847 hectares. The 4 Ramsar sites are Black River Lower Morass, Mason River Protected Area, Palisadoes – Port Royal and Portland Bight Wetlands and Cays.

Currently in Jamaica there are 2 core guidelines which are used for coastal management interventions and beach restoration.

The NRCA Guidelines for the Planning, Construction and Maintenance of Facilities for Enhancement and Protection of Shorelines (Circa 1995); and the Draft Guidelines for the Relocation and Restoration of Jamaica's Coastal Resources: Corals, Seagrasses & Mangroves, A Guide for Developers (2010). Additionally, the National Coastal Management and Beach Restoration Guidelines (2017) provides 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.

The Climate Change Policy Framework and Action Plan states 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"[46].

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.

The National Development Plan Jamaica Vision 2030 outlines Goal 4:

"Jamaica has a Healthy Natural Environment", 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 also well aligned with the United Nations Sustainable Development Goals 13 and 14 which targets Climate Action and Life on Land.

The World Bank Country Partnership Strategy (CPS) FY2014-2017 (Report No. 85158-JM), 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).

Mangrove preservation is well aligned, keeping in mind the projections of climate change and its impacts as presented in the Third National Communication to the UNFCC 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).

3

The Flood Protection Benefits and Restoration Costs for Mangroves in Jamaica

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3. The Nature Conservancy, Arlington, VA, USA

Methodology

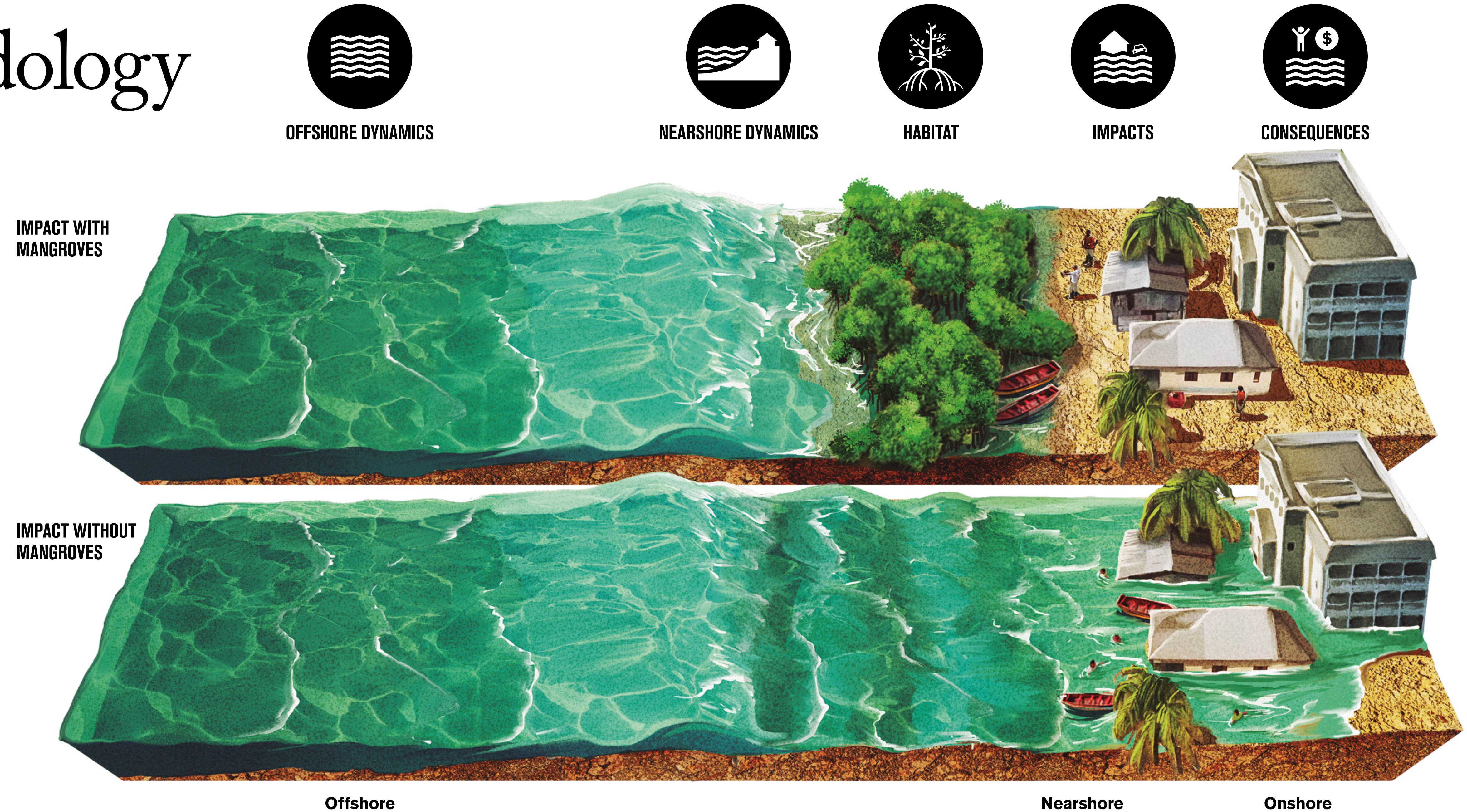


FIGURE 12
Expected Damage Function Approach.
Source: Beck and Lange, 2016.

To value the coastal protection benefits provided by mangroves, this work follows the Expected Damage Function approach, commonly used in engineering and insurance sectors and recommended for the assessment of coastal protection services from habitats. The protection benefits provided by mangroves are assessed as the flood damages avoided by keeping mangroves in place. The results are presented in terms of the number of people and the value of property flooded with and without mangroves.

First, the offshore conditions of water-levels and waves are determined using meteorological and hydrodynamic models that analyse data on a large stochastic set of 462 tropical cyclones. This stochastic set is built by extending a historical dataset of 46 tropical cyclones within a 100km radius around the coastline of Jamaica. Then, hydrodynamic models are used to estimate how the offshore waves and water-levels for each of these 462 storm events transform as they approach the shoreline, and how the presence (and absence) of mangroves affects the distribution of total water levels at the coastline. The outputs from these models are then combined with topography to calculate the inland flooding that occurs under two scenarios: with current mangrove and without mangroves (i.e., assuming all mangroves are lost).

While these analyses do not separately examine the effects of coral reefs, their benefits are included within the bathymetry datasets for these models.

This work combines multiple relevant datasets for coastal dynamics from IH Cantabria and for assets from various sources. To calculate the exposure of people and built capital within the coastal floodplain, the study uses global datasets on population and built capital (residential and industrial property) that are available in 1km^2 grids. The assessment uses regional depth-damage functions to estimate flood damages for population and built capital based on two internationally recognized sources: HAZUS and JRC.

Coastal Protection Ecosystem Services Assessment

Mangrove forests in Jamaica provide

US $32.65 Million

in annual flood reduction benefits to built capital

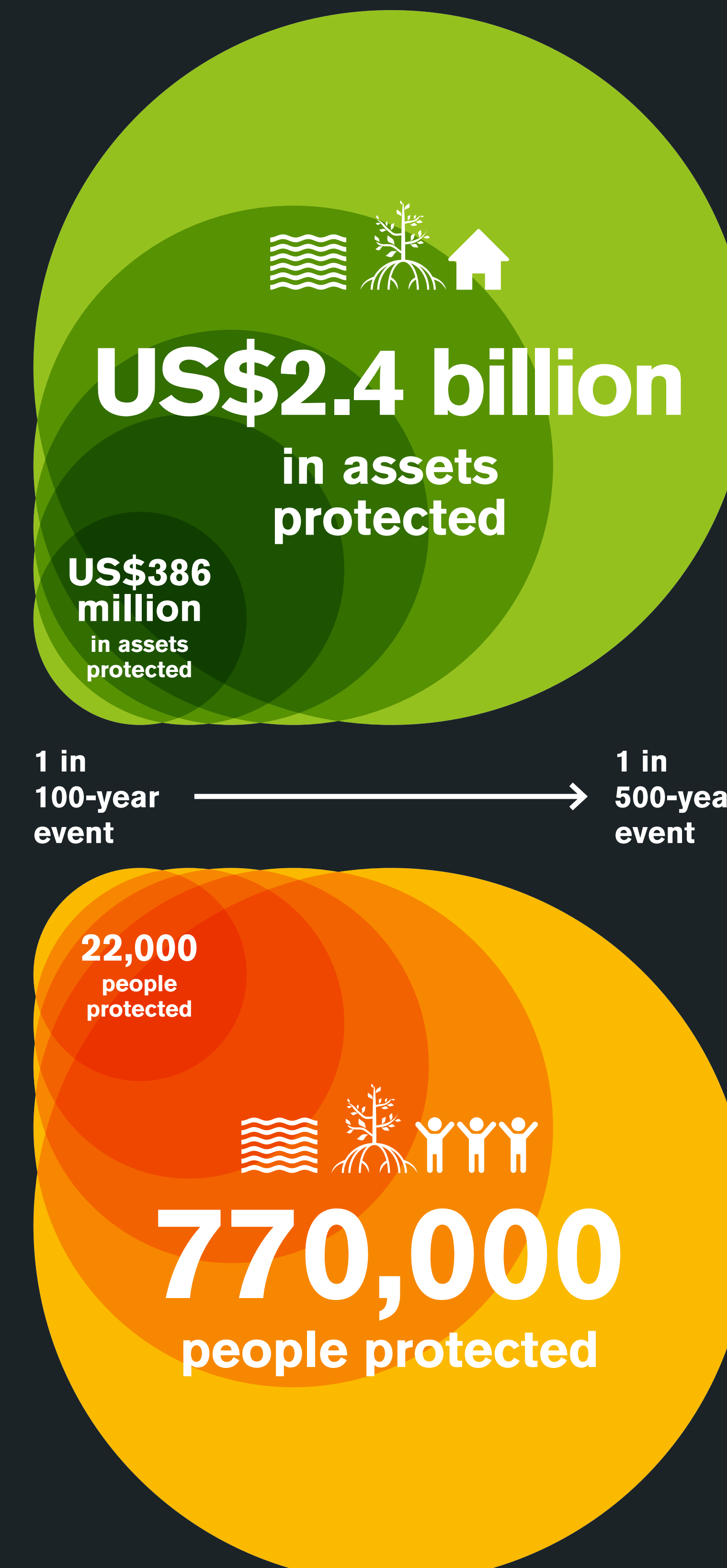
SUMMARY OF MANGROVE COASTAL PROTECTION IN JAMAICA

At present, coastal flooding from storms in Jamaica is estimated to result in US$136.4 million in damages every year, in the presence of mangroves. If these mangroves were lost, the expected damages from flooding would increase to US$169 million annually. Thus, mangrove forests in Jamaica provide over US$32.6 million in annual flood reduction benefits to built capital (on average around US$2,500 per hectare per year). This represents a nearly 24% annual reduction in flood risk. The loss of Jamaica's mangroves would further result in a 10% increase in the total number of people flooded every year, many of whom live in poverty.

FIGURE 13

Mangrove benefits are most apparent for higher intensity storm events.

Source: UCSC-IHC-TNC.



Mangroves in this area protect some US$3.5 million in built stock every year. Results show that during Hurricane Dean (2007), mangroves were able to reduce water levels around 0.3 and 0.6 meters. This apparently small contribution was responsible for Mitchell Town remaining safe against the storm surge thanks to the protective role of the mangroves, otherwise, a 1 meter water layer would have covered the streets of the village.

WITH MANGROVES

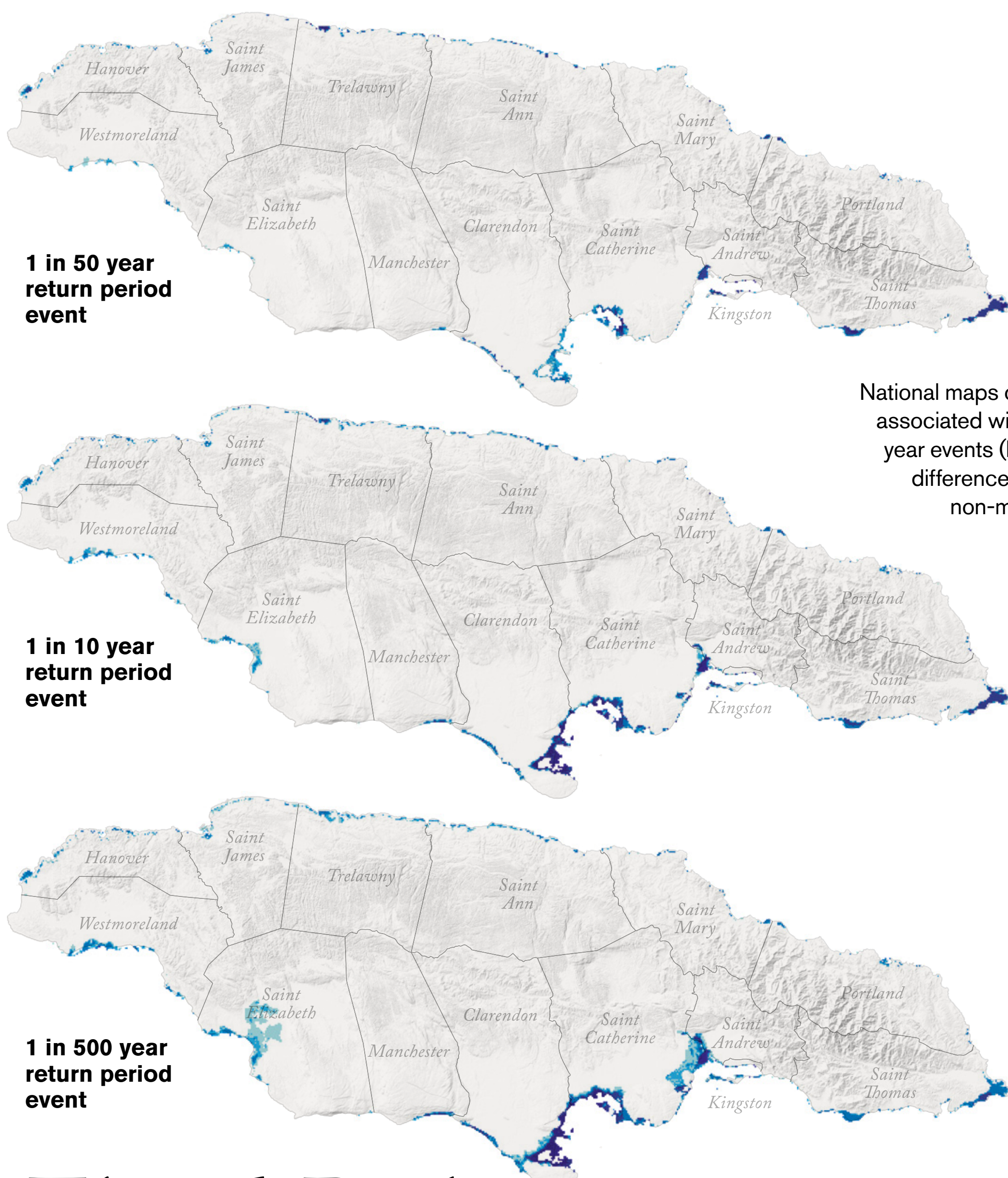
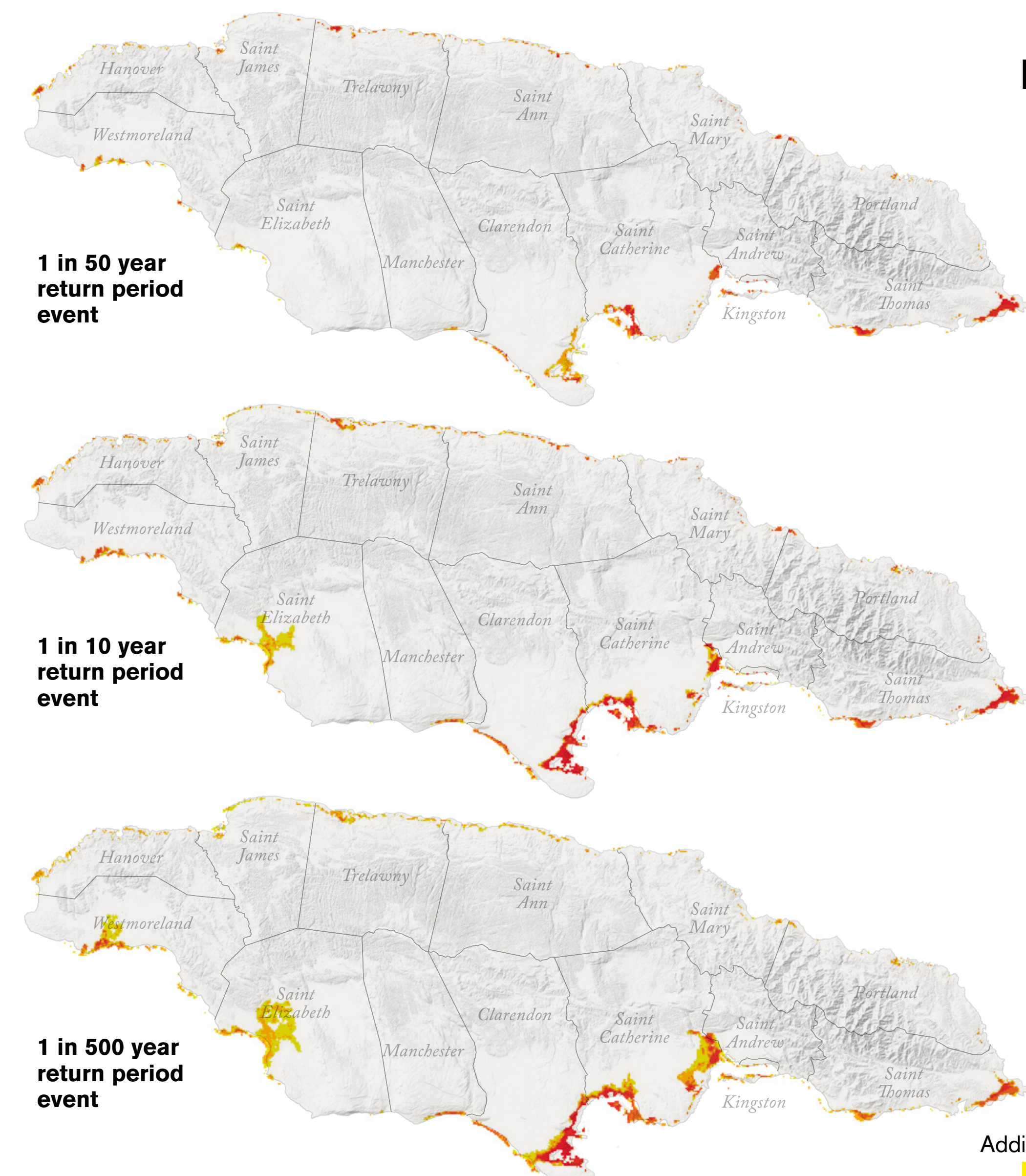


FIGURE 14

National maps of the flood heights associated with 1 in 50 and 500 year events (left panels) and the differences of the mangrove-non-mangrove scenarios (right panels).

Flood Height (m)
0 1 2 3 4 5

WITHOUT MANGROVES



Additional Flood Height (m)
0 0,5 1 1,5 2 2,5

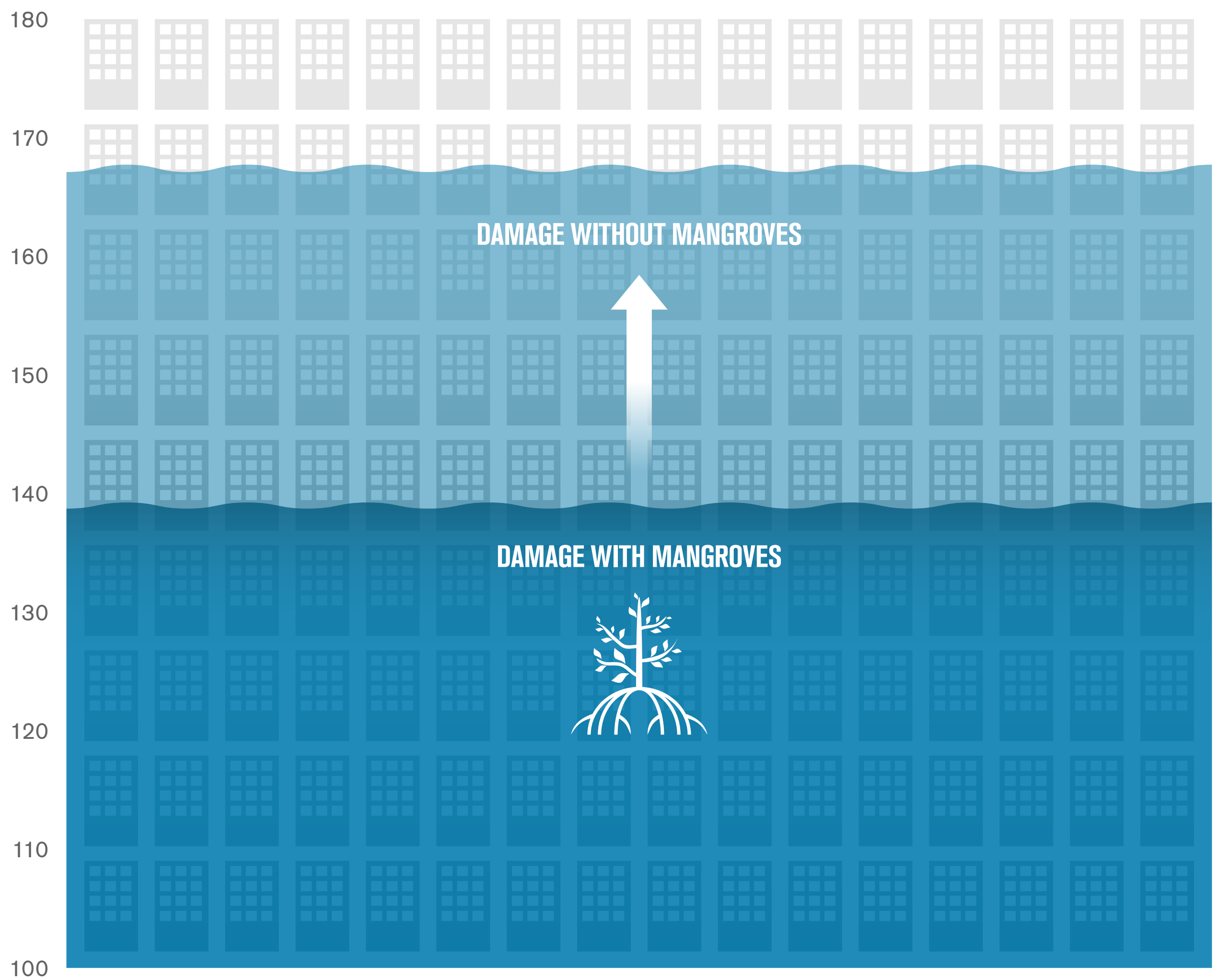
Flood Risk

Mangroves reduce flooding extents and heights across all storm frequencies. The detailed modelling work here allows us to provide spatially explicit, nationwide maps at high resolution of i) baseline flood risks, and; ii) the distribution of economic benefits from mangroves. The protective benefits of mangroves are shown in the right panels of the figure on flood heights, in terms of the flood heights that would occur if mangroves were lost, for the 1 in 50 (i.e. 2% annual chance), 1 in 100 (i.e., 1% annual chance) and 1 in 500 (i.e., 0.2% annual chance) year storm events.

Comparisons of the mangrove and non-mangrove scenarios indicate higher effectiveness in the Black River Bay, where the intricate configuration of the channels and mangrove patches play an important role in slowing down the water. In other sites like the Morant Point, Kingston, Old Harbour Bay and some areas of the north coast, where mangroves extend more along the coast, the reduction of the flood height is less evident, with an average reduction of about 0.5 to 1m for the 1 in 50 flood event. For the 1 in 500 year event, the protection against flooding is more widespread. For such a high-intensity event, areas like the Westmoreland Parish or Falmouth began to experience significant storm surge reduction (up to 2m).

Total Stock Damage

(USD Million)



Avoided Damages to Stock

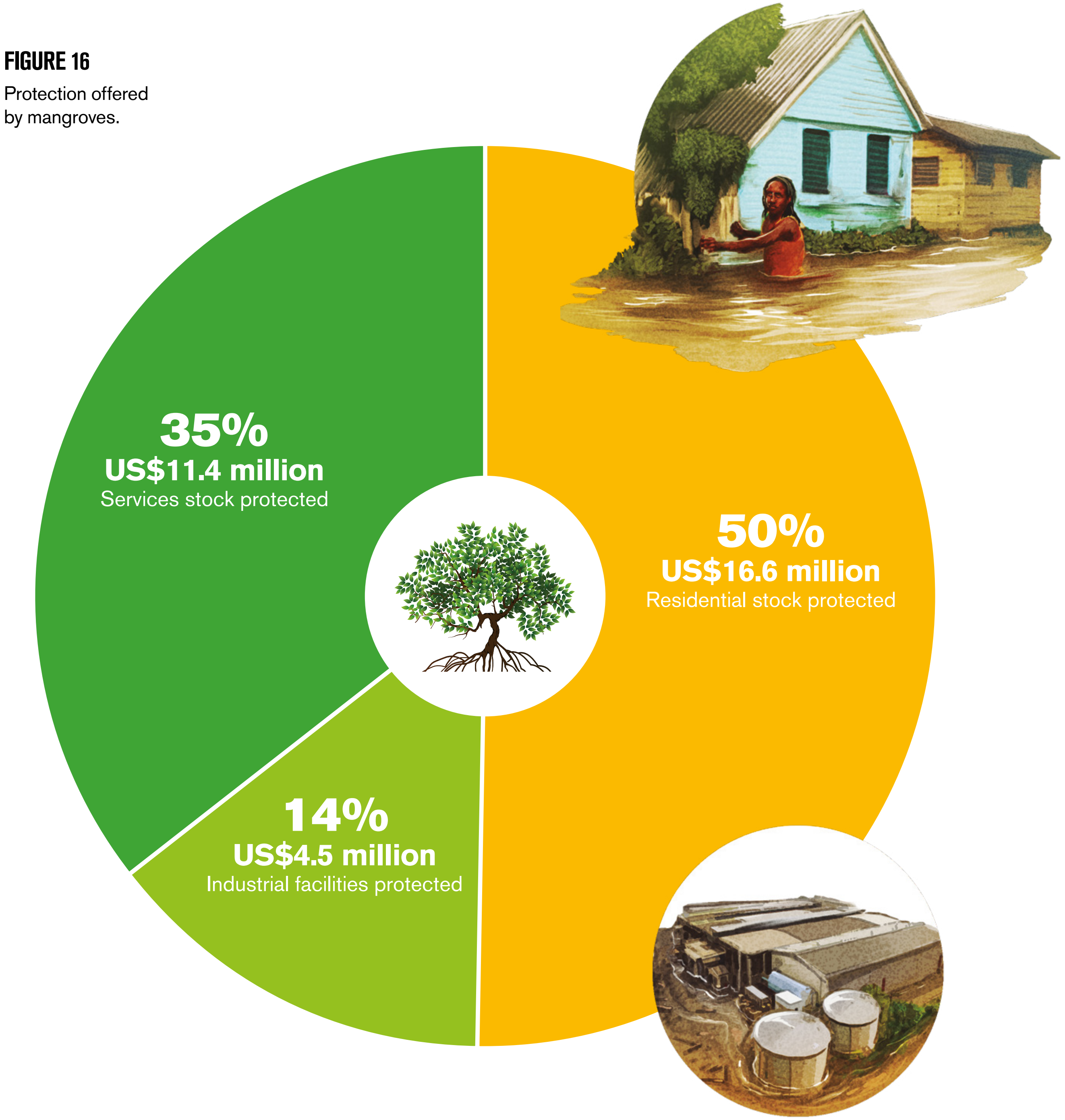
By reducing flood heights and extents, mangroves reduce damages to people and built capital. Damages to built capital can be separated into different stock categories: residential, industrial and services.

FIGURE 15

Current flood risk and Annual expected benefits from mangroves for flood risk reduction across Jamaica in terms of (averted) damages to property.

FIGURE 16

Protection offered by mangroves.

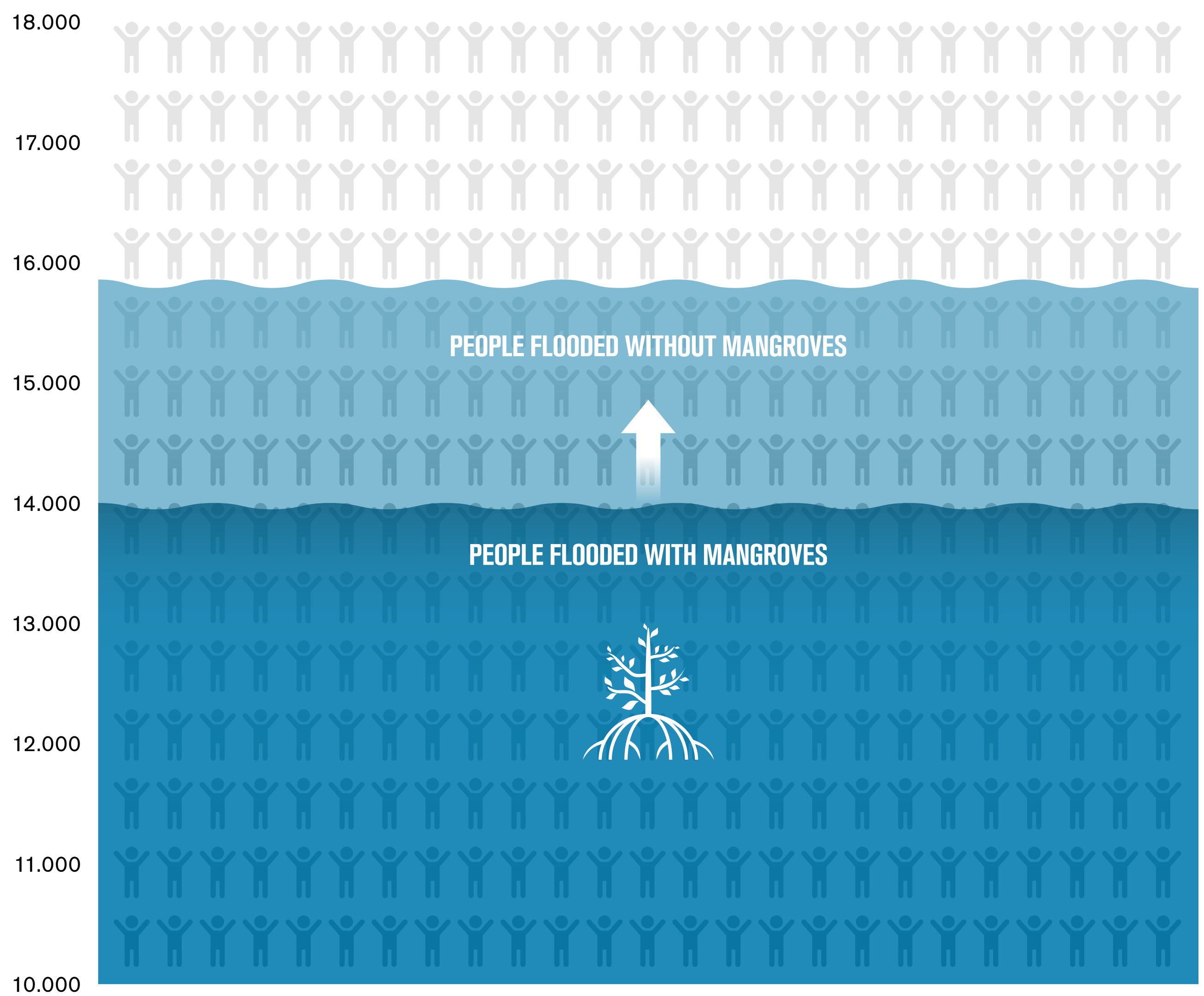


This means that the protection offered by mangroves (US$32.6 million per year for all Jamaica) translates into a protection of US$16.6 million for residential stock (50% of total stock protected), US$4.5 million for industrial facilities (14%) and US$11.4 million protection for services stock (35% of total stock).

People Flooded Annually

FIGURE 17

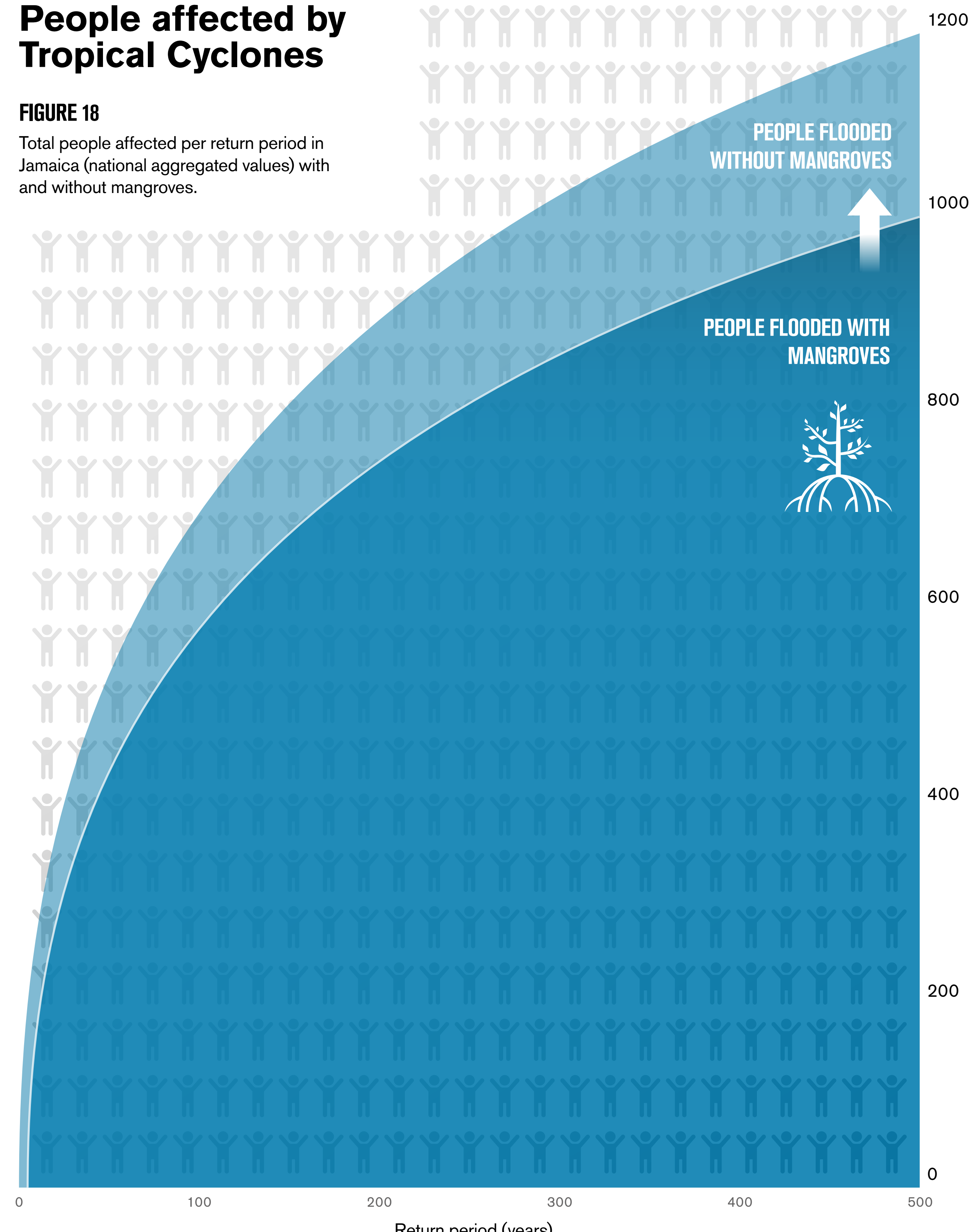
Current flood risk and Annual expected benefits from mangroves for flood risk reduction across Jamaica in terms of (averted) people affected.



People affected by Tropical Cyclones

FIGURE 18

Total people affected per return period in Jamaica (national aggregated values) with and without mangroves.



Annual Expected Benefits per Hectare of Mangroves

For tropical cyclones, mangroves reduce annual property damages by more than 23%, with an annual value of more than US$32 million.

In some places, vulnerable populations (i.e. people under poverty) receive some of the flood protection benefits from mangroves, though these numbers are small due to the relatively low proportions of people under poverty that live in coastal areas.

The average risk reduction benefits against tropical cyclones from mangrove forests across Jamaica are around US$2,500 per hectare per yr, though these values can be significantly higher in more populated areas or areas that suffer from more frequent and larger surges such as Morant Point (in the east), Kingston, Hunts Bay and Old Harbour Bay areas (in the south).

In the western part of Old Harbour Bay, for example, the flooding from a 1 in 500 year storm event can exceed 5m. In Hunts Bay, coastal mangroves totalling 200 hectares provide risk reduction benefits of over US$1 million/year, with an average annual value exceeding US$5,000 per hectare per yr. In the event of a 1 in a 100 year storm these mangroves avoid damages of more than US$30 million, resulting in an average value of more than US$154,000 per hectare.

Most of the mangroves in the Montego Bay area are around the wastewater treatment plant and most of the changes in flooding are contained seaward of the plant and Bogue Road. Mangroves provide the most protection for wave conditions below a 1 in 50 year return period.

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Surprisingly, there is less attenuation of the maximum water levels for the 100 years return period wave conditions. This effect is due to the appearance of resonant modes within the bay as the wave period increases. However, in this case there is no direct impact from the mangroves to assets or population, mainly because these elements are not located in the area directly protected by the mangroves. Even in these situations, mangroves offer other risk reduction benefits in terms of trapping sediments and building elevation.

MAXIMUM WATER LEVEL WITH MANGROVES | **DIFFERENCE WITHOUT MANGROVES**

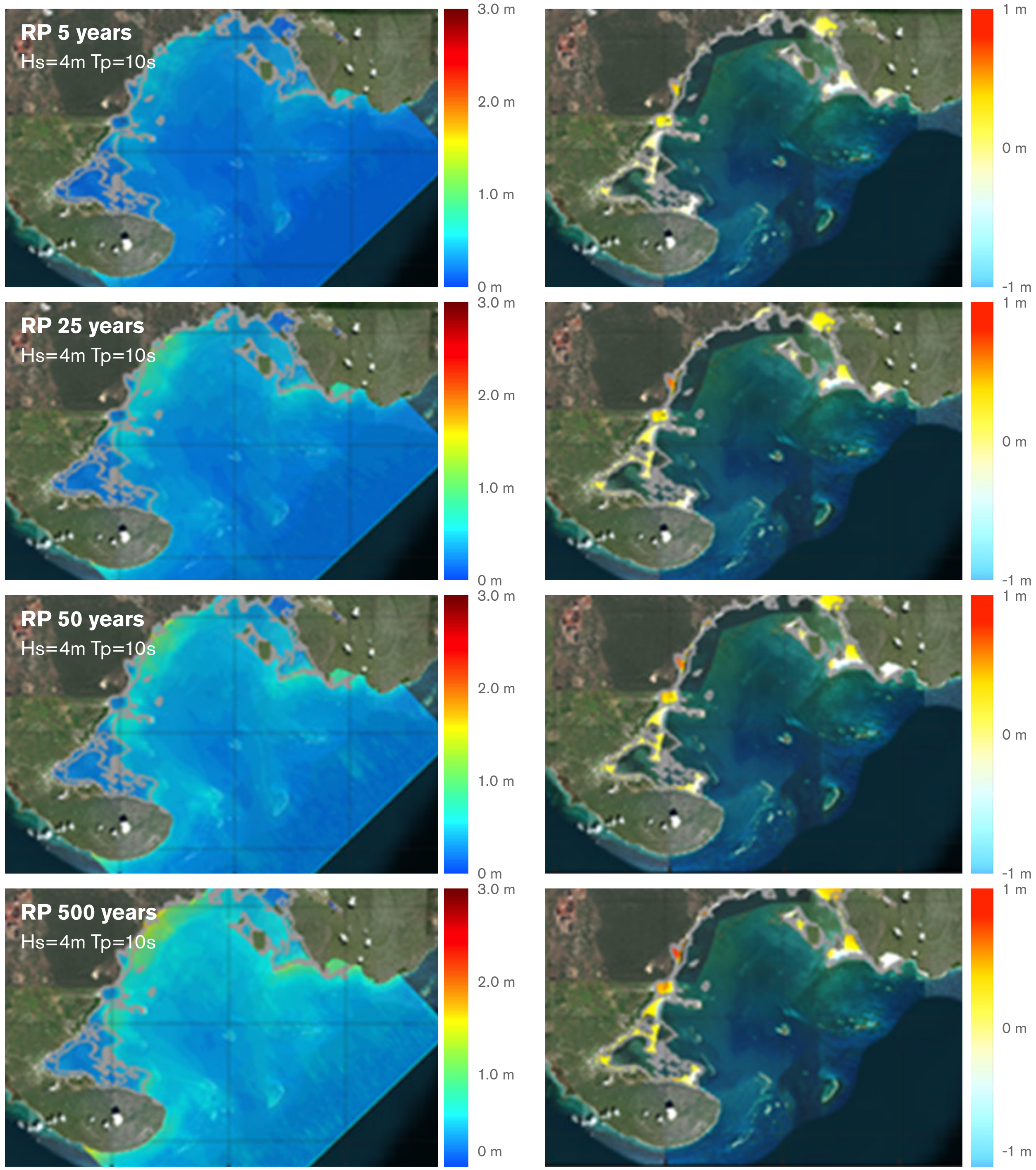


FIGURE 19

Results of the maximum water level for the 5, 25, 50 and 100 years return periods in Old Harbor Bay (left panels) and differences of the overland flood heights of the same simulations without mangroves. Mangrove forests are delimited by grey lines.

Hs: significant wave height
Tp: wave period
RP: storm period e.g., (1 in 5 year event).

Old Harbour Bay Case Study

For Old Harbour Bay, the benefits from mangroves are most evident during more intense tropical cyclone events which cause more flooding and damage, compared to smaller wave-driven flood events. According to these results, most of the population in Old Harbour Bay is not at risk due to wave-driven flooding, including the most vulnerable settlements such as Portland Cottage. Old Harbour Bay is oriented to the prevailing wave conditions (from the Southeast) however, wave propagation to the mangrove areas is interrupted by shallow fringing reefs that produce dramatic wave dissipation by breaking waves. Even so, the results show a clear increase of the total water level ranging between 0.8m (5 years return period) and 1.8m (100 years return period) in the centre of the bay. The role of the mangroves is evident as water levels remain under 1 m over the forested areas (Peake, Colon and Santa Helena Bays) for wave conditions below 50 years return period. Maximum water levels are predicted between Port Esquivel and the Old Harbour power plant where mangroves are not present.

The average differences (between mangrove and non-mangrove) are below 0.4m for the 1 in 100 year storm event. These differences can be largest in the inner parts of the mangrove forest as to the right of the Salt River or leeward of the Great Goat island. In these places, two combined factors make the attenuation more evident: the greater width of mangrove forests and the angle at which waves approach the mangrove forests (i.e., more or less perpendicular).

These reductions in flood heights, though small, can translate into significant protection for people and built capital. In the Old Harbour Bay study site mangroves protect US$3.5 million in built stock every year.

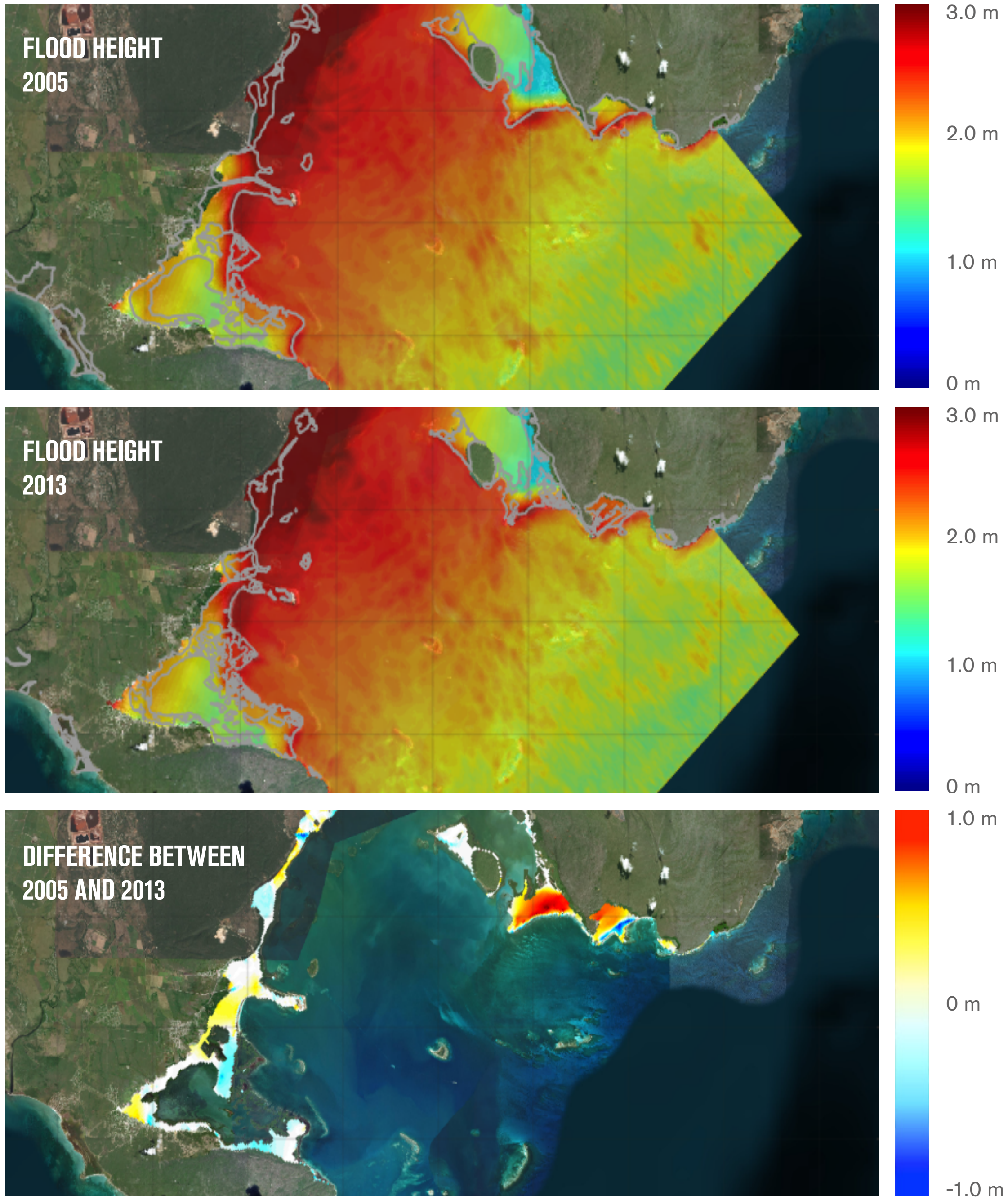


FIGURE 20

Results of the flood height comparison between 2005 and 2013 mangrove extents for a 50-years return period tropical cyclone event. Top left: Flood extent for 2005 mangroves (GOJ data). Top right: Flood extent for 2005 mangroves (GOJ data). Bottom: Differences in flood height between both scenarios.

Between 2005 and 2013, Old Harbour Bay lost 1,811 hectares of mangroves. This degradation in mangrove cover results in an increase in flood height from 0m to 0.4m, reaching in some areas an exceptional 0.8m.

This translates to the value of the lost mangrove area between 2005 and 2013 of US$990 per hectares per yr accounting for an annual total of US$1.8 million of lost mangrove benefits in Old Harbour Bay. Conversely, this represents the potential value of restored mangroves in this region (i.e., US$990 per hectares per yr).

In 2007, category 4 Hurricane Dean passed just south of Jamaica, bringing heavy rain, high winds, huge waves and storm surge, especially to the eastern and south eastern parishes of Jamaica. In Rocky Point and Portland Cottage, 889 houses sustained damage to varying intensity. Approximately 65% of these housing units sustained major damage or were destroyed due to the storm surge. This study shows the places where the presence of coastal mangroves helped reduce flooding and damages during Hurricane Dean. It is noteworthy that despite the presence of a large mangrove forest around the Portland Cottage, flood heights exceeded 4m above the mean sea level, and the water passed from West Harbour to the Carlisle Bay. The comparison between both scenarios indicates that mangroves were able to reduce water levels around 0.3m and 0.6m. This apparently small contribution was responsible for Mitchell Town remaining safe against the storm surge thanks to the protective role of the mangroves, otherwise, a 1m water layer would have covered the streets of the village.

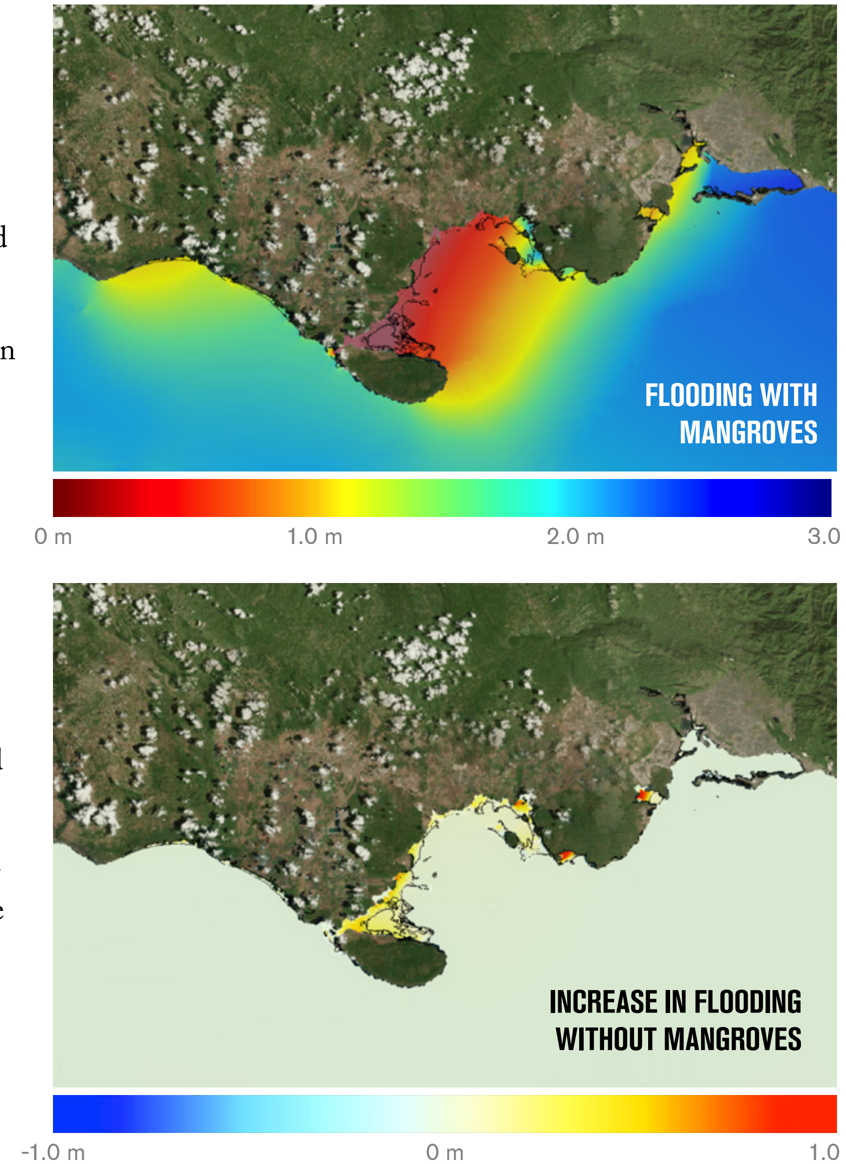


FIGURE 21

Storm surge along the southwestern Jamaica produced by hurricane Dean in August 2007 for the mangrove scenario (upper panel) and differences of removing mangroves from the model setup (bottom panel).

Costs and Potential for Mangrove Restoration

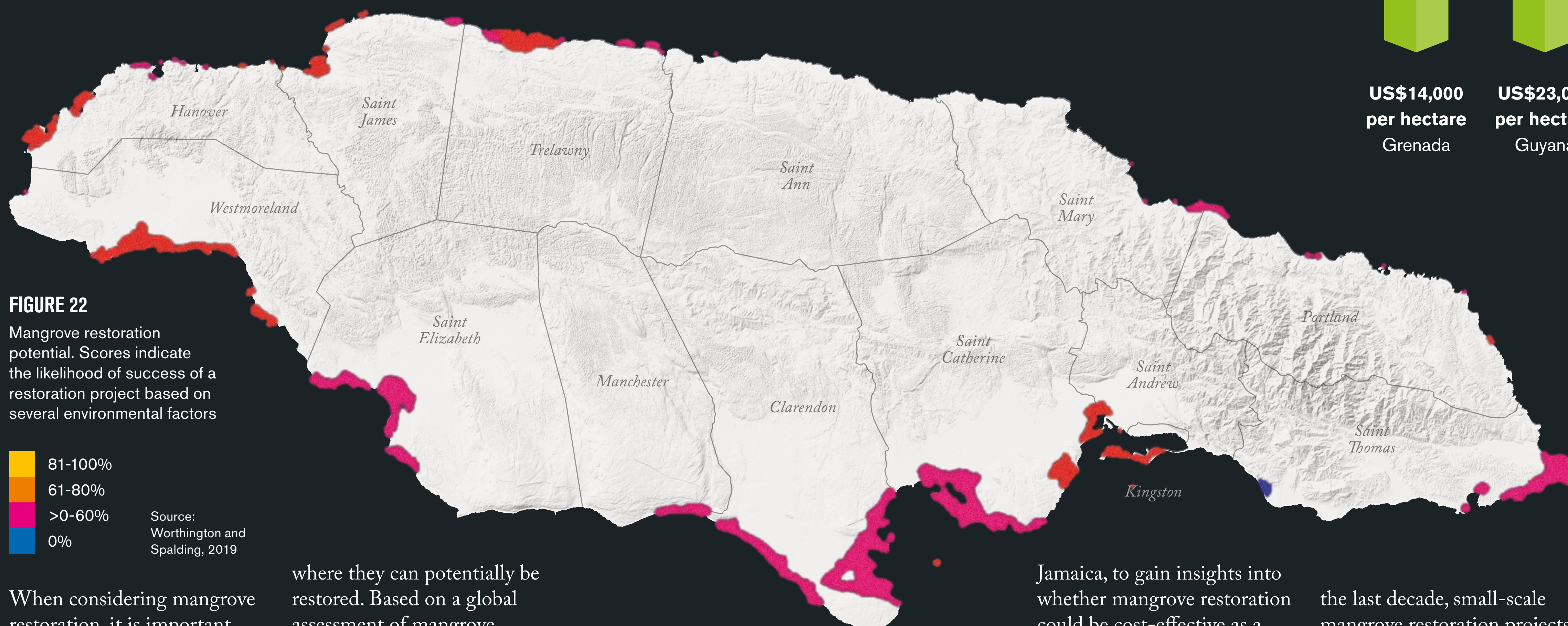


FIGURE 22

Mangrove restoration potential. Scores indicate the likelihood of success of a restoration project based on several environmental factors

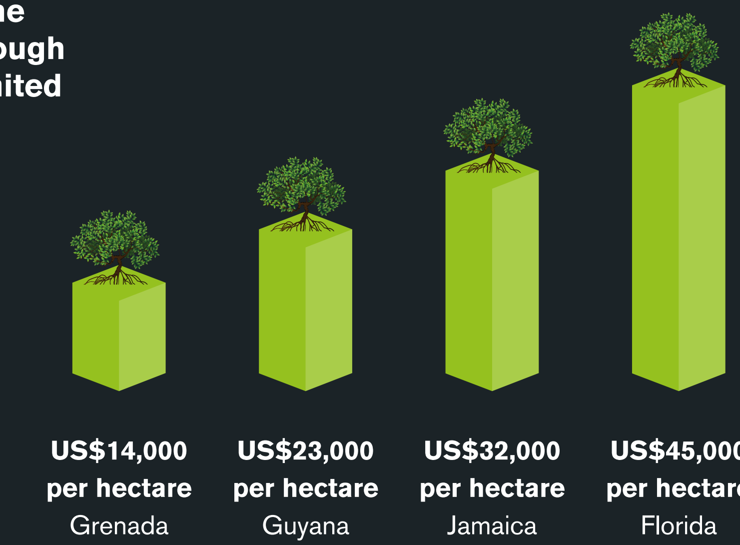
When considering mangrove restoration, it is important to assess where they can be restored and whether such restoration can be cost-effective. The first step in the assessment is to understand where mangroves have been lost in the recent past and where they can potentially be restored. Based on a global assessment of mangrove change, which provides a potential restoration score at the national scale for Jamaica, an estimate of more than 770 hectares of mangroves have been lost in Jamaica over the past two decades. However more than 70% of these mangroves could be potentially restorable. In this Study, the modelled predictions of mangrove benefits was combined with information on the costs of mangrove restoration in Jamaica, to gain insights into whether mangrove restoration could be cost-effective as a coastal protection measure.

While the coastal resilience benefits of mangroves are well recognized, less is understood about the cost-effectiveness of restoring these habitats to provide these benefits. During the last decade, small-scale mangrove restoration projects (totalling a few hundred hectares) have been or are being implemented in Jamaica[47]. Typically, these restoration projects involve either active planting of mangrove saplings in areas with degraded or lost mangroves, or hydrological restoration to establish the right conditions for mangrove establishment[48].

Increasingly, the institutions that fund and manage mangrove restoration projects are focusing on the returns on investment of a project as a means to inform where to prioritize investments in restoration efforts. As a result, mangrove restoration projects are often focused on specific ecosystem service benefits such as carbon sequestration or coastal protection. Yet, poor understanding of the costs of mangrove restoration can limit investments in mangrove restoration for coastal resilience.

Mangrove restoration costs less than US$50,000 per hectare across the Caribbean region though data on costs are limited and variable.

Sample restoration project costs:



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The costs of mangrove restoration can be extremely variable depending on project location and site conditions.

For example, a recent restoration project on Palisadoes road in Kingston was US$250,000 per hectare, which is higher than the regional average. The most significant cost in this restoration project (>80% of total project cost) was for fencing to keep out solid waste. This was necessary at this site but is an unusually high expense and may not have been necessary in other projects in the Caribbean. If not for this expense, the costs of mangrove restoration would be cheaper in Jamaica than observed elsewhere in the Caribbean.

In general, some of the factors that can influence costs include:

1. **Availability and costs of land and permitting**
2. **Costs of obtaining and transporting the material**
3. **Costs of designing and constructing the project**
4. **Costs of monitoring and maintaining the project post-construction**
5. **Restoration technique and availability of local, voluntary manual labour**
6. **Need for hydrological restoration or specialized equipment**
7. **Size and economies of scale**
8. **Maintenance and monitoring activities**

Even the most expensive mangrove restoration projects in Jamaica, and globally, are orders of magnitude cheaper than large coastal protection structures.

In Jamaica, limited data indicate that sea-dykes and levees to protect the Kingston Harbour can cost over US$11 million per km. Generally, across the Caribbean, seawalls and levees on the shoreline can cost up to about US$6 million per km, whereas offshore breakwaters are much costlier at about US$20 million per km. These costs do not include the high expenses for repairing damage or upgrading in response to changes in sea level.

Mangrove restoration is also generally cheaper per hectare than coral reef restoration which range from US$640,000 per hectare (Jamaica) to more than US$1 million per hectare in other areas across the Caribbean region.

On the benefits side of the analysis, it can be shown that given the application of appropriate discount rates, then it is highly likely that a cost benefit ratio would be in favour of the mangrove restoration option. In terms of benefits, one hectare of mangroves in Jamaica provides on average more than US$2,500 per year of direct flood reduction benefits from tropical cyclones; if considered over a 30-year period (with a 4% discount) the average benefits per hectare for a mangrove conservation or restoration project would exceed US$43,000 in coastal protection benefits alone.

It should be noted that this assessment only looks at coastal protection benefits and does not incorporate analysis of other ecosystem services. The cost of avoided damages and carbon sequestration are typically easier to estimate, however the inclusion of additional ecosystems services that may be more difficult to quantify (for e.g. water quality, forest products and erosion prevention) would generate a higher and more accurate estimate of the total benefits from mangrove restoration projects.

4

Local Scale Assessments on Mangrove Ecosystems Status and their Role in Coastal Resilience

Lead Authors: Arpita Mandal[1], Rose-Ann Jasmine Smith1, Taneisha Edwards[1], Robert Kinlocke[1], Simon Mitchell1, Camilo Trench[2], Mona Webber[2], Patrice Francis[2], Adrian Spence[3]

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2. Institute of Marine Sciences, University of California Santa Cruz, Santa Cruz, CA, USA
3. The Nature Conservancy, Arlington, MD, USA

Brief methodology

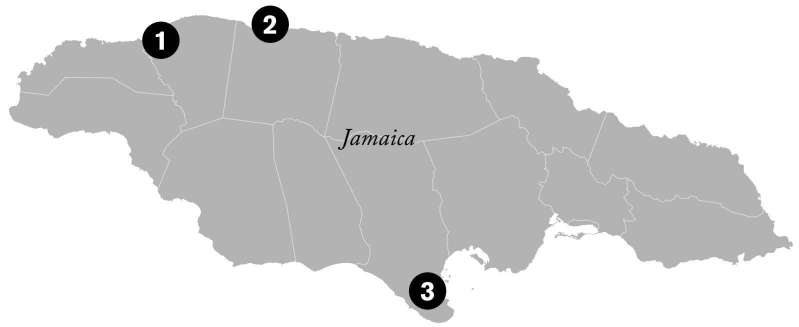
The sites for the study were selected based on consultation with NEPA, World Bank, local on-the-ground organizations, as well as through field visits.

The primary considerations were:

- Proximity to the communities
- Mix of sheltered site and one that is more open to wave energy
- Plots where there are no major pools or channels
- Ease of accessibility by land was a consideration but not a priority

The three sites selected were:

1. **Bogue Lagoon in Montego Bay, St. James**
2. **Salt Marsh in Falmouth, Trelawny**
3. **Portland Cottage in Portland Bight, Clarendon**



Data Collected in Each Location

ECOLOGICAL ASSESSMENT AT THE LOCAL LEVEL

- Mangrove species composition and relative abundance (for diversity)
- Mangrove Trunk Diameter (DBH)
- Mangrove height and canopy width
- Prop roots/aerial roots network
- Ecosystem services: Fisheries production using light-traps to collect fish larvae and other water column fauna

PHYSICAL ASSESSMENT

- Flooding and Coastal Erosion
- Sediment Sampling and Assessment
- Surface Accretion and Soil Surface Elevation
- Wind Data and Wave Parameters
- Water Quality and Soil Health
- Bathymetry and shoreline dynamics

SOCIO ECONOMIC ASSESSMENT AT THE LOCAL LEVEL

- Assessment of poverty levels
- Mangrove habitat goods & value extracted
- Current provision of services provided by mangroves
- Perception of coastal protection from mangroves
- Observed changes in mangroves
- Willingness amongst the people to participate in mangrove restoration

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Bogue Lagoon

Socio-Economic

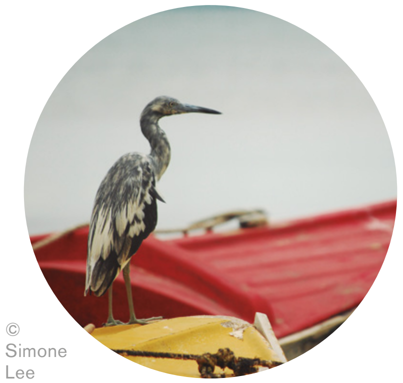
SOCIO-ECONOMIC CONTEXT

Bogue Lagoon is located 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. Some 60 businesses were interviewed to gather data.

Most of the respondents (66%) had tertiary education, with 46% having university degree. The mean length of business operation was about 12 years. On average, businesses had about 11 employees, with the maximum number of employees being 70. The maximum value of business was close to US$2.9 million, while the mean value was approximately US$21,000.

BOGUE LAGOON



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SENSITIVITY

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 (20%) was above the level of the wall skirting. Twenty percent of the respondents also reported that they were prevented from going to work due to the effects of flooding. Specific reference was made 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. It generally appears that 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

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. Only one business indicated that it secured flood insurance as a means of mitigating future impact.

ISSUES AFFECTING MANGROVE SERVICES

Decreases in the mangrove forest was also a noteworthy observation by most respondents (46%) in Bogue Lagoon area. Most of the respondents who provided reasons for this attributed it to the removal of the mangrove forest for development, particularly for tourism and industrial.

Shoreline development (land reclamation) and shoreline erosion were reported by 75% and 57% of respondents respectively as having a big impact on the mangrove forest.

Pollutants including garbage, sewage and industrial affluent are considered to be the major issues facing mangrove forest. Pollution not only affects mangrove growth, but also restoration activities.

Some 71% of respondents said that waste disposal (garbage and sewage) is having an adverse impact on the mangrove forest. Most (60%) also said that deforestation was having a very big impact on the mangrove forest.

MANGROVE MANAGEMENT AND RESTORATIVE EFFORTS

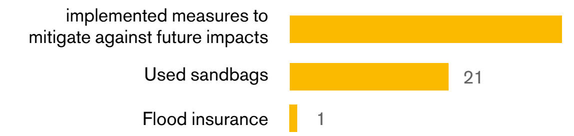
Bogue Lagoon provides a great opportunity for private public partnerships involving business stakeholders.

It should be noted that 21 respondents were managers of businesses in the Bogue area and 76% expressed their willingness to become involve in restoration activities. There was no statistically significant difference between male and female respondents.

FIGURE 23

Strategies to minimize the effects of floods

Percentage of respondents

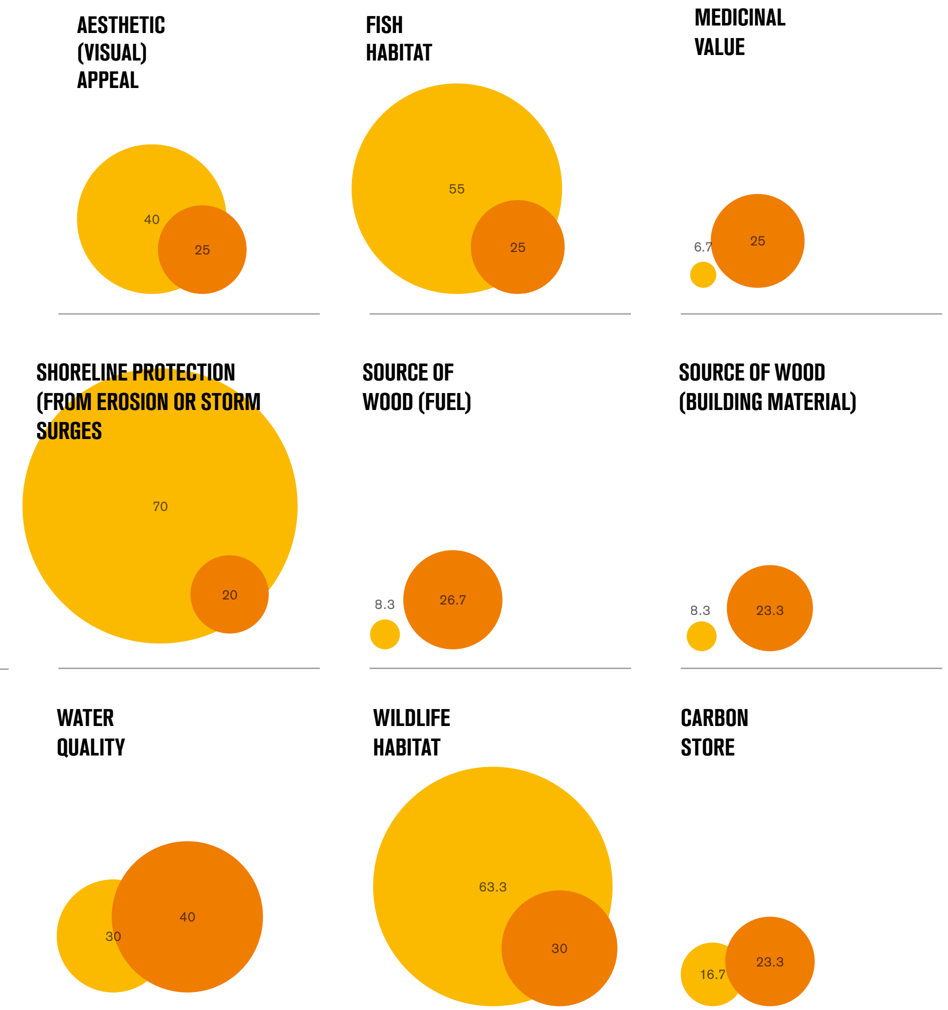


Mangrove Value

Percentage of respondents

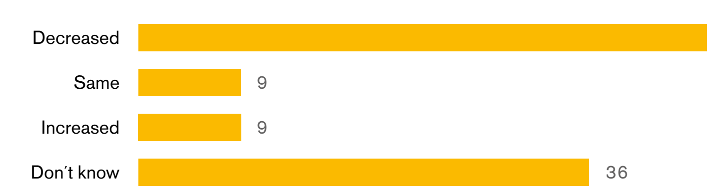
Very important

Important



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

Percentage of respondents



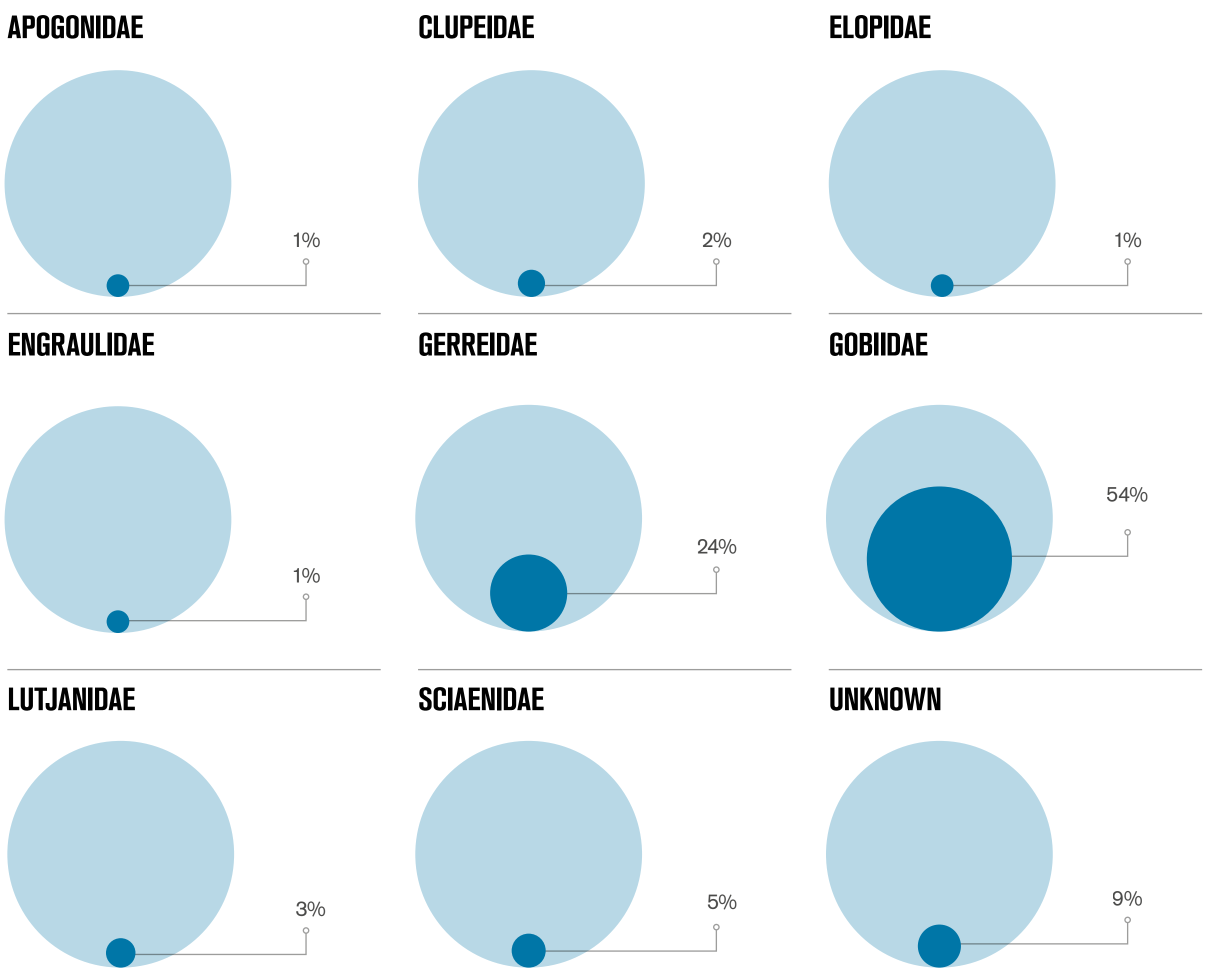
Site 1

Total percentage

Percentage contribution

FIGURE 24

Percentage contribution of each family at Site 1 and Site 2, Bogue Lagoon.



ECOSYSTEM SERVICES

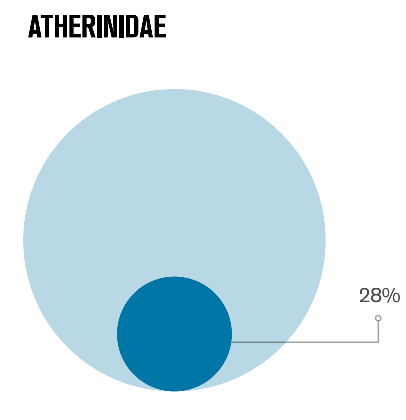
Fisheries production using light-traps to collect fish larvae and other water column fauna.

While ichthyoplankton abundance and species richness varied significantly between the 3 mangrove areas and so could be plotted for comparison, 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 so as to accurately represent the larvae associated with these mangrove areas.

Site 2

Total percentage

Percentage contribution



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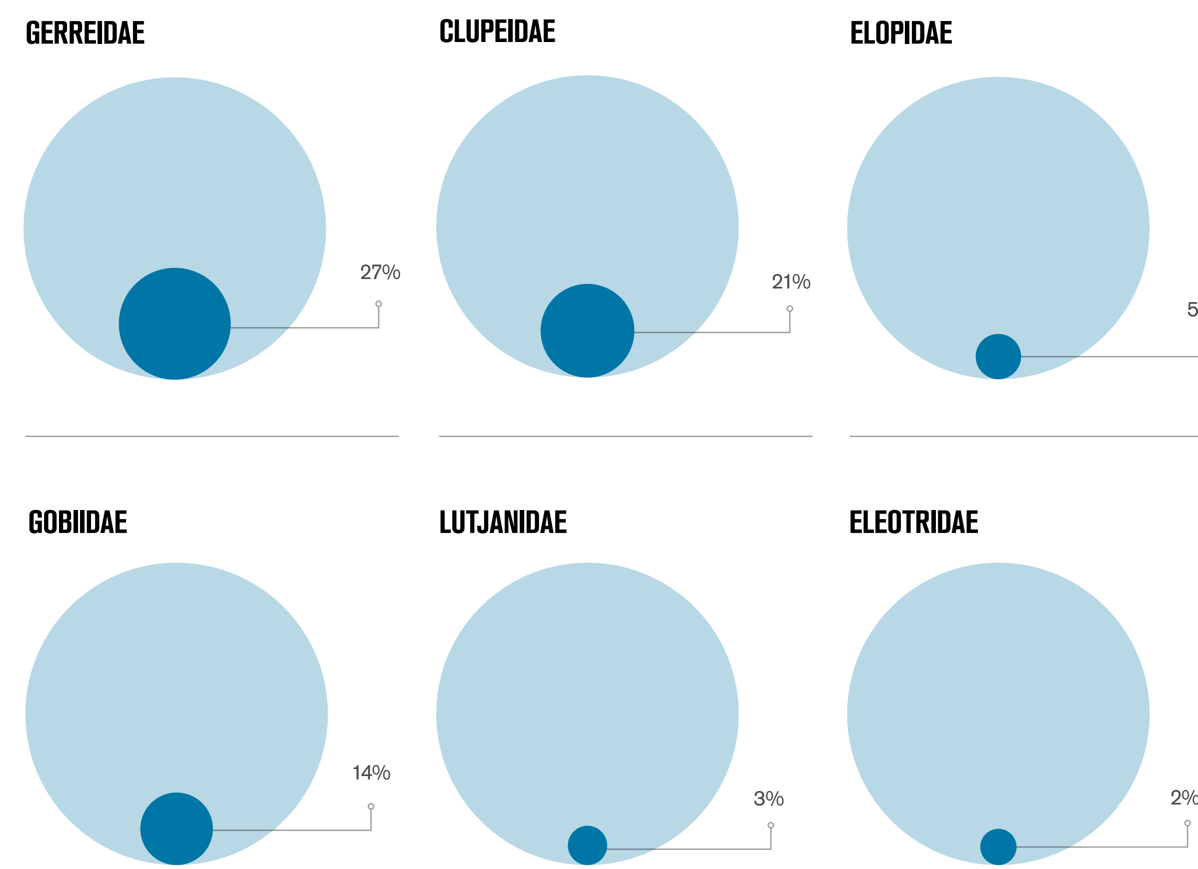


BOGUE LAGOON

Ecological

FIGURE 25

Mangrove Biometrics at Bogue Lagoon.

Mangrove species composition and relative abundance (for diversity)

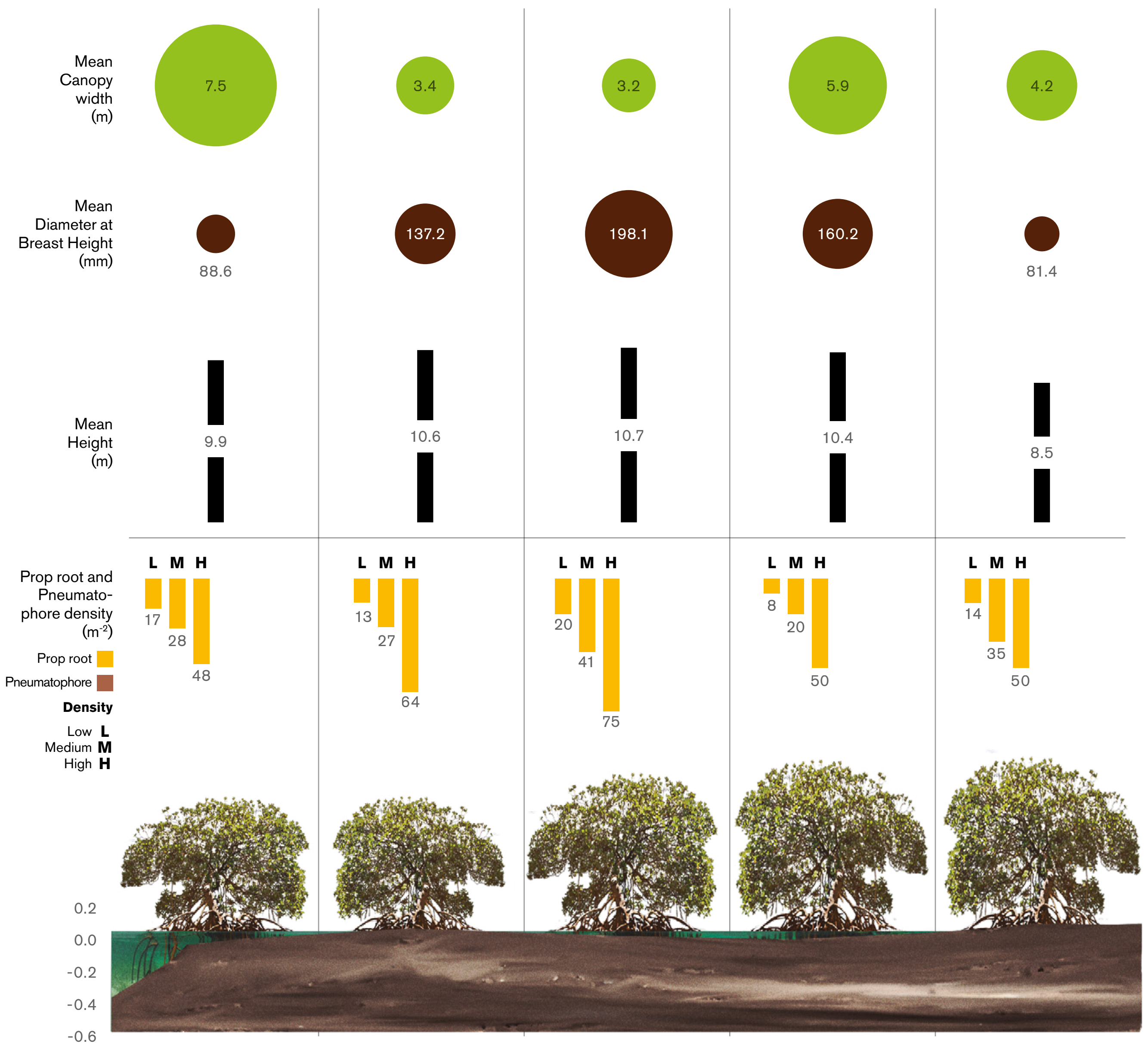
0.08 Trees of red mangrove by m²

Mangrove species composition and relative abundance (for diversity)

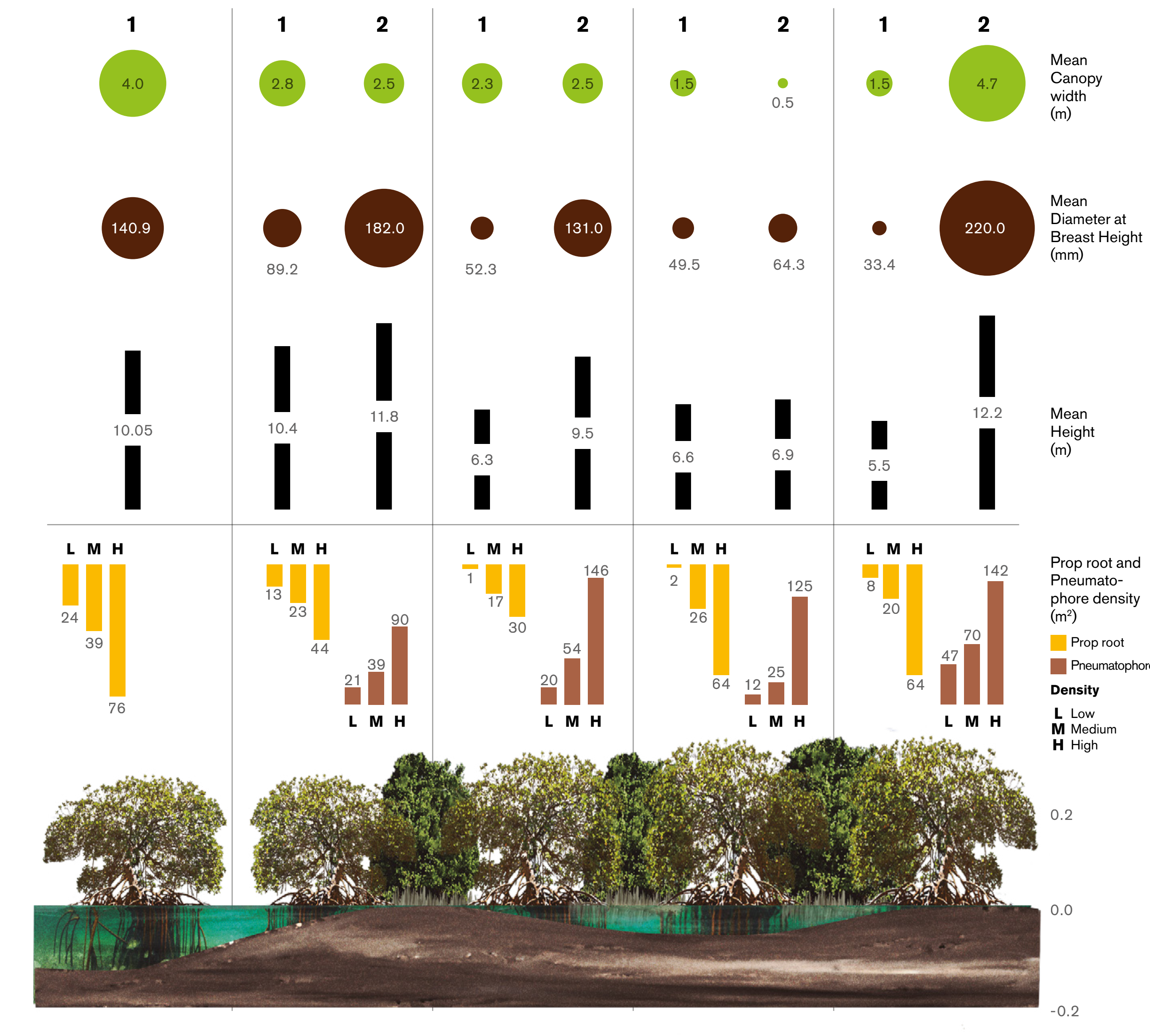
1 0.12 Trees of red mangrove by m²

2 0.02 Trees of white mangrove by m²

Site 1



Site 2



Mangrove Biometrics

MANGROVE SPECIES COMPOSITION AND RELATIVE ABUNDANCE (FOR DIVERSITY)

Mangroves tend to grow in relative monospecific stands within a forest.

Low diversity is therefore expected within mangrove ecosystems as "succession and species accumulation is inhabited". Species such as white mangrove *(Laguncularia racemosa)* has a greater ability to regulate internal osmotic conditions and thus do better in hypersaline conditions.

MANGROVE HEIGHT AND CANOPY WIDTH

It has been established that mangrove tree height typically decreases with increasing salinity.

Mangrove trees often experience 'normal' salinity or is lower at the water's edge, but hypersaline conditions often progress further from the sea.

PROP ROOT/AERIAL ROOT NETWORK

Similar studies concluded that red mangrove *(Rhizophora mangle)* "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". 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. A decrease in density towards land was expected due to the red mangrove trees at the water's edge having a better opportunity to grow higher and denser because of tidal inundation.

Previous studies also saw pneumatophore density varying in similar manner to the tree height and Diameter at Breast Height (DBH). The study 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.

Physical

Physical status of the mangrove ecosystems

ELEVATION AND TOPOGRAPHY

The site has a moderately undulating terrain which influences the biogeography of the mangrove species with red mangrove occupying most seaward and at the lowest elevations, and white mangrove occupying more landward or higher elevations.

Pockets of different or no species of trees can be found in a zone based on the change in elevation.

The transect at Site 1 in Bogue Lagoon had an elevation that ranged from 0.4m below Mean Sea Level (MSL) to 0.02m above MSL. As a result, the transect was often inundated by water and the red mangrove species 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.

ELEVATION CHANGE

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 also 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.

SEDIMENT AND LITTER RETENTION, AND ACCRETION

Despite having abundant re-emergent stream and influence of the Retirement/Montego River, there was no measureable vertical accretion at either sites over a 3 month or 6 month period.

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, 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 substrates vertical accretion in anoxic conditions.

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. Questions about the ability of a mangrove system to withstand subsidence and rising sea-level depends on its health, root production, leaf

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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 root 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 and other anthropogenic stressors.

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.

BOGUE LAGOON

HORIZONTAL VARIATION (PROGRADATION/ RETREAT) OF MANGROVE COASTLINE

The length of the coastline that has accreted is 2.46km 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 214m^2 per year. It should be noted that the site of the accretion has a large sewage treatment system behind it which may enhance its growth and stability.

It has been 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 (1.04km) 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 per year 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 previous studies, showing that activities limited to a particular plot of land can actually cause harm to other areas. 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.

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.

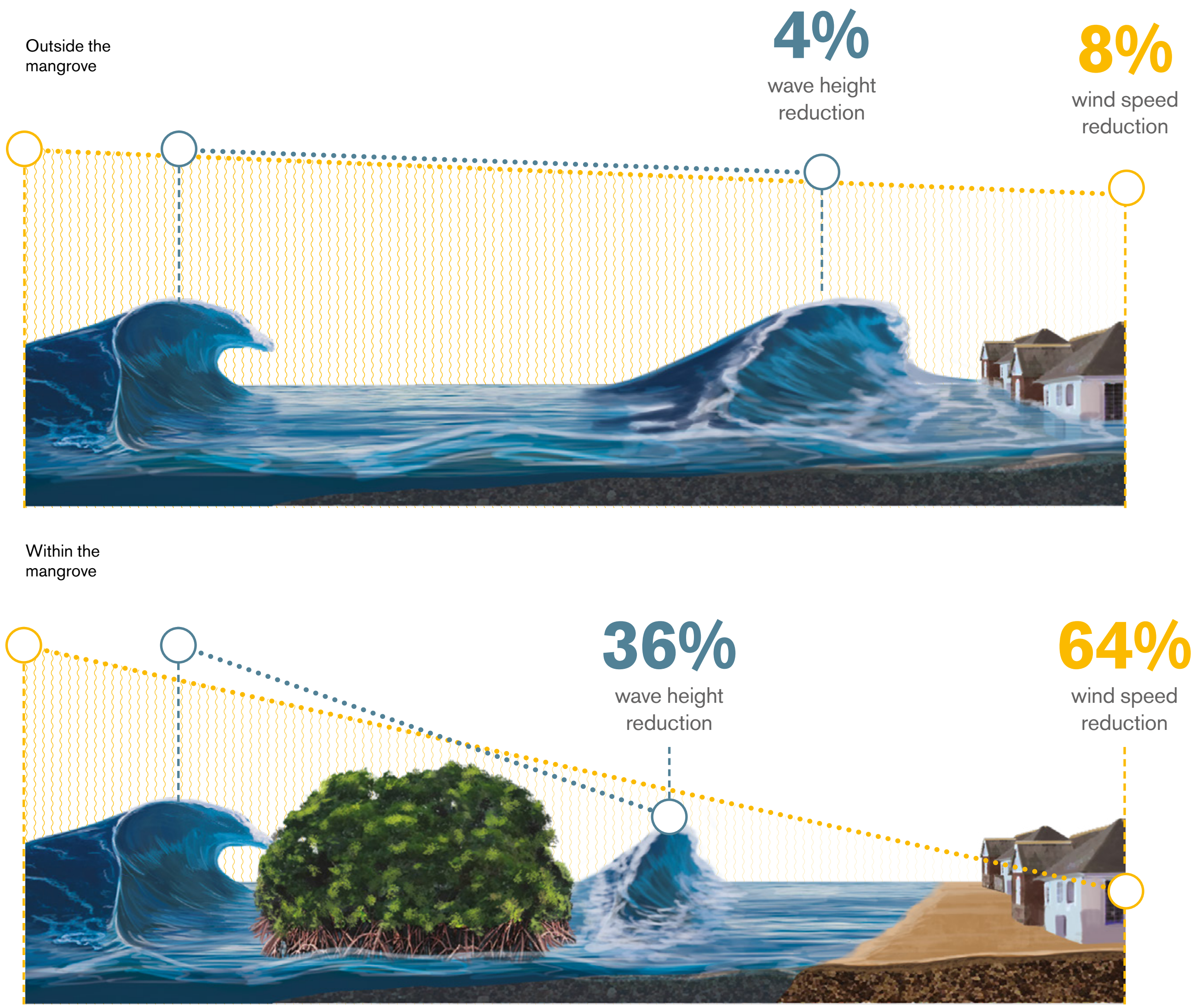
FIGURE 26

Spatiotemporal lateral erosion (red) or accretion (yellow) on the coastline from 1961 to 2017, where mangrove trees occupation increases migrates seaward or retreats landward.

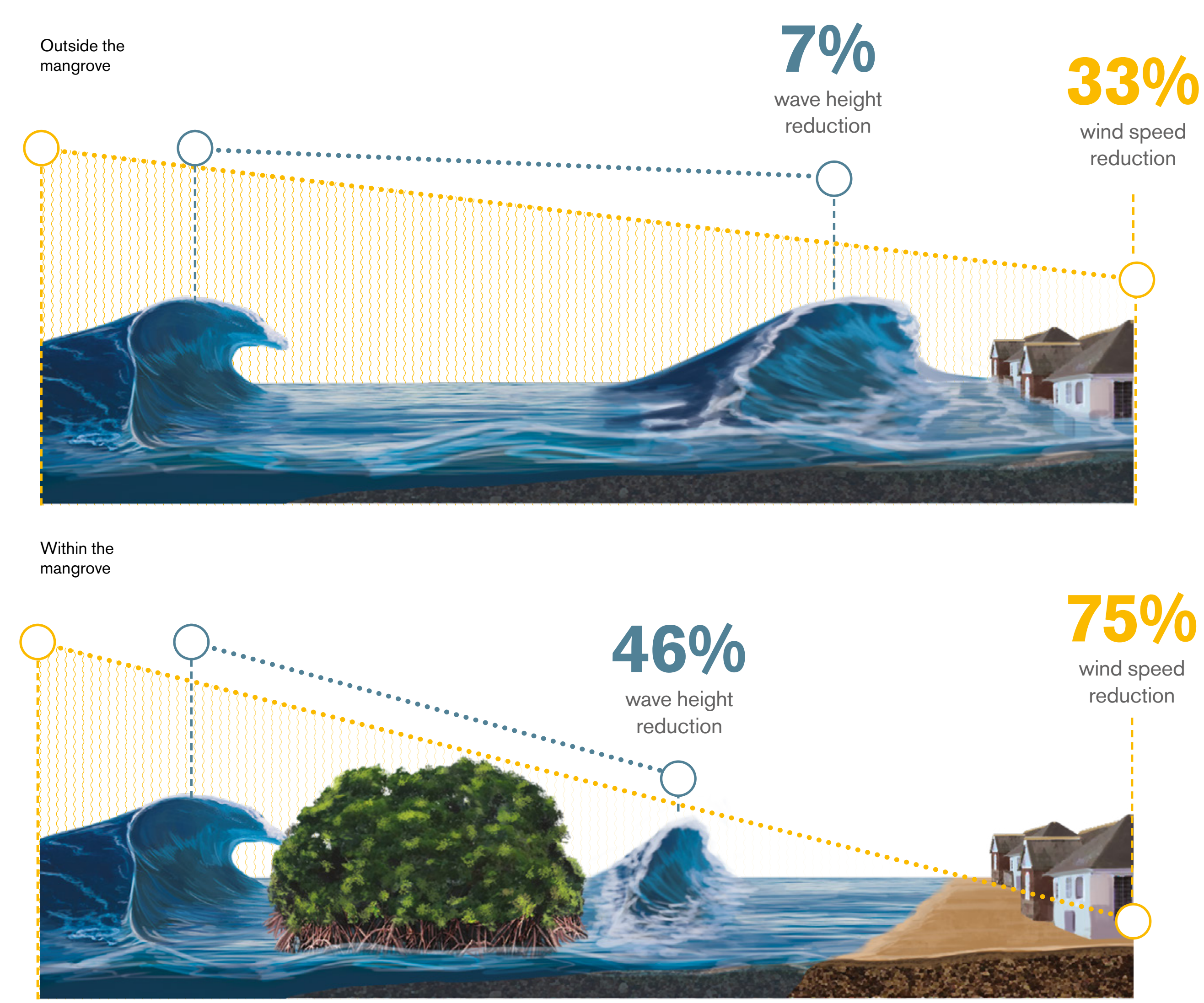
Mangrove Cover Source: UCSC.
Image: NASA, ESRI.

BOGUE LAGOON

Site 1



Site 2



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.

Reduction of wind speed outside the mangrove forest is as a result of resistive (frictional) forces, however retardation is accelerated within the mangrove structure.

For every 1 m distance a wave travels within the red magnroves, it is attenuated by 0.8%.

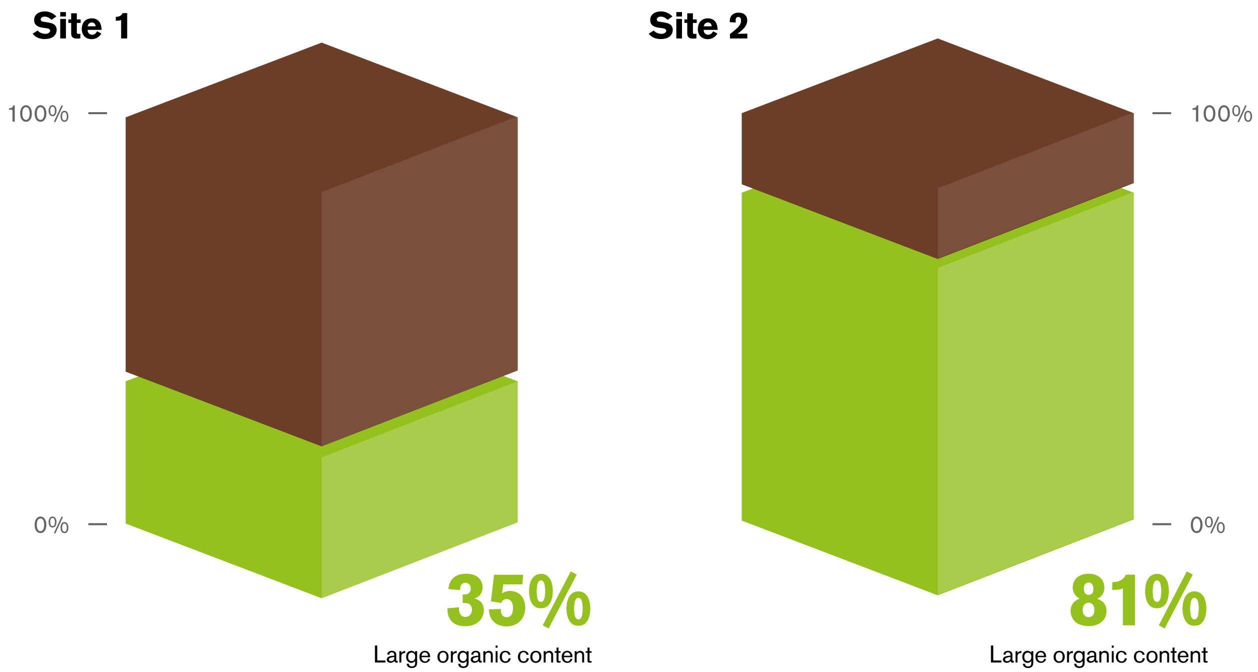
Generally, the waves are gentle wind waves in this sheltered setting, but in the event of a storm these attenuation rates will make a significant mitigation, which would be absent where there are no mangrove trees (especially red mangroves). Their roots serve to reduce the speed, energy and wave height and offer substantial ecosystem services in a micro-tidal regime affected by occasional storms. Some resistive forces from the sea-floor retarded the waves outside the mangrove's seaward limit including sea-grass.

FIGURE 27

Depicts percentage reduction in wind and wave energies outside and within the mangrove at Bogue Lagoon.

Waves have been oversized for easy interpretation.

BOGUE LAGOON



SUBSTRATE CONSTITUENTS AND PROPERTIES

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. The coarse-grained carbonate component of the sediment at Site 1, consisted of small molluscs, foraminifers, broken plates of Halimeda (green marine algae) 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.

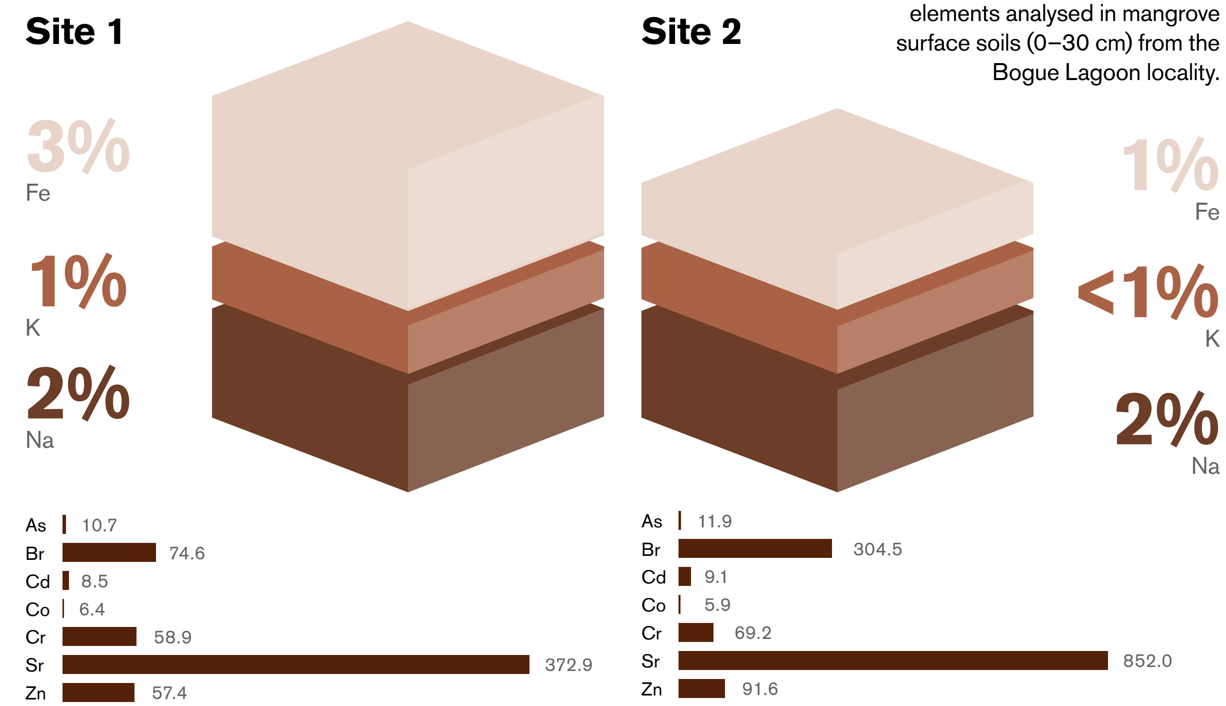
Transport may have occurred during past storm events, as no evidence of fluvial sediment coming in (precipitation events) is recognised. This again points to low sedimentation rates and vulnerability of the mangrove, as it will not be able to trap sediments if sediment is not being provided and redistributed in the system. 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 by percentage weight on a texture classification of soils, for the Bogue Lagoon in areas where samples were collected, with one exception from Site 1 that plots as a silty sand.

FIGURE 28

Mean plant percentage removed by handwashing together with percentage loss from hydrogen peroxide digestion of organic matter for each studied at Bogue Lagoon.

FIGURE 29

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



Soil Quality

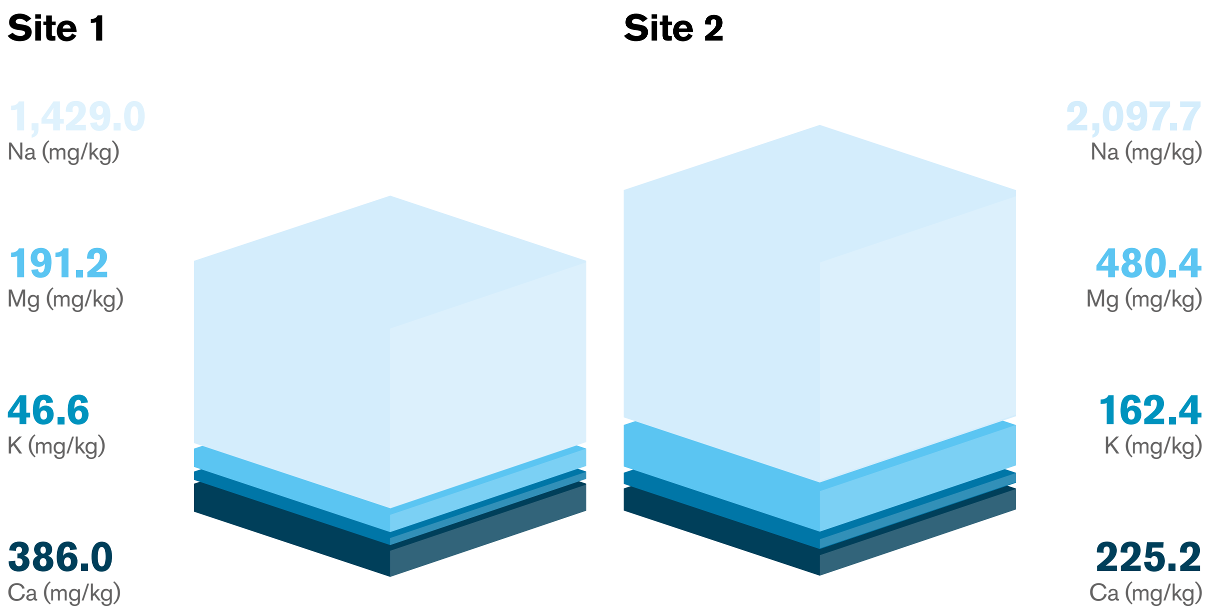
ECOSYSTEM CARBON BIOGEOCHEMISTRY

The Soil Organic Matter (SOM) and Soil Organic Carbon (SOC) contents of the soils varied within and between sites. 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% to 31% (median 16% and mean 15%), while that of Bogue Lagoon Site 2 ranged from 8% to 73% (median 46% and mean 43%). 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: 2%, 18%, 9% and 9%; and 5%, 42%, 27% and 25%, respectively.

At Bogue Lagoon the mean concentrations of As, Cd, Co, Cr, Fe, K and Na in the soil 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.

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

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.



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.

FIGURE 30

Water quality parameters determined in situ at Bogue Lagoon.

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

Results would suggest that freshwater inflows (ground and surface) are probably an important control on salinity of this ecosystem. The Dissolved Oxygen (DO) concentrations at the Bogue Lagoon sites generally fall below the threshold concentration (5mg 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 is characteristic of bicarbonate species of marine origin, but there may also be contributions from the dissolution of carbonates in the underlying limestone bedrock.

FIGURE 31

Water quality parameters determined in situ at Bogue Lagoon.

ELEMENTAL WATER QUALITY

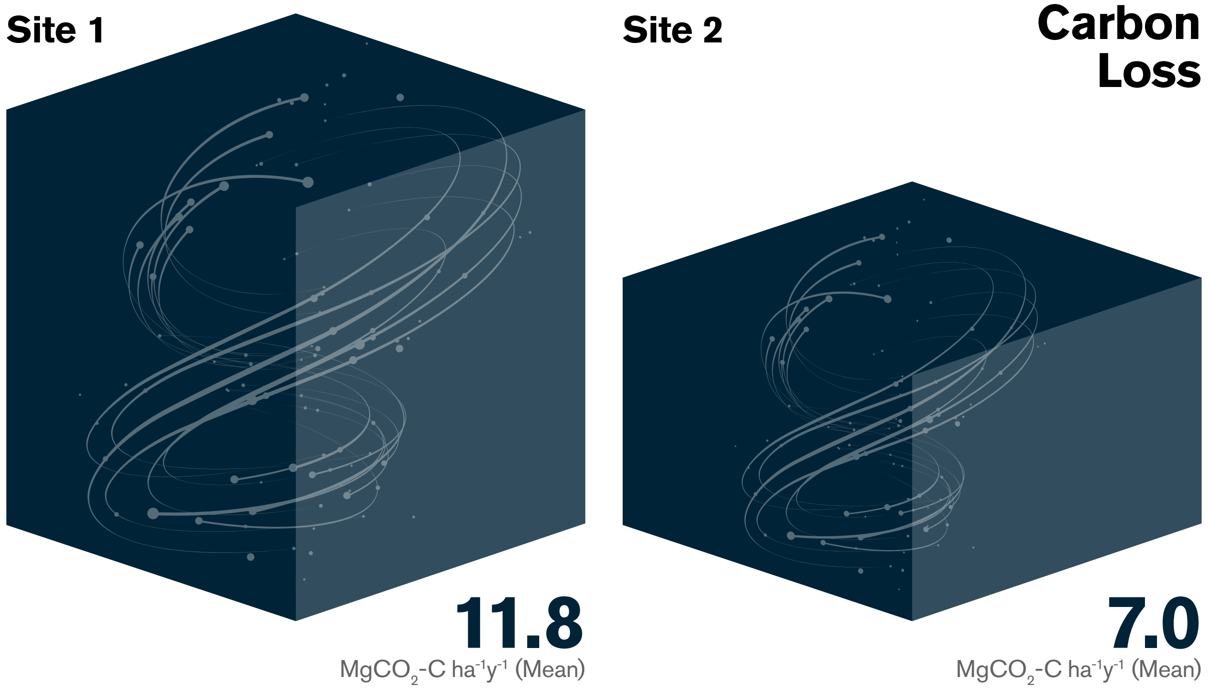
These elements are essential for plant growth, and can be further divided in macronutrients (K, Ca, Mg) and micronutrients (Na) as a function of the quantity in which they are required for plant growth. While there is no discernible pattern in the data, the mean concentration of Ca appears to be higher 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 about 2 for Site 1 and less than 1 for Site 2. These values would suggest that there is limited lithological control on water chemistry. These results are consistent with background concentrations of dissolved ionic species in local waters free of contamination from industrial processes and atmospheric deposition.

While the data presented here provide some context for water quality and ecosystem health, it is also important to note that for a comprehensive overview of water quality and ecosystem health, indicators such dissolved organic matter, faecal coliform, phosphates and nitrates (beyond the scope of this Report) should be considered. 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.

BOGUE LAGOON

FIGURE 32

Carbon Loss



SOIL CARBON FLUX AT BOGUE

The primary losses of carbon form mangrove ecosystems are due to tidal export and mineralization by soil microbiome (autotrophic respiration).

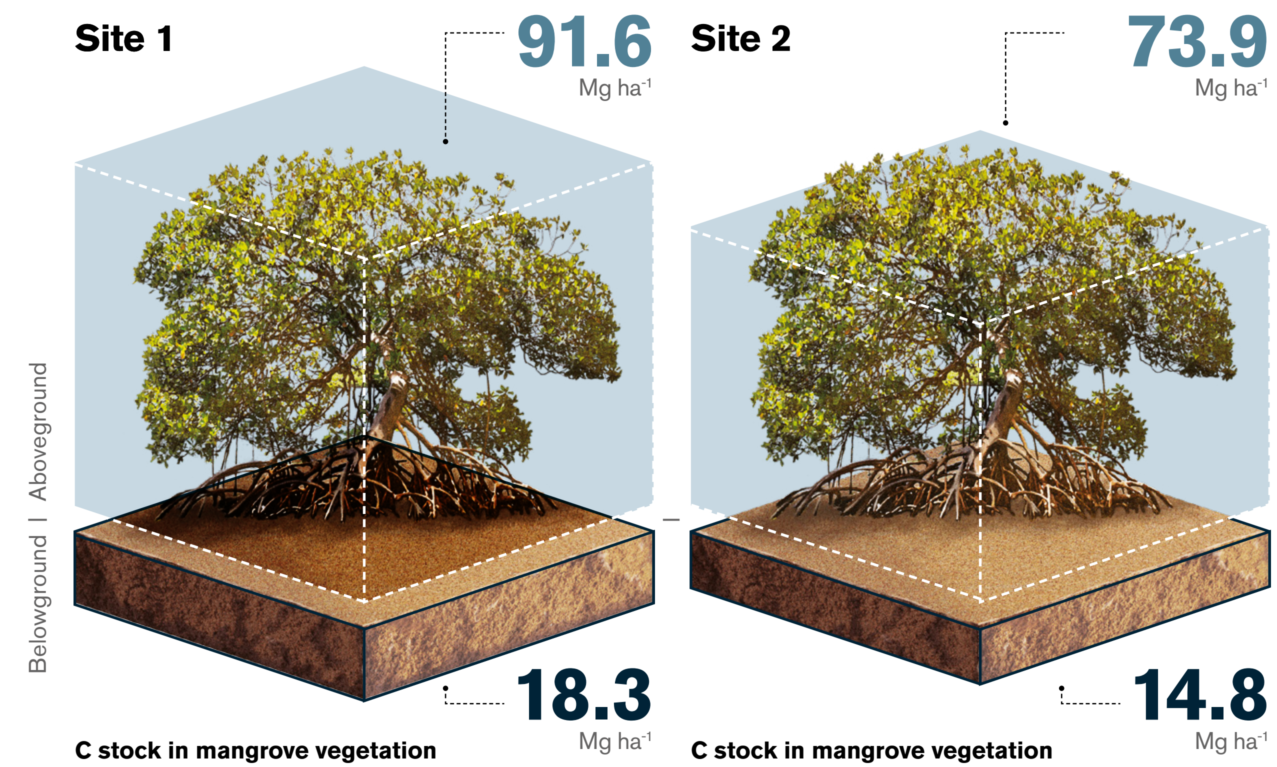
These variations may be due in part to the transitions between well aerated sandy soils (of varying organic content) to organic-rich soils inundated by marine waters. Additionally, variation in soil temperature at the local sites, differences in the quantity and quality of DOC, and losses of mangroves due to natural and anthropogenic forcing may play crucial roles.

Generally, low soil flux rates would suggest that there is little or no SOM or 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 AT BOGUE

When considered with net primary productivity, this data set may be used to provide insights into the whole-ecosystem carbon stocks. Overall, both sites appear to be significant carbon sinks. This area is also wet mostly, but is not always inundated by water, and is mostly colonized by red mangrove based on the geomorphological suitability of that species to occupy areas with maximum inundation.

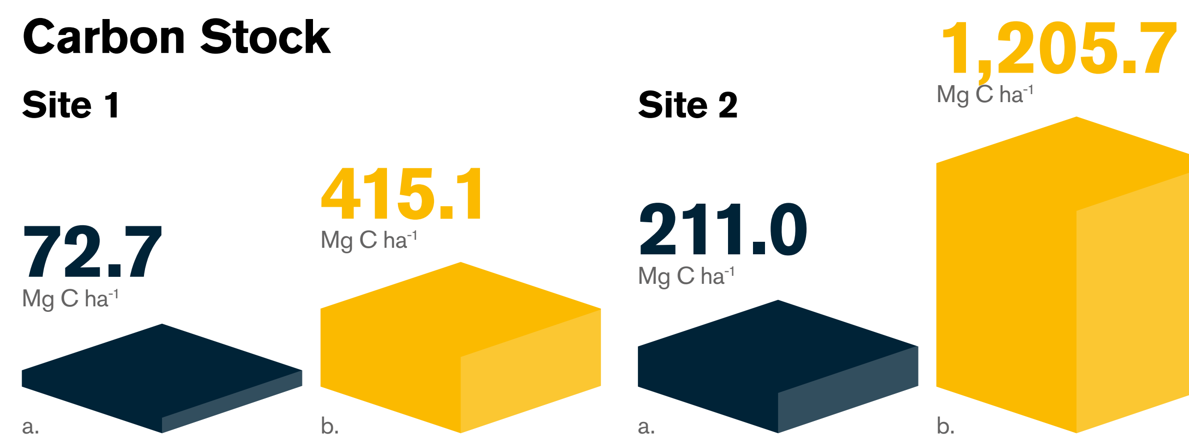
Biomass



Site 1 — **C stock in mangrove vegetation** (Mg ha^{-1}) 51.7

Site 2 — **C stock in mangrove vegetation** (Mg ha^{-1}) 41.7

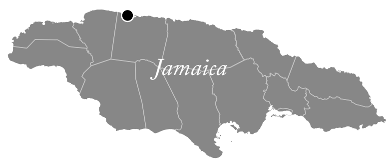
Carbon Stock



a. Stock estimates (Mg C ha^{-1}) determined using the mean bulk density value of regional mangrove soils[49]
b. Stock estimates (Mg C ha-^{1}) determined using bulk density value from a pedotransfer function[50]

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. Although primary data collected was not specific to household heads, majority of respondents (48%) have secondary school education and only 7% have university level education. About 25% have less than secondary education. There was no statistically significant difference between gender and education level.

Primary data revealed that the main household income is through self-employment (45%) followed by employment in the private sector (41%). Although remittance as a source of income for 5% households, it is possibly an important additional source of income for 28% of households who reported that they received remittances in the last 6 months. For the 78 respondents who responded to whether the households were able to save from their last income, the results show majority (51%) of households said yes. Still, a large percentage (49%) 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, 52% owned the land, while a notable 26% were squatters. Majority of the houses of the sample population (72%) are constructed from concrete and blocks. Additionally, most households had access to electricity. Some 79% have water piped into their dwelling and only 9% used pit latrines.

SALT MARSH

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Vulnerability to Coastal Flooding

EXPOSURE

Like Portland Cottage and Bogue Lagoon, 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. 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.

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. Approximately 9% of the individuals residing in the households surveyed attained tertiary level education – a proportion that closely approximates national levels of 8%. Unemployment rates approximated 16% and may also be considered to align closely with national estimates.

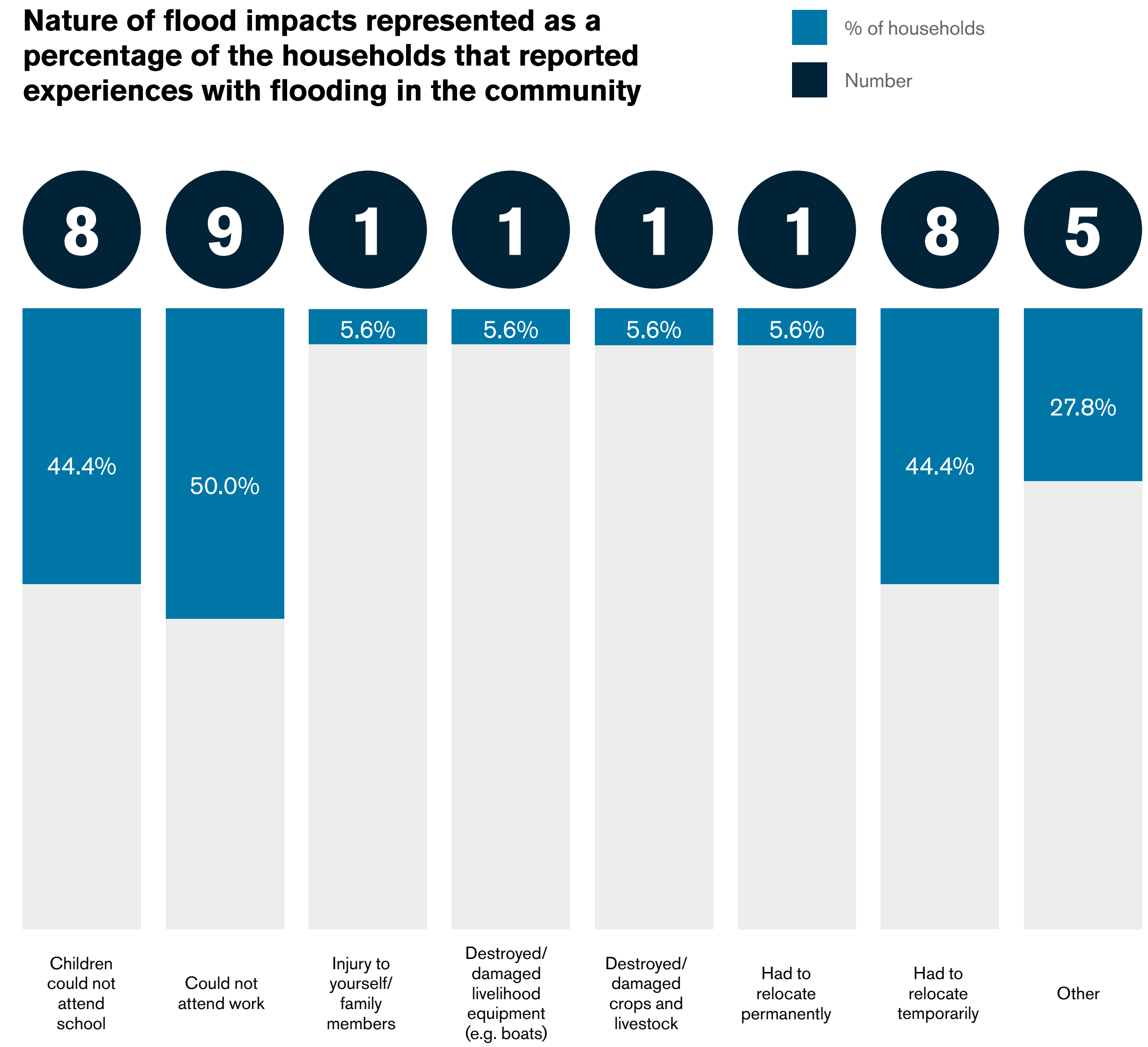
Reported income levels, for the month prior to the survey, were generally low as median income was US$120. Approximately 47% stated that they were able to save from last month's income and 12% indicated that they had outstanding loans. The fact that several of the respondents had relatively favourable 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.

PERCEPTION OF ECOSYSTEM SERVICES PROVISION

The survey did not reveal many fisher folk. Only 14 persons (17% of the respondents) said that there were fishermen, and only 6 of these respondents

FIGURE 33

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



reported that fishing was done in the mangrove, mainly for domestic use and to a lesser extent commercial sales.

Still, oysters, shell, shrimps and crabs are some of the other catch extracted from the mangrove. It is therefore not surprising that majority (95%) of the respondents stated that do not earn any other income or livelihood from the mangrove.

ISSUES AFFECTING MANGROVE SERVICES

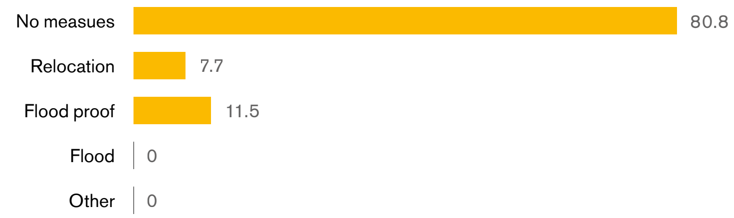
In Salt Marsh, 46% of the respondents reported a decrease in the mangrove forest. A qualitative look at the reasons for these changes revealed that majority of the respondents (24 respondents) attributed it to the cutting down of trees particularly for housing development.

SALT MARSH

FIGURE 34

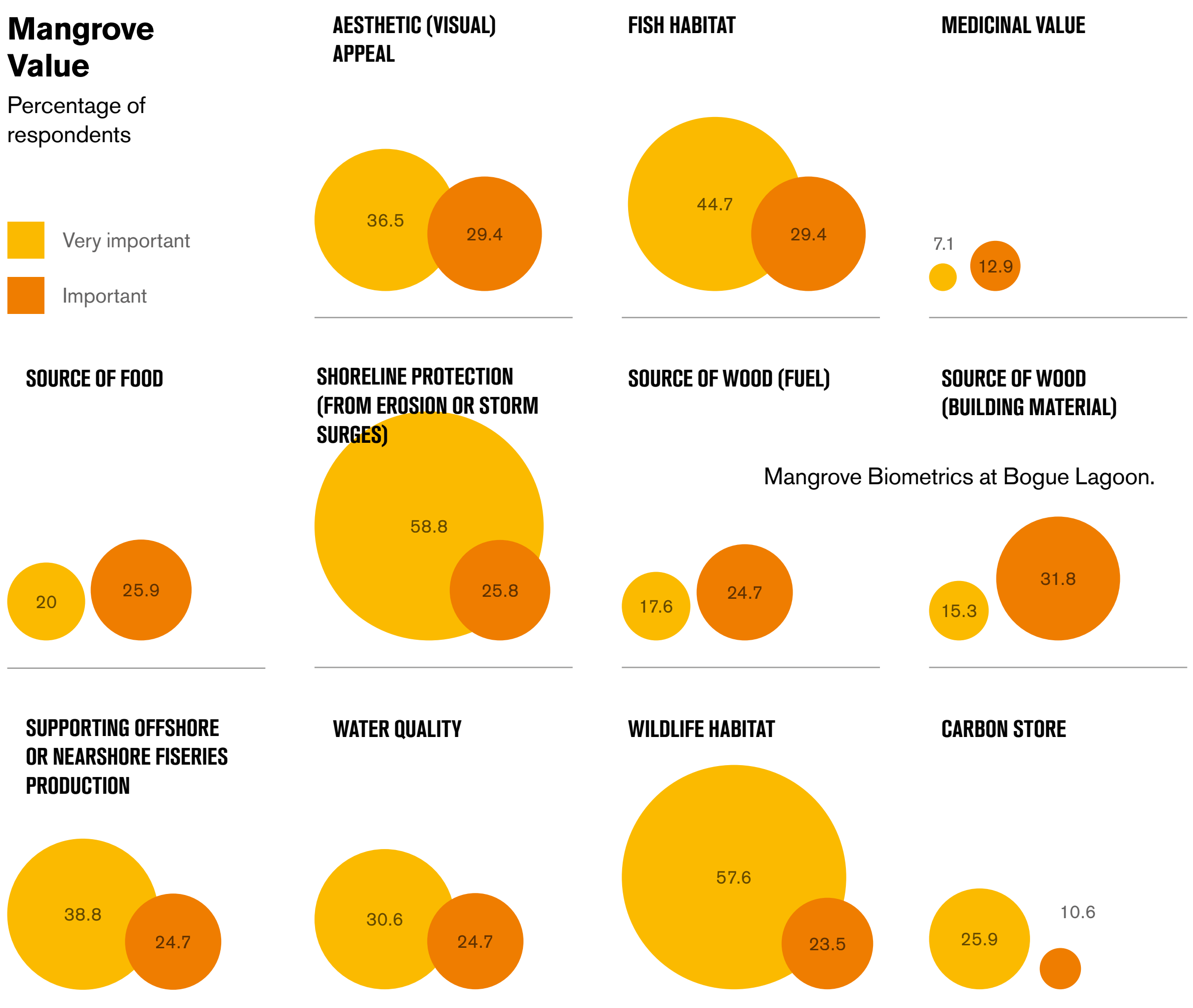
Measures implemented to reduce impact of future flood events

Percentage of respondents



Mangrove Value

Percentage of respondents



Observed changes in mangrove forest in Salt Marsh for the last 10 years (2008-2018)

Percentage of respondents

Mangrove Biometrics at Bogue Lagoon.

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MANGROVE MANAGEMENT AND RESTORATIVE EFFORTS

Opportunities for Private Public Partnership

Respondents in Salt Marsh show a strong willingness to become involved in mangrove restoration activities with the majority (67%) expressing that interest, and only 25% and 8% saying 'no' or 'don't know' respectively. There was no statistically significant relationship in looking at the data by gender.

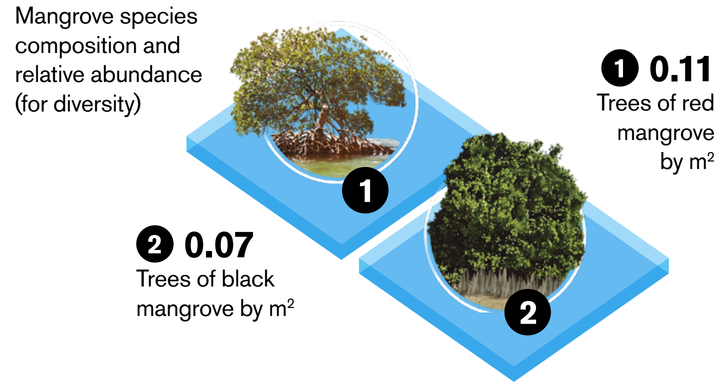
However, the majority of the residents (94%) are not currently involved in mangrove restoration activities. There is therefore an opportunity and a need to involve the community into such activities that may not only minimize the current negative impacts on mangrove forest, but also promote its growth and restoration.

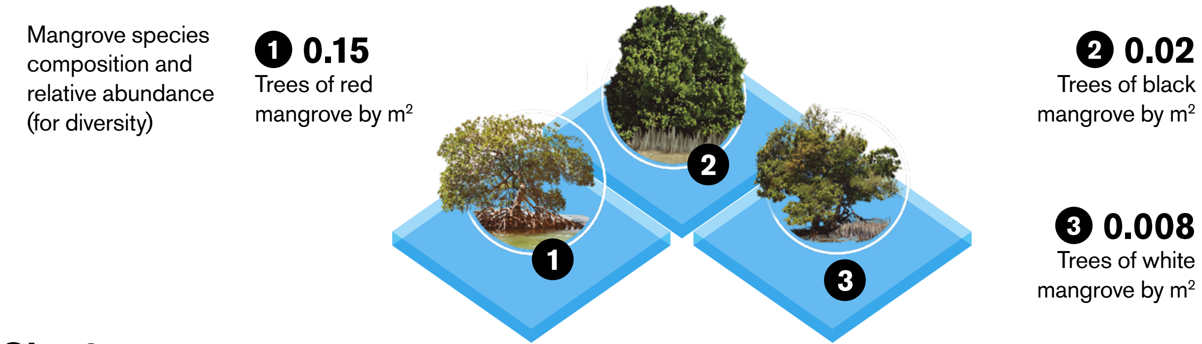
SALT MARSH

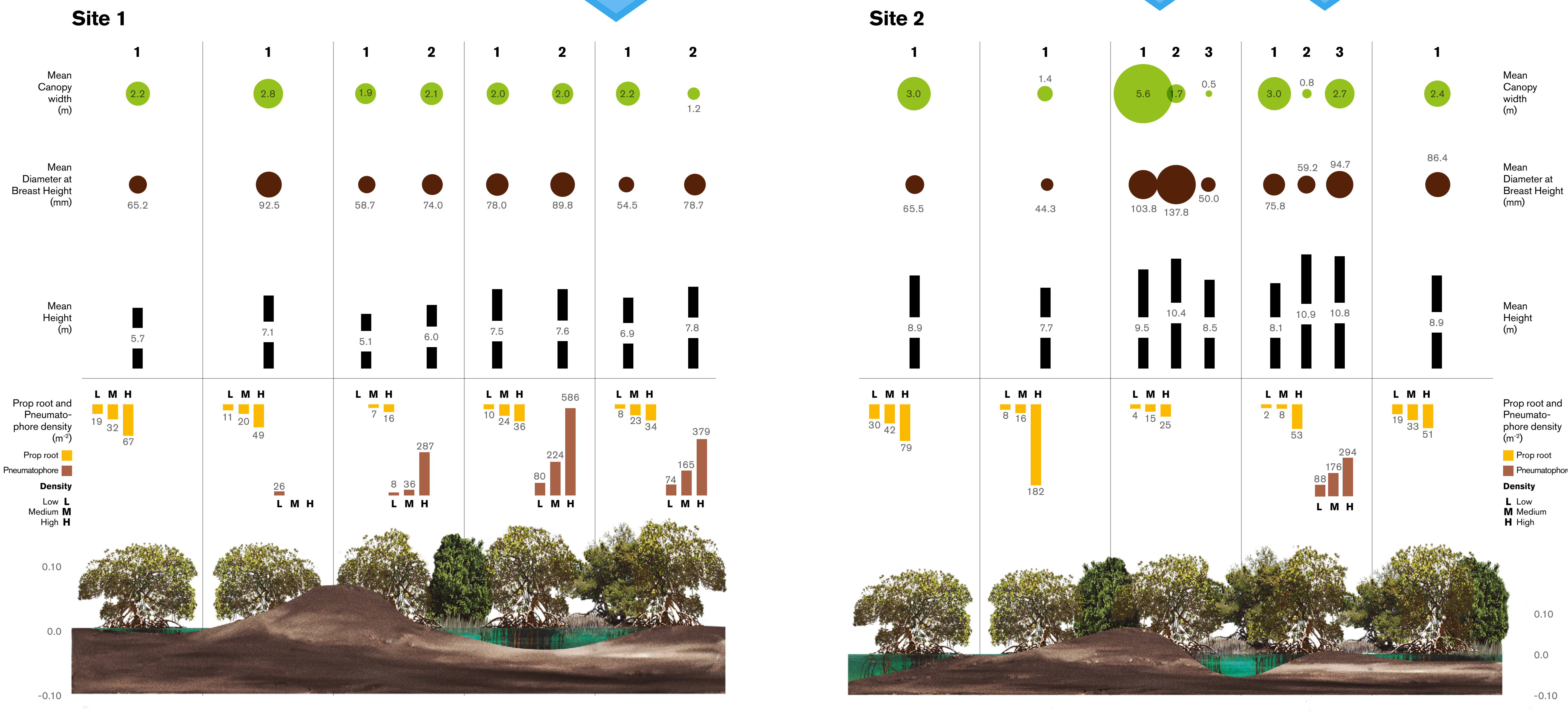
Ecological

FIGURE 35

Mangrove Biometrics at Salt Marsh.







SALT MARSH

Mangrove Biometrics

MANGROVE SPECIES COMPOSITION AND RELATIVE ABUNDANCE (FOR DIVERSITY)

Red mangrove was the dominant species found within the Salt Marsh study location. Black mangrove as well as white mangrove were also identified within the study location with white mangrove only being present at Site 2. The coastal associate species seaside mahoe was observed at both sites. This low diversity is expected as mangroves tend to grow in relative monospecific stands within a forest preventing succession and species accumulation.

The Salt Marsh area is a forest with intermediate structural development, that is, it has a DBH between 4.5 and 14.8 cm and the mean height of the most developed trees was between 5.7 and 13.7 m.

PROP ROOT/AERIAL ROOT NETWORK

Prop root densities were expected to decrease with increasing distance from the water's edge towards land.

Physical

ELEVATION AND TOPOGRAPHY

The elevation at Salt Marsh is attributed to the 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.

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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 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 red mangrove at the highest elevation between 23 and 28m. As elevation changes, the trees that occupy the landscape also change. For example, red mangrove occupies the seaward extent and the areas with the lowest elevation between 30 and 50m along the transect.

ELEVATION CHANGE

Elevation change ranged from -0.09 to 1.25 mm m^{-1}, with a mean of 0.50 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} for Site 2. The reasons for this variability between Sites 1 and 2 is unclear but may be related to the variability of the hydroperiod between the times of data capture.

SEDIMENT AND LITTER RETENTION AND ACCRETION

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 0.90 g. The variation from sites 1 and 2 is as a result of the variations with tree density and types.

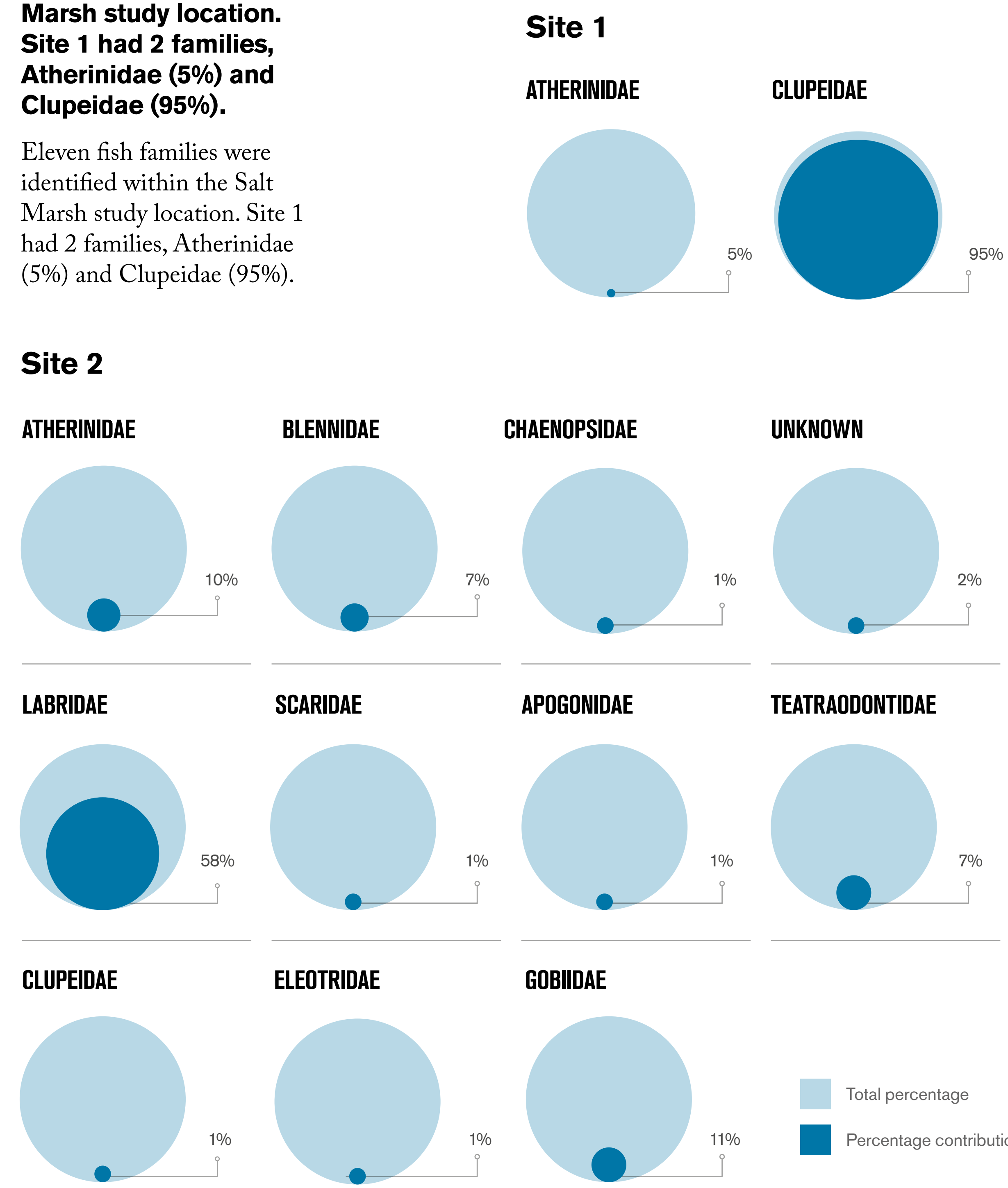
ECOSYSTEM SERVICES

Eleven fish families were identified within the Salt Marsh study location. Site 1 had 2 families, Atherinidae (5%) and Clupeidae (95%).

Eleven fish families were identified within the Salt Marsh study location. Site 1 had 2 families, Atherinidae (5%) and Clupeidae (95%).

FIGURE 36

Percentage contribution of each family at Site 1 and Site 2, Salt Marsh.



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 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. 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.

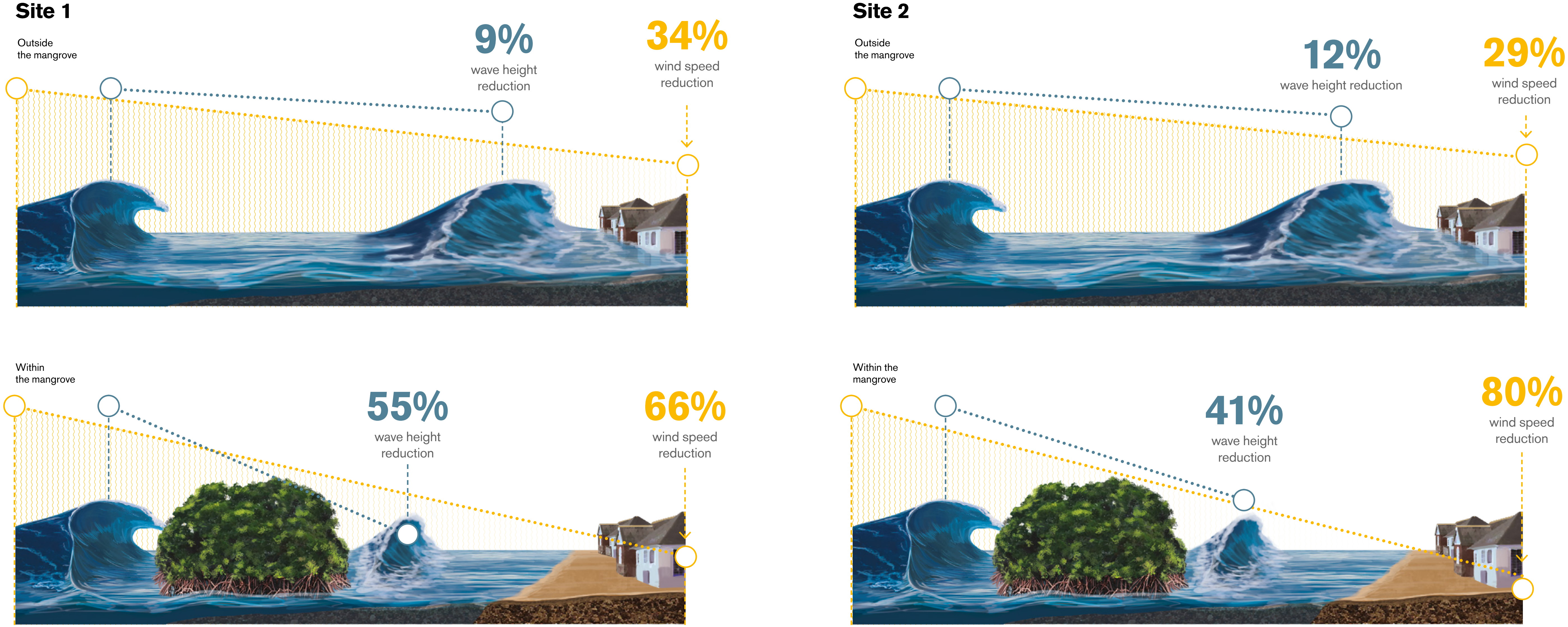
The long stretch (1 km) of erosion in the vicinity of the junction of Rodney Street and the north coast main road network may be attributed to marl dumping on the land that was reclaimed. Additionally, across the bay on the landward side of the peninsula, a similar long stretch of erosion (0.8 km) may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

FIGURE 37

Spatiotemporal lateral erosion (red) or accretion (yellow) on the coastline from 1961 to 2017, where mangrove trees occupation increases migrates seaward or retreats landward.

Mangrove Cover Source: UCSC.
Image: NASA, ESRI.

SALT MARSH



WIND, WAVE PARAMETERS & ATTENUATION

Reduction of wind speed and wave energies outside of the mangroves are as a result of frictional forces determined by the physiography and morphodynamics of the sites and the fair-weather conditions experienced on the days of sampling. At Site 2, mean wave height reduction was higher than at Site 1 (80% and 66% respectively) and may be related to higher wave energies and depth at Site 2. 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.

FIGURE 38

Depicts percentage reduction in wind and wave energies outside and within the mangrove at Salt Marsh.

Waves have been oversized for easy interpretation.

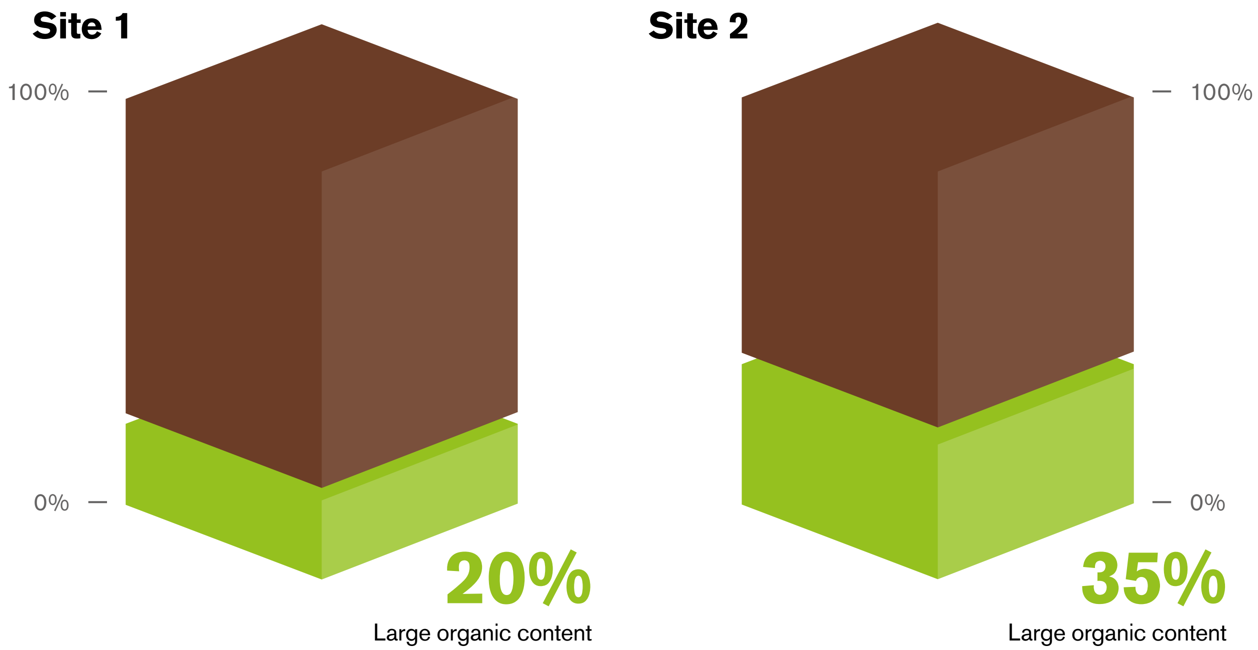


FIGURE 39

Mean plant percentage removed by handwashing together with percentage loss from hydrogen peroxide digestion of organic matter for each studied at Salt Marsh.

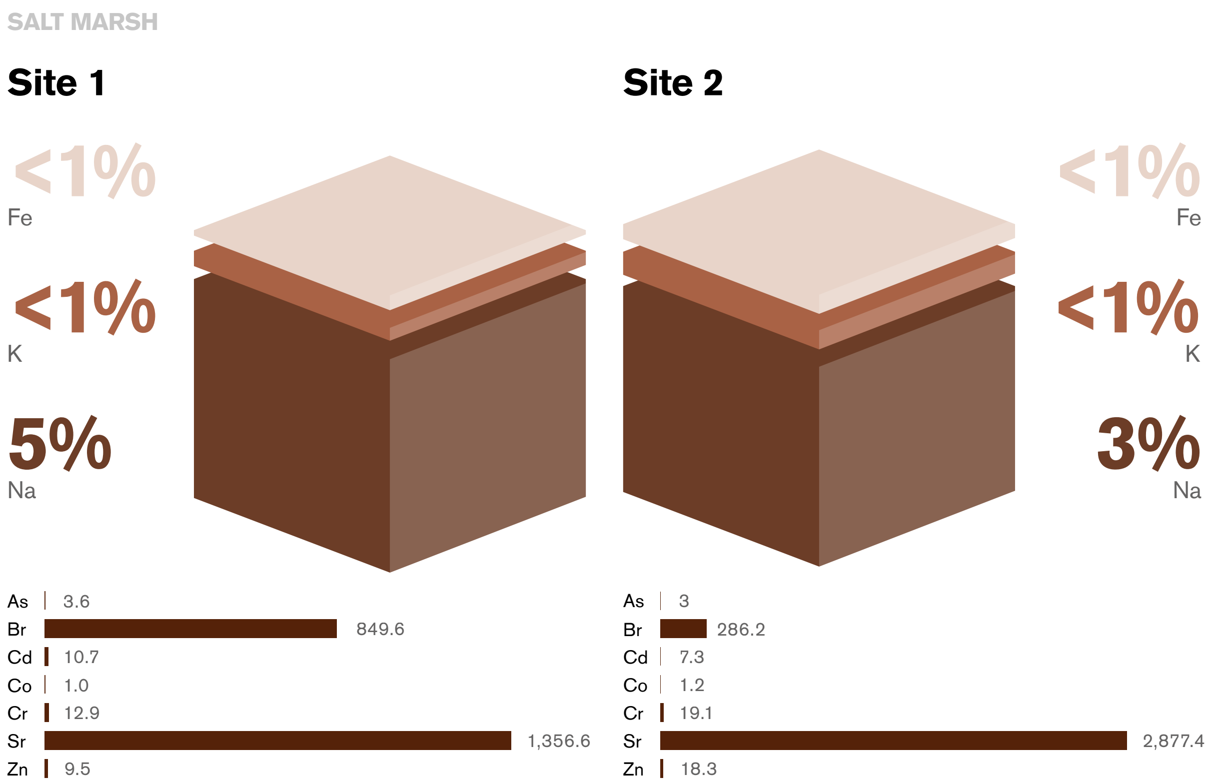
SUBSTRATE CONSTITUENTS AND PROPERTIES

SOC percentages were much lower at Salt Marsh than compared with other locations because of the composition of the substrate, which was very sandy with an abundance of skeletal and non-skeletal carbonate grains.

The texture and composition at Salt Marsh is 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. However, the immediate and long-term effects of these coarse-grained carbonate sediments within this system at Salt Marsh is unclear, 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, while in other instances it can help against a fast pace of rising see level. 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.

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. Therefore, the high carbonate sand content in the mangrove sediments indicates significant landward transport of sediment.



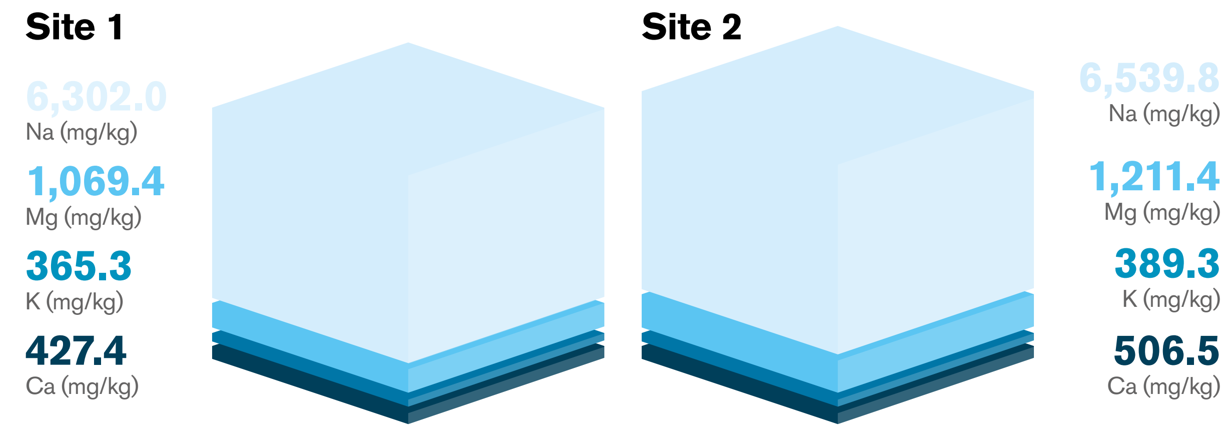
Soil Quality

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 to these coastal soils. Similarly, the mean concentration of Na in the soils is greater than the global mean, but within the 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. 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.

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.

FIGURE 40
Concentrations of major and trace elements analysed in mangrove surface soils (0–30 cm) from the Salt Marsh locality.



Water Quality

The mean temperatures of the Salt Marsh sites are similar to those for the Portland Cottage sites.

While the mean salinities for both sites are indistinguishable (~35gKg^{-1}). Conductivity values are also comparable (mean = 59MScm^{-1} for Site 1, and 56MScm^{-1} for Site 2). The concentrations of Total Dissolved Solids (TDS) are also lower than the minimum value (500mg L^{-1}) for brackish waters. The median DO concentrations are relatively higher that the threshold concentration (5mgL^{-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. This could have potentially adverse impacts on a number of vital biotic and abiotic processes not adaptable to these conditions.

FIGURE 41
Water quality parameters determined in situ at Salt Marsh.

FIGURE 42
Water quality parameters determined in situ at Salt Marsh.

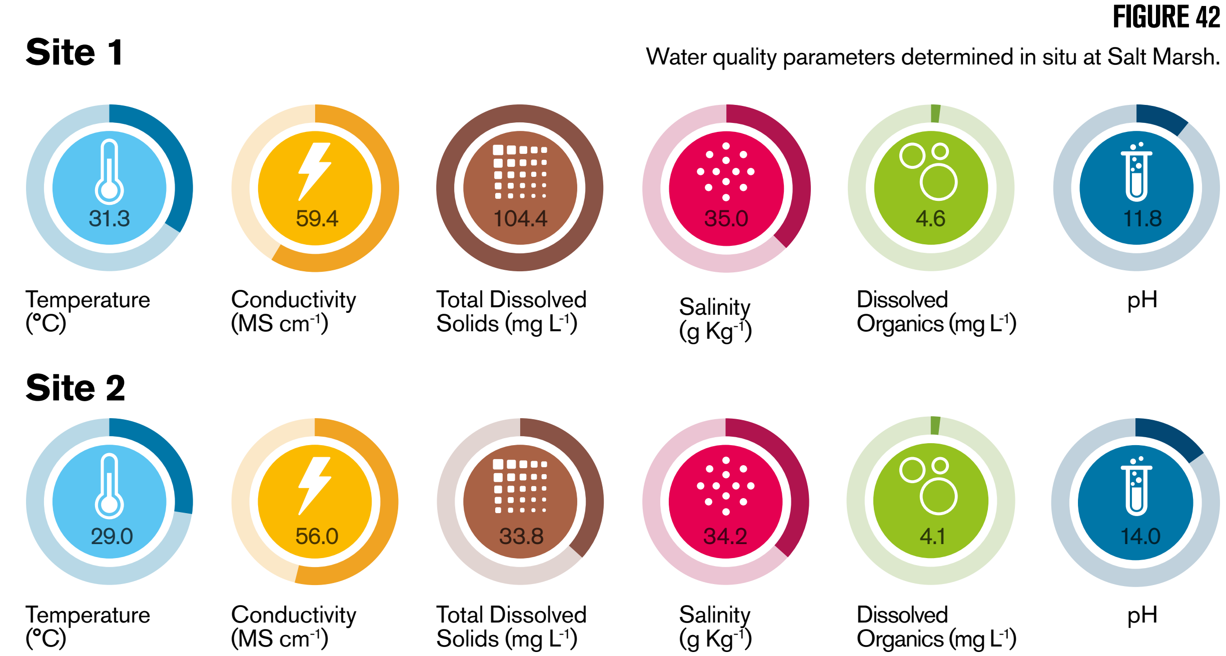
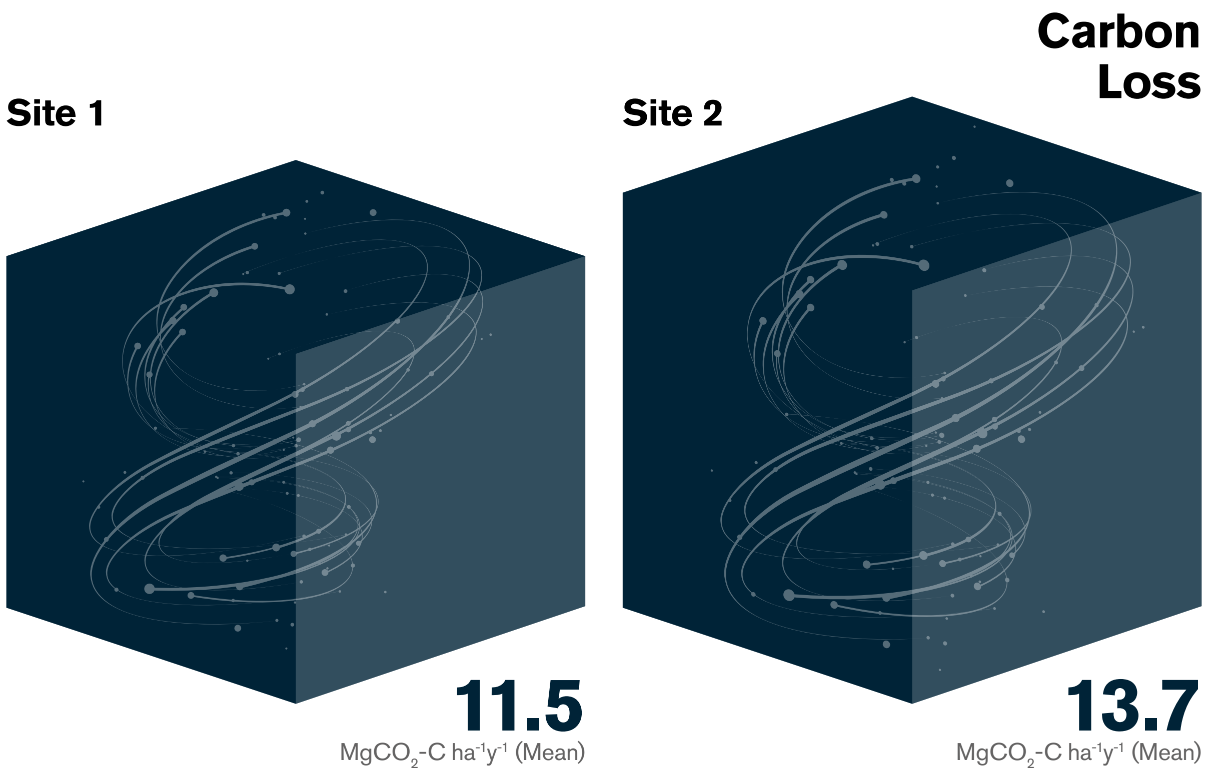


FIGURE 43

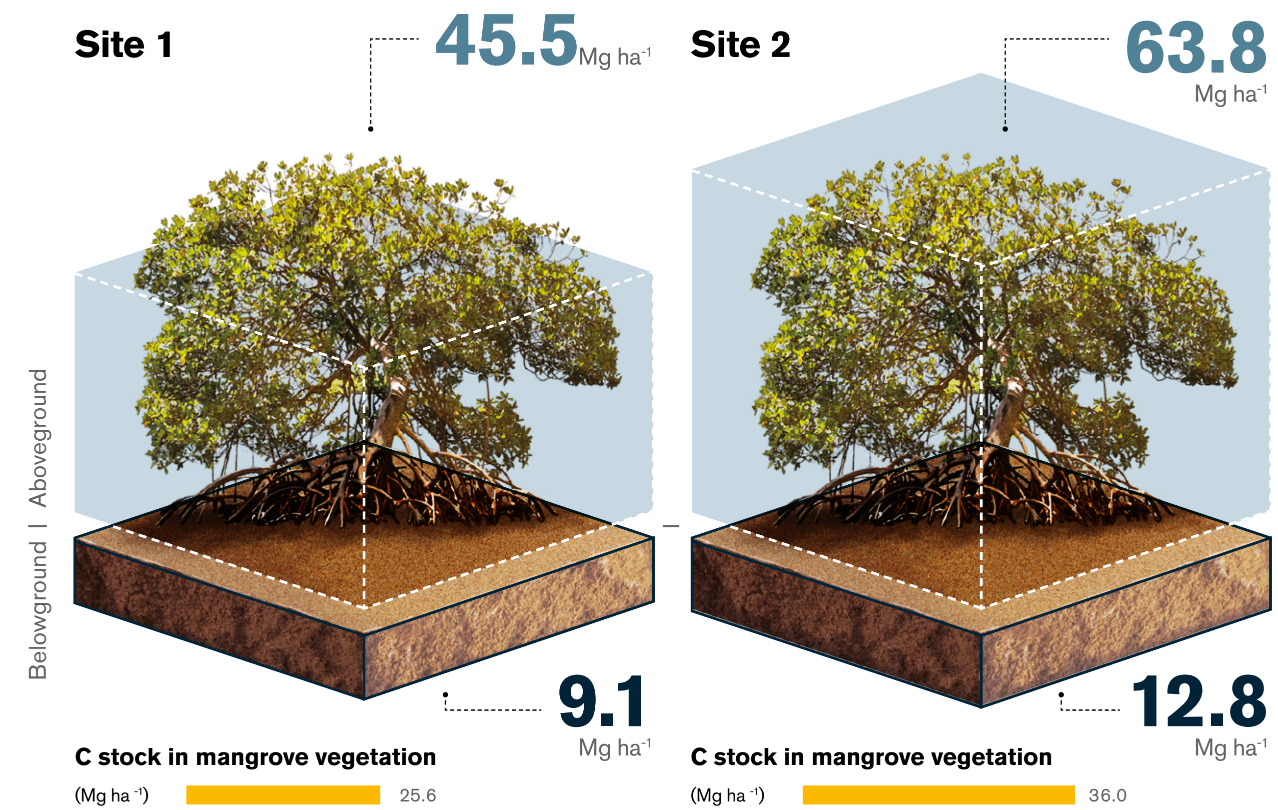


Soil Carbon Flux

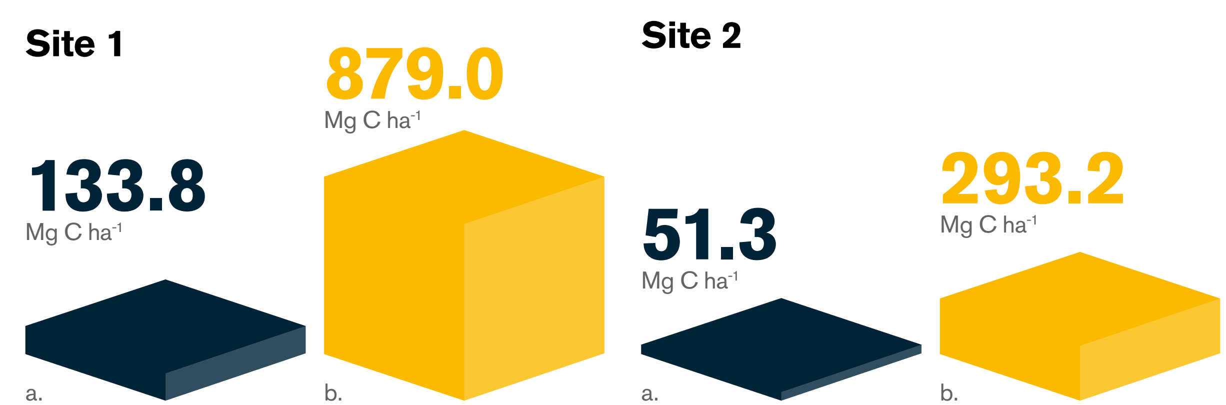
Soil carbon flux at the Salt Marsh sites demonstrate the largest spatial variability.

Site 1 shows a median flux of 1.94μmolm^{-2}s^{-1} and a mean value of 3.62μmolm^{-2}s^{-1}, while Site 2 exhibits a median value of 2.28μmolm^{-2}s^{-1} and a mean of 3.05μmolm^{-2}s^{-1}. The median and mean carbon loss (expressed as $MgCO_2$-Cha^{-1}y^{-1}) are summarized on this page. 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. Site 2 has a higher live tree carbon stock than Site 1. These differences may be due in part to species richness. The carbon stock estimates for the Salt Marsh sites are slightly more variable than the other locations. Overall, the carbon stock estimates mirrored the mean SOM and SOC values.

Biomass



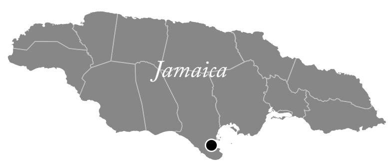
Carbon Stock



a. Stock estimates (Mg C ha^{-1}) determined using the mean bulk density value of regional mangrove soils[49]
b. Stock estimates (Mg C ha^{-1}) determined using bulk density value from a pedotransfer function[50]

Portland Cottage

Socio-Economic



SOCIO-ECONOMIC CONTEXT

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. Among the issues noted are high levels of adult (25 years and over) and youth (14 to 24 years) unemployment, high levels of illiteracy and low levels of numeracy. Field data supported low levels of education with about 40% of respondents having less than secondary to high secondary education, and only 4% attaining university level education. There was no statistically significant difference between male and females.

Further, the majority of household income (60%) is obtained through self-employment. Of this amount, 15% stated that they had paid employees. Remittances are also a major source of obtaining funds for many households, with 45% of respondents stating that they obtained remittances in the last 6 months.

Of the 97 respondents who reported on savings in the household, 65% 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.

PORTLAND COTTAGE

A significant percentage of houses (80%) and the land on which homes are built (74%) are owned by residents. Most (70%) of the homes are constructed from concrete and blocks, with only 10% of the households within the sample constructed from wood only.

Primary data also revealed that 70% households had access to electricity, but a significant amount (20%) shared electricity. Further it was revealed that 24% of households used public stand pipe or private piped water. While 45% of households had toilets in their dwellings, a noteworthy percentage (41%) use pit latrines.

Vulnerability of Coastal Flooding

EXPOSURE

The location and topography of Portland Cottage positions the community as being highly exposed to the effects of coastal inundation from storm surges and other environmental changes which may occur from the impacts of hydrometeorological hazards.

The community contains approximately 699 dwellings, many of which are located in close proximity to 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.

SENSITIVITY

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. This suggests that risk differentiation is essentially expressed in relation to distance from the coastline and elevation. Approximately 89% of respondents reported an experience with flooding while living in the community.

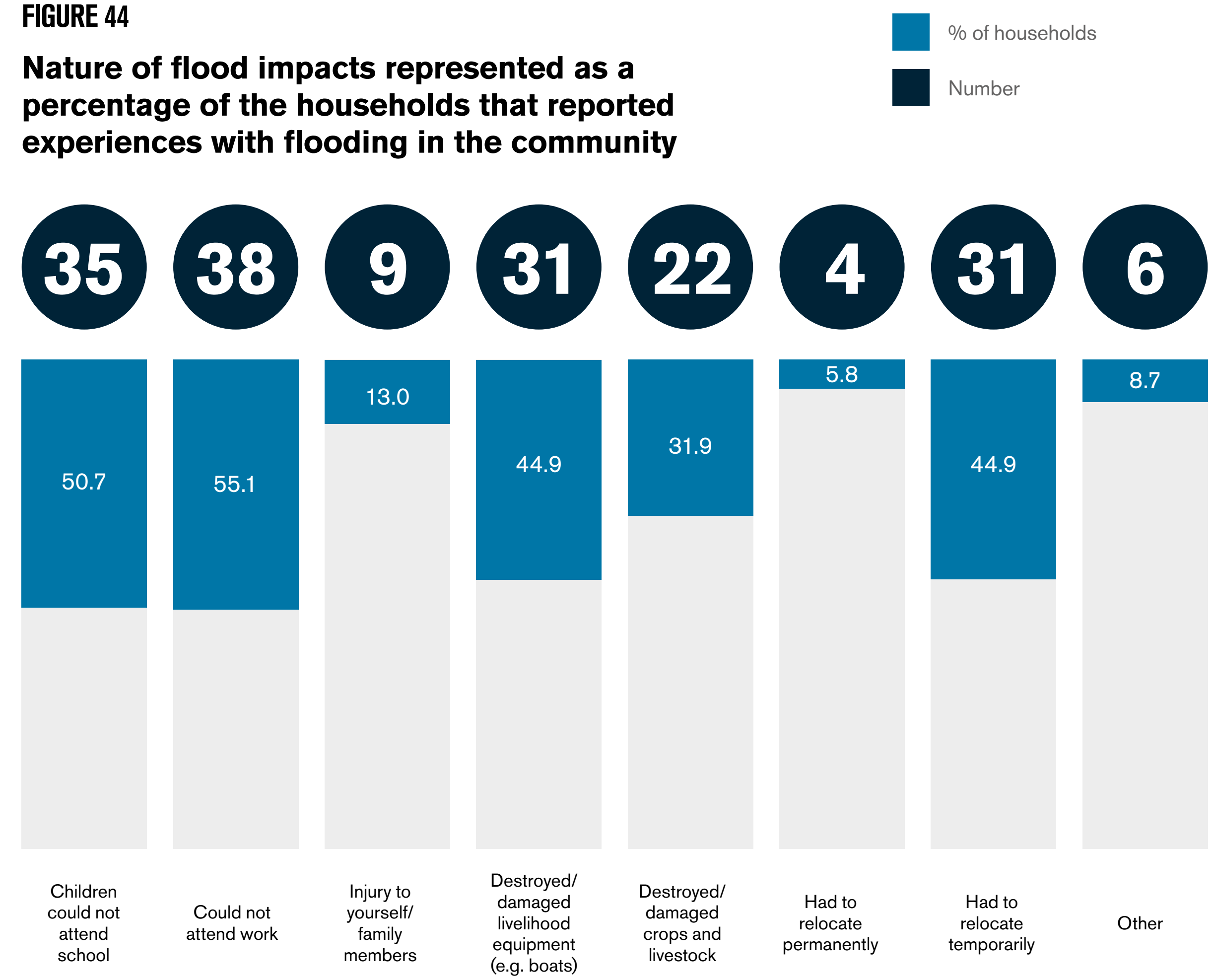
ADAPTIVE CAPACITY

Other dimensions of vulnerability include the socio-economic 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 5% of the individuals residing in the households surveyed attaining tertiary level education – a proportion that falls far below national level estimates of 8 %. Adaptive capacity is also conditioned by the high unemployment rate (34%) which significantly exceeds the national average (14%).

Reported income levels, for the month prior to the survey, were generally low as median income was US$134 per month. The fact that several of the respondents had relatively favourable debt profiles (12%) but unfavourable savings profiles (33%) indicates the existence of a potentially compromised adaptive capacity. 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. Additionally, only 2% stated that they had insurance which protected them from flood damage.

FIGURE 44

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



ECOSYSTEM SERVICES PROVISIONS

Only 37 (36%) of the sample were fishermen. Those who fish in the mangrove stated that they fish mainly for home use, and to a lesser extent for sale only in the community. 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. Income from the sale of fish on a weekly basis according to information sourced from 11 respondents ranged from US$221.06 to US$2954.74 with an average of US$89. The volume of fish has also decreased according to 81% of respondents.

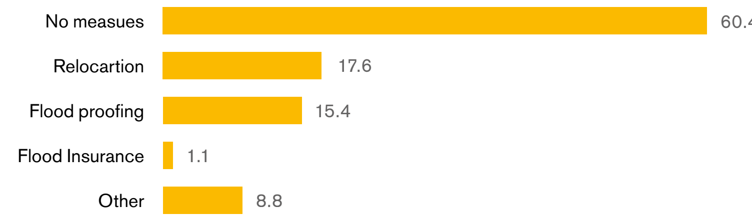
Snapper, grunt and parrotfish are primarily consumed in these communities and amounted to 28%, 33% and 24% of respondents respectively. However, catches from the mangroves also include sprat, jack, and doctorfish. Apart from fish, it was reported that oysters, shells and more importantly fish bait and crabs were also extracted.

PORTLAND COTTAGE

FIGURE 45

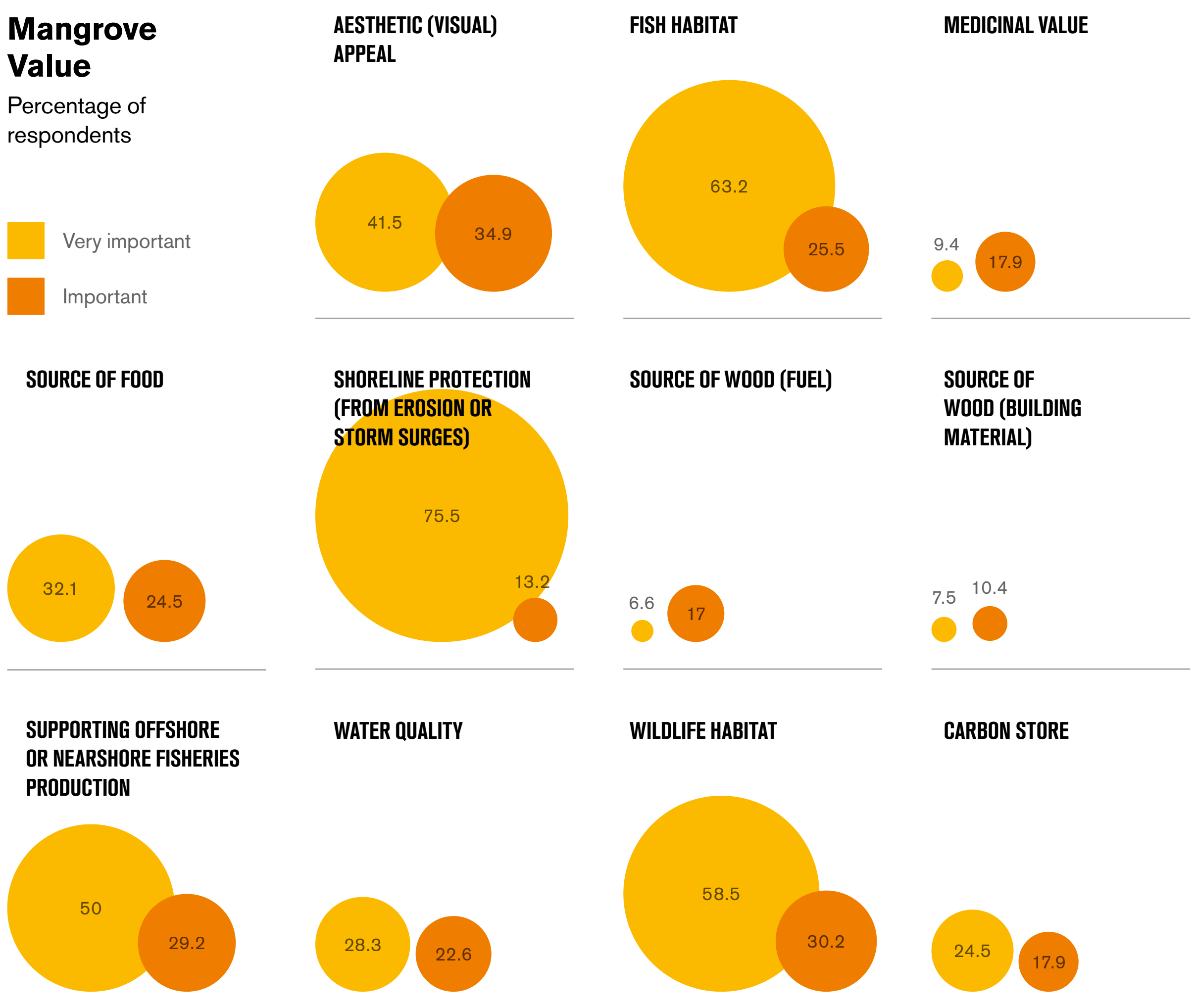
Measures implemented to reduce impact of future flood events

Percentage of respondents



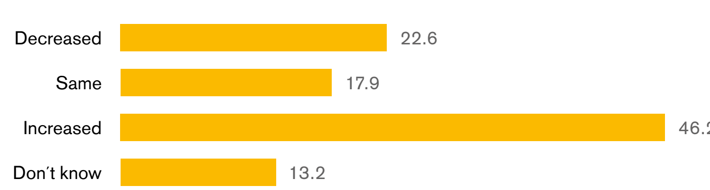
Mangrove Value

Percentage of respondents



Observed changes in mangrove forest in Portland for the last 10 years (2008-2018)

Percentage of respondents



ISSUES AFFECTING MANGROVE SERVICES

The majority of respondents felt the mangroves had increased, and this was attributed mainly to restoration activities. Several respondents used keywords such as planting or replanting, reforestation and restoration as the reasons behind this increase. Others noted that persons have stopped cutting down the trees and that the occurrence of less hurricanes have allowed the seeds to settle and grow. On the contrary, several respondents noted a decreased in the mangrove forest which they believed has been caused by pollution, overfishing and drought.

MANGROVE MANAGEMENT AND RESTORATIVE EFFORTS

A noteworthy percentage of respondents (36%) said that they are aware of restoration activities for the mangrove forest in Portland Cottage. Still, the majority (64%) said they are unaware of these activities. This suggest the need for improvement in sharing of information among the community members. In order to ensure restoration activities are effective and maintained, community involvement need to be a critical part of the process.

OPPORTUNITIES FOR PRIVATE PUBLIC PARTNERSHIP

There is opportunity for involving the community in mangrove restoration as majority of the respondents (72%) stated that they are willing to be a part of the process.

Ecological

MANGROVE BIOMETRICS

The Portland Cottage area is a forest with low structural development - DBH between 1.6 and 3.1cm, and mean height of the most developed trees between 2.4 and 4.7m.

The Portland Cottage location was covered by an almost homogenous, dense stand of red mangrove trees with infrequent occurrences of black mangroves and white mangrove trees.

Mean DBH generally decreased towards the landward end of the transect for all species except the white mangrove which remained constant between the 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. 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.

MANGROVE HEIGHT AND CANOPY WIDTH

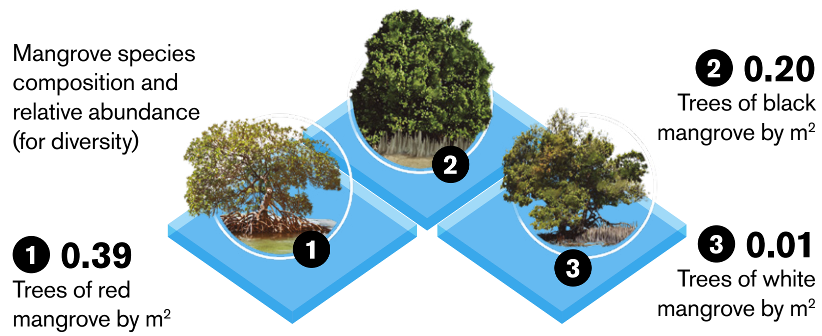
The height of mangrove vegetation typically decreases with distance from the water's edge along low energy coastlines but increases with distance along high energy coastlines.

PORTLAND COTTAGE

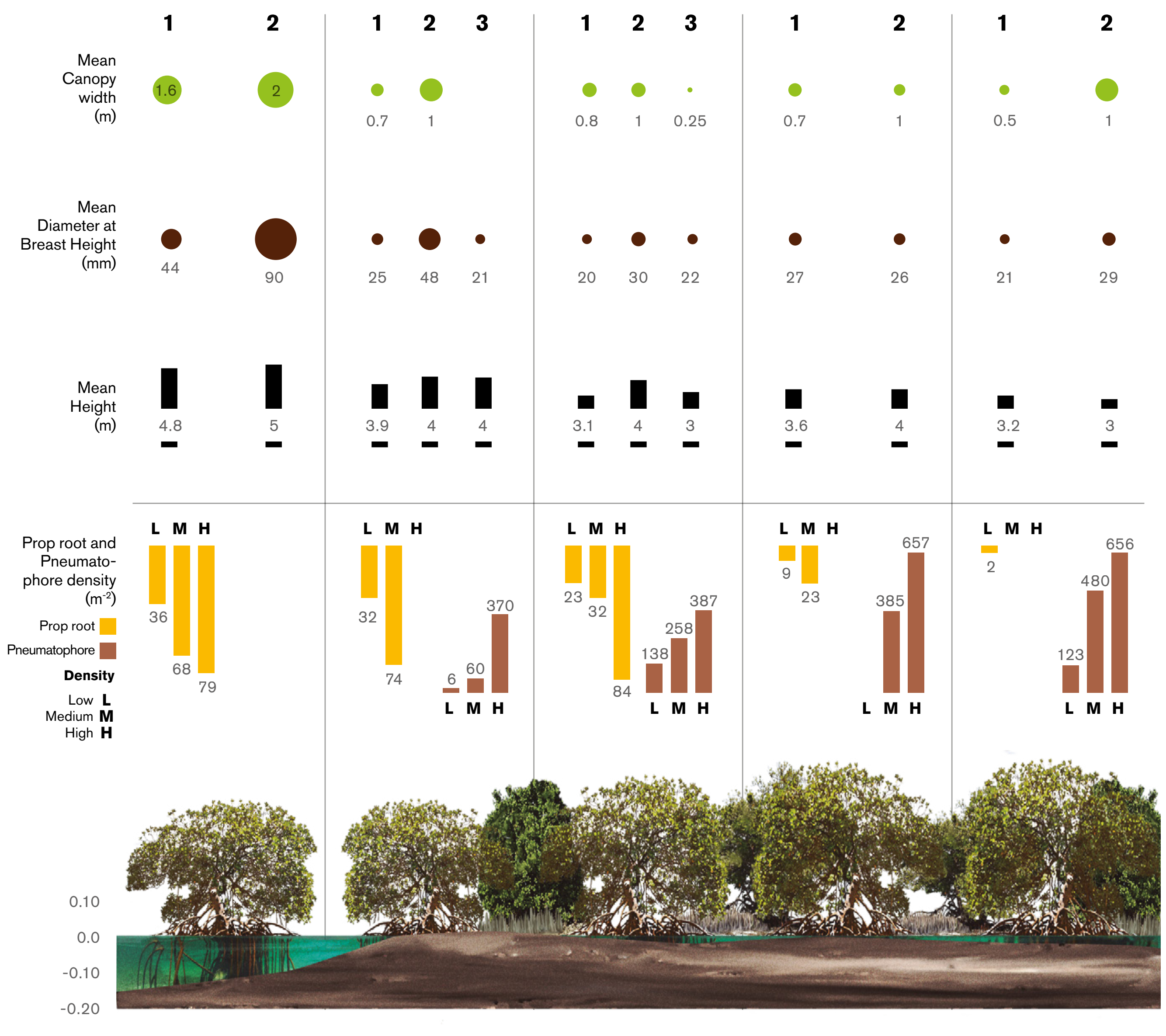
Mangrove Biometrics

FIGURE 46

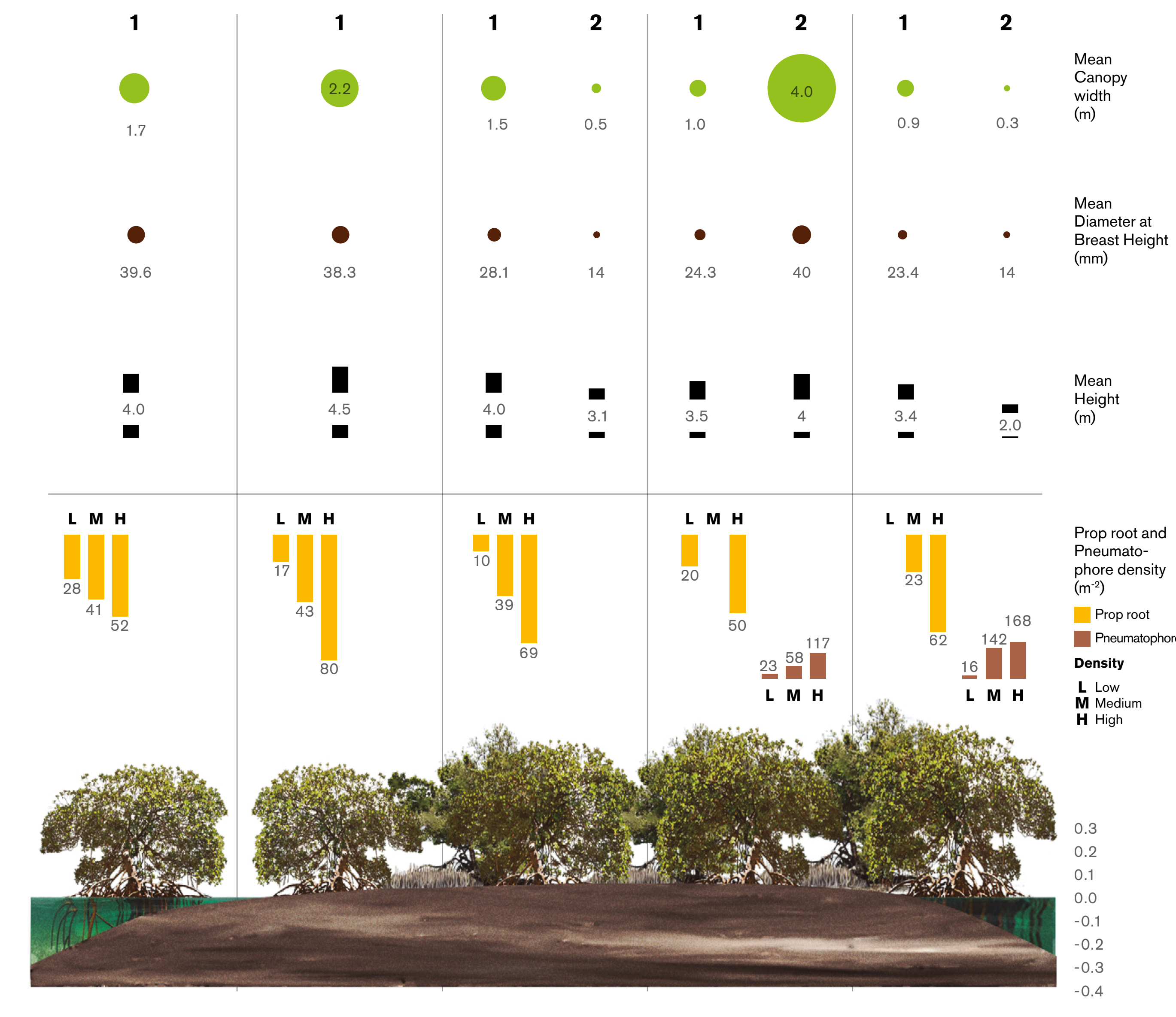
Mangrove Biometrics at Portland Cottage.



Site 1



Site 2



PORTLAND COTTAGE

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Mean height showed a general decline towards land. The pattern and range of tree heights are similar to forest studies along the north coast of Jamaica, mangrove forests in Portland (Errol Flynn Marina), Seville and Falmouth, which show 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. All species' canopy width decreased landward towards the end of transect, with the exception of the black mangroves which showed a tremendous increase at 30-40m before declining at 40 – 50m.

PROP ROOT/AERIAL ROOT NETWORK

Representation of the high prop root density category was absent between 10 and 20m; 30 and 40m; and 40 and 50m. 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.

Ecosystem Services

The fish nursery ecosystem service of mangroves 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

Site 1 is dominated on the seaward end by red mangroves, but also has abundant black mangroives (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.

Site 2 is dominated by red mangroves. Unlike Site 1 there is no undulating profile, but a gentle rise and a 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. These basinal features landward of both sites and without vegetation suggest some sort of ponding especially taking into 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.

SEDIMENT & LITTER RETENTION AND ACCRETION

Accretion was negative at Site 1 in Portland Cottage, as evidenced by the absence of erosion of the horizon markers. There was no leaf litter because there were no trees at the site of the RSET and in the vicinity of the horizon markers.

Sediment supply is significantly higher at this location than all other locations 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 the Montego Rivers at Bogue Lagoon, and the Martha Brae at Salt Marsh, this river brings abundant siliciclastic sediments from the Central Inlier, and occasionally floods.

ELEVATION CHANGE

Based on the study period of 4 months, Site 1 showed a negative accretion (-1.03mm m^{-1}), while Site 2 showed accretion of mean 1.1mm m^{-1}. The positive elevation could be attributed to root mass increase and/or in combination with the hydroperiod 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. 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, it is believed that 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 (3.8km) than the length of the coastal area with long-term erosion (8.2km). The area of lateral accretion seaward is 19.2 hectares at a rate of $3.4km^2yr^{-1}$. In addition, a smaller area of 8.2 hectares landward (at Site 2) that was unvegetated in 1961 is now vegetated in 2017. The area eroded is 55 hectares of the seaward section at a rate of $9.8km^2yr^{-1}$. 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. On a 1961 aerial photograph, areas to the northwest of the study area was prime farmland. Today it is deforested in some sections whereas other areas appear as abandoned shrub land.

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. 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. 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. 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 forests at Portland Cottage are therefore offering reduced coastal protection ecosystem services.

FIGURE 47

Spatiotemporal lateral erosion (red) or accretion (yellow) on the coastline from 1961 to 2017, where mangrove trees occupation increases migrates seaward or retreats landward.

Mangrove Cover Source: UCSC.
Image: NASA, ESRI.

PORTLAND COTTAGE

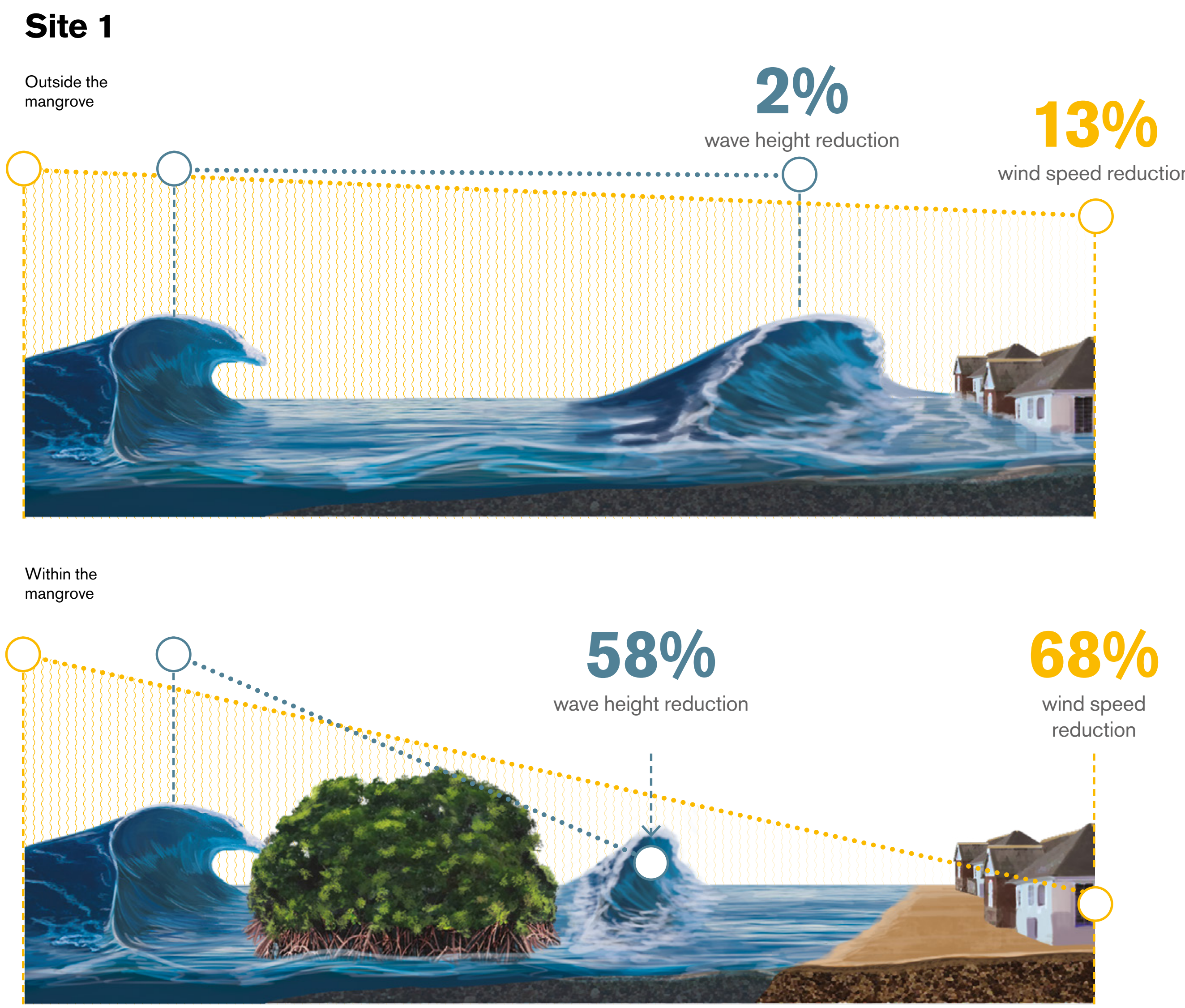
Wind and Wave Parameters & Attenuation

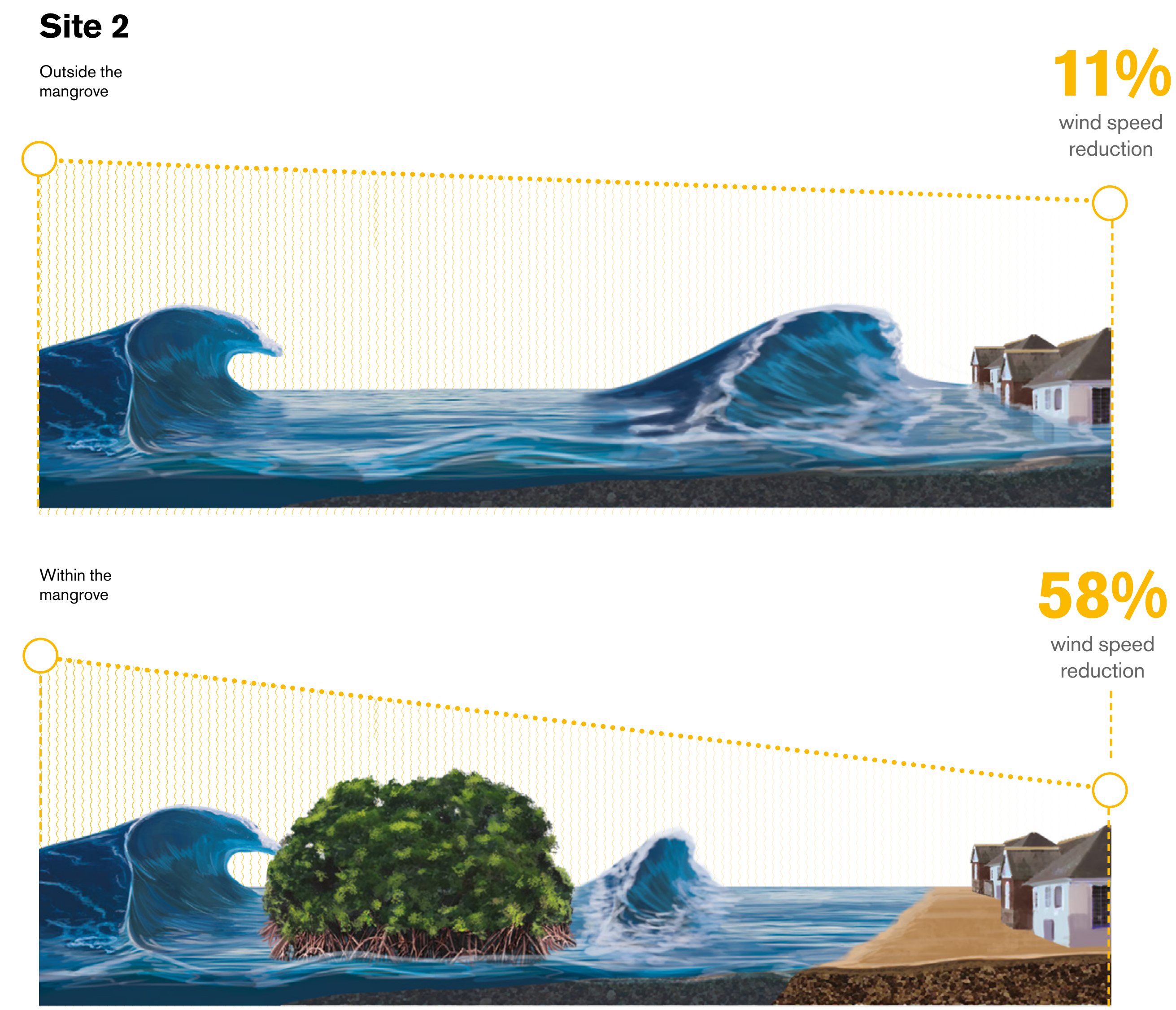
FIGURE 48

Depicts percentage reduction in wind and wave energies outside and within the mangrove at Portland Cottage.

Waves have been oversized for easy interpretation.

Due to technical difficulties, complete data for Portland Cottage Site 2 was not presented.





PORTLAND COTTAGE

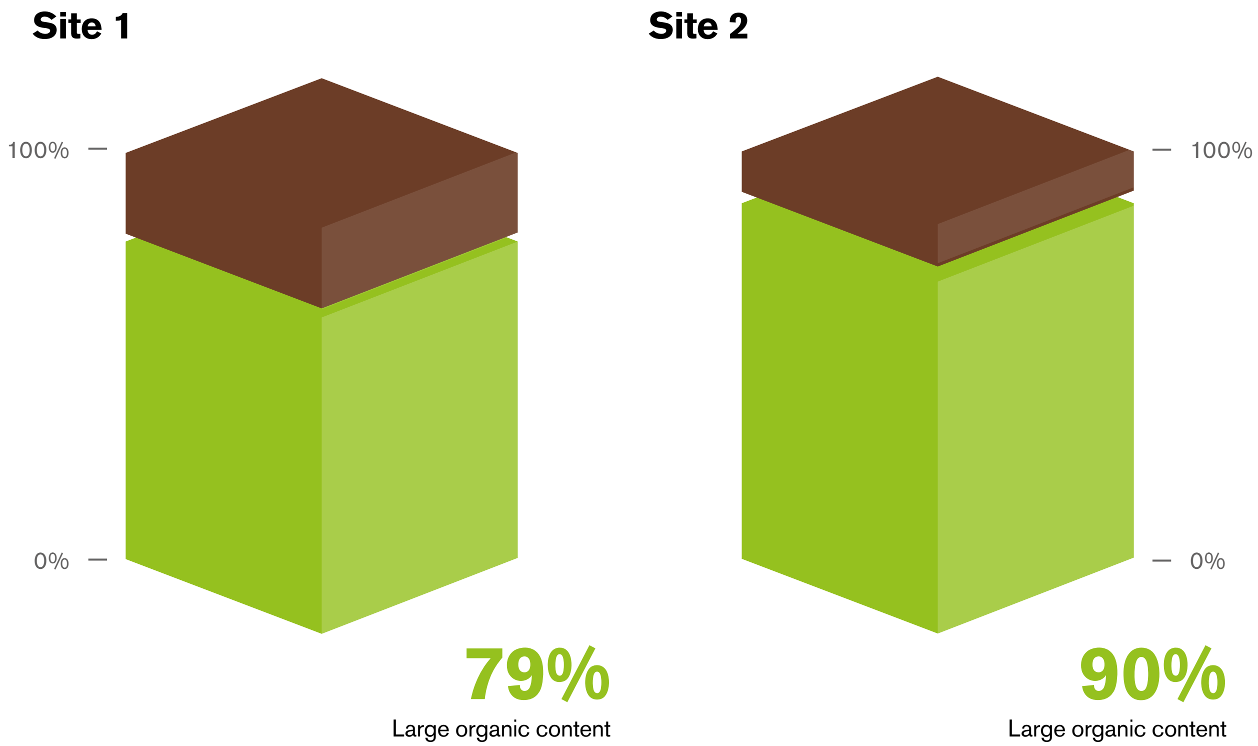


FIGURE 49

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)

Substrate Constituents and Properties

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 seagrass beds, and associated sediment production may be low in this region, or has not been 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. This absence warrants further study as this could also be related to the state of these mangal systems.

PORTLAND COTTAGE

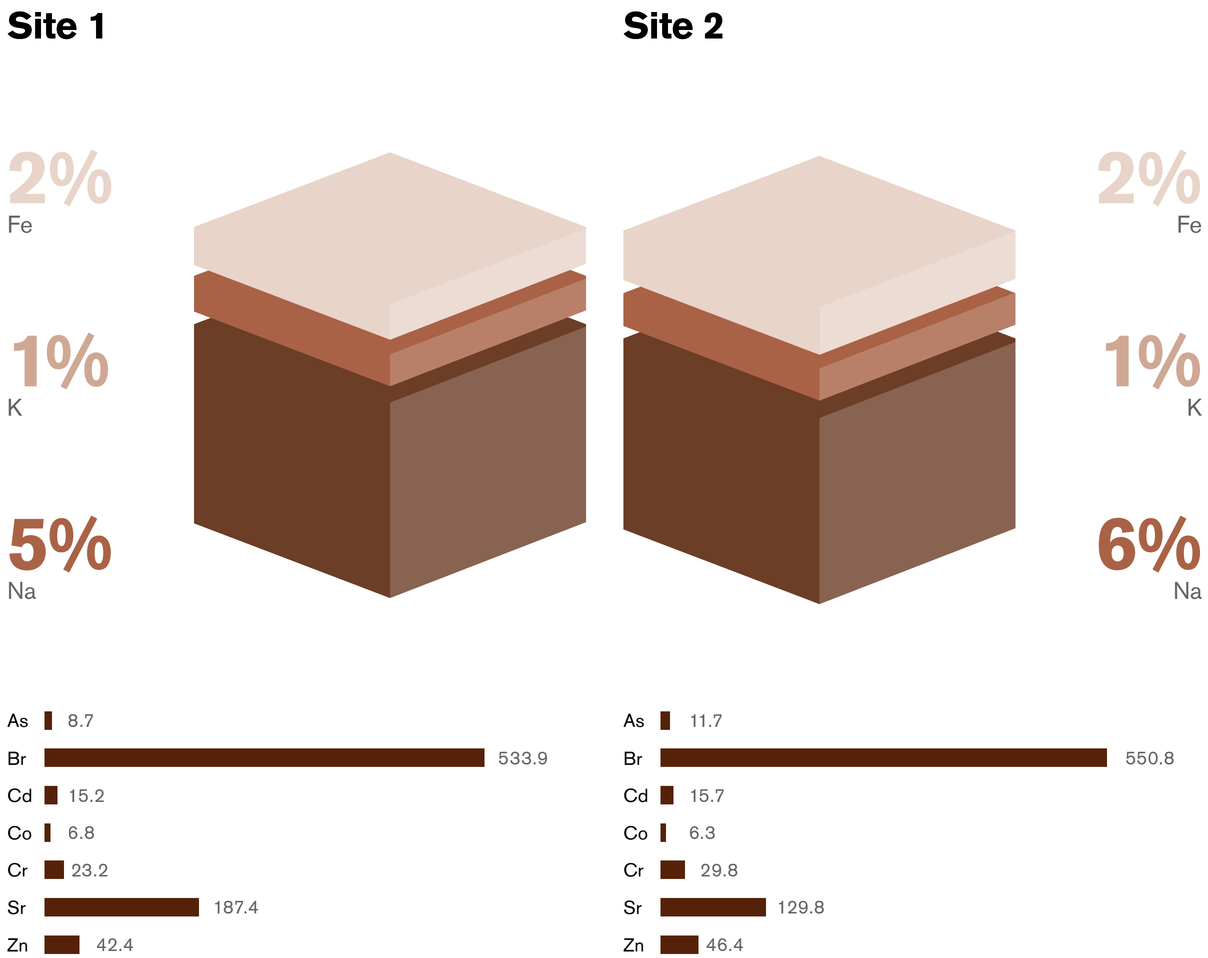


FIGURE 50
Concentrations of major and trace elements analysed in mangrove surface soils (0–30 cm) from the Portland Cottage locality.

Soil Quality

ECOSYSTEM CARBON BIOGEOCHEMISTRY

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

Water Quality

These results would suggest that enrichment by evaporation is likely 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 (500mgL^{-1}) for brackish waters. The average DO concentrations generally fall below the threshold concentration (5mgL^{-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 9.0), whereas Site 2 is weakly acidic (pH 6.8), 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.

FIGURE 51
Water quality parameters determined in situ at Portland Cottage.

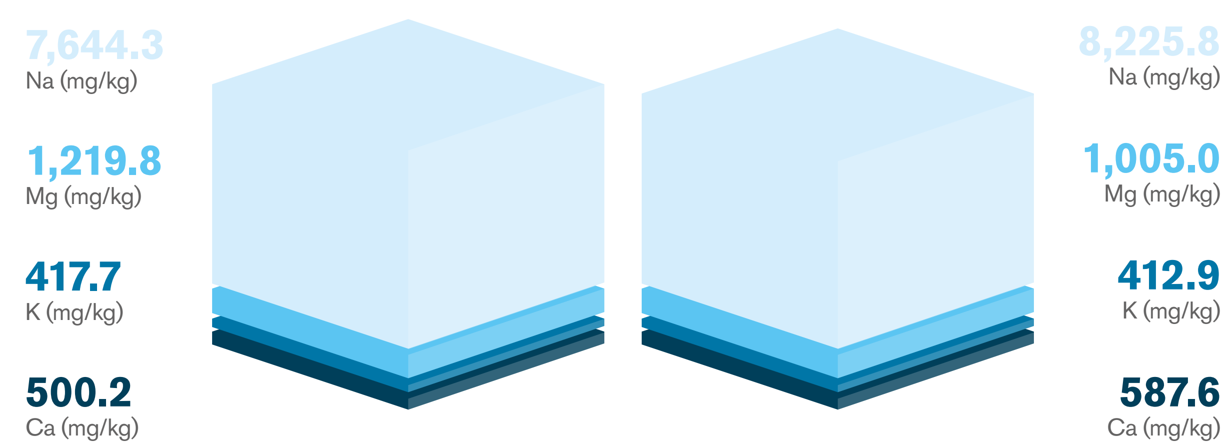


FIGURE 52
Water quality parameters determined in situ at Portland Cottage.

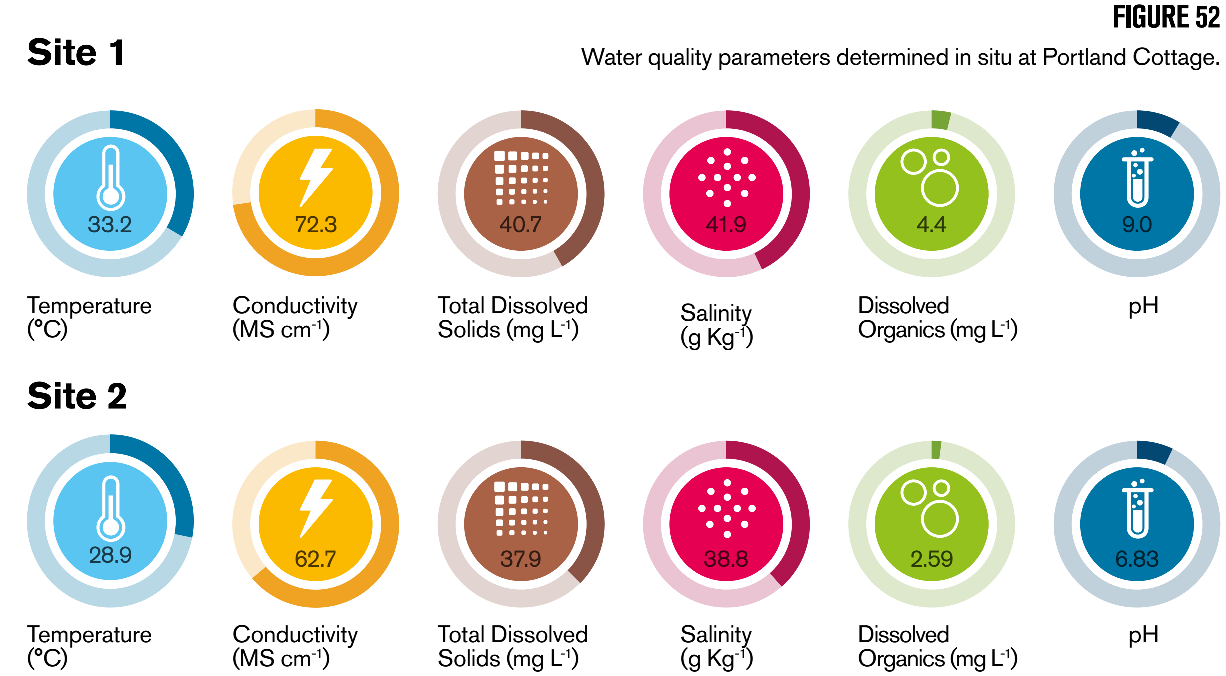
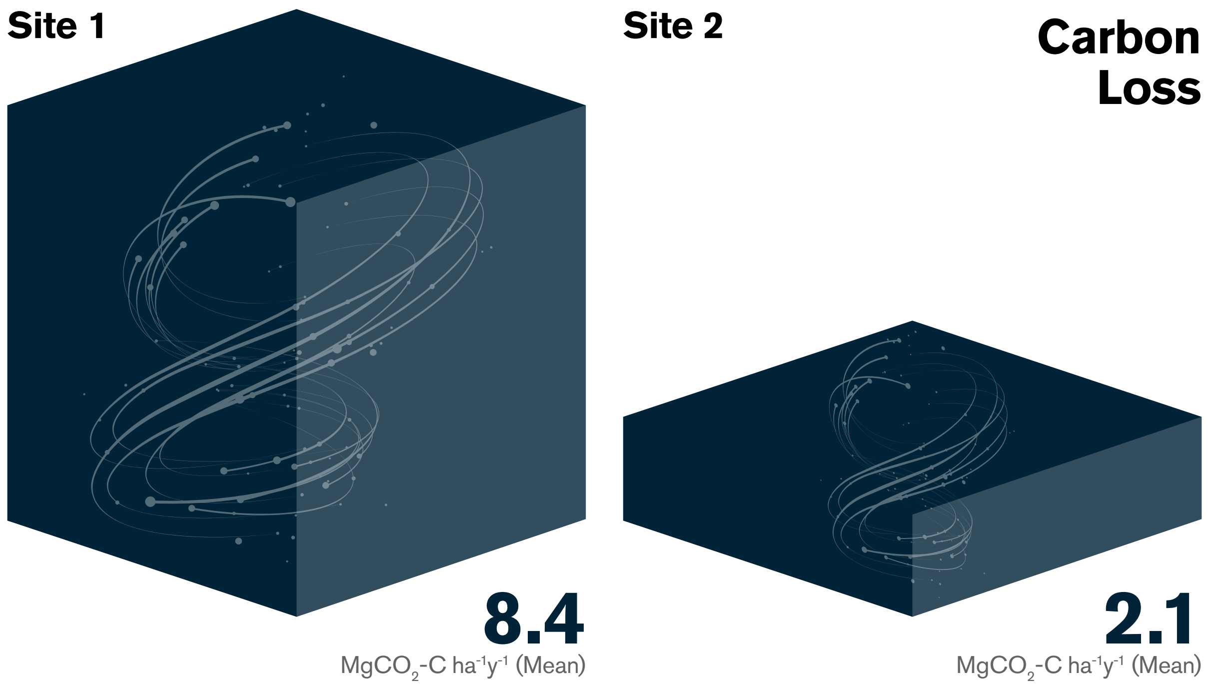


FIGURE 53

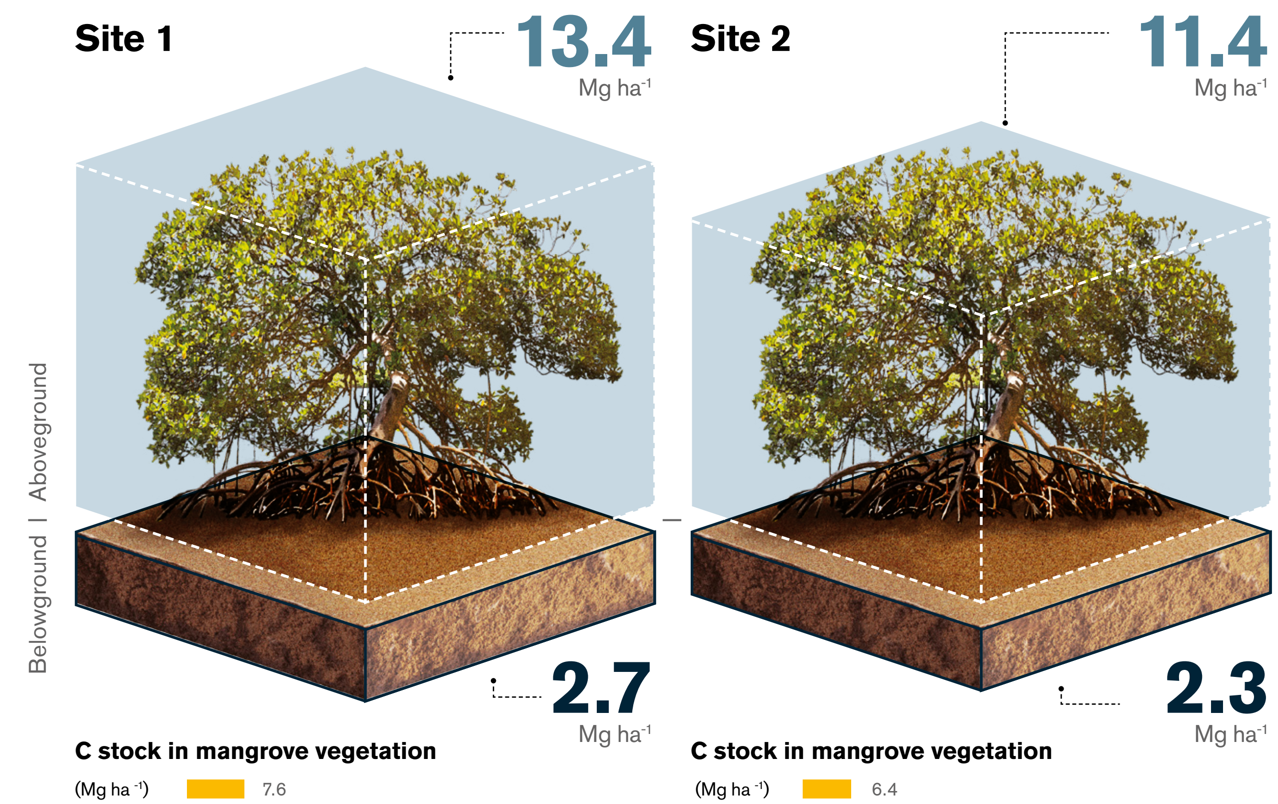
Carbon Loss



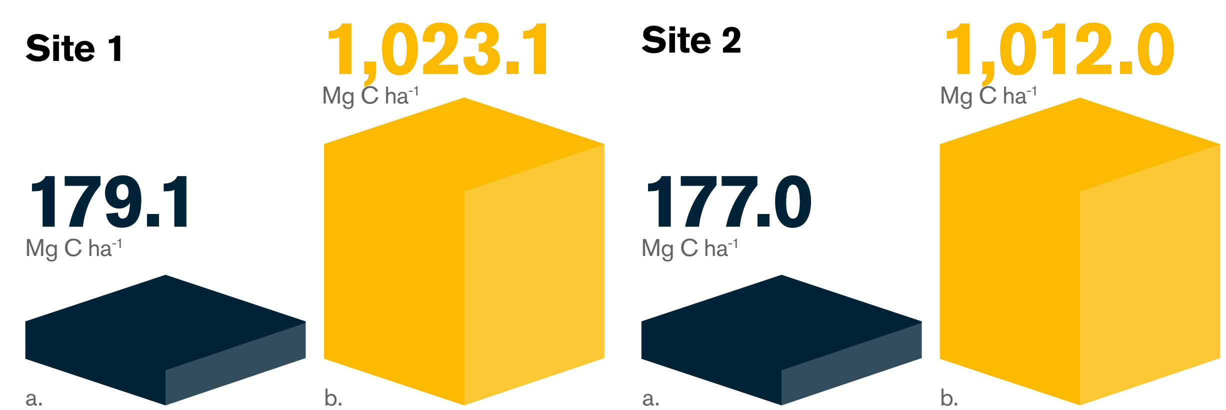
Soil Carbon Flux

Portland Cottage 1 and 2 yielded soil carbon stock estimates of approximately 179 Mg C ha^{-1} and 177 Mg C ha^{-1}, respectively. 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.

Biomass



Carbon Stock



a. Stock estimates (Mg C ha^{-1}) determined using the mean bulk density value of regional mangrove soils[49]
b. Stock estimates (Mg C ha^{-1}) determined using bulk density value from a pedotransfer function[50]

Broad Comparisons

Associations between assessments

PORTLAND COTTAGE

BOGUE LAGOON

SALT MARSH

ECOLOGICAL COMPARISONS OF OVERALL FOREST AREAS

The mangrove communities' ecological features and associated services can be compared across the three locations using spatially significant parameters. Only red mangrove parameters (tree numbers, tree height, DBH, canopy width and medium prop root density) as well as ichthyoplankton were found to vary significantly between the 3 locations. The indications are that while having the largest number of trees and prop root density (for medium plots), the red mangrove 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 3 forests indicate that Bogue Lagoon, while having the lowest red mangrove tree density, is the healthiest forest since the red mangrove 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 mangroves with Bogue Lagoon 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. For example, 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 considered to be quite unique for each location. 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 5 of the study transects showed the transects ranging between just below to just above Mean Sea Level (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). 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 Lagoon offers 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 3 study locations) and to neighbouring parishes of 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 Lagoon and Salt Marsh, but lateral erosion was more predominant at Portland Cottage, possibly as a result of recent hurricanes.

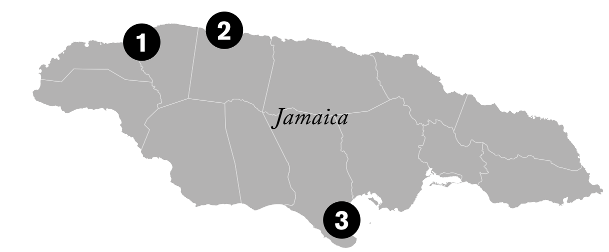


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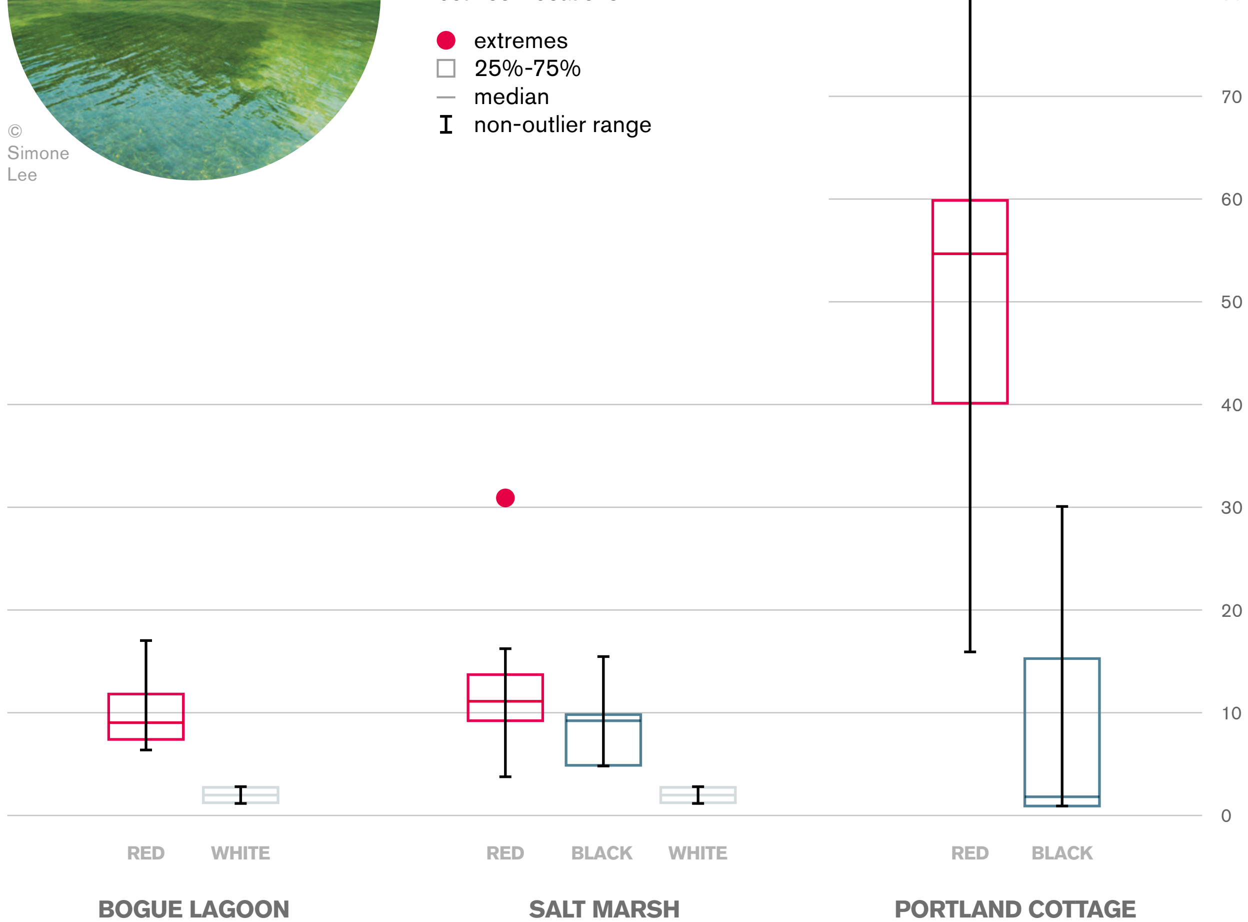
FIGURE 54

Median red, black and white mangrove tree abundances between locations.

- extremes
- 25%-75%
- median
- non-outlier range



COMPARISON OF STUDY LOCATIONS USING TREE ABUNDANCE

Abundance of adult trees was one such parameter that occurred at all locations and while red mangroves were found at all forest areas, black and white mangroves were not seen within the sampling areas at Bogue Lagoon and Portland cottage respectively. Portland Cottage had the greatest abundance of red mangrove trees (over 50 per transect) while Salt Marsh and Bogue Lagoon were similar with approximately 10 per transect. Abundance of black mangrove 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). Abundance of white mangrove trees were similar at Salt Marsh and Bogue Lagoon (2 and 2.5, respectively)

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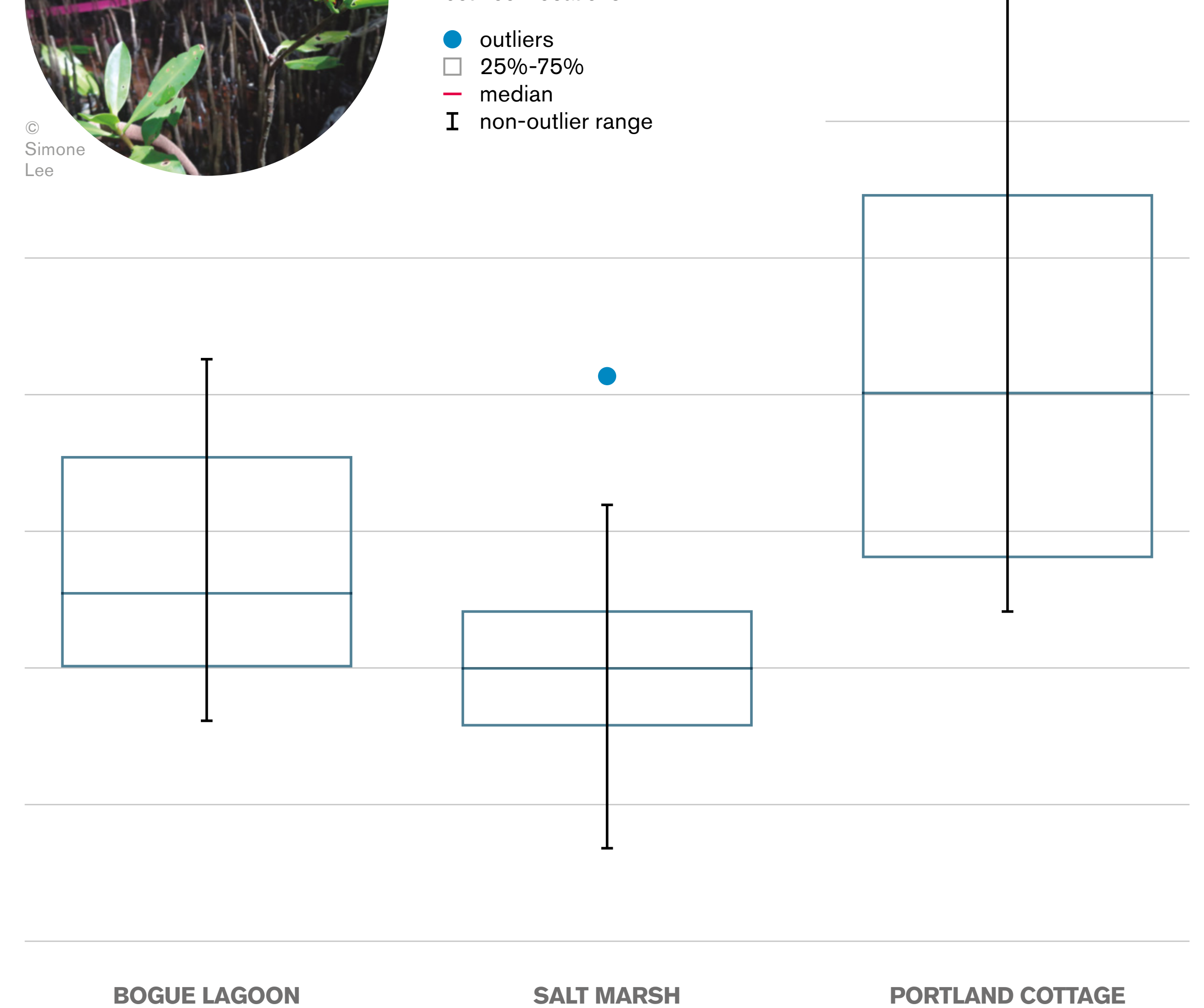
FIGURE 55

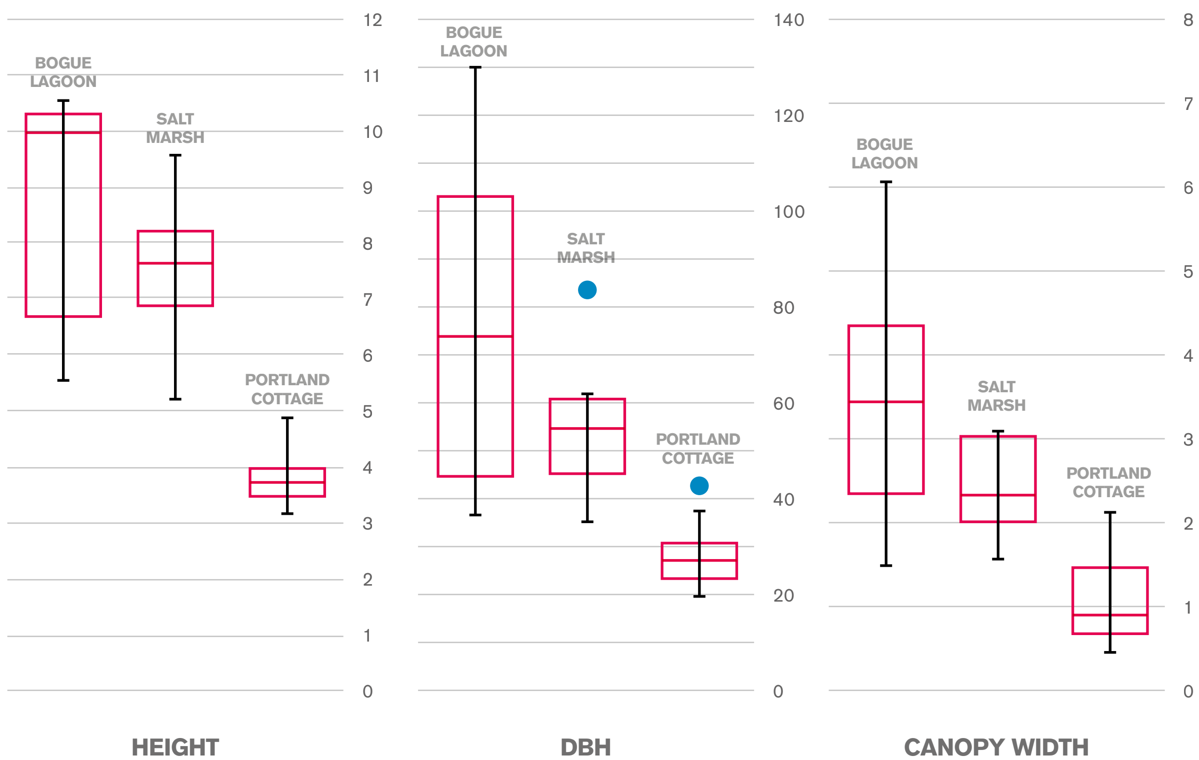
Median Red mangrove prop roots (medium density) between locations.

- outliers
- 25%-75%
- median
- non-outlier range



COMPARISON OF STUDY LOCATIONS USING ROOTING SYSTEMS

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



COMPARISON OF SITES USING TREE FEATURES (HEIGHT, DBH AND CANOPY WIDTH)

FIGURE 56

Median red mangrove height, DBH and canopy width between locations.

outliers ●
25%-75% ☐
median –
non-outlier range I

Only red mangrove trees occurred with sufficient spread between forests to have their tree features (height, DBH and canopy width) compared. Height of red mangrove trees was greatest at Bogue Lagoon and lowest at Portland Cottage. Bogue Lagoon also had the greatest DBH and canopy width. Therefore, although having the lowest abundance of red mangrove trees, the protective services of the Bogue Lagoon 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 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 Cottage 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.

It was felt that overall comparison between forests using tree parameters (where possible) indicates that Bogue Lagoon should offer the greatest protective services followed by Salt Marsh, with Portland Cottage mangroves being least able to protect land and associated infrastructure.

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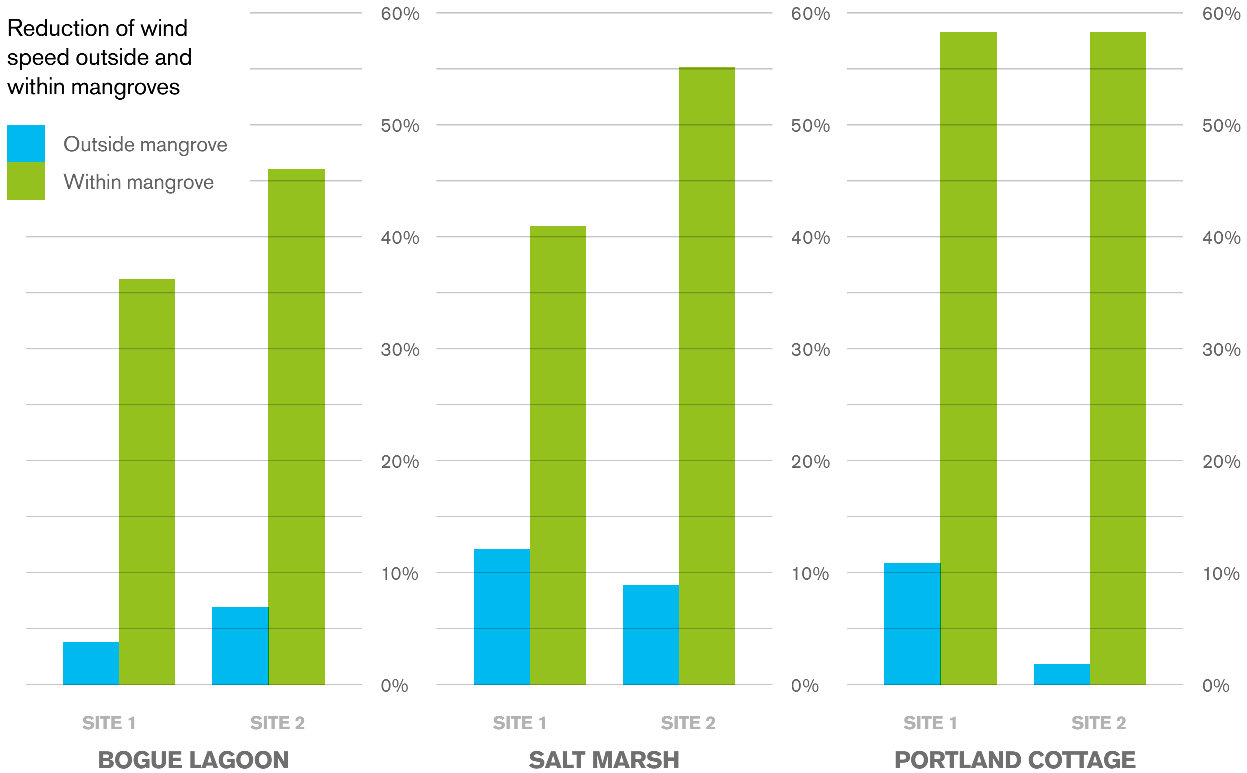
FIGURE 57

Reduction of wind speed outside and within mangroves



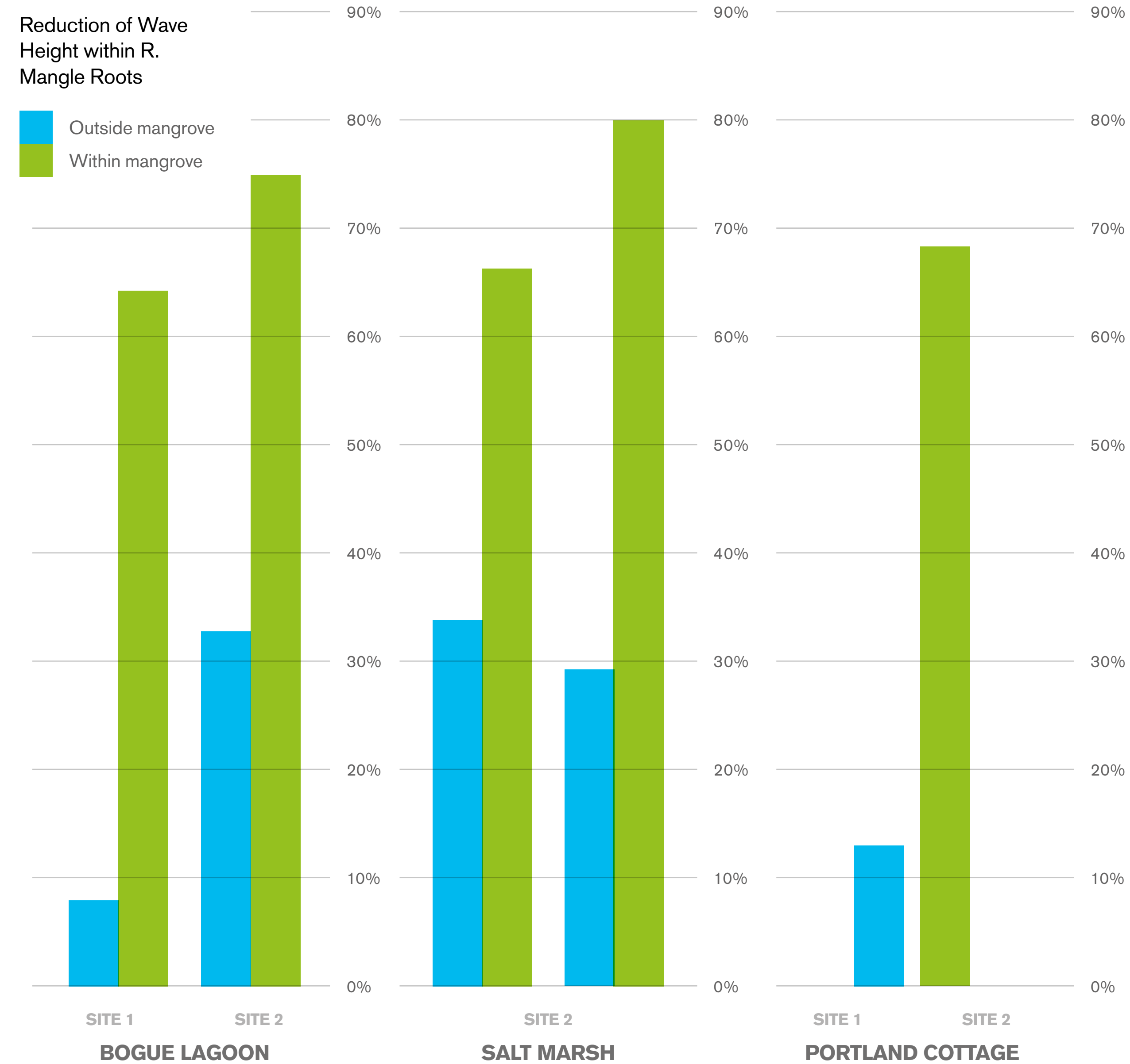
Merging Ecological and Physical Data

MANGROVE CANOPY/ TREE DENSITY AND WIND

Because 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 red mangrove density within the first 0 to 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, red mangrove DBH is 40 and 45 mm respectively for Sites 1 and 2. Red mangrove is more dense at Site 2 than Site 1, and as such saw moderate reduction in wind speed within the edge of the forest seaward. At Bogue Lagoon there is a considerably 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 Lagoon saw more wind speed reduction within the edges of the mangrove than Portland Cottage, 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 red mangrove trees within 0-10m of the transect was smaller at Salt Marsh than Bogue Lagoon, the densities were similar and the percent wind reduction also appeared to be similar. Therefore tree density is considered most important.

FIGURE 58

Reduction of Wave Height within R. Mangle Roots



PROP ROOT DENSITY AND WAVE ATTENUATION

The prop root density at Bogue Lagoon and Salt Marsh Sites 2 shows higher densities within the first 10 m landward from the water's edge than Sites 1. Sites 2 also 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.

5

Mangrove Benefits Beyond Flood Risk Reduction

Lead Authors: Dr. Peter Edwards, Dr. Adrian Spence,
Dr. Mona Weber, Camilo Trench, and Patrice Francis

Brief Methodology

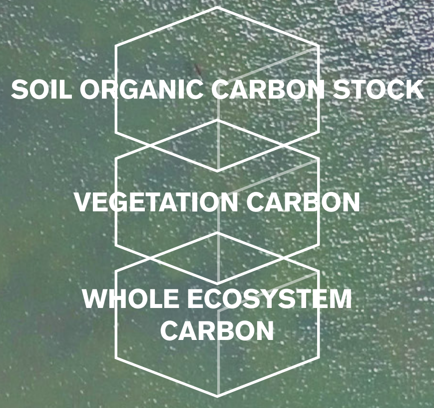
Where feasible, this analysis incorporated site level information (social and biophysical) into the estimates of economic values.

The aim is to provide complimentary social and economic information on the additional co-benefits of ecosystem services beyond coastal protection.

The analyses for each of the key ecosystems relied heavily on literature and benefit transfer approaches.

An examination of the relevant mangrove ecosystem service and economic valuation literature will be the basis for developing the methods to be applied to the ecosystem services of interest. This will include but not be limited to approaches such as benefit transfer methods, social cost of carbon, among others, when necessary.

The site-based information gathered from UWI was used in some instances to scale up or impute estimated values from other locations that fit the (physical and socioeconomic) conditions of each of the sites.



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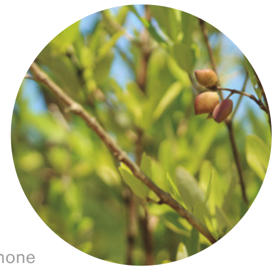

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Blue Carbon

FIGURE 59
Whole ecosystem carbon stocks.

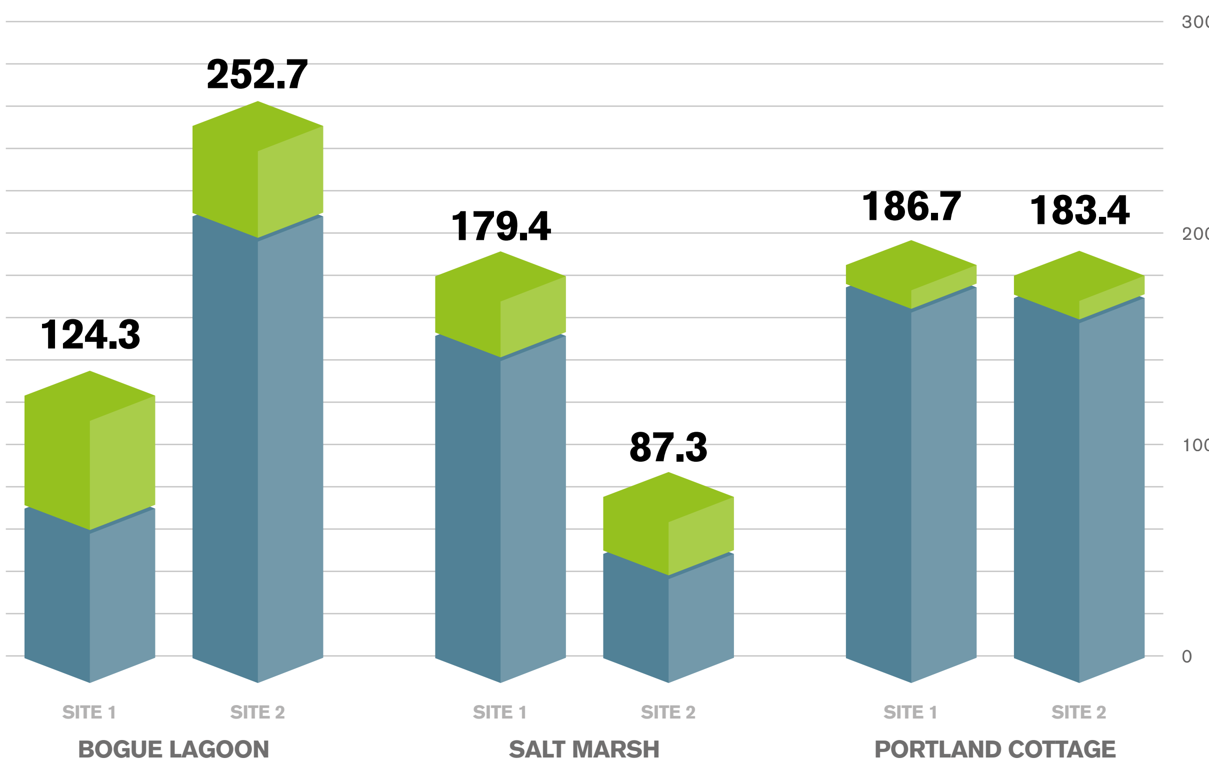
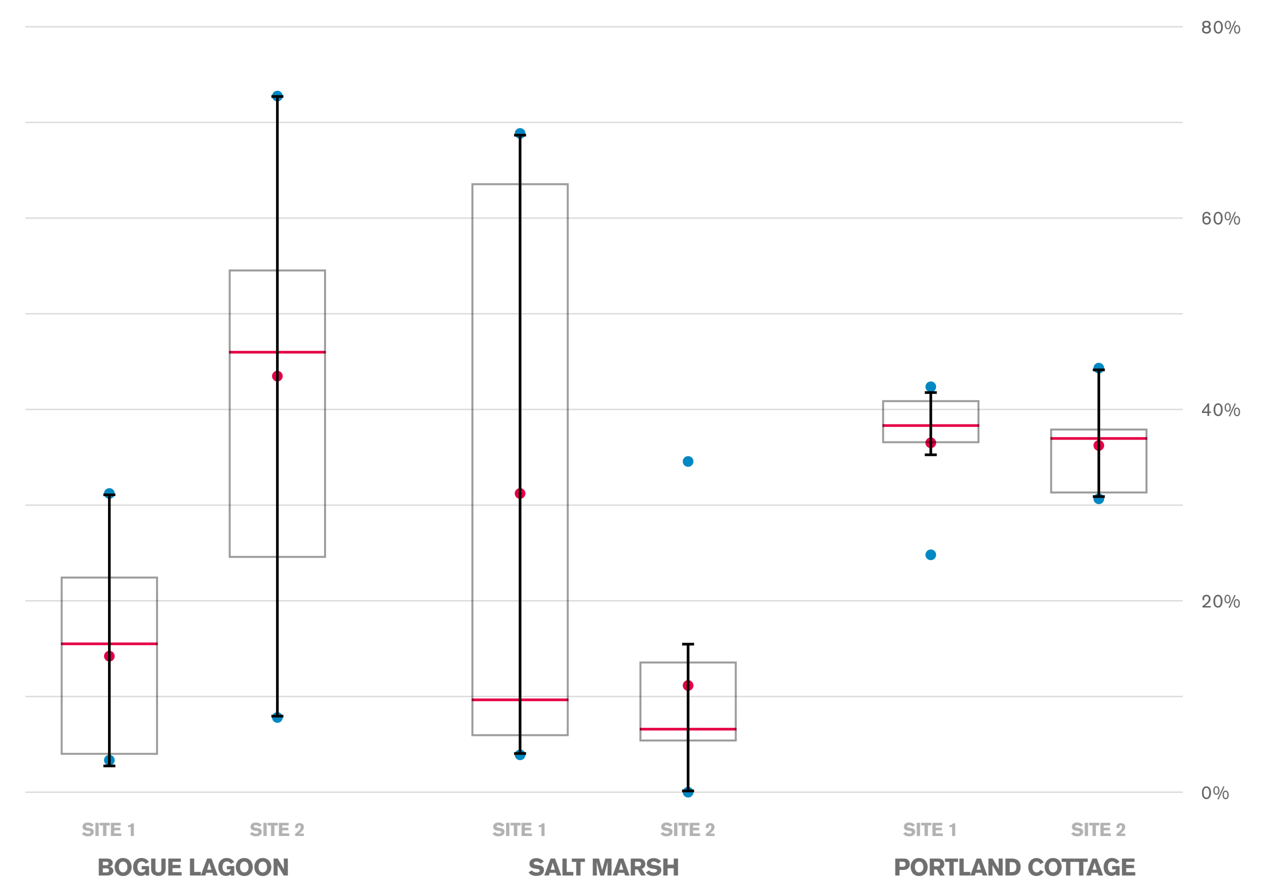


FIGURE 60
Soil organic matter content of mangrove surface soils (0–30 cm).



Site level Assessments

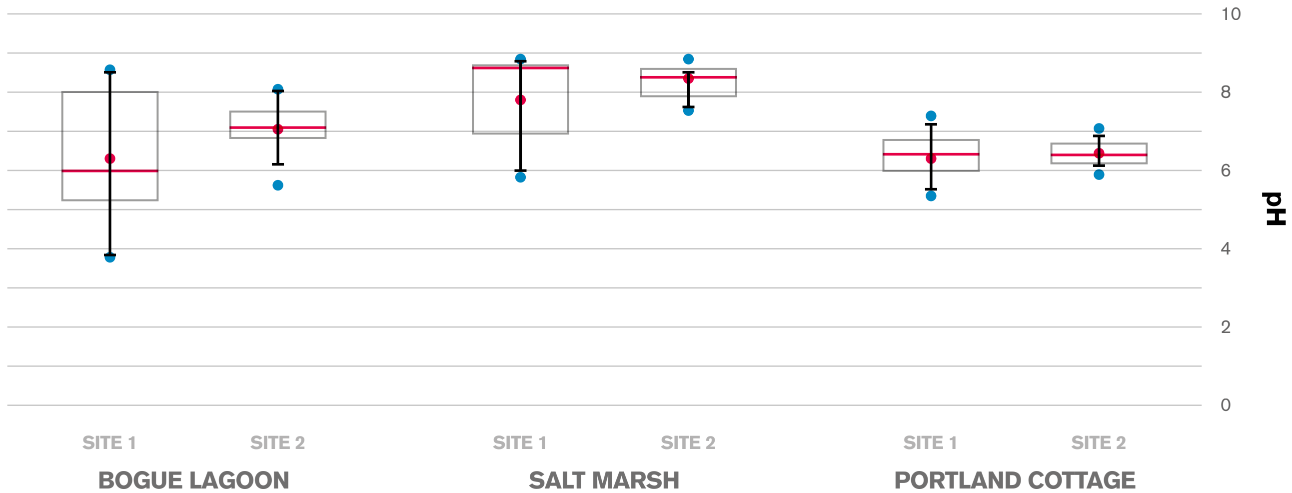
MANGROVE SPECIES COMPOSITION AND CARBON

In order to better understand the interlinkages between the ecological and physical aspects of the forests, we examined the relationships (positive and negative) between mangrove species and carbon stocks. Results indicate a significant, 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. 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.

SOIL ATMOSPHERIC CARBON FLUX, SOIL CARBON STOCKS AND ABOVE GROUND CARBON STOCKS

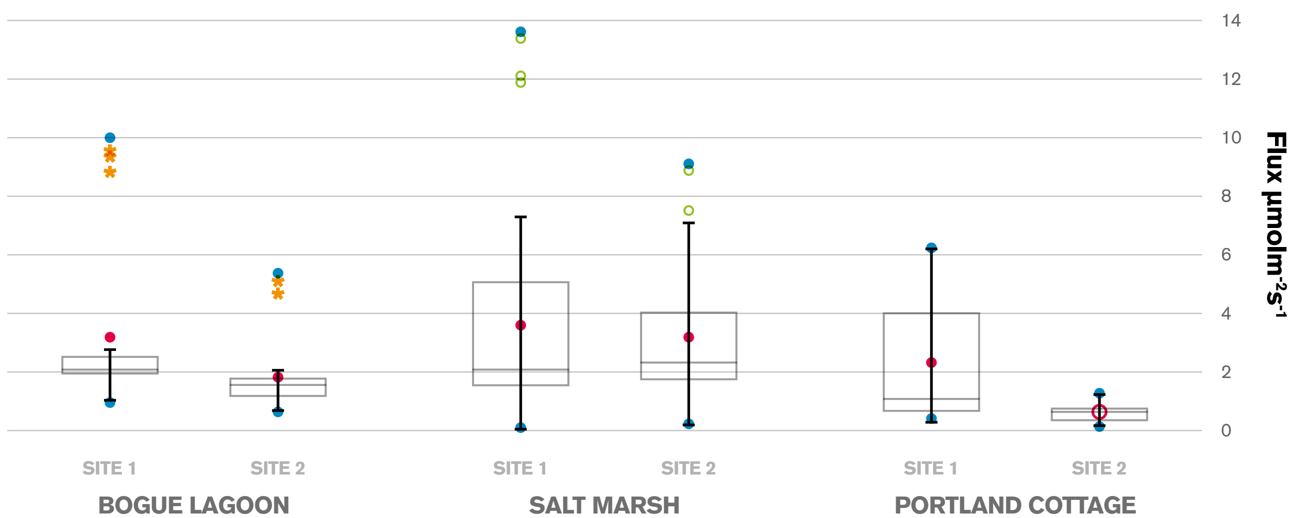
On average, mangroves contain three to four times the mass of carbon typically found in boreal, temperate, or upland tropical forests. Much of this carbon storage, however, is at risk of being lost, because mangroves are among the most threated and rapidly vanishing ecosystems globally, with habitat loss rates similar or greater to those in tropical forests.

In response to this trend, there has been an increased focus on the development and implementation of market-based mechanisms such as carbon offsets, to credit mangrove conservation for associated emissions reductions. This is largely modelled on the REDD (reduced emissions from deforestation and degradation) programs designed to protect tropical forests. The purpose of these programs is to provide market incentives to reduce emissions from deforestation by, for example, encouraging developing countries to reduce deforestation in return for compensation from developed countries committed to emission reductions.



maximum and minimum values
mean
summarizing data distribution include the quartiles
median
range of values that fall within the inner fences

FIGURE 61
Soil organic carbon content of mangrove surface soils (0-30 cm).



maximum and minimum values
mean
summarizing data distribution include the quartiles
median
range of values that fall within the inner fences
mild outliers
extreme outliers

FIGURE 62
CO_2 Flux.

Economic Valuation

The estimates for the economic value of sequestered carbon for the project study sites are based on an application of the Tier 1 approach. It should be noted that Tier 1 assessments typically come with large error ranges for both above ground and soil carbon estimates. The Tier 1 assessment of a carbon stock within a project area is achieved by multiplying the area of an ecosystem by the mean carbon stock for that ecosystem type. The mean value of 386MgCHa^{-1} is therefore multiplied by the respective site areas to provide estimates of carbon stock. The mangrove areas for the study sites are; Portland Bight 254.2 hectares, Bogue 66.2 hecatres and Salt Marsh 24.5 hectres. As part of this analysis we also estimate carbon sequestration values for the total estimated mangrove as per the Land Use and Land Cover (LULC) categorisation reported in the 5th National Green House Gasses (GHG) report. This estimated area for Jamaica is 9,715 hectares.

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The basic calculations are as follows:

Mean Carbon (MgC Ha^{-1}) * Area (Ha) = Mg (or T) of Blue Carbon in Study Site

Total Potential CO_2 emissions per hectare ($MgCO_2$ Ha^{-1}) = Mg C * 3.67

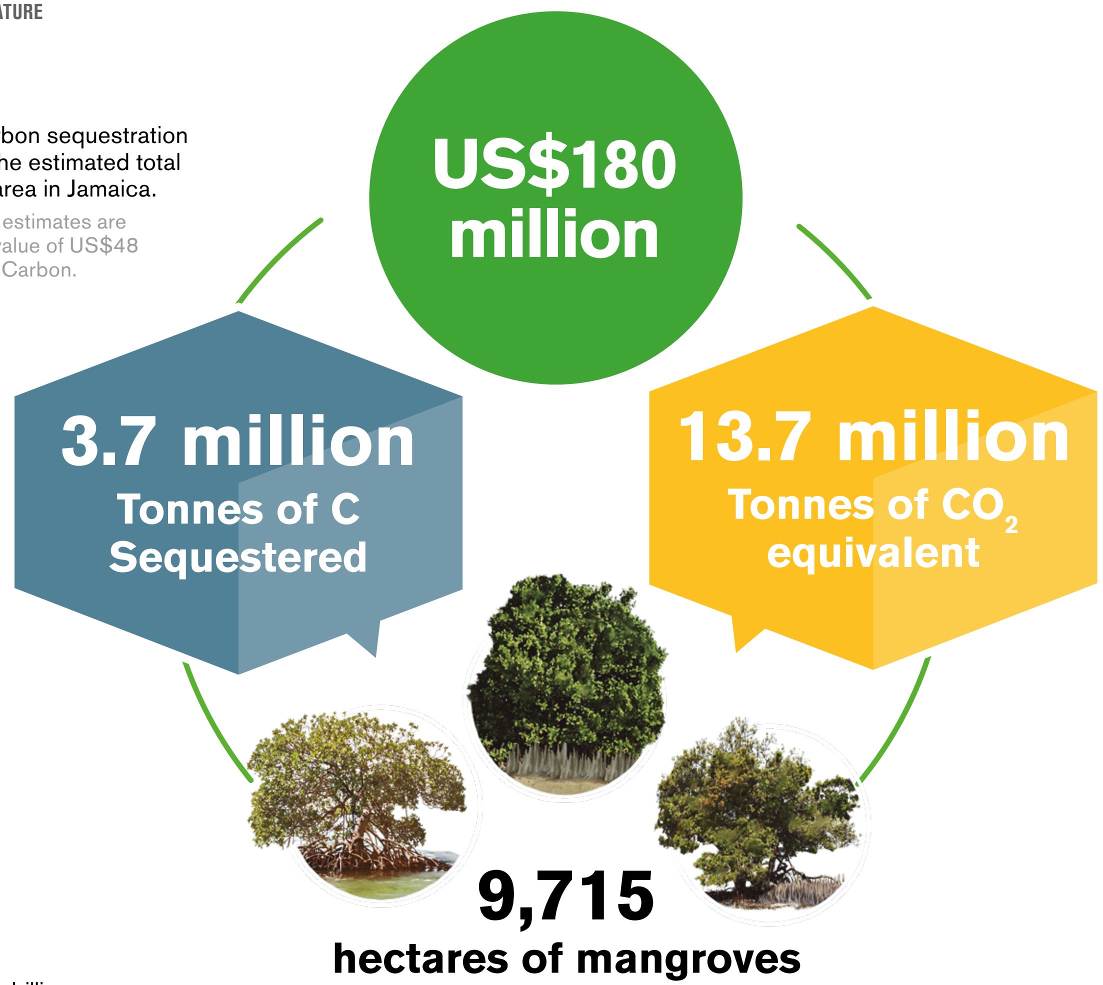
Carbon sequestration value = MgC * X$/MgC = X$

The Net Present Value (NPV) of annually sequestering carbon at the rate estimated above for a 100 year time frame was also calculated. This represents the value over time of keeping the mangrove forests intact. The sensitivity analysis compares discount rates ranging from 0% to 10%. It should be noted that for standard infrastructure development projects the typical discount rate used is 3%. For most carbon valuation studies the discount rate of interest

FIGURE 63

Annual Carbon sequestration values for the estimated total mangrove area in Jamaica.

Note: These estimates are based on a value of US$48 per tonne of Carbon.



m: million, b: billion

	PORTLAND COTTAGE	BOGUE LAGOON	SALT MARSH	COMBINED SITES	JAMAICA TOTAL
Area (Ha)	254.2	66.2	24.5	344.9	9,715
Tonnes C Sequestered	98,121	25,553	9,457	133,131	3.7 m
Tonnes of CO_2 equivalent	359,778	93,695	34,676	488,148	13.7 m
Estimated Price T^{-1} C (Social Cost of Carbon)					
US$48 (Latin America)	$4.7 m	$1.2 m	$453,936	$6.4 m	$180 m
Rate of time Preference					
0% PRTP = $677	$66.4 m	$17.3 m	$6.4 m	$90.1 m	$2.5 b
1% PRTP = $360	$35.3 m	$9.2 m	$3.4 m	$47.9 m	$1.3 b
3% PRTP = $44	$4.3 m	$1.1 m	$416,108	$5.8 m	$165.0 m

is usually set at 1 to 1.4%. Part of the controversy with discount rates is that to account for intergenerational equity issues, discount rates for carbon should be set at zero given the longer time frames of climate and carbon cycling. However, the resulting price estimates for carbon are typically quite large and as a result may have little real world policy application. It can still be instructive to show the value over these longer time frames for trade off purposes. Based on the results of the sensitivity analysis we can examine the annual value of carbon sequestration as well as the future value of carbon over a 100 year life span. These estimates are based on a value of US$48 per tonne of Carbon.

INCORPORATING SITE LEVEL DATA

The previous analysis relied on the global average taken from the literature. The UWI team also conducted an analysis of carbon stock as outlined in the companion report. We also use the lower and upper bound of $CMgHa^{-1}$ to assess the actual Social Cost of Carbon (SCC) based on these estimates. The UWI component estimated carbon flux, standing biomass and soil organic carbon for the 3 locations. Using the mean bulk density value from a pedotransfer function, estimates were shown to be higher than the global average of 386 $MgCHa^{-1}$. The average soil organic carbon stocks ($MgCHa^{-1}$) were 1,023.1 for Portland Cottage, 1,205.7 for Bogue Lagoon and 878 for Salt Marsh. These site-specific averages were also used to estimate SCC.

FIGURE 64

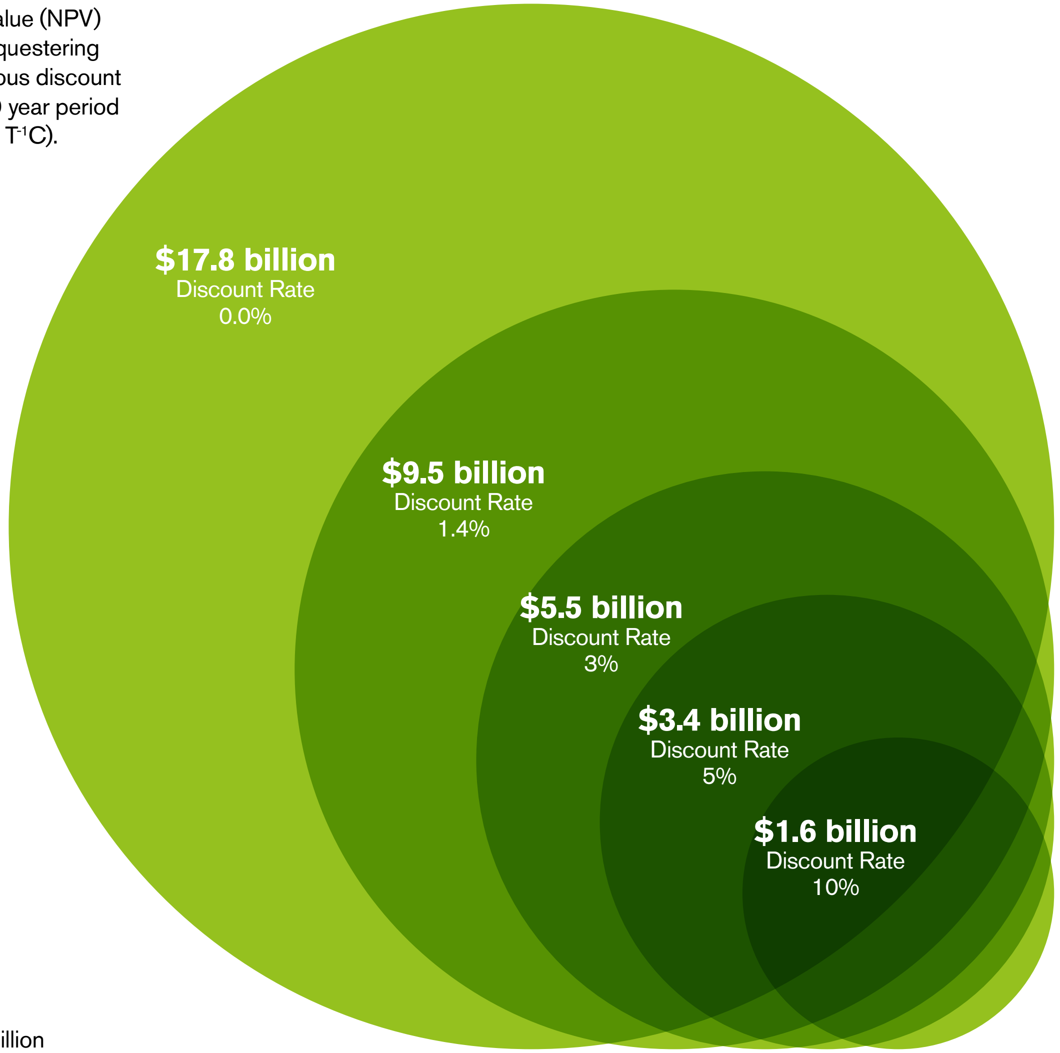
Site specific carbon sequestration values for mangrove study sites.

m: million, b: billion

	PORTLAND COTTAGE	BOGUE LAGOON	SALT MARSH
Avg Soil Carbon Stock ($MgCHa^{-1}$)	1023.1	1205.75	878
Area (Ha)	254.2	66.2	24.5
Tonnes C Sequestered	260,077	79,821	21,511
Tonnes of CO_2 equivalent	953,616	292,676	78,874
Estimated Price T^{-1} C (Social Cost of Carbon)			
US$48	$12.5 m	$3.8 m	$1.0 m
Rate of time Preference			
0% PRTP = $677	$176.1 m	$54.0 m	$14.6 m
1% PRTP = $360	$93.6 m	$28.7 m	$7.7 m
3% PRTP = $44	$11.4 m	$3.5 m	$946,484

FIGURE 65

Net present value (NPV) of annually sequestering carbon at various discount rates over 100 year period (SCC US$48 T⁻¹C).



m: million, b: billion

	Discount Rates				
	0.0%	1.4%	3%	5%	10%
SCC= US$48 T^{-1}C	NET PRESENT VALUES (100 YEARS)				
PORTLAND COTTAGE	$466.3 m	$248.0 m	$144.2 m	$89.0 m	$42.8 m
BOGUE LAGOON	$121.4 m	$64.6 m	$37.6 m	$23.2 m	$11.1 m
SALT MARSH	$44.9 m	$23.9 m	$13.9 m	$8.6 m	$4.1 m
COMBINED SITES	$632.6 m	$336.5 m	$195.7 m	$120.7 m	$58.1 m
JAMAICA TOTAL	$17.8 b	$9.5 b	$5.5 b	$3.4 b	$1.6 b

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DISCUSSION

Carbon Values

Using a global soil carbon stock average of 386 $MgCHa^{-1}$ and a SCC of US$48 T^{-1} C, the value of annual sequestration for Portland Cottage, Bogue Lagoon and Salt Marsh are respectively US$4.7 million, US$1.2 million and US$453,936.

Net Present Values calculated for a 100 year timespan show estimated values for keeping carbon sequestered ranging from US$4.1 million (Salt Marsh) to US$466 million (Portland Cottage).

However, when estimates of soil carbon stock for each location were used with the same SCC the value of annual sequestration for Portland Bight, Bogue Lagoon and Salt Marsh are US$12.5 million, US$3.8 million and US$1 million respectively. The site-specific economic SCC values are higher than the global average. Similarly, the NPV for a 100 year timespan at different discount rates are higher than the estimates using the global carbon stock average. These value estimates are influenced by the choice of discount rate and represent the avoided costs to society of not releasing this stored carbon to the atmosphere.

The site-specific results confirm that based on the carbon stocks at these 3 locations, there is significant carbon sequestration economic value. Estimating the economic benefits of sequestering carbon forms the basis for the development of carbon markets. Jamaica through these study sites and more broadly other mangrove forested areas could seek to partner with stakeholders to develop a blue carbon market. This could be in the form of trading on the international market (REDD+ schemes or other private markets) or possibly develop an indigenous or local carbon market. This may require engaging the hotel sector, major infrastructure developers and agriculture as part of the process.

Nearshore Fisheries

Site Level

Mangrove fisheries benefits are typically derived from two key ecological mechanisms. The first, is the high level of primary productivity from the mangrove trees and from other producers in the mangrove environment that supports secondary consumers. This high level of primary productivity forms the basis of food chains that support a range of commercially important species. The second is the physical structure (habitat) that they provide, creating attachment points for species that need a hard substrate to grow on, as well as shelter from predation and a benign physical environment. These two mechanisms combine to make mangroves particularly effective as nursery grounds for juveniles of species that later move offshore or to adjacent habitats such as coral reefs.

Many offshore species are found in mangroves during part of their life cycle, most commonly as juveniles. Indeed, juveniles of some species of penaeid prawn are found almost exclusively in mangroves. Many fish species are also found in mangroves as juveniles, and studies have demonstrated the movement of juveniles from mangroves to coral reefs and other offshore habitats. For Jamaica, studies showed that over 220 species of fish use mangroves to lay their eggs and feed. This includes many commercial fish such as grunt, snapper, snook, tarpon, barracuda and mackerel. Furthermore, important reef cleaners such as parrotfish are highly dependent on mangroves for breeding.

In addition to nursery services, mangroves also support commercial harvest of fin and shellfish species these include mullets, crabs, oysters and other estuarine species. While some species use mangroves only at certain life history stages - for example snapper may live in the mangrove as juveniles before moving to coral reefs as adults - other species live outside the mangrove but enter it at high tide to feed. This highlights the potential importance of habitat linkages in enhancing fish productivity, while also making it challenging to isolate the role of mangroves in supporting fisheries in such mixed habitat systems.

Estimating the economic value of mangrove-associated fisheries is challenging, particularly at regional or global scales. Estimation of the proportional contribution to commercial (or subsistence) fish harvest is typically very data limited. An additional challenge of these estimates is the underlying complexity and variability of the types of fisheries. Several studies are limited to individual target species or specific fishing methods, and as a result capture only a part of the total fisheries value. Estimates for the economic contribution of mangrove habitat support to offshore fisheries can also vary spatially given differences between quality of the habitat at the seaward edge or "fringe" of the mangrove forests as compared to further inland.

The science underpinning our understanding of the role of mangroves has grown and show strong evidence that supports their effects in enhancing coastal and cross-shelf fisheries. Annual commercial fish harvests from mangroves have been valued at from US$6,200 per km² in the United States to US$60,000 per km² in Indonesia.

Other studies have produced estimates with ranges between 5 to 25% contribution of mangrove to offshore fishery. Another study estimated a 32% contribution of the local fishery landings by mangrove, an equivalent of US$6,000 per hectare. Yet another study on the contribution of Malaysian mangroves to nursery areas, coastal food chains and fisheries show that net fisheries contribution of mangrove forest amounted to US$846 per hectare per year.

In the context of climate change and resilience (ecological and human), mangrove values for fisheries need to be viewed in a host of different contexts. In many countries it is often the case that (subsistence) inshore fisheries are more valuable as a protein source in coastal communities where there is no agriculture, or where poverty prevents the purchase of other protein sources. It is therefore important to keep in mind that higher numbers of vulnerable populations engaging in low value fisheries may have a more important localized social economic impact that higher value commercialized catch.

There are additional protective roles that mangroves serve linked directly to fisheries. The provision of safe refuges for boats and fishing equipment in mangrove lagoons and forests during storm events is a regulating ecosystem service that translates to avoided costs of damage. Storm refuge systems exist in many jurisdictions where special permission is granted to areas typically not permitted for boat owners to use mangrove safe areas.

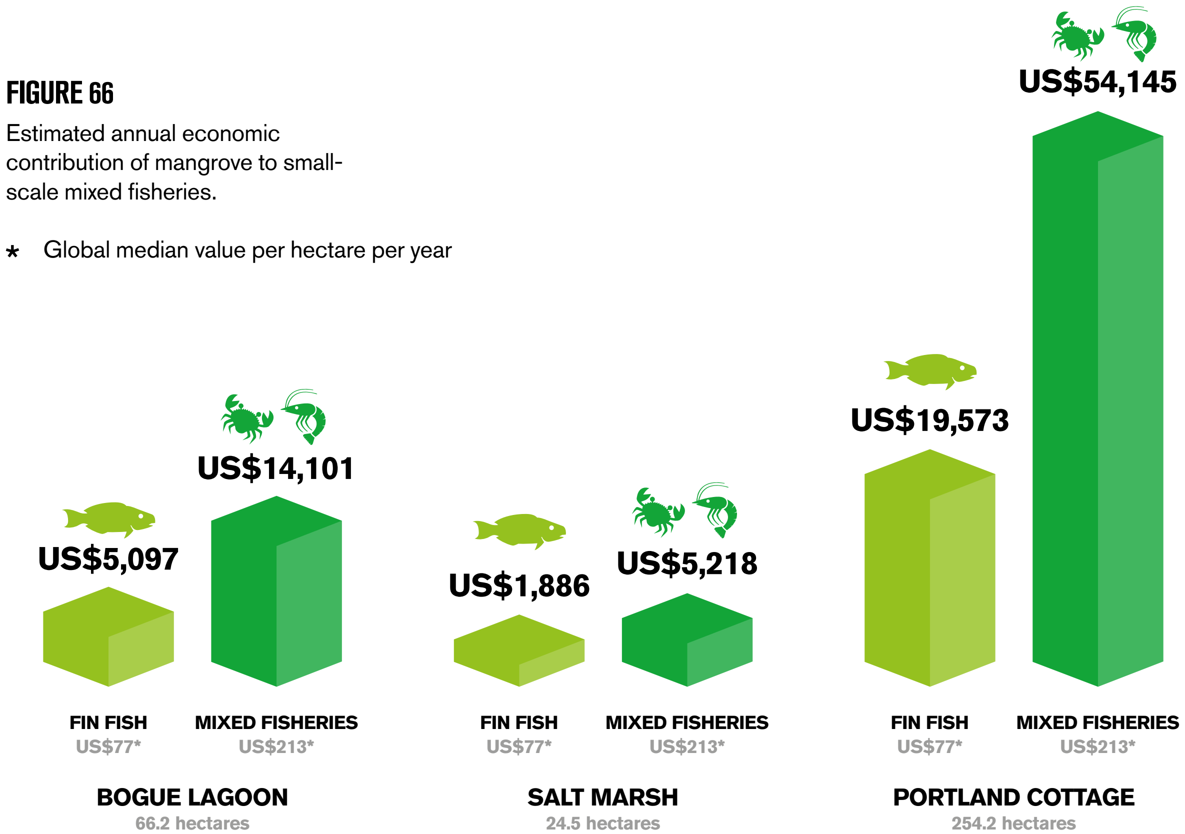
Economic Valuation

The estimates of value per site outlined are based on a review of related literature and subsequent benefit (value) transfer. There are studies with broad range estimates of mangrove-associated fisheries economic values often in excess of US$1,000 per hectare per year. Based on a comparison of a variety of studies that included a range of mangrove types and fisheries, the global median value of US$77 per hectare per year for (fin) fish, and US$213 per hectare per year for mixed species fisheries was used for this analysis. These median values are within the context of a wide variation value. For example, for mixed-species fisheries, the values ranged from US$17.50 to US$3,412 per hectare per year. These median values are used as the value transfer estimates for the Jamaican mangrove sites.

FIGURE 66

Estimated annual economic contribution of mangrove to small-scale mixed fisheries.

* Global median value per hectare per year

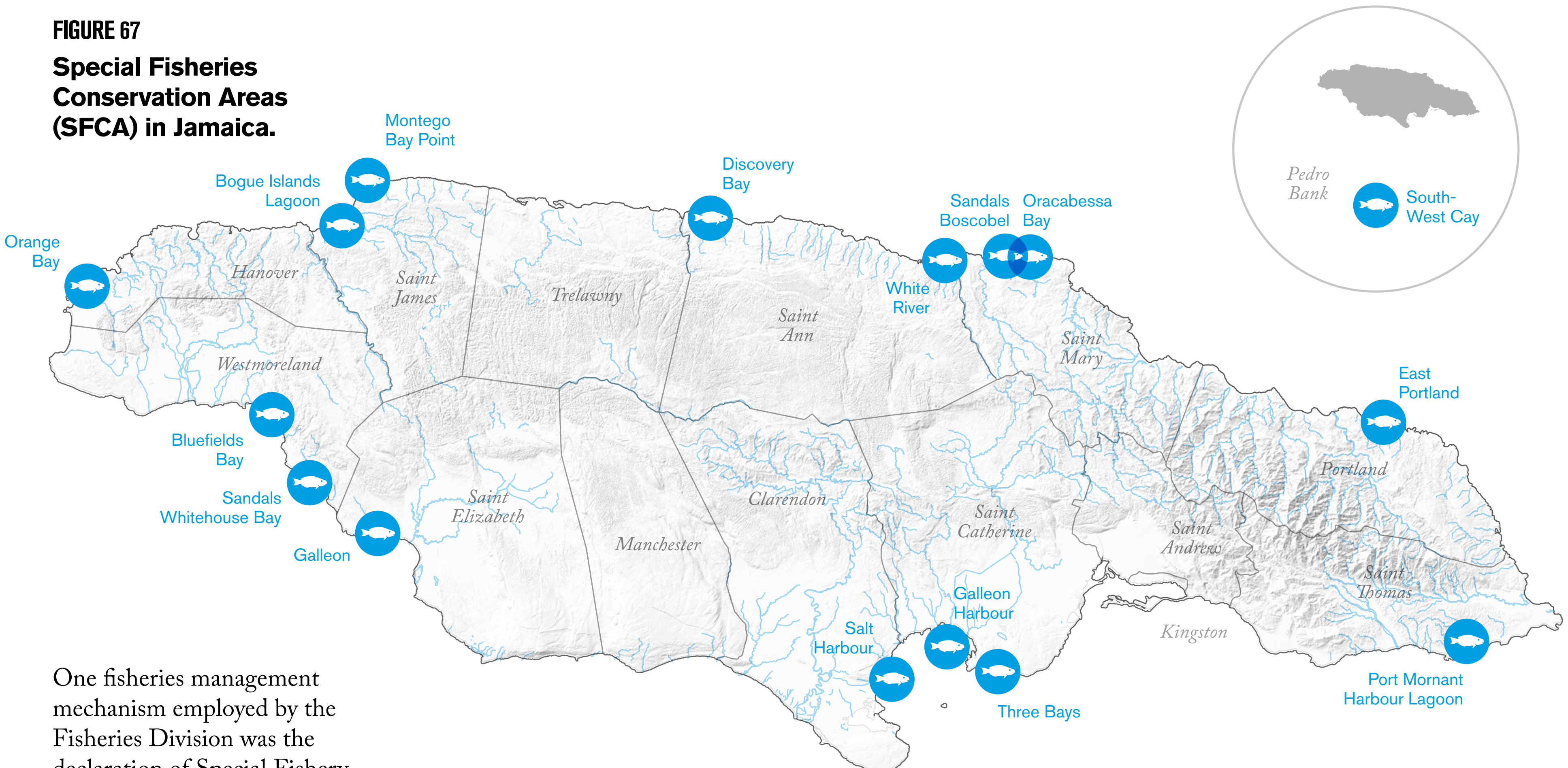


These estimates show that the economic contribution from these sites are relatively modest in comparison to other systems. However, these are relatively small areas and limit their ability to contribute more significantly to fishers' incomes. As indicated previously, these figures are based on median global estimates with wide ranges. These extrapolations, especially when expressed as simple averages, are therefore highly uncertain. Such global extrapolations also miss the spatial variability in mangrove-associated fishery values due to both local ecological factors, and a host of social, cultural and economic influences. The complexity of the different fishery types, scales, and fishing methods likely present at or adjacent to these three mangrove sites, coupled with the lack of current data on fish catch or number of fishing vessels meant that for this analysis it was not possible to develop a model linking the mangrove ecology and juvenile fish larvae with observed catch. These results should therefore be understood in this context. Fisheries landing data for beaches that may be in the proximity of these sites are not readily available. Economic information from fishing beaches may be influenced by nursery or spill-over effects and can be used to make stronger linkages and highlight the role that mangroves play in supporting nearshore commercial fisheries.

When considering the 3 study locations, in the context of all fishing beaches island-wide, there are fishing beaches that may benefit from the presence of mangrove stands. The figures below illustrate the proximity of fishing beaches to each study site. The fishing activity from each beach may be in part be supported by the mangrove forests.

FIGURE 67

Special Fisheries Conservation Areas (SFCA) in Jamaica.



One fisheries management mechanism employed by the Fisheries Division was the declaration of Special Fishery Conservation Areas (SCFA), also known as fish sanctuaries. Each SFCA varies in size, ecosystems present, and management. This management approach aims to protect and enhance the fish stock and to promote increased biodiversity in coastal and marine areas.

An examination of the figure above shows that many of the SFCA include mangrove forests. In fact, these areas were selected based on a number of criteria including the presence of a reef system and/or shallow waters abutting mangrove stands in their presence. It should be noted that there are currently two SFCAs established at 2 of the 3 study locations (Bogue Lagoon and Portland Cottage) and a third is proposed for Salt Marsh.

To date there is limited data that indicates success (or lack thereof) of the SFCAs. Of those with publicly available data, the Oracabessa Bay SFCA has reported a 1,313% increase in fish biomass between 2011 and 2014.

Incorporating Site Level Data

At the 3 study locations, light traps were secured to red mangrove prop roots and used to collect fish larvae samples. Sampling was conducted during new moon phases. Fish larvae from these samples were identified, enumerated and then used to provide information on; richness, presence of commercially important species and their relative abundance. The UWI biological team noted some major limitations with this approach including short time frame for study, and the inability to sample more than one location at a time. Based on some of the limitations cited above, adult fish species were not sampled.

Larval contribution to commercial fisheries

Unfortunately, not much of the larval data collected at these sites can be used to extrapolate the contribution to fisheries. It was however notable that for some locations commercially relevant larval species included snappers and clupeid family (which are typically used as bait fish). It was also noted that adult fish use the mangroves seasonally (for spawning) or diurnally (for feeding) but also stated 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.

Social Dependence

Even in the absence of catch data for commercially important adult species, the socio-economic assessment was able capture information from respondents surrounding these locations. Residents in Portland Cottage and Salt Marsh depend heavily on mangrove fisheries products to subsidize their household protein requirements. At Portland Cottage, fishers reported earning an average of US$93 per week from mangrove related fishing activity. In addition to commercial sale of fish products, respondents indicated a high level of dependence on fish and other mangrove products to supplement their protein intake (subsistence).

DISCUSSION

Other Potential Benefits

RECREATIONAL FISHING

The implementation of low impact types of mariculture activities could be an additional area of benefit for vulnerable communities. It should be noted that this is not large-scale aquaculture that may involve the destruction of existing mangrove stands for example shrimp farming. Instead mangroves are perfect locations for introducing low impact mariculture approaches. This may require the rejuvenation of previous Jamaican efforts

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to raise oysters *(Crassostrea rhizophorae* and *Isognomon alatus)* and other bivalves. These species occur naturally in the study sites and may already be subject to some level of harvest. The need to implement programs and frameworks to ensure that the fisheries sector is more resilient and adaptive to climate change has been an on-going initiative of many national economies and is considered necessary for Jamaica. Mangrove forests are excellent locations to support alternative livelihood strategies. One component of the fisheries related project from the Pilot Program for Climate Resilience (PPCR) is looking at the potential for sustainable and low impact aquaculture of oysters. The fisheries PPCR subcomponents have a focus on alternative livelihoods. Two of which are most applicable to mangrove forests, namely;

LOW IMPACT MARICULTURE

The implementation of low impact types of mariculture activities could be an additional area of benefit for vulnerable communities. It should be noted that this is not large-scale aquaculture that may involve the destruction of existing mangrove stands for example shrimp farming. Instead mangroves are perfect locations for introducing low impact mariculture approaches. This may require the rejuvenation of previous Jamaican efforts to raise oysters *(Crassostrea rhizophorae* and *Isognomon alatus)* and other bivalves. These species occur naturally in the study sites and may already be subject to some level of harvest. The need to implement programs and frameworks to ensure that the fisheries sector is more resilient and adaptive to climate change has been an on-going initiative of many national economies and is considered necessary for Jamaica. Mangrove forests are excellent locations to support alternative livelihood strategies. One component of the fisheries related project from the Pilot Program for Climate Resilience (PPCR) is looking at the potential for sustainable and low impact aquaculture of oysters. The fisheries PPCR subcomponents have a focus on alternative livelihoods. Two of which are most applicable to mangrove forests, namely;

Promoting Community-based Aquaculture – which involves the establishment of fish farm clusters in selected communities, contracting new fish farmers and providing inputs and farming materials by partnering with aquaculture/processing enterprises, and providing training. This subcomponent would support fisher folk, women and youth in targeted fishing communities to invest in aquaculture.

Developing Coastal Mariculture/Polyculture – which are commercially viable and ecologically important with the aim of increasing marine-based sustainable livelihoods activities that keep the communities' seafaring traditions alive.

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DISCUSSION

Mangrove Fisheries Benefits

Jamaican wetlands and mangroves are decreasing in many coastal areas due to human activity and this has important implications on sustaining Jamaica's social and economic development. For example, the loss of mangroves means major breeding grounds for fish, crabs, shrimps, prawns and other commercial and non-commercial marine life are no longer available. This in turn, reduces the possibilities of sustaining the livelihoods of over 23,000 licensed fisherfolk as well as many more who fish informally.

Mangrove fisheries are particularly important in developing countries like Jamaica, as they provide a critical source of food and income for many who have few livelihood alternatives. These ecosystems support a broad range of fishing methods and result in the exploitation of a wide range of species. Mangrove forests also support inshore mixed species artisanal fisheries conducted with limited equipment, on foot or from open boats. This type of fishing is usually linked to small-scale commercial purposes and subsistence fisheries where the catch is primarily used to feed the fisher, family members and close community, with limited market transactions.

6

Limitations, Conclusions and Implications

Limitations

These results are obtained using the best available datasets and a high-resolution process-based model.

These datasets and model come with inherent limitations in their ability to represent reality. Previous studies by the UCSC-IHC team and others have identified topography as one of the key datasets for accurate representation of coastal flooding. The national scale study (UCSC-IHC-TNC) obtained and used a highly accurate 6m LIDAR topography dataset for the entire country which represents a significant improvement over previous assessments.

One limitation of the UCSC-IHC-TNC study was the availability of high-resolution bathymetry which is crucial for estimating nearshore and coastal waves, and water levels. To overcome this, a freely available global 1km dataset for offshore analyses was combined with a commercially obtained 10m resolution dataset for Jamaica, for the analyses of nearshore and coastal regions. A state-of-the-art numerical modelling system (ADCIRC + SWAN) was used to accurately represent nearshore coastal wave and water levels and their interaction with mangrove vegetation.

Given the short time-frame, and the simultaneous data collection and analyses conducted at the local and national scales, one limitation with the UCSC-IHC-TNC's model was the use of a uniform roughness coefficient to represent the effect of mangroves. Based on published studies, constant values have been assumed throughout Jamaica, which roughly represent the friction associated with these ecosystems. More detailed studies, such as the one conducted by UWI, in which accurate information is available on mangrove forests (density, trunk width, vertical structure) would allow modeling waves and storm surge by calculating the forces of drag produced by each single submerged element of the tree, and no longer considering an equivalent roughness. These data have been initially collected in three sites, and results have been presented in the local-level report from UWI. In the future, it is expected that the NEPA will continue with this data collection and analysis, for monitoring and decision-making efforts.

The experience in the socio-economic assessment at the local level suggests that greater reconnaissance work from the beginning, involving field mapping, will help in understanding population within the demarcated area for the socio-economic assessments. Additional information from fisherfolks within the various communities would be valuable to allow for greater understanding of fish data and value provided to fisheries by mangroves. Further, interviews and focus groups may support household surveys especially in understanding other socio-economic benefits provided by mangrove forest such as ecotourism.

The physical component of this multidisciplinary project is complimentary to the ecological and socio-economic evaluations and has provided a baseline of local-level data not in existence before. However, replicating this effort in other areas is necessary for better quality data, and decision-making. 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, and did not occur during the collection of the data. Deeper cores should be considered to understand the palaeo-sedimentology, 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 centimetre 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 stability 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. In addition, National Land Agency benchmarks and fixed GPS installation are needed for satellite altimetry for long-term assessment of deep subsidence rates that occur as a result of tectonic activity in the region. This will help understanding the role and rate of deep tectonic subsidence at all sites, and potential risk to coastal hazards.

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

Since the production and release of particulate and dissolved organic carbon (DOC represent a primary loss pathway, it would be useful to investigate the hydrological controls on particulate organic carbon (POC) and dissolved organic

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carbon (DOC) 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 carbon dioxide (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.

In addition, biological oxygen demand (BOD) and chemical oxygen demand (COD) analyses of water samples should be done to complement dissolved oxygen (DO) measurements.

The economic estimation approaches used here rely heavily on well-collected physical and biological information that can be used to impute economic or other benefits. However this study was limited by data gaps and unavailability, instead relying heavily on desktop research, literature reviews and basic value transfer approaches in order to provide a mixture of quantitative and qualitative information on the benefits of mangroves beyond coastal protection. For example, global estimates of per hectare carbon stock were primarily used and supplemented by the more site specific results from UWI. Global estimates were also used to estimate mangroves' contribution to fisheries due to a lack of data on fisheries landings, catch per unit and sales. It was therefore difficult to make a direct link between fisheries catch and the potential beneficial role mangroves play, particularly as nursery areas for juvenile fish.

Finally, it is important to highlight that the results presented in this report, and underlying reports (see "Original Content and Further Reading" section), are based on best available data from secondary sources, and data collected at only three priority sites. Further efforts are needed from the Government, civil society organizations, academic sector and private sector, to improve data quality and support science-based decision making.

Conclusions

Jamaica faces substantial flood risk from coastal storms and mangroves provide considerable flood risk reduction benefits.

Annually, the value of Jamaica's mangrove forests for flood risk reduction to the nation's-built capital is more than US$2,500 per hectare.

This represents a nearly 24% annual reduction in flood risk. The loss of Jamaica's mangroves would further result in a 10% increase in the total number of people flooded every year. Mangrove benefits are most apparent for high intensity storms of 1 in 200 year return periods. During these storms, mangrove forests protect 177,000 people and nearly US$2.4 billion or 50% of the total affected population and built capital. This translates to economic benefits of more than US$186 million per hectare of mangroves.

Additional analyses of recently lost mangroves in Old Harbour Bay show that the loss of these mangroves has resulted in the loss of flood protection benefits of more than $1.8 million each year.

Conversely, this represents the potential value of restored mangroves in this region at almost US$1,000 per hectare per year. As we describe in our assessment of mangrove habitat status across Jamaica, the loss and gain of mangrove extents is a mixed story. While a lot of areas like Old Harbour Bay have lost critical and valuable mangroves over the last decade, other areas such as parts of Kingston have also seen valuable gains in mangrove extents which in turn can be expected to offer valuable additional flood protection benefits.

The restoration potential analyses are based on available spatial datasets of mangrove extents for the country.

More detailed assessments of realistic restoration potential will require refined analyses of land-use patterns across the country to identify where mangrove restoration action will be possible versus not (for example, it will be difficult to restore mangroves in areas that have since been converted to intense urban use such as an airport).

Mangrove restoration costs are influenced by factors unique to coastal and inter-tidal ecosystem restoration projects.

Since these typically happen in the inter-tidal zone, the availability and price of land are important factors. Large-scale projects on government owned land typically have much lower unit costs than smaller projects on private lands[51]. Another critical issue is ease of permitting for activity in offshore and inter-tidal locations, especially in countries like the USA where the modification of coastal and marine waters is governed by strict regulations. While in some locations like Florida the clearing of existing mangrove forests cannot happen without a permit, similarly, new activity in coastal waters – including ecological restoration – also requires permits from multiple agencies. This process can often be time-consuming and costly[52]. Larger projects on government-owned land typically have easier, expedited permitting processes than projects on private land, substantially reducing these initial costs. For restoration projects that primarily involve mangrove planting, labour costs and the availability of volunteers to offset these costs can make a significant difference to the overall cost of the project. Often, restoration projects involve voluntary mangrove planting activities that are also combined with outreach and education initiatives. Projects involving hydrological restoration and sediment management can be substantially more expensive due to the need for specialized equipment, labour and, in some cases, the purchase and transportation of sediment from external sources. While most projects reviewed in this study do not report maintenance and monitoring costs and efforts, this is nevertheless an important and significant aspect of successful mangrove restoration. Examples of mangrove maintenance include clearing debris after hurricanes, removing invasive species and maintaining hydrological flows. The costs of these activities will depend on the scale of the project and the availability of volunteers.

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The factors influencing the costs of coastal protection structures are broadly similar to the factors for restoration projects.

Typically, coastal structures like seawalls and levees take up less space than a mangrove restoration project, though the taller a structure, the more space it generally requires, and the costlier it becomes[53]. Artificial structures can also be costly to build in terms of material, labour and expertise; and costly to maintain in terms of repairing damage or upgrading in response to changes in sea-level. Offshore structures such as sea dykes or offshore breakwaters are typically costlier due to more difficult working environments. The costs of offshore structures will also be significantly influenced by the depth of water at the installation site[54].

Implications and the Way Forward

There is growing awareness and interest within the development agenda in nature-based solutions for DRM, but the incorporation of ecosystem benefits to DRM strategies has been relatively limited in practice. Nevertheless, ecosystem services can play a role in DRM strategies, as multiple sectors, such as the re/insurance sector, could review and update risk management approaches by incorporating natural capital and eco-services to manage risks and reduce their economic impacts. Furthermore, environmental degradation leads to increased risk, but this is not yet explicitly incorporated in risk models. Indeed, the decline of natural capital in coral reefs, seagrass beds and mangroves could lead to a reduction in coastal protection and marine fish production, comprising the livelihoods of coastal dependent communities that rely on fisheries and tourism, among others[55].

Mangrove conservation and restoration can be an important part of the solution for reducing coastal risks in the Jamaica, especially as those risks increase with climate change. This Report has advanced the understanding in how to evaluate coastal risk reduction from ecosystems, through the assessment of how loss of mangroves can increase coastal flood risk, and has identified potential risk reduction measures based on the conservation and restoration of mangrove habitats.

The social and economic valuation of mangroves that has been generated in this study, can inform the policy and practice of many Jamaican agencies, businesses and organizations across development, aid, risk reduction and conservation sectors as they seek to identify sustainable and cost-effective approaches for risk reduction. In addition, the ecological and physical assessments conducted under this study reveal the current health status of mangroves, and the implications in coastal resilience.

By showing the spatial variation of the flood reduction benefits provided by mangroves, these results can identify the places where mangrove management may yield the greatest returns. By valuing these coastal protection benefits in terms used by finance and development decision-makers (e.g. annual expected benefits), these results can be readily used alongside common metrics of national economic accounting, and can inform risk reduction, development and environmental conservation decisions in the Jamaica.

To date, the great majority of climate resilience financing efforts take into consideration underlying exposure and vulnerability assessments that focus on built infrastructure and social conditions (health, education etc.), but generally ignore the natural capital, in spite of its contribution to risk reduction, recovery and resilience. In addition, the post disaster damage losses and needs assessments, which intend to estimate the extent of disaster effects and impacts across all sectors and estimate the recovery needs, generally overlook damages and losses in natural ecosystems. This situation is due to the fact that there are few ecological datasets related to natural capital and valuation of ecosystem services, as well as social reliance on natural resources, which are not usually gathered in a systematic way by government agencies. As a consequence, the estimated damages and losses leave thousands of people dependent on natural resources for food and livelihoods with an inadequate recovery strategy after a natural event.

These results have important implications for the consideration of nature-based solutions within adaptation, insurance, hazard mitigation and disaster recovery decisions. The results presented here show that mangroves offer significant benefits for flood risk reduction and overall coastal resilience, and that restoring mangroves can be cost effective for flood risk reduction particularly when compared to the costs of grey infrastructure.

In addition to informing disaster risk management and climate change adaptation efforts, the results presented in this study including fisheries provision, carbon sequestration, erosion control, and wind attenuation, are essential to understand the value of mangrove ecosystems in coastal resilience and climate change mitigation.

Making all this information available could help build bridges between funding sources (and government programs) and align environmental and disaster risk management goals.

The results presented in this report can be used by public agencies to inform hazard mitigation, disaster recovery, and resilience financing funding decisions. Following hurricanes (for example Hurricane Maria and Irma in 2017, and Hurricane Dorian in 2019) significant aid and support has flowed into the Caribbean and much of this support is going to build or re-build gray infrastructure including dikes, levees and seawalls. The results presented here show that it can also make economic sense to support restoration of mangrove with disaster recovery funds, and to incorporate mangrove conservation and restoration activities as part of build-back-better strategies.

In the past nature-based measures for coastal protection, such as mangrove restoration, were not assessed for their cost effectiveness for risk reduction, because rigorous values of their coastal protection benefits, as well as a general understanding of the ecosystem status were missing. These services can now be rigorously valued to inform national accounting, cost-benefit analyses and comparisons of different coastal protection options, including natural, hybrid and built defenses. Many funders (from development banks to climate adaptation funds) could be compelled by assessments that show where nature-based solutions such as mangrove restoration have greater benefit-cost rations. This assessment provides much of the core material for such a benefit cost assessment across the country, and the Caribbean region.

The results presented here on flood reduction benefits and costs also could be used to support national applications to the Green Climate Fund, World Bank, IDB and other supporters of infrastructure, disaster risk management and adaptation projects in the region. Even where these costs of restoration may seem high it is important to note that (i) the benefits of restoration can extend over long time periods, (ii) include indirect flood reduction benefits (i.e. to especially vulnerable populations), and (iii) also include many co-benefits such as fisheries and tourism.

Numerous programs can incorporate these results into their plans and analysis, including, but not limited to, the National Environment and Planning Agency (NEPA), Office of Disaster Preparedness and Emergency Management (ODPEM), Water Resources Authority (WRA), National Works Agency (NWA), Jamaica Social Investment Fund (JSIF) and the Planning Institute of Jamaica (PIOJ).

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These results can be considered in risk industry models, which may influence insurance premiums in Jamaica and the development of innovative finance mechanisms to support mangrove management. By incorporating natural capital and ecosystem services (co-benefits such as fisheries) into disaster risk financing strategies, the re/insurance industry could also become a driver of change in developing nations such as Jamaica, and other SIDS. This industry could have an active role in incentivizing governments and planners on the adoption of nature-based solutions for coastal protection that could range from physical investments such as mangrove replanting, to non-structural solutions such as expanding protected areas. Risk transfer options could be explored such as resilience bonds that provide up-front capital expenditure for solutions such as ecosystems' enhancement, that could also help protect built assets and local livelihoods.

This work can also be used to inform the development of insurance approaches like the Caribbean Oceans and Aquaculture Sustainability FaciliTy (COAST) developed by the World Bank and the Caribbean Catastrophe Risk Insurance Facility (CCRIF SPC), and those being tested on the MesoAmerican Reef in Mexico[56] where a policy has been taken out on the reef based on the flood protection benefits to coastal hotels and the Mexican economy. The value of the policy was determined in part by the costs of restoring benefits if the reef were damaged in a storm. This study will allow testing similar approaches in Jamaica.

This study can also have significant implications on poverty reduction as the conservation and restoration of mangrove habitats will contribute to food security through fisheries provision, and livelihoods maintenance including tourism and fishing.

Finally, this effort funded by the Program on Forests (PROFOR) through the World Bank was able to involve sixty-one Jamaicans (76% of the total workforce), ranging from government officials, to professors, and university students. This has important repercussions on capacity building at the local scale, as the country is more capable to replicate this effort, and to explore new opportunities in which coastal ecosystems can help reduce climate risks.

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Acronyms

ADCIRC	ADvanced CIRCulation
BOD	Biological Oxygen Demand
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
CCRIF	Caribbean Catastrophe Risk Insurance Facility
COAST	Caribbean Oceans and Aquaculture Sustainability FaciliTy
COD	Chemical Oxygen Demand
CCAM	Caribbean Coastal Area Management Foundation
CPS	Country Partnership Strategy
DBH	Diameter at Breast Height
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
DVRP	Disaster Vulnerability Reduction Project
Eco-DRR	Ecosystem-based Disaster Risk Reduction
EDF	Expected Damage Function
FAO	Food and Agriculture Organisation of the United Nations
FEMA	Federal Emergency Management Agency
GDP	Gross Domestic Product
GHG	GreenHouse Gas
GOJ	Government of Jamaica
GWP	Global Warming Potential
Ha	Hectare
HRRACC	Hazard Risk Reduction and Adaptation to Climate Change
ICENS	International Centre for Environmental and Nuclear Sciences
IH Cantabria	Hydraulics Institute, University of Cantabria
IKI	International Climate Initiative
IPCC	Intergovernmental Panel on Climate Change
JRC-EU	Joint Research Commission – European Union
JSIF	Jamaica Social Investment Fund
Km	Kilometre
LIDAR	LIght Detection And Radar
LULC	Land Use and Land Cover
m	meter
MBMP	Montego Bay Marine Park Trust
MSL	Mean Sea Level
NBS	Nature Based Solutions
NEPA	National Environment and Planning Agency
NPV	Net Present Value
NRCA	Natural Resources Conservation Act
NWA	National Works Agency
OC	Organic Carbon
ODPEM	Office of Disaster Preparedness and Emergency Management
PIOJ	Planning Institute of Jamaica
PPCR	Pilot Program for Climate Resilience
PROFOR	World Bank Program on Forests
REDD+	Reduced Emissions from Deforestation and Degradation
RSET	Rod SET
SCC	Social Cost of Carbon
SE(M)	Standard Error (of the Means)
SFCA	Special Fishery Conservation Areas
SIDS	Small Island Developing States
SLR	Sea Level Rise
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SWAN	Simulating WAves Nearshore
TDS	Total Dissolved Solids
TNC	The Nature Conservancy
UCSC	University of California Santa Cruz
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollars
UWI	The University of West Indies
WRA	Water Resources Authority
WB	World Bank
yr	Year

List of figures

Glossary

A

Adaptive Capacity
The social and technical skills and strategies of individuals and groups that are directed towards responding to environmental and socioeconomic changes.

Anoxic
is a description of the environment - without oxygen.

Autochthonous
formed or originating in the place where found

Allochthonous
formed elsewhere than in situ and hence not autochthonous

B

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

Blue Carbon
is the carbon captured by the world's coastal ocean ecosystems, mostly mangroves, salt marshes, seagrasses and potentially macroalgae.

Bioturbation
the disturbance of sedimentary deposits by living organisms.

C

Conductivity
Conductivity is the measure of the ease at which an electric charge or heat can pass through a material.

Carbon Sequestration
the process involved in carbon capture and the long-term storage of atmospheric carbon dioxide or other forms of carbon to mitigate or defer global warming.

Coastal Squeeze
intertidal habitat loss which arises due to the high water mark being fixed by a defence and the low water mark migrating landwards in response to sea level rise.

Carbon Offsets
reduction in emissions of carbon dioxide or other greenhouse gases made in order to compensate for emissions made elsewhere. Offsets are measured in tonnes of carbon dioxide-equivalent (CO_2e).

Carbon Flux
the amount of carbon exchanged between Earth's carbon pools - the oceans, atmosphere, land, and living things - and is typically measured in units of gigatonnes of carbon per year (GtC/yr).

D

Discount Rates
the expected rate of return for an investment

F

Foraminifers
members of a phylum or class of amoeboid protists characterized by streaming granular ectoplasm for catching food and other uses; and commonly an external shell (called a "test") of diverse forms and materials.

G

Gas Flux
flow of volatile gas emissions from a specific location

GPS
Global positioning system

H

Homogenous
material or system has the same properties at every point; it is uniform without irregularities.

Horizon Markers
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

Hydroperiod
the number of days per year that an area of land is wet or the length of time that there is standing water at a location.

I

Ichthyoplankton
are the eggs and larvae of fish.

In situ
in the original place

L

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

Lithological
branch of geology that studies rocks - their origin and formation and mineral composition and classification.

N

Net Present Values
the difference between the present value of cash inflows and the present value of cash outflows over a period of time.

Pedotransfer Function
predictive functions of certain soil properties using data from soil surveys.

P

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 −log10 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

Prop Roots
Roots that extend from the main tree stem into the ground providing support to the tree

S

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

Sensitivity
degree to which a system will respond to a change in climatic conditions.

Siliciclastic
rocks are clastic noncarbonate sedimentary rocks that are almost exclusively silica-bearing, either as forms of quartz or other silicate minerals.

Spatio-temporal
taking into consideration both space and time

Substrate
an underlying substance or layer, the layer from which organisms thrive, it may be soil, peat, sand or a combination in this study

T

Tier 1 approach
employs the gain-loss method described in the IPCC Guidelines and the default emission factors and other parameters provided by the IPCC

Total Dissolved Solids
Total dissolved solids is 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

V

Vulnerability
Extent to which changes in climatic condition may damage or harm a system

W

Wave/Wind Attenuation
reduction in the strength of wave/wind

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