

# MANGROVES

MONITORING AND EVALUATION MANUAL

# JAMAICA





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## Glossary

<b>Anemometer</b>	Device used for measuring wind speed, and is also a common weather station instrument
<b>ASTM</b>	Refers to ASTM International, or American Society for Testing and Materials, which is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services
<b>Auger</b>	A drilling device, that usually includes a rotating helical screw blade called a "flighting" to act as a screw conveyor to remove the drilled out material, which in this study is soil or substrate
<b>Bathymetry</b>	The measurement of depth of water in lakes, seas or oceans. In other words, bathymetry is the underwater equivalent to hypsometry or topography
<b>Benchmark</b>	A standard or point of reference against which measurements may be compared by the installer or other; which in this study is a steel pole, fixed by cement
<b>Buffer</b>	In GIS, a zone around a map feature measured in units of distance or time
<b>Conductivity</b>	Rate at which an electric charge or heat passes through a material.
<b>Depth sounder (Echo sounder)</b>	Device for determining water depth or detecting objects in water by measuring the time taken for sound waves to return to the instrument from the object or benthos.
<b>Gas flux</b>	Flow of volatile gas emissions from a specific location
<b>Geochemistry</b>	The study of the chemical composition of the earth and its rocks and minerals
<b>GPS</b>	Global positioning system
<b>Horizon marker</b>	Layer of powder, dust, glitter, feldspar powder, kaolinite which is laid down on the surface of a soil to later serve as an indicator of soil level. White lime was used in this study.
<b><i>In situ</i></b>	"in the original place/appropriate position"
<b>Lateral accretion</b>	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 bar or in a coastal zone
<b>Loss on ignition</b>	Test used in inorganic analytical chemistry, particularly in the analysis of minerals. It consists of strongly heating ("igniting") a sample of the material at a specified temperature, allowing volatile substances to escape, until its mass ceases to change
<b>Matlab</b>	Fourth-generation programming language and numerical analysis environment

<b>Oceanlyz</b>	MATLAB toolkit useful for constraining wave parameters from pressure loggers and gauges
<b>pH</b>	<p>Expression of 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 <math>-\log_{10} c</math>, where <math>c</math> is the hydrogen ion concentration in moles per liter.</p> <p>literal meaning-‘potential for hydrogen’.</p>
<b>Plot</b>	Area of a known size
<b>Pneumatophores</b>	Mangrove aerial roots specialised for gaseous exchange which grow upward (protruding from the soil/water) from the submerged primary root system.
<b>Polyethylene</b>	Tough, light flexible synthetic resin made by polymerizing ethylene, chiefly used for plastic bags, food containers, and other packaging
<b>Prop roots</b>	Roots that extend from the main tree stem into the ground providing support to the tree. In the case of mangroves these may also allow for gaseous exchange.
<b>PVC</b>	Polyvinyl chloride, is a common, strong but lightweight plastic used in construction. It is made softer and more flexible by the addition of plasticizers
<b>Rset</b>	Rod Set Elevation Table
<b>Salinity</b>	Amount of salt dissolved in a specific quantity of water.
<b>Sapling</b>	Plant greater than 0.5m but less than 1.5 m high
<b>Sedimentologist</b>	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
<b>Seedling</b>	Young plant less than 0.5 m high
<b>Site</b>	Area of interest or spatial location of a structure
<b>Spatial Analysis</b>	A type of geographical analysis which seeks to explain patterns of human behavior and its spatial expression in terms of mathematics and geometry, that is, locational analysis
<b>Statistical inference</b>	The theory, methods, and practice of forming judgments about the parameters of a population and the reliability of statistical relationships, typically on the basis of random sampling
<b>Statistics</b>	Branch of mathematics dealing with data collection, organization, analysis, interpretation and presentation



<b>Substrate</b>	An underlying substance or layer; the layer from which organisms thrive; it may be soil, peat, sand or a combination in this study
<b>Taphonomy</b>	The branch of palaeontology that deals with the processes of fossilization and useful evidence about the organism life and behaviour up to fossilisation
<b>Ternary Diagram</b>	Ternary plot, ternary graph, triangle plot, simplex plot, Gibbs triangle or de Finetti diagram is a barycentric plot on three variables which sum to a constant.
<b>Total dissolved solids</b>	Measure of the dissolved combined content of all inorganic and organic substances present in a liquid in molecular, ionized or micro-granular suspended form
<b>Transect</b>	Line or narrow area within area site along or within which points are established for collecting data
<b>Tree</b>	In this study, plant greater than 1.5 m high
<b>Vertical accretion</b>	Material that accumulates when deposits from rivers or coastal activity result in a higher sediment level
<b>wave attenuation</b>	Reduction in the strength of wave
<b>YSI 566</b>	One device that measures multiple water parameters
<b>zooplanktologist</b>	Person who studies zooplankton taxa

## Acronyms

<b>ASA</b>	Analytics and Advisory Services
<b>DBH</b>	Diameter at Breast Height
<b>DO</b>	dissolved oxygen
<b>ED</b>	Enumeration District
<b>FAO</b>	Food and Agriculture Organization
<b>GOJ</b>	Government of Jamaica
<b>NRCA</b>	Natural Resource Conservation Authority
<b>NEPA</b>	National Environment and Planning Agency
<b>ODK</b>	Open Data Kit
<b>ODPEM</b>	Office of Disaster Preparedness and Emergency Management
<b>PROFOR</b>	Program for Forests
<b>RSET</b>	Rod Surface Elevation Table
<b>SDC</b>	Social Development Commission
<b>SIDS</b>	Small Island Developing States
<b>TNC</b>	The Nature Conservancy
<b>UWI</b>	The University of the West Indies
<b>WB</b>	World Bank

## **Purpose of Document**

As a part of ongoing work on disaster risk reduction and protection of coastlines the Government of Jamaica (GOJ) had received funding from the World Bank (WB) Program on Forests (PROFOR) to implement the Analytics and Advisory Services (ASA) titled “*Assessment and Economic Valuation of Coastal Protection Services Provided by Mangroves in Jamaica*”. This activity was supervised by the World Bank, and led at the local level by the National Environment and Planning Agency (NEPA).

This manual (which is one outcome of the project) may be used by a wide range of stakeholders such as NEPA, Office of Disaster Preparedness and Emergency Management (ODPEM), parish disaster coordinators, Forestry Department and any others who can benefit from information on data collection methods on aspects of mangrove monitoring and evaluation. This manual has been separated by areas of interest, namely Components (i) Socio-economic (ii) Ecological and (ii) Physical data collection methodologies. It also includes a section on Economic Valuation methods under ‘Further Monitoring’. The manual also indicates how data collected on these different components can be combined to create a holistic approach to investigating coastal ecosystems, flood risk and damage to life and livelihood as well as mitigation using nature based solutions (i.e. mangroves).

## **Introduction**

Jamaica, the third largest island in the Caribbean, has been impacted by tropical storms and hurricanes (due to its location in the Atlantic hurricane belt), which has resulted in massive losses to life and livelihood. The Planning Institute of Jamaica (PIOJ) reports six severe hydro-meteorological events in Jamaica during the period 2002-2007 which resulted in massive flooding, damage to infrastructure and losses totalling US\$1.02 billion<sup>1</sup>. Much of the affected communities and towns are coastal and the repeated flood events have also resulted in coastal erosion.

In light of the extreme events affecting life and livelihood in Jamaica, and the growing vulnerability of coastal communities to inundation and erosion, The GOJ has developed national strategies and policies to promote resilient developments. One such, The National Development Plan “Vision 2030 Jamaica” identified *Sustainable Management and Use of Environmental and*

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<sup>1</sup> PIOJ (2002, 2004, 2005a, 2005b, 2007, 2008, 2009, 2010 and 2012)

*Natural Resources (Outcome 13), and Hazard Risk Reduction and Adaptation to Climate Change (Outcome 14)* as priority areas for the country's long-term development strategy<sup>2</sup>.

The concept of using mangroves as natural barriers to coastal erosion came into scientific knowledge and developed into policies following the 2004 Indian Ocean Tsunami and the 2005 storm surge from Hurricane Katrina that affected New Orleans. The World Bank (2016) study on the impact of mangroves in lowering erosion in the countries of Philippines, Guatemala, Rwanda, Colombia, Costa Rica, Indonesia and Botswana suggest that wave height can be reduced by 13 to 66% over a 100-meter-wide mangrove belt and by 50 to 100 % over a 500-meter-wide mangrove belt<sup>3</sup>.

### Habitat status of mangroves in Jamaica

Mangroves are halophytic (salt tolerant) plants which have the ability to thrive in the extreme conditions found in coastal intertidal zones. They are tropical or subtropical and primarily found in areas with low-oxygen and slow-moving waters; which are also sites of sediment accumulation<sup>4</sup>. Currently mangroves cover 167,000 -181,000km<sup>2</sup> in 112 countries but the majority are considered to be in a degraded condition<sup>4</sup>. Mangrove forest types, classified as fringing, riverine, over-wash and basin, can be found throughout most Small Island Developing States (SIDS) in the Caribbean (Antigua and Barbuda, Bahamas, Barbados, Cuba, Dominica, Dominican Republic, Grenada, Haiti, Jamaica, St. Kitts and Nevis, St. Lucia, St. Vincent and Grenadines, Trinidad and Tobago, Anguilla, Aruba, British Virgin Islands, Cayman, US Virgin Islands, Guadeloupe, Martinique, Montserrat and Turks and Caicos). Of the 70 "true" mangrove species found worldwide, 4 are found across the Caribbean – Red Mangrove (*Rhizophora mangle*), Black Mangrove (*Avicennia germinans*), White Mangrove (*Laguncularia racemose*) and Button Mangrove (*Conocarpus erectus*).

Approximately 20-35% of mangroves have been lost since the 1980s worldwide<sup>5</sup>, while specifically in the Caribbean, 24-28% has been lost<sup>6</sup>. The major reasons for the reduction in mangrove area are coastal and urban development, pollution (including solid waste), extraction of fuel-wood, as well as conversion for aquaculture and agriculture<sup>7</sup>.

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<sup>2</sup> <http://www.vision2030.gov.jm/>

<sup>3</sup> World Bank (2016)

<sup>4</sup> Basha (2018)

<sup>5</sup> FAO (2007); Polidoro et. al. (2010); Webber et. al. (2016)

<sup>6</sup> McKee et. al. (2007); Gilman et. al. (2008); Polidoro et. al. (2010)

<sup>7</sup> Polidoro et. al., (2010)



In 1987, about 29% of Jamaica's coastline was covered by mangrove forests representing approximately 9,700ha. Estimates from 2010 indicated the main coastal wetland areas of the country (Figure 1) where mangroves are found, amounted to approximately 11,670ha. This has increased to 16,740ha as mentioned in the "*Status of Jamaican Mangroves*"<sup>8</sup>, however the increase is said to be due to areas previously excluded from the 2005 mangrove survey, being included in 2011.

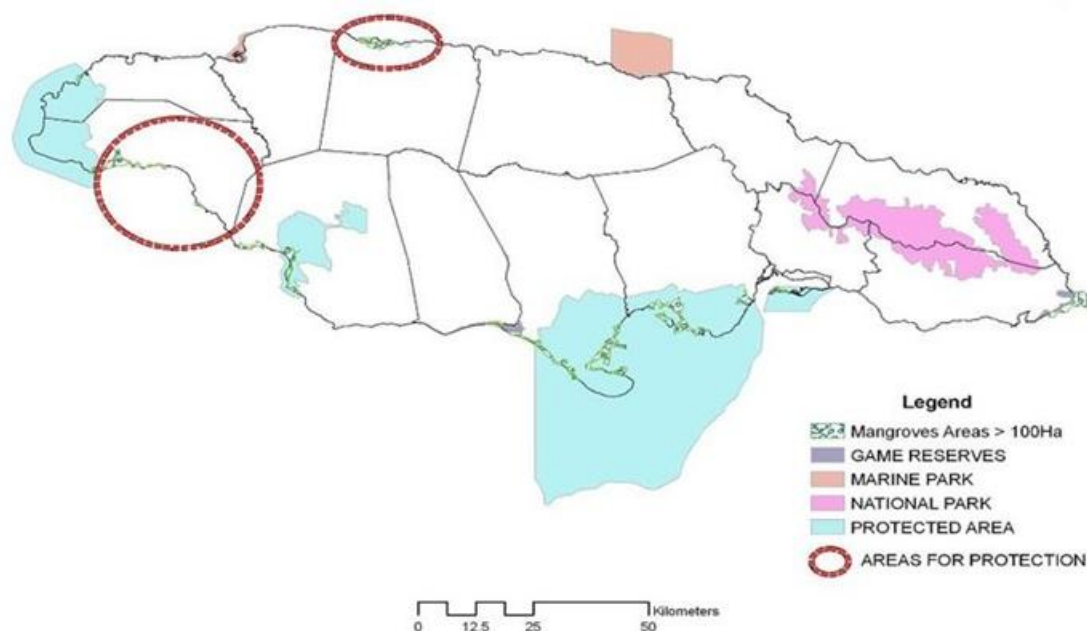


Figure 1: Map showing distribution of mangrove areas within protected areas of Jamaica (Modified from NEPA, 2014)

Of the 7 south coast parishes, 5 showed an increase in wetland coverage over a 6-year period from 2005 to 2011<sup>9</sup>. St. Catherine and Clarendon were the only parishes that showed a decrease in wetland area over time. In 2011, approximately 1,584ha of land in St. Catherine was classified as wetland. This is a decrease of just over 50% from that classified in 2005, while Clarendon showed a 40% decrease in wetland area; from 3,860ha to 2,334ha. Conversely, a section of the Negril Great Morass located within Westmoreland showed an increase of approximately 42% from 1,815ha in 2005 to 2,584ha in 2011. In St. Thomas, there was a marginal increase of 3% or 66 hectares, which was associated with the inclusion of the mangroves surrounding the Yallahs Salt Ponds. Comparisons have been made between mangrove area coverage surveys using remote sensing carried out in 2005 by The Nature Conservancy (TNC) and surveys (which incorporated ground-truthing) conducted in 2012 by NEPA. The most significant increase in coverage was 300% recorded for Kingston and St. Andrew in the 2012 surveys; this was again attributed to newly documented areas that were excluded in the 2005 survey. The status in

<sup>8</sup> NEPA (2014)

<sup>9</sup> NEPA (2012)

2012 showed that the 3 parishes along the north coast including Westmoreland (when verified against the desktop survey in 2011 for mangrove coverage) showed an increase in mangrove coverage ranging from 9.3% to 99.7% for St Ann and Hanover. St James on the other hand showed a 6% decrease. In all instances where there was an increase in wetland coverage this was attributed to areas being omitted in the 2005 survey.

Despite this apparent large increase in area (due to changes in assessment methods), significant areas of Jamaica's mangrove forests have depleted due to the change in land use patterns. The majority of the depletion is seen for areas where coastal developments have taken place particularly along the North Coast.

### Importance of mangroves

Mangroves provide a range of ecosystem services, including:<sup>10</sup>

Supporting & Regulating Services	Provisioning Services	Cultural Services
<ol style="list-style-type: none"><li>1. Habitat for juvenile fish that are important both as essential components of coral reef and other ecosystems and are important commercial species;</li><li>2. Carbon sequestration;</li><li>3. Climate regulation;</li><li>4. Shoreline stabilization;</li><li>5. Water filtration and pollution regulation.</li><li>6. Coastal Protection and Resilience</li></ol>	<ol style="list-style-type: none"><li>1. Fisheries production</li><li>2. Aquaculture production</li><li>3. Pharmaceutical generation</li></ol>	<ol style="list-style-type: none"><li>1. Recreation &amp; tourism;</li><li>2. Educational opportunities</li><li>3. Aesthetic &amp; cultural values.</li></ol>

Therefore, the reduction of coastal mangroves in Jamaica has several consequences including an increase in coastal erosion, since mangroves act as natural breakers of wave and wind force. The decrease in mangrove area further affects biodiversity and is consequently likely to cause reduction in commercial and non-commercial fisheries, which is an important livelihood for many coastal communities. Finally, mangrove depletion will result in reduction of natural sediment and

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<sup>10</sup> Webber et. al. (2016)

nutrient filters, and loss of carbon reservoirs; all of which are important for climate change adaptation mitigation, and disaster risk management.

## Site Selection

The following criteria are important to consider when selecting a Monitoring site for investigating the coastal protection services of mangroves:

- Proximity to communities or important infrastructures
- Sites with proximate sheltered and exposed (high wave energy) areas
- Sites with continuous and fairly homogeneous forest cover, uninterrupted by pools or channels as much as possible
- Accessibility to the selected sites by land is considered but not a priority

It should be noted that each mangrove forest is different, so criteria may vary. Those above are considered ideal for areas which provide strong protective services. However, areas which do not satisfy all may still offer some degree of protection. Aerial photography or satellite imagery should be used to determine the conditions/features of the site as well as size, and ideal placement of transects and plots.

## **Component 1: Socio-Economic Monitoring**

### **Theoretical Framework**

The effects of coastal flooding, among other natural hazards, have long been understood within the context of prevailing socio-economic conditions. Research has extensively indicated that socio-economic characteristics may compound levels of vulnerability and have implications for recovery and resilience<sup>11</sup>. More specifically, poor communities have been positioned as disproportionately less able to cope with the impositions of environmental threat and are therefore in greater need of intervention initiatives which seek to reduce inherent vulnerabilities<sup>12</sup>.

Socio-economic domains provide particularly useful insight when intersected with demographic variables such as age, gender and dependency ratios<sup>13</sup>. In this regard women and older cohorts have commonly been constructed as more vulnerable. The role of women in the household and their contribution to income and other conditions therefore presents important scope for examining how households and, by extension communities, hazards such as flooding. Additionally, variables such as the strength of community ties and willingness to participate have also been found to influence the ways in which communities negotiate natural hazards<sup>14</sup>.

Understanding the social and economic context therefore represents an important pivot in assessing the value and role of ecosystems which shape and are in turn shaped by socio-economic conditions of those reliant on the resource. Specifically, mangrove ecosystems arguably have significant value in the social and economic systems of the communities in relatively close proximity. This can be viewed both from the perspective of the role that it plays in potentially offsetting the threat of physical hazards, such as storm surges, and also in relation to their value in socio-cultural and economic systems which are directly and indirectly influenced by their presence.

In this manual, the socio-economic component sets out to understand this through two broad objectives:

1. The social and economic value of the ecosystem services including the number of livelihoods that benefit from mangrove existence.

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<sup>11</sup> Cutter et. al. (2003); Adger (2006); Baptiste and Kinlocke (2016)

<sup>12</sup> Adger (2006); Kesavan and Swaminathan (2006)

<sup>13</sup> Hann et. al. (2009); Cutter et. al. (2003)

<sup>14</sup> Hahn et al (2009); Orencio and Fujii (2013)



2. The impact of mangroves on protection of coastal infrastructure and estimate losses thus avoided

A household survey was developed to provide a quantitative assessment of these changes and their social and economic implications.

## Methods of Data Collection

The method of data collection can be considered in stages. These are outlined below.

### Step 1: Conduct Field Reconnaissance and Secondary Data Collection

Conduct **field reconnaissance** to understand the spatial layout of the communities and demarcate boundaries within which the assessment will be conducted. This may also be useful for developing the questionnaire survey. For example, observations from the reconnaissance fieldwork could facilitate the classification of communities into residential and commercial which would further inform the type of questions asked.

It may be important here to **liaise with community members** to bring awareness of the data collection process that will be taking place in the community and the objective of this process. In so doing, bonds may be established which can allow for a smoother data collection process. Liaising with community members is also effective in demarcating boundaries where a researcher may be interested in a specific community or area of interest. This process can also help in gaining some insight into specific areas of interest in the community which may be useful in developing the survey instrument.

Use **Secondary Data Sources** to gather information on the demographic characteristics of the community. The National Census Data will be a vital resource here and the population from which the sample is selected may be based on estimates of the Enumeration District (ED) or alternative other sources such as the Social Development Commission (SDC). ED boundaries represent administrative divisions used for the collection of census data. A single community may comprise several EDs or may be entirely contained within an ED. EDs are used to facilitate more efficient management of population counts and are delimited by the number of households contained within each unit. For urban areas, this is limited to 150 households per ED and for rural areas this number is 100 households<sup>15</sup>. These spatial units comprehensively cover the island.

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<sup>15</sup> PIOJ (n.d.)

On the other hand, SDC boundaries are delineated based on a combination of natural, cultural and administrative features<sup>16</sup>. While population estimates based on these boundaries may represent an appropriately nuanced estimate of community size, the national data set lacks comprehensive coverage and does not include some communities in the island. This may undermine cross community comparisons based on population estimates. Consider the administrative scale at which the census data was collected. Note that data at the level of the enumeration district may present a challenge if researchers are only interested in specific areas within that enumeration district. In such circumstances, the most appropriate method would be to count the houses or businesses in this delineated area of interest. This number would be a subset of structures within the larger enumeration district but would be a more precise representation of the population of interest.

### Step 2: Develop Primary Data Collection Approach

**Compute the sample** based on selected parameters. For example, in this study the sample size was calculated at the 95% confidence level and a margin of error of  $\pm 10\%$ . The following equation may be used:

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

Where:  
Z = Z value (e.g. 1.96 for 95% confidence level)  
p = %age picking a choice, expressed as decimal  
(.5 used for sample size needed as this is a best fit for equal probability across categories)  
c = confidence interval, expressed as decimal  
(e.g., .04 =  $\pm 4$ )

It should however be noted that these calculated samples were an overrepresentation of the population as the calculation was done based on the entire ED. This approach was taken as the population of the smaller, more specific area of interest was unknown. The larger sampling frame was used as the basis for sampling as it would inevitably translate to an overrepresentation of the smaller area provided numbers were relatively close to the estimated proportions. Nevertheless, it is accepted that the most appropriate method of determining sample would have been through field mapping during reconnaissance.

**Determine the sampling technique** which may involve the use of probability or non-probability techniques and the choice is ultimately conditioned by factors such as resources, time and geographical scale. For example, the census method involves visits to each structure of

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<sup>16</sup> PIOJ (n.d.)

interest within the delineated study area. In this way each element the population had an equal chance of being selected.

**Develop survey for quantitative assessment** of the various indicators. Including appropriate stakeholders in the development and design of the survey instrument to ensure all critical components are captured and reflect the expectations of stakeholders.

In designing the survey, consider the following:

- The need for data to be disaggregated by gender
- Assessment of poverty levels in the community using primary and secondary data
- An assessment of socio-economic data including types of goods, estimated value, asset evaluation
- Observed changes in mangrove over the years and the impact of these changes
- Current provision of services provided by mangrove and its importance- number of livelihoods that benefit from mangrove existence disaggregated by gender
- Opportunities for engaging persons in mangrove restoration activities
- Flood risk and coping capacity.
- Dominant land use of the community area (e.g. residential vs commercial)

A sample survey can be found in Appendix 1: Socio-economic Survey Instrument. It includes the following sections:

Section A: Household Demographics

Section B: Housing Characteristics

Section C: Commercial Demographics

Section D: Fishing and Other Livelihoods

Section E: Mangroves Knowledge, Uses and Importance

Section F: Flooding Risk and Coping Capacity

Section G: Mangrove Management and Restorative Efforts

It is recommended that **piloting the survey instrument** be done prior to conducting data collection. This allows for the identification of difficult, ambiguous or repetitive questions. Amendments should be made as necessary following this process.

### **Step 3: Conduct Field Training and Data Collection**

Prior to commencing fieldwork, ensure that **fieldworkers are trained** in the use of the instrument and that they are familiarised with the content and administration of the survey instrument. If mobile data collection tools are utilized, train data collectors in the manipulation and management of mobile devices and the user interface associated with the relevant software,

such as the open source software, Open Data Kit (ODK)<sup>17</sup>. Appendix 2: Screenshots of Socio-economic survey using ODK illustrates how the sample survey could be developed in Microsoft Excel and how it is visualised after upload in ODK on mobile devices. However, the use of ODK will require training and may be costly. Other options for collecting such data may include online programs such as Google Forms and Survey Monkey or the traditional paper-based survey. The online methods are however dependent on how many people you need to contact and the characteristics of these people. They also do not facilitate offline collection and storage of data which is more appropriated for field work.

**Assign field supervisors** with relevant skills and knowledge in mobile data collection to manage any issues which may emerge in the field. It is also recommended that field workers work in pairs for security purposes especially when working in new or unknown areas.

#### Step 4: Monitor Data Quality Standards

Data quality standards cannot be seen as a separate stage, but a continuous process from determining the sample to collection and entry of data. Consider the following conditions in the evaluation of data quality:

- Validity by ensuring that the data meets the objectives of the study and represents the intended result. The multi-stakeholder approach to developing the questionnaire is an important step to achieving this.
- Integrity by minimizing any errors that may arise from data entry and manipulation. The choice of using ODK helps with minimizing errors as data are automatically uploaded in various format thus reducing any errors that occur in data entry. The training in the ODK prior to data collection also helps with this. Once data is uploaded to the database and subsequently imported into a statistical software of your choice, data cleaning should be conducted to identify outliers and errors. This may be done by generating charts and tables for each of the variables in the dataset.
- Reliability by ensuring consistent both in terms of the data collection processes and analysis across time, items and researchers.

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<sup>17</sup> <http://opendatakit.org>



## Analyses of Socio-economic Data

Analyse data using descriptive and inferential statistics. Consider disaggregation of data based on various parameters which may include gender or location. Details of some key analyses are provided below.

### Assessment of poverty levels

Use descriptive statistics to examine a number of variables including household income, ability to save, dependency on social welfare, characteristics of home etc. The results can be support by existing secondary data.

### Goods & value extracted

Use cross-tabulations to assess information on fishing and other goods extracted, particularly from mangrove areas, by community. Use inferential statistics to compare means as it relates to income, if data is provided. The data collected may be limited in this area due to lack of knowledge, in some cases, or unwillingness to provide.

### Current provision of services provided by mangroves

This is the number and type of livelihoods that benefit from mangrove existence disaggregated by location, gender etc. Use cross-tabulation to compare fishing livelihoods and other livelihoods that might be directly related to mangroves across various parameters such as communities and gender. For example, a cross tabulation can be done by looking at fishing in mangrove areas according to community (Table 1).

*Table 1: Fishing activity in mangrove areas of Portland Bight and Salt Marsh*

Name of community	Fishing in Mangroves			
	Yes	No	Don't Know	Total (frequency)
Portland Bight, Clarendon	54.2%	45.8%	0	24
Salt Marsh, Trelawny	42.9%	50.0%	7.1%	14
Total (%)	50.0%	47.4%	2.6%	38

### Coastal protection from mangroves

Conduct cross-tabulations to compare vulnerability to coastal flooding based on flood experience in the community (Table 1Table 2). Use data on the value of businesses and homes (secondary data from property valuation supplemented by primary data which

may include annual earnings and number of employees etc.) and estimated income from goods extracted from the sea to estimate avoided losses.

*Table 2: Shows the %age (%) of people who have experienced coastal flooding in the communities.*

Name of Community	Experience Coastal Flooding in the Community	
	Yes (%)	No (%)
Portland Bight	88.7	11.3
Salt Marsh	34.1	65.9
Bogue	22	76.3
Total	54.4	45.2

### **Observed changes in mangroves**

Includes possible reasons for such changes and current management or restorative efforts by community members to restore mangrove and their willingness of communities and opportunities for engaging persons in mangrove restoration activities disaggregated by gender as part of the "Cost-effectiveness Assessment". Use cross-tabulation to explore observed changed in mangroves and opportunities for engaging persons in mangrove restoration activities (Table 3, Table 4, Table 5).

*Table 3: Observed changes in Mangroves in Bogue, Portland Bight and Salt Marsh*

Name of the Community	Changes observed in the extent of the mangrove forest over the last 10 years			
	Decreased	Same	Increased	Don't know
Bogue, St. James	46.7%	8.3%	8.3%	36.7%
Portland Bight, Clarendon	22.6%	17.9%	46.2%	13.2%
Salt Marsh, Trelawny	45.9%	20.0%	14.1%	20.0%
Total	36.3%	16.3%	26.3%	21.1%

*Table 4: Shows the %age (%) of willingness amongst the people to participate in mangrove restoration.*

Community	Willingness to participate in mangrove restoration efforts (%)		
	Yes	No	Don't Know
Bogue	65	13.3	20
Portland Bight	71.7	18.9	9.4
Salt Marsh	67.1	24.7	8.2
Total	68.5	19.5	11.6

*Table 5: Shows the %age (%) of willingness to participate in Mangrove Restoration disaggregated by Gender for Portland Bight.*

Gender of Respondents	Yes (%)	No (%)	Don't Know (%)	Total Respondents
Male	71.2	26.9	1.9	52
Female	73.6	11.3	15.1	53
Total	76	20	9	105

Use inferential statistics to excavate latent patterns in the dataset (see Table 6). The application of inferential statistics may range from the use of basic statistical tests such as the Chi squared test to more complex explorations involving the use of regression models. It is recommended that the Chi squared test or other bivariate analyses be used for initial diagnostics and as a precursor for more in-depth probing of patterns within the data set.

*Table 6: The association between gender and selected variables based on the results of the Chi Squared test*

	$\chi^2$	d.f.	p value
Responses to flooding			
– No action taken	0.65	1	0.406
– Relocated	1.24	1	0.264
– Flood proofed home	0.09	1	0.991
– Took out flood insurance	1.23	1	0.267
Other variables			
Time taken to recover from last flood event	2.71	5	0.735
Willingness to participate in restoration activities	1.20	2	0.548
Current involvement in restoration activities	1.72	1	0.189

## **Component 2: Ecological Monitoring**

### **Theoretical Background**

The methods used to measure the structural attributes of mangroves such as species composition, biomass indicated by Diameter at Breast Height (DBH), tree height and density are based on the methods identified by Cintron and Novelli (1984) in the methods of studying mangrove structure.

Two different heights (1.3 m and 1.5 m) can be used to determine DBH. The measurement of DBH at a height of 1.3 m is to maintain the standard used currently in Jamaica while the 1.5 m facilitates comparison with global assessments as done by Hortsman et al. (2014).

According to Hortsman et al. (2014), *"For reliable representation of vegetation in mangrove wave attenuation models, detailed site specific information on vegetation characteristics such as stem and root diameter are important"*. Establishing 3 subplot quadrats (0.5x0.5m/1m<sup>2</sup>) representing a low, average and high pneumatophore/prop root density, counting the total number of pneumatophores and determining the above ground length/height and diameter of 20 randomly selected roots are based on accepted methods<sup>18</sup>. The assessment of all pneumatophores is an improvement based on the difficulty of making unbiased 'random' selections under the given field conditions.

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<sup>18</sup> Dahdouh-Guebas et al. (2007); Hortsman et al. (2014)



## Methods of Data Collection

### Resources required

Mangrove assessments require the following list of tools/equipment:

- GPS unit
- Dura copy waterproof copier paper / Waterproof tablets or smartphones with Open Data Kit forms preloaded
- Pencils and Permanent markers
- Clipboard
- 100 m fiberglass open reel tape
- 10 m fiberglass open reel tape
- Flagging tape
- Caliper/DBH tape
- 7.5m Telescoping pole / 2 m graduated pole
- 1m pole/ ruler
- Digital camera
- Modified Light trap<sup>19</sup>
- Cable ties
- Ethanol
- Fish ID guides
- Stereomicroscope
- Appropriate field gear (Long-sleeve shirts and trousers, hat, waterproof rubber boots).

With a team of 6 persons, 1 transect can be completed within 3 hours. However, this timing depends on accessibility within the forest as well as the length of transect being assessed.

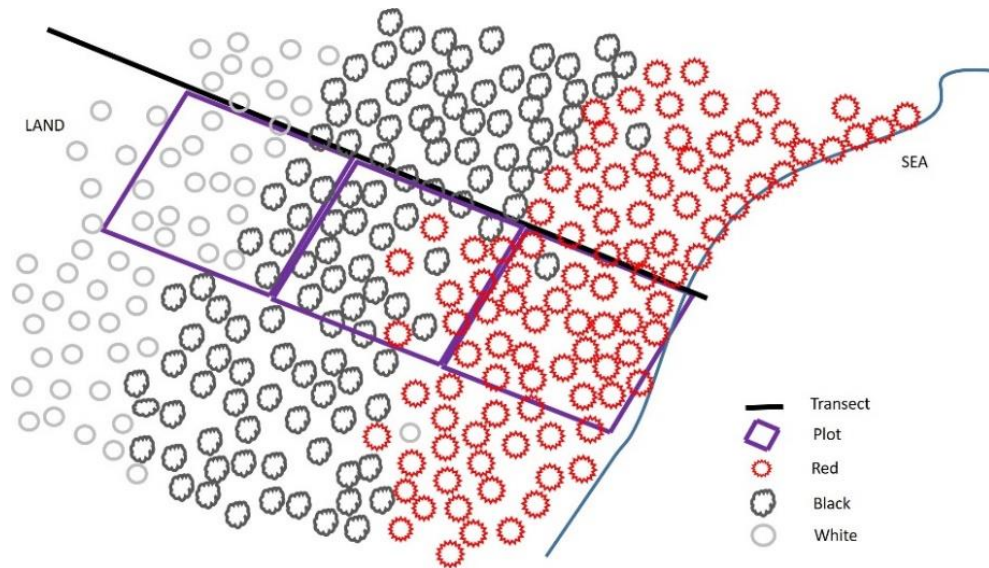
### Mangrove species composition and relative abundance (for diversity)

1. Fill in data sheet (Appendix 3: Vegetation assessment data sheet) with date, time of assessment; site and/or location name; name(s) of researchers; and any other notes such as level of human/ natural disturbance.
2. Establish a transect (Figure 2) running from the seaward edge of the forest to the inland areas (maximum transect line length is dependent on the area being assessed, therefore transect can be 50m; 100m or longer). Furthermore exact placement of vegetation plots will be informed by reconnaissance (Appendix 4: Reconnaissance data sheet).

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<sup>19</sup> Jones (2006)

3. Use a handheld GPS unit to record the location of the limits of each transect i.e. the start position and end position of transect.



*Figure 2: Example of monitoring transect and plot setup (Created by Patrice Francis, 2019).*

4. Establish replicate vegetation plots of 10 X 10 m along each transect by marking trees with flagging tape or paint. The length of each side of the plot should be 10 m where possible. However, if there is insufficient space 'linear plots' of 5 x 20 m can be used.
5. Identify the type and number of tree species and record the results on the data sheet.

### **Mangrove Trunk Diameter (DBH)**

Mangrove tree trunks come in a variety of formations (Figure 3). To determine the correct point to measure DBH, use the guide below.

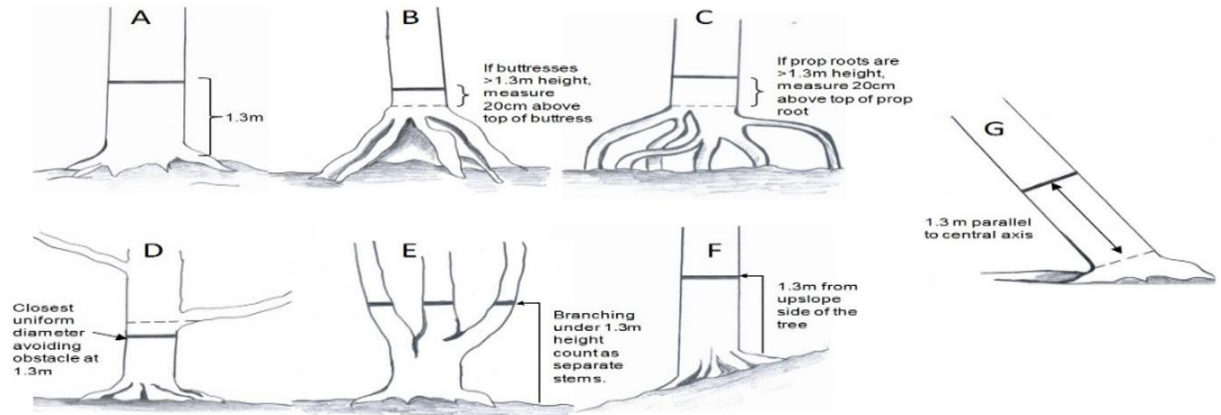


Figure 3: Measuring stem diameter<sup>20</sup>

- (A): Place a 2 m pole to stand upright next to trees within each 10 x 10 m plot and mark off 1.3 m and 1.5 m heights.
- Buttresses (B): measure diameter 20 cm above top of buttress.
- Prop roots (C): measure diameter 20 cm above top of prop root.
- Abnormal swelling (D): Measure diameter at the closest point where there is a uniform stem above / below the abnormality.
- Branching below 1.3 m (E): Measure all diameter as separate trees; Branching at 1.3 m (E): Measure all diameter as a single tree.
- Sloping tree (F): Measure 1.3 m from upslope side of tree
- Leaning tree (G): Measure 1.3 m along the central axis of the trunk(s) and take measure of both sides if the trunk splits into two, counting as separate trees.

Once you have determined point of measurement:

1. Use a calliper/tree diameter tape to determine the DBH at 1.3 m and 1.5 m respectively for all trees within the plots.
2. Categorize the diameters into five groups: (0–10 mm, 10–25 mm, 25–100 mm, 100–200 mm and >200 mm).
3. Select a representative tree from each category and determine the diameter at 0.1 m, 0.5 m, 1.0 m and 2 m heights.
4. Record the results on the data sheet.

<sup>20</sup> Modified from Murdiyarso and Kauffman (2015)

### **Mangrove height and canopy width**

1. Place a telescoping pole/ 2 m pole beside the tree to be measured.
2. Adjust the pole to the highest point of the tree and determine its height.
3. Place a meter ruler/graduated tape on the ground from edge to edge of the tree crown and determine the width of the canopy.
4. Record the results on the appropriate field data sheet (Appendix 3: Vegetation assessment data sheet).

### **Prop roots/aerial roots network**

1. Establish three subplots (1 X 1 m) representing low, medium and high prop root pneumatophore densities within each 10 X 10 m plot (Figure 4). These subplots should be established before completing tree measurements to prevent damage to pneumatophores/prop roots.
2. Count the total number of pneumatophores/ prop roots within each subplot.
3. Select twenty (20) random pneumatophores/prop root (if possible) per subplot and determine their height as well as diameter at 0.1 m or 0.5 m.
4. Record the results.

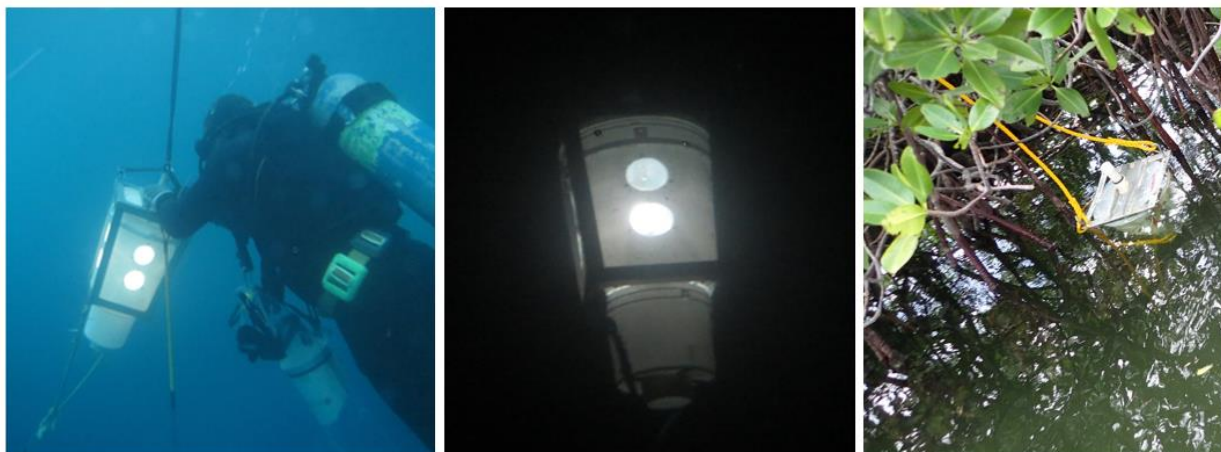


*Figure 4: Samples of 1 X 1 m subplots representing low (left), medium (centre) and high (right) prop root (top) and pneumatophore (bottom) densities*

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

1. Check calendar for date of new moon.
2. Prepare lights for illuminating the light traps before deployment on the day of the new moon by checking and changing batteries.
3. Turn lights on as trap is being deployed and leave illuminated (Figure 5)
4. Attach light traps to red mangrove roots hanging in at least 1 m water depth (Figure 5), secure traps to the prop roots using cable ties and leave lighted traps in place overnight.





*Figure 5: Examples of light trap deployment in deep water with light on (left and centre) and in mangrove prop roots (right)*

5. Collect light traps early next morning preferably at sunrise to prevent predation of fish larvae by zooplankton.
6. Collect organisms from light trap collection bucket and immediately preserve sample in ethanol.
7. In the lab, decant each the sample for storage in 200 ml bottles in 70% ethanol.
8. Identify fish larvae to family or species by using a trained ichthyologist and with the aid of identification guides for Atlantic species<sup>21</sup>. Each type of larvae may be viewed under a stereo microscope, photographed in lateral view (scale included in the frame) and with fin rays clearly displayed. Enumerate types of larvae based on each photograph and determine total numbers.
9. Identify other organisms under a stereo microscope by using a trained zooplanktologist and with aid of identification guides for Atlantic species<sup>22</sup>. Different organisms may be photographed (scale included in the frame) in lateral and dorso-ventral planes and enumerated based on each photograph.
10. Record the results and determine the numbers per volume of sample and hence the relative abundance of each fish family/species.

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<sup>21</sup> Suggested guidebooks: C.D. Todd; M.S. Laverack and G.A. Boxshall “*Coastal Marine Zooplankton: A Practical Manual for Students*”; William J. Richards “*Early Stages of Atlantic Fishes: An Identification Guide for the Western Central North Atlantic Books I-V*”; G.E. Newell and R.C. Newell “*Marine plankton, a practical guide.*”; J. Wickstead “*Marine Zooplankton*”; William Johnson and Dennis Allen “*Zooplankton of the Atlantic and Gulf Coasts: A Guide to Their Identification and Ecology*”



## Timing and Frequency

The level of interest, benefits of sampling as well as the monitoring cost will influence the time intervals and frequency of monitoring<sup>22</sup>. Based on forest dynamics as well as the nature of location (whether it is prone to natural disturbances such as hurricanes), monitoring should be done every 2 years. If cost is a major issue then the forest could be monitored every 5 years<sup>23</sup>. Monitoring should be done as close to same time of year as possible. It is recommended that monitoring of ecosystem services for fisheries production, be conducted monthly for one year, however, monitoring between February – April when water temperatures are minimal may also be used<sup>24</sup>.

## Data management

1. Create a spreadsheet in Excel for each mangrove site and enter the data from your field data sheets using the layout of the field-data sheets.
2. Check the field data sheet against the data you entered in the computer and correct any mistakes made during the data entry.

## Analyses

### Mangrove species composition, relative abundance and diversity

Count the total number of each tree species encountered at each location and plot these data as shown in the example below (Figure 6).

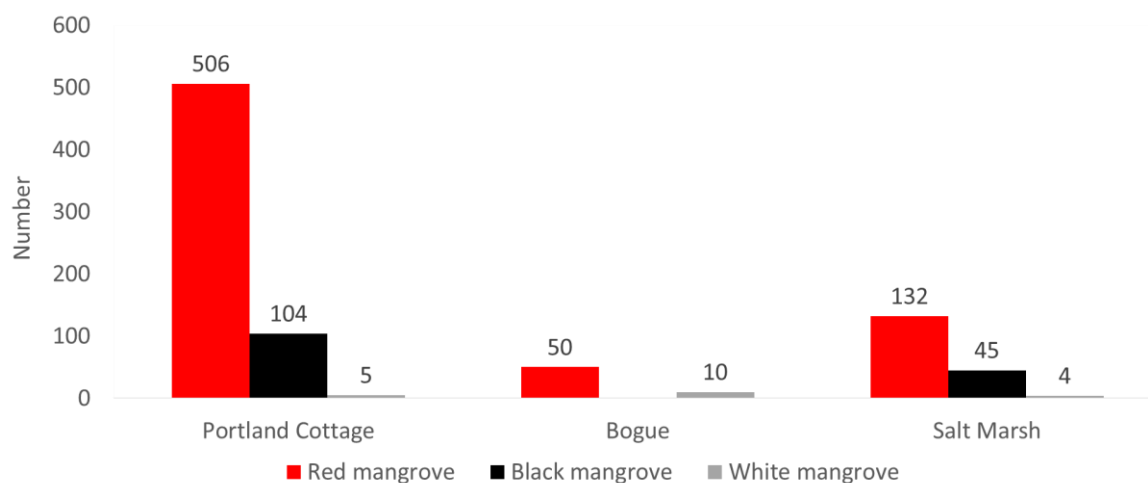


Figure 6: Graph showing the number of trees at different locations.

<sup>22</sup> Kaufmann and Donato (2012)

<sup>23</sup> Pearson et al. (2005)

<sup>24</sup> Munro et. al. (1973)

Use the Simpson's index to determine diversity.

$$D = 1 - \left( \frac{\sum n(n-1)}{N(N-1)} \right)$$

n = the total number of organisms of a particular species

N = the total number of organisms of all species

### Mangrove trunk diameter (DBH)

Calculate the mean (with standard error - SE) diameter at breast height per species / plot/location as shown in the example below (Figure 7).

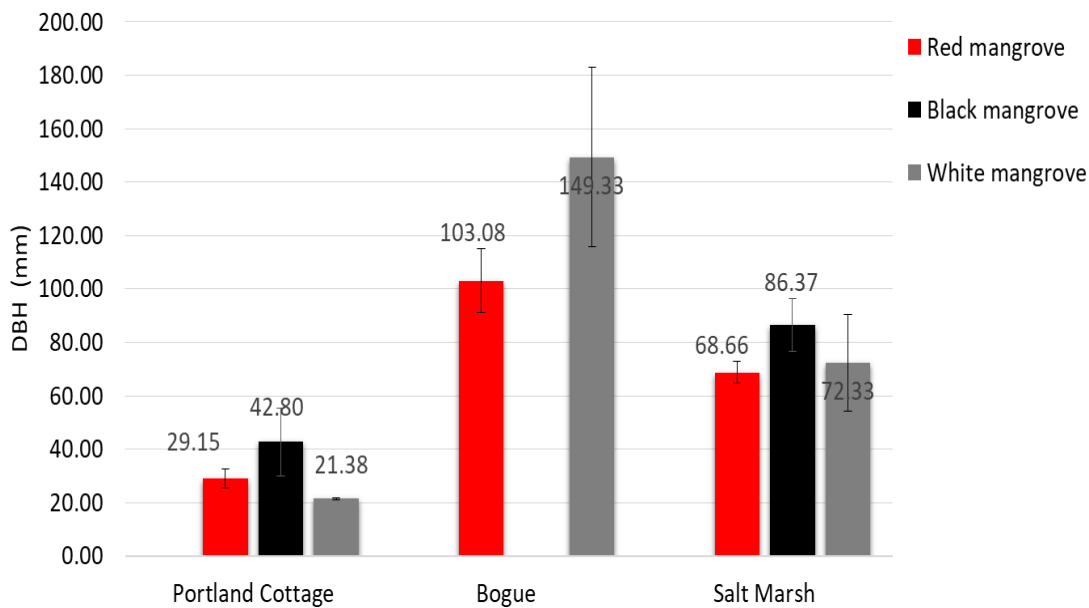


Figure 7: Graph showing the mean diameter at breast height per species at different location

### Mangrove height and canopy width

Calculate the mean (with SE) height and canopy width per species / plot.

### Prop roots/aerial roots network

Count the total number pneumatophores/ prop roots per subplots.

Determine the mean (with SE) root height/diameter for each density at each area.

## Component 3: Physical Monitoring

### Theoretical Background

Several methods are used to evaluate the physical attributes of mangroves. Mangroves have been reported to prevent and reduce damages from extreme events by wave and wind attenuation, soil stabilisation and keeping up with sea level rise<sup>25</sup>. To understand the physical conditions of the mangrove, researchers must establish some baseline data and identify sampling sites for continued monitoring and study. Mangrove forests are considered important sinks that allow for the accumulation and storage of marine and terrigenous sediments because of the trapping effects of the root and shoot structures<sup>26</sup>. Mangroves act as soil builders and can if healthy keep up with sea-level rise by maintaining a positive surface elevation change exceeding the rate of sea-level rise for a locality.

Contextual and spatial data on the experience of flooding by residents of communities in proximity to mangrove forest are paramount to understand the risks and experience of loss or damage and the extent of ecosystem services provided in the reduction of storm damage<sup>27</sup>. The data can be mapped and represented spatially. The trends of lateral erosion or accretion overtime are calculated using Geographic Information System (GIS). Vertical erosion or accretion is assessed using a benchmark and horizon markers following previously accepted methods<sup>28</sup>. Soil and water samples are collected to evaluate the characteristics and constituents of the substrate and its health.

Baseline data such as bathymetry, wave pressure water level and wind parameters are collected to validate and support additional levels of analysis towards the constraining of ecosystem services provided by mangroves in the form of wave attenuation, and wind reduction.

### Methods of Data Collection

#### Flooding and Coastal Erosion

Utilize primary data gathered from the socio-economic questionnaires administered in Component 1 above.

- Import to a GIS platform and project the spatial and descriptive data.
- Choose suitable symbols and display accordingly.

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<sup>25</sup> Horstman et. al. (2014); Krauss et. al. (2003); Kumara et. al. (2010); McKee et. al. (2007)

<sup>26</sup> Kumara et. al. (2010)

<sup>27</sup> Barbier (2016)

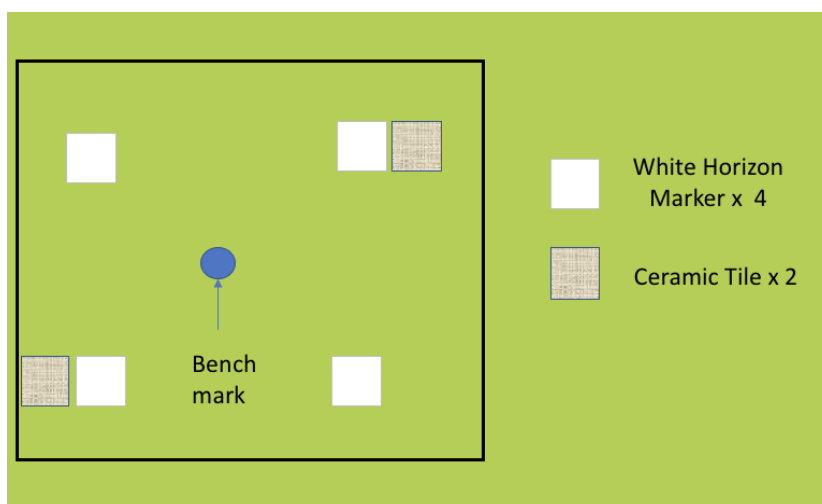
<sup>28</sup> Cahoon et. al. (1997); Cahoon et. al. (2002); Horstman et al. (2014); Krauss et. al. (2013)

### Sediment Sampling and Assessment

1. Using an Edelman combination soil auger or other suitable auger collect in duplicates or as needed representative soil samples (0–30 cm depth) along transect at each study site.
2. After collection, place the soil cores in double strength polyethylene bags, and seal the bags.
3. Label the bags with permanent marker or affix labels that correspond to data sheet or field note book, be sure to use a unique sample identifier for the site, transect and sample.
4. Complete data sheet or field book with relevant details such as waypoint number, sample number, colour and also include any other notes, such as types of mangrove trees if any are associated with the sediment.
5. Transport samples to the laboratory under ambient conditions and process within 24 to 48 hours of collection or store the samples in ambient conditions until processing.

### Surface Accretion

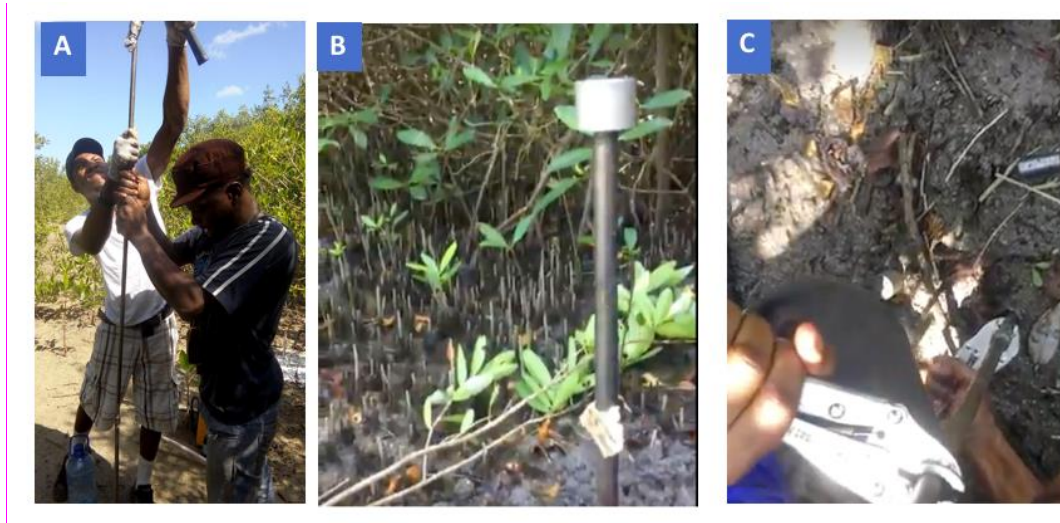
1. Install permanent benchmarks to set up the experimental sites (Figure 8). Additional details can be accessed from USGS records<sup>29</sup>.



*Figure 8: Typical set up for benchmark and horizon markers (not drawn to scale). The measurements in the field will vary according to suitable substrate for placement. Record the specifics unique to your site following the template of Appendix 5: Benchmark Set Up Sheet.*

<sup>29</sup> <http://www.pwrc.usgs.gov/set/>

2. Hammer steel or stainless steel rods of known lengths, pre-threaded and joined by coupling into the mangrove substrate until no further penetration is possible (Figure 9). Cement this benchmark into the ground at each site to ensure it remains vertical and fixed.



*Figure 9: (A-C) Installation of benchmark, with lengthening of the steel as necessary and subsequent hammering into the substrate until no further downward movement is achieved*

3. Note the proportion of the total length of the benchmark that has been inserted in the mangrove substrate.
4. Record the length of the benchmark exposed above ground. Install 30 x 30 cm floor tiles to trap accreted sediment at the benchmark site in conjunction with four powder horizon markers at each site.
5. Insert locators for the horizon markers and tile with coloured or flagged PVC pipes to be able to locate them again (Figure 10).
6. On a sketch of the experimental plot, add details, with accurate measurements and dimensions of horizon markers and sediment plate so they can be found for measurements at subsequent field exercises. Use template provided in Appendix 5: Benchmark Set Up Sheet.





*Figure 10: Different views and setting of installed horizon marker and sediment plate (tile) for accretion or erosion records. A: Horizon marker being laid down at Portland Cottage site 2, it is important to dust off roots so the horizon marker is flat. B: Horizon marker at Plot 2 Freeport and adjacent tile, C: Horizon marker covered by a thin layer of sediment, thickness of sediment is being checked with a spade and ruler. D: Horizon marker with no sediment, only sparse leaf litter after a month at Freeport, E: Horizon marker with leaf litter at Bogue Rd, F: Horizon marker and Sediment tiles with negligible sediment after 2 months. G: Horizon marker eroded in sections at Portland Cottage Site 1.*

7. Use the high precision, balanced, lighter-weight, mechanical levelling device called a Rod Surface Elevation Table (RSET)<sup>30</sup>, which is detachable from the benchmark, to measure surface elevation of the mangrove substrate (Figure 11).
8. Be sure to mark the level from which the measurement on the benchmark was taken by fixing and maintaining an engraving and tape.
9. Record these measurements of the sediment pins at each site using a compass for bearing and steel ruler for each cardinal bearing and record 9 repeatable readings which are one inch apart for each bearing (Figure 11).

<sup>30</sup> Modified from Cahoon et. al. (2002)



10. Repeat these RSET measurements at each subsequent site visit.
11. Take note if sediment is trapped on the tiles at each subsequent visit. If sediment is on the tile, remove it for weighing and analysis.
12. Check the horizon markers at each site visit and record the thickness of any sediment accreted above the horizon (Figure 11C)<sup>31</sup>



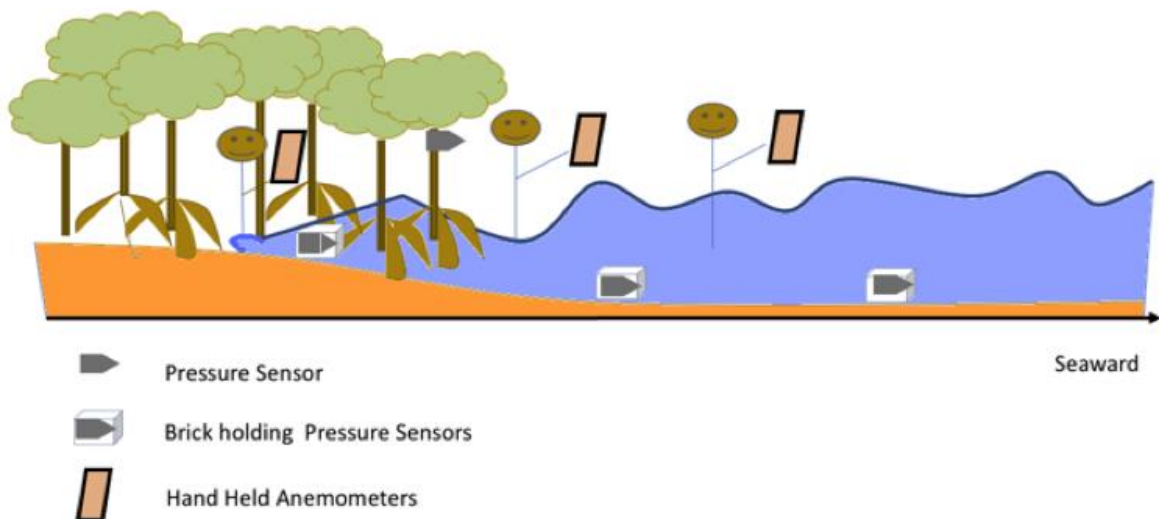
*Figure 11: Elevation measurements are being taken with a RSET removable device. A: Set up at Plot 1 Freeport, St. James, B: Measurement at freeport plot 1, C: Measurement at Portland Cottage site 2, D: Measurement at Rodney Street Site, E: Measurement at Bogue Road site.*

### Wind Data

1. Collect the wind data using three hand held anemometers simultaneously, along a seaward transect (Figure 12 and Figure 13A) and within the shelter of the mangroves at predetermined time intervals.

<sup>31</sup> Cahoon and Lynch (1997) and McKee et. al. (2007)

2. Set the anemometers to record the average wind speed, at the predetermined start time, hold the anemometer for 120 s in the prevailing wind direction as determined by the persons operating it at the time of data collection.
3. Record the GPS location at which the wind speed was taken along with corresponding wind speed on a chart at each time interval.

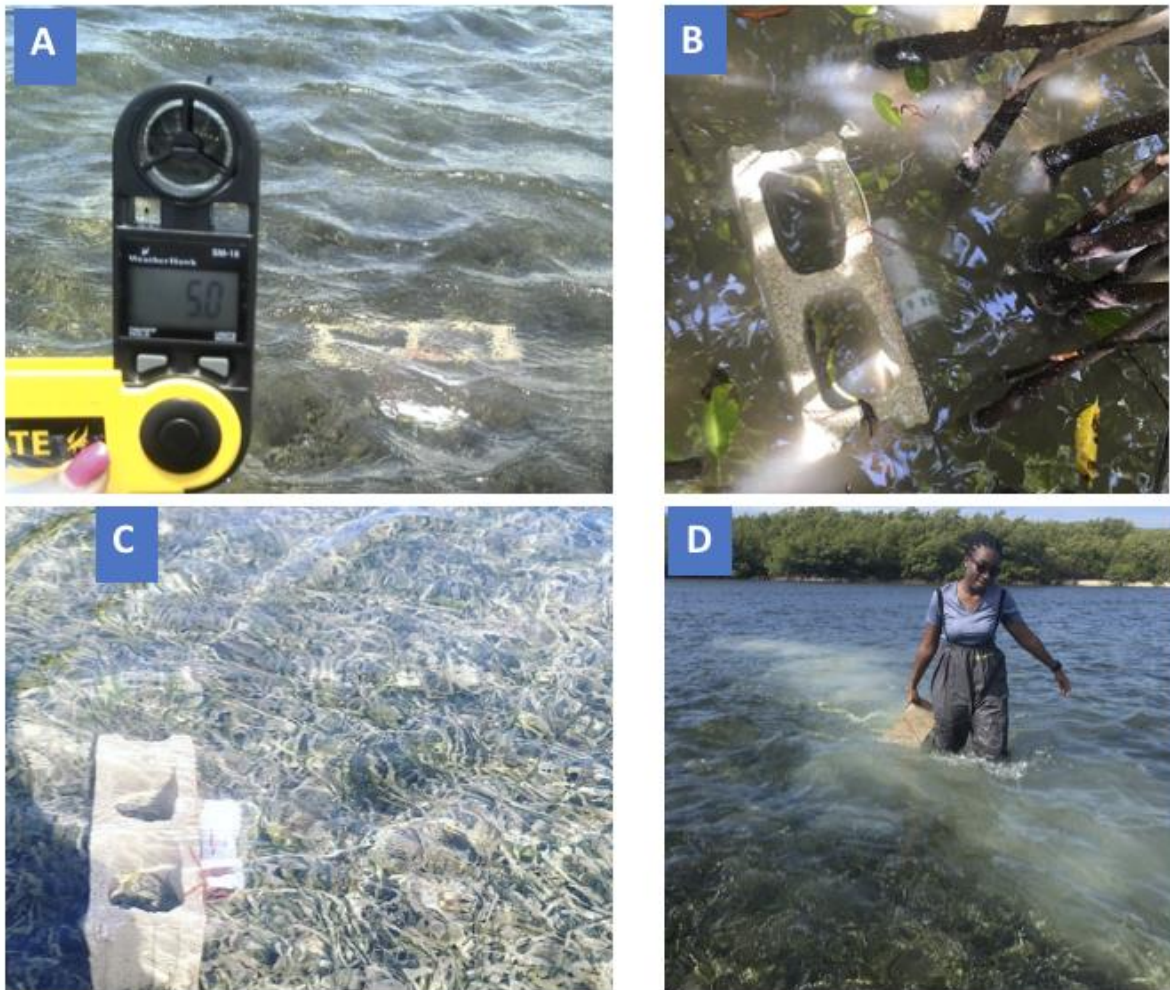


*Figure 12: Idealised sketch showing the concept and location for deploying pressure sensors to determine water wave parameters, and the spatial arrangement of researcher for collecting wind speed along a coast-perpendicular transect using hand-held anemometers*

### Water Level and Pressure

1. Pre-determine and set the time and date for data collection of the U20L-02 Water Level Logger following their manual using a computer.
2. Install the loggers in a PVC pipe and affix to concrete blocks to ensure that they remain stationary at consistent height above the sediment below the water.
3. Deploy the U20L-02 Water Level Logger along a seaward to landward transect with the most landward being placed within the roots of the mangroves at a location affected by water waves (Figure 12 and Figure 13).
4. Place the second logger in the middle of transect, seaward outside of mangrove roots.
5. Place the third logger at the most seaward position of wading or suitable location (Figure 13) according to the site characteristics.

6. Affix a fourth pressure logger to a mangrove tree along the same transect and collect ambient atmospheric pressure for corrections to water level data extraction later (Figure 13).
7. Measure the start and end time water levels for (MATLAB) corrections later, along with GPS coordinates for the sites deployed.



*Figure 13: Photos of physical deployment and use of equipment to capture physical parameters. A: Wind anemometer being used to collect average wind speed over a period of 120 s being held in the prevailing wind direction, B: Deployment of pressure sensor protected by PVC fixture and horizontally mounted to a brick within mangrove roots affected by waves, C: A more seaward location of deployed pressure sensor at the Rodney Street Site in a bed of sea-grass, D: Field student carries a pressure sensor attached to a brick to a more seaward location for deployment.*



## Water Quality

1. Collect 3 or more water samples at varying intervals seaward along transect using 1 L acid-washed High-Density Polyethylene (HDPE) bottles or two 500 ml bottles per sample (Figure 14A, B and D) under fully mixed conditions.
2. Record sample coordinates and unique identifier in GPS device and field notes.
3. Prior to collection, rinse each container with a small quantity of water collected at each site to homogenize.
4. Record dissolved oxygen (DO), pH, salinity, conductivity, total dissolved solids and water temperature, *in situ* using YSI 556 multi-probe system or other suitable multi-parameter water probe (Figure 14C).
5. Place samples immediately on ice and transport to a temporary holding facility (with refrigeration) or directly to the laboratory, prepare and freeze for further analysis within 24 to 48 hours (Figure 14D).
6. Submit samples to appropriate analytical facility to be analysed for trace elements, nutrient loadings and stable isotope composition.



Figure 14: Evaluating the physical parameters of the water within mangrove systems. A: acid-washed HDPE bottles left to dry prior to field day, B: Water is collected along a transect at each site, depending on the water level along the transect, it may take multiple tries to fill bottles, C: YSI collected *in-situ* water parameters, the data and time is recorded along with corresponding GPS coordinates, D: Sample bottles are labelled and stored according to protocol for analysis.

### Bathymetry and shoreline dynamics

Three people in addition to the boat captain are necessary for this method of bathymetry data collection.

1. Collect bathymetry for the study sites using two hand held Hondex brand digital depth sounders (Figure 15).
2. Collect the depth data at each site following a pre-determined track for your study area according to the limitations of each site, for example avoid rocky shallow reef areas, which the boat cannot access.
3. Each data collector/researcher should deploy the depth sounder on each side of the boat and record the depths at 40s intervals while boat stops or cruises at a rate of 5-8mph.
4. Record the depths from both sounders along with stored corresponding GPS waypoints.



*Figure 15: Use of depth sounders along with GPS to collect bathymetry data. A: Hondex digital depth sounder devices are shown. B: device should be emerged in water and held vertically to collect depth readings, C: two depth readings are collected simultaneously along with GPS coordinates.*

### Soil health

1. Oven-dry samples and homogenize.
2. Sieve samples to obtain <2mm and <150µm size fractions. Use a standard ASTM nest of sieves in a mechanical shaker to evaluate grain size<sup>32</sup>.
3. Submit fractions for geochemical analysis, taphonomic and constituent analysis.

### Soil-atmospheric carbon flux

1. This requires an automated gas flux system consisting of a survey chamber and a control unit equipped with an infrared gas analyser.
2. Place ten to twenty 10 cm or 20 cm diameter PVC soil collars 5-6 cm in soil surface at least 2 h before commencing data collection (Figure 16A, B and C).
3. Mount survey chamber on soil collar and engage data acquisition for no more than 10 min/collar (Figure 16D and E).
4. Process gas flux data using proprietary software, statistical and GIS software packages.
5. Data can be presented in a variety of ways, but may be best represented spatially.



*Figure 16: Equipment and process of collecting gas flux data. A: Collar deployed in substrate, B: Collar can be deployed if the substrate is saturated, C: collar deployed and marked with flagging tape along with GPS to facilitate easier relocation and measurements, D and E: Survey chamber mounted to collar and allowed to collect readings for 10 minutes per collar after equilibration period of 2 h has elapsed.*

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<sup>32</sup> Carver (1971)



## Soil carbon biogeochemistry

### Soil organic matter and organic carbon

The determination of soil organic matter (SOM) content by dry combustion – loss on ignition (LOI) requires an analytical balance, a furnace, ceramic crucibles and a desiccator.

1. Determine mass of empty ceramic crucible.
2. Dry crucibles to constant weight at 105°C in furnace overnight. Allow crucibles to cool in desiccator before weighing.
3. Accurately weigh 0.5 g of the <2 mm soil fraction into crucibles and dry soil to constant weight at 105°C for 24 h. Allow soil to cool in desiccator before weighing. Determine dry mass of soil by mass difference.
4. Combust dried soil at 550°C for 4 h, then cool samples in desiccator before weighing.
5. Calculate LOI (weight %) =  $100 * ((\text{mass of post } 550^{\circ}\text{C ash})/(\text{mass of post } 105^{\circ}\text{C dry sample}))$ .
6. Soil organic carbon content = LOI (weight %) \* 0.58.

### Soil organic carbon stocks

1.  $\text{SOC}_{\text{STOCK}} (\text{Mg C ha}^{-1}) = \text{SOC} (\%) \times \text{BD} (\text{g cm}^{-3}) \times \text{depth of soil (cm)}$   
SOC (%) = the percentage of soil organic carbon measured  
BD = bulk density (mass per unit volume of dried soil).
2. BD can be determined in the laboratory from appropriate sampling or through calculations using appropriate pedotransfer functions.

### Aboveground biomass and carbon stock

Determine aboveground (and belowground) biomass (ABG) and carbon stocks using regression allometric models:

1.  $\text{ABG}_{\text{est}} = \exp (-2.187 + 0.916) \times \ln (\rho D^2 H)) = 0.112 \times (\rho D^2 H)^{0.916}$   
(ABG)<sub>est</sub> = estimated ABG (Kg)  
exp = exponential  
ln = natural log  
D = diameter at breast height (cm)  
H = height (m)  
 $\rho$  = wood specific density ( $\text{g/cm}^3$ )

Note, diameter at breast height and tree height data are determined at component 2 of this manual, the ecology section, while wood density data is obtained from the literature. Tree carbon is calculated from biomass using a factor of 0.47, and belowground carbon stock is assumed to be 20 % of the above ground stock

## Analyses

### Flooding and Coastal Erosion

Analysis of Primary Data from the questionnaires

These steps will require familiarity with a GIS programme.

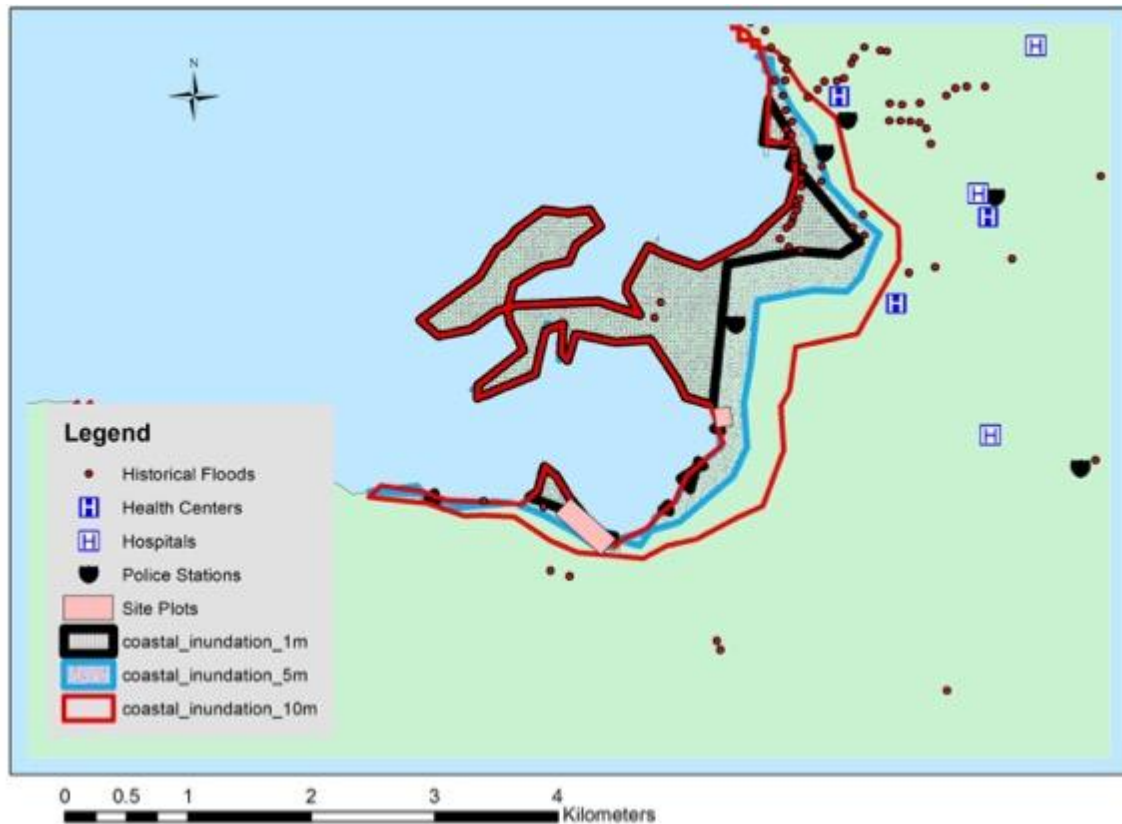


1. The data and corresponding GPS coordinates collected from the questionnaires can be mapped and presented in a geographic information system. To do this: Plot the coordinates for the respondents who experienced flooding.
2. Run spatial queries to determine the limits of flooding such as closeness to contours either by nearest distance or buffers.
3. Categorise and display the experience of flooding and other parameters collected from the questionnaire in relation to the study plots.

### **Analysis of Relevant Secondary Data collection**

These steps will require familiarity with a GIS programme:

1. Import flooding shapefiles received from Ministry offices or colleagues into your study and overlay in GIS to create maps of reported flood extent.
2. Use these water levels of flooding to overlay the GIS Data layers so as to see the extent of reported flooding in proximity to infrastructure and the study plots (Figure 17).
3. Create buffers related to the vectors above to highlight communities and national infrastructure such as hospitals, roads, police stations etc. that are affected by flooding in the case of extreme events.

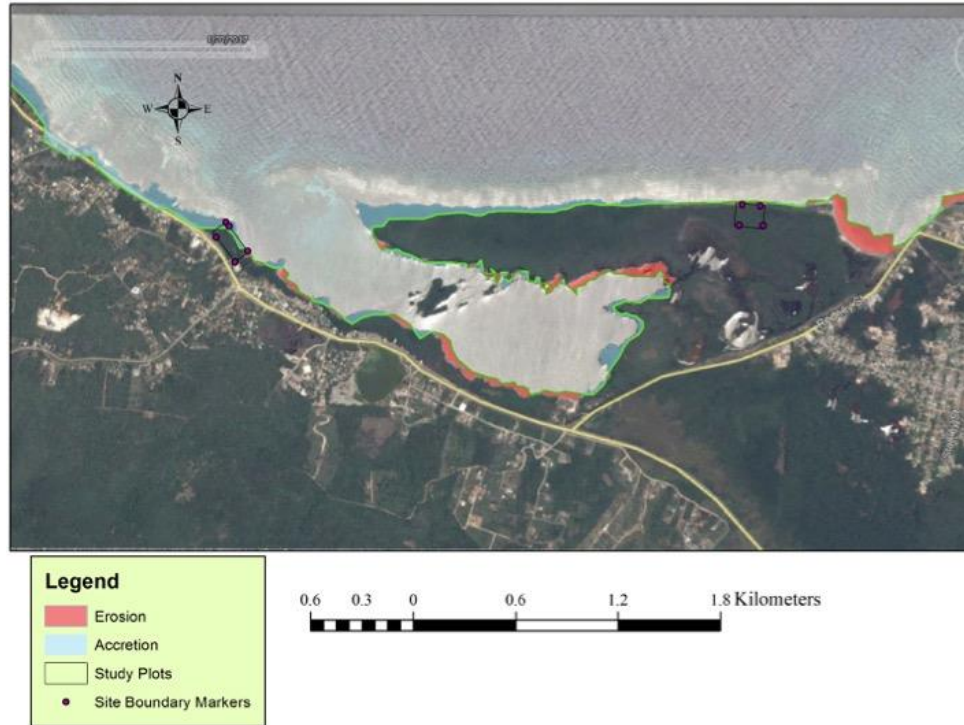


*Figure 17: Analysis of secondary flood data in GIS, Map shows reported experience of flooding and predicted extents of inundation from storm surges for 5 and 10 m in relation to critical infrastructure, Montego Bay*

### **Permanent Coastal Erosion**

These steps will require familiarity with a GIS program:

1. Collect aerial photographs and clean satellite imagery (rasters) for your study sites.
2. Georeference raster imagery in a GIS.
3. Create vector files for the historical coastlines.
4. Compute by spatial algebra the lateral permanent erosion or accretion as in the example of Trelawny (Figure 18).
5. Differentiate if relevant land reclamation results from prograding coastlines.



*Figure 18: Map of long-term lateral erosion or accretion constrained from spatial analysis of historic images of the coastal zone.*

## Sediment Sampling and Assessment

### Lab analysis of Sediments

1. Consult a trained sedimentologist to assess the samples for grain size, skeletal grain taphonomy, peat content and constituent analysis in a reputable sedimentary lab.
2. Report %ages of peat in sample or organic content loss on ignition.
3. Report the normalised %ages sediments by grain size of silt sand and clay to classify the substrate.
4. Plot the %ages on a ternary diagram to determine the sediment textural classification of the sediment
5. Evaluate coarse fraction where available for skeletal or non-skeletal biogenic or inorganic grains
6. Deliver a fraction of each sediment sample collected to a reputable natural science lab that can determine:
  - the oxide content of the sediment
  - elemental chemistry
  - metals and nutrients

### Surface Accretion and Soil Surface Elevation

1. Calculate the difference of the mean elevation change between time 1 and time n (a subsequent reading) or all 9 measurements for each cardinal direction at each

benchmark either sequentially for site visits or between the first measurement at installation and the last measurements.

2. Using a standard methods in a spreadsheet calculate the mean, standard deviation, standard error, maximum and minimum to record and interpret the dominant accretion or erosion processes at each site at the benchmark.
3. Calculate the rate of accretion, erosion and subsidence using the result from 1 above divided by the time in between measurements.
4. Comment if erosion was observed by absence of the horizon marker.
5. Accretion/Erosion – Subsidence = Elevation change<sup>33</sup>.

## Wind Data and Wave Parameters

### Wind energy attenuation

1. Subtract the most landward wind speed from the speed recorded just outside the mangrove to determine the % reduction within the mangrove canopy (Table 7).
2. Calculate the % reduction of wind speed along the transect from the most seaward measuring point to the midpoint outside the mangrove the mangrove canopy (Table 7).

*Table 7: Sample data for wind energy attenuation analyses*

Sites	Mean Wind Speed (m/s)			Reduction in Wind Speed (%)	
	Within Mangrove Forest	Outsides mangrove Forest Canopy	Wading Depth (Open Coast)	Outside Mangroves	Within Mangroves
<b>Bogue Lagoon Site 1</b>	2.9	4.3	4.5	4	36
<b>Bogue Lagoon Site 2</b>	3.1	5.3	5.7	7	46
<b>Portland Cottage Site 1</b>	2.5	5.8	5.9	2	58
<b>Portland Cottage Site 2</b>	2.4	5.1	5.7	11	58
<b>Salt Marsh Site 1</b>	3.4	6.8	7.5	9	55
<b>Salt Marsh Site 2</b>	4.1	6.1	6.9	12	41

3. Compute these for each sets of measurements.

<sup>33</sup> Cahoon and Lynch (1997); Calloway et. al. (2013)

4. Calculate mean for each site and report wind speed reduction within the mangrove canopy against the outside of the mangrove canopy.

### **Wave Parameters and Attenuation**

1. Consult a trained data miner/programmers to use MATLAB toolkit OCEANYLZ version 1.4<sup>34</sup> or other suitable code to compute wave parameters from data collected by U20L-02 Water Level Logger.
2. From the output of (a) simplify the data for highest, lowest, mean and standard deviation for each parameter such as wave height, and wave velocity (at each site).
3. Calculate and report in table format or graph the % attenuation or reduction in wave energy between the distances along the transect, outside of the mangroves from open coast to a midpoint and from a midpoint to within the roots of *R. Mangle*.

### **Water Quality and Soil Health**

1. Present trace element, nutrient loading and isotopic data as reported from outsourced laboratory analysis
2. Additional statistical interrogation may be required based on data volume and complexity.
3. Export or tabulate the water quality data ascertained by the YSI Probe, the results can be reported as mean values for each site (Table 8) or analysed individually along a transect.

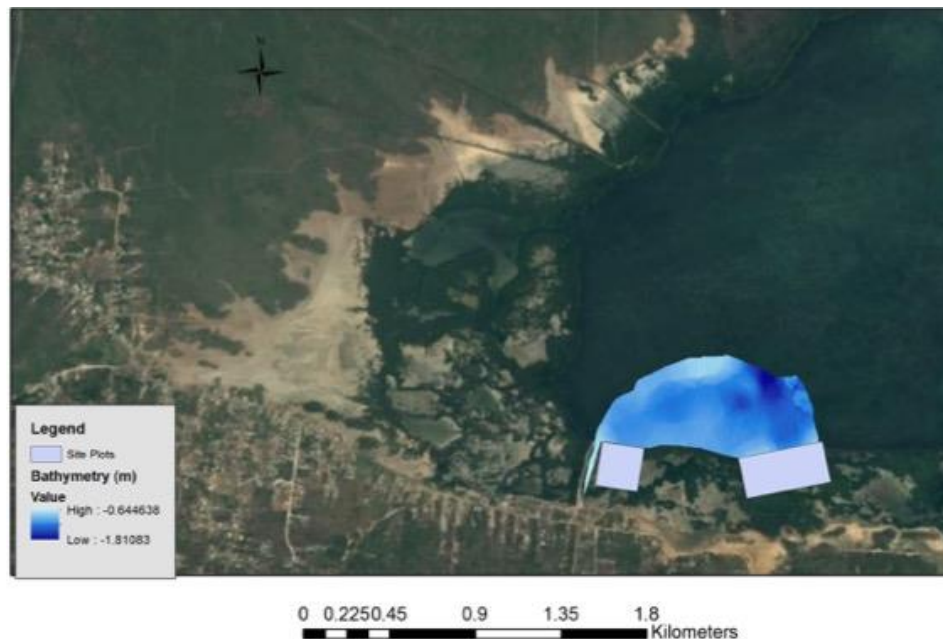
*Table 8: Sample data for mean mangrove water parameters recorded at each site*

Site	Temp , °C	Conductivity, mg/cm	Conductivity, MS/cm	Total Dissolved Solids, g/L	Salinity , PSU	Dissolved Oxygen, %	Dissolved Oxygen, mg/L	pH
<b>Portland Cottage 2</b>	29	58	63	38	39	42	3	7
<b>Portland Cottage 1</b>	33	63	72	41	42	79	4	9
<b>Bogue Site 1</b>	25	12	12	8	7	21	2	8
<b>Bogue Site 2</b>	28	26	28	17	16	37	3	11
<b>Salt Marsh</b>	29	52	56	34	34	64	4	14
<b>Rodney Street</b>	31	53	59	104	35	81	5	12

<sup>34</sup> Karimpour and Chen (2017)

### Bathymetry and shoreline dynamics

1. Record the GPS points and depth data as X, Y and Z in a spreadsheet and then project in Arc GIS to represent bathymetric data in vector format.
2. The vector format can then be transformed to raster (Figure 19).



*Figure 19: Bathymetry overlay on satellite imagery of a section of the Bay at Portland Cottage*

## Further Monitoring Evaluation

### Improvements to Methodology

The socio-economic component can be improved by greater access to data that can provide asset value. If possible, such data can be obtained from real estate companies since households or business might either be unaware or unwilling to provide an estimated value on their businesses. Greater reconnaissance work in the beginning involving field mapping will help in understanding population within the demarcated area which can allow for a probability sampling.

It would have been valuable to obtain information from fishers within the various communities to allow for greater understanding of fish data and value. A household survey geared towards household heads or a respondent who can provide information on the household can still result in gaps where that respondent is unable to provide valuable and necessary information as it relates to fish livelihoods.

For the ecological and physical components drones can be used in reconnaissance visits to determine discontinuity in the forest for efficient placement of transects and plots. Furthermore, reconnaissance can be designed so as to provide details of zonation; transition and type of zones. The benchmark was designed for continued monitoring of vertical sediment accretion or erosion in wetlands, however, the horizon markers are not expected to last as long either due to burrowing organism or in-between cycles of erosion. Therefore, new horizon markers should be installed over time at the sites to sustain continued monitoring and usefulness of the benchmark.

A real time kinematic global positioning system set up could be used in conjunction with the sediment elevation analysis to demarcate the topography more efficiently, however they are exceptionally expensive and may not be practical to rent or borrow for mangrove sites in Jamaica.

There are some limitations associated with this manual. The first limitation is that the components are multi-disciplinary and advanced, therefore, replication will need a team of specialist dedicated to using this manual in conjunction with other material such as the references provided. The foregoing is because the document length is restrictive and cannot capture all of the considerations taken for each site and methods and analysis used or tweaked in acquiring relevant data that will be presented in the results for the PROFOR project. The team can almost always find less advanced or more advanced methods and that will be dependent on the needs of those who would wish to replicate the methods, the budget available, the length of monitoring, or what is accepted in peer review process which is always changing as continued research either methods to be less ideal or more superior. Furthermore, sites tend to differ from each other in unique ways and may affect the usefulness of the methodology, or how they need to be executed. Additionally, the availability of material for the methods may vary from region to region, for example, most of the references used feldspar powder for the horizon markers, that product was not available here in Jamaica and our budget did not allow us to consider shipping it to Jamaica, we initially thought of using thin-set (used in tiling), but the colour of the type we got did not stand out enough as a suitable long term horizon marker and we modified for that by using white lime instead.



## What to do with the information

The socio-economic component can provide some context to the communities under investigation by looking at their characteristics. It can be used in collaboration with the physical data to assess communities' level of vulnerability to coastal flooding. Communities' knowledge and awareness of the mangrove changes and the reasons behind these can be used to support the changes identified through the ecological component. Also, of great importance, is the value of the mangroves and the opportunities for private/public partnerships in restorative efforts. This will support both physical and ecological data.

With regards to the ecological section, the attempt is to correlate ecological parameters with the physical parameters. For example, do the number of trees correlate with soil surface elevation or any other physical parameter? The level of forest disturbance (garbage pollution etc.) could also be explained by socio economic data collected.

The socio-economic data, together with the ecological and physical data sets are complimentary in evaluating ecosystem services provided by mangroves to the communities in their vicinity. With baseline data, several hypotheses can be tested regarding processes in mangrove strands and indices can be created for use as inputs for models to determine vulnerability and any other desirable query. The results of this study can also be used for comparison with other sites that will be studied in the future.

## Linkages to other Economic Values

The geophysical and ecological information collection while useful on its own can be used along with social and economic information to demonstrate the importance of mangroves to people. In some instances, the biophysical information can be used to model potential benefit streams to a variety of beneficiaries including people directly dependent on the mangroves and wider national or global society. The economic linkages that can be explored are in addition to the benefits associated with damage reduction. These include benefits associated with climate regulation (carbon sequestration), contribution to nearshore fisheries, contribution to soil stabilization and reduced erosion as well as possible water quality improvements. Some of these are discussed below.

In addition, an example of economic values of coastal resilience services provided by mangroves, including: coastal flood risk reduction, fisheries provision, erosion control, carbon sequestration, among others, could be found in the final report of the PROFOR funded *"Assessment and economic valuation of coastal protection services provided by mangroves in Jamaica"*. For more information please contact NEPA and/or ODPEM for details.

### **Economic Value of Carbon Sequestration**

One of the major ecosystem services associated with mangrove forests are their ability to trap and sequester carbon dioxide which is a known green-house gas. Sequestering carbon has an economic value linked to the savings from removing a unit of CO<sub>2</sub> from the atmosphere. This value is typically expressed in the market or through other calculations such as the social cost of carbon<sup>35</sup>. The PROFOR study collected some site-specific information on carbon stock (including flux) in three areas: Portland Cottage, Bogue Lagoon, and Saltmarsh in Falmouth. It would be beneficial for future efforts to expand the spatial coverage of sampling. This might be through increased number of soil cores or wider distribution of the instruments used to measure sub surface carbon stocks. Simultaneously, a representative sample of mangrove units should be taken that provides a representative distribution of aboveground biomass. The combination of above and below-ground soil carbon stocks should improve the site level accuracy of carbon stock. This may also assist in improving the global scale models that are being used for calculating sequestration rates. With more accurate site level carbon stock estimates these can be used to calculate the economic benefits of CO<sub>2</sub> removal from the atmosphere. There are recent publications that present updated methods for measuring carbon<sup>36</sup>. To improve the site level information on carbon stock at these side these comprehensive approaches should be considered. The literature on the social cost of carbon has also advanced with some recent theoretical contributions<sup>37</sup>. These recent approaches take into consideration how the social cost of carbon may differ between developed and developing countries. Social cost of carbon estimates should include factors such as appropriate discount rates, uncertainty and variable time scales.

### **Fisheries economic values**

The current analysis has two components currently that could be linked to fishing benefits. This includes data on commercially important larval fish species (light trap analysis) and some information from the household surveys indicating frequency of harvesting and consumption. For this project one of the main gaps is how larval fish information be incorporated into models that can then be used to provide estimates of contribution to commercial catch (of adults). This information could be more beneficial if it was combined with simultaneously collected biological data the corresponding adult species using appropriate fish census techniques. This may require a combination of fish counts (adapted for mangroves) in conjunction with other traditional in-water fish census techniques including belt transects (AGGRA and others) and/or

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<sup>35</sup> Tol (2000)

<sup>36</sup> UNEP (2011); Lopez and Nespa (2015); FAO (2016)

<sup>37</sup> Tol (2018)

stationary counts<sup>38</sup>. Biological sampling of harvestable adults that utilize mangroves and associated ecosystems (seagrass beds and coral reefs) should generate data that can then be extrapolated into estimates of economic contributions. Larval and fish census data thus improving the models of mangrove nursery contribution to nearshore fisheries. Recent work provide some additional information that could be used to develop more locally appropriate models of fish productivity<sup>39</sup>. This will require improved site-specific information on commercial or artisanal catch information. Another data gap is information related to mangrove crab harvest and other invertebrates such as oysters. It is necessary to paint a complete picture of biomass harvested from these mangrove systems. Even if it is difficult to assign monetary values to this data it can be used to demonstrate the role mangroves play in providing a source of protein source, contributions to subsistence diets and/or supplementary income. Some of this information should be cross-referenced with the community survey data collected in the socioeconomic survey component.

One key component that may be outside the control of the research team is the collection of relevant catch data (per unit effort, species targeted, sales etc.) from fishers who operate from beaches that may benefit from the nursery role of the corresponding mangrove forests. This may require national collection by the Fisheries Division or a specific data collection exercises supported by other means. Data collection could be restricted to species (fin and shellfish) that require or depend on mangrove habitats for a significant phase of their life cycle. Collection of these types of data (larval, household dependence, commercial catch) will provide a more comprehensive picture of the economic importance of mangrove dependent fish species. This data may also be critical for improving the accuracy of other bio-economic models that have been previously used for other sites<sup>40</sup>.

### Economics of shoreline stabilization

Combining information on nearshore oceanography (wind, waves), root density (prop roots and pneumatophores) and historical data on erosion and accretion can be used to reflect the role mangrove forests can play in securing infrastructure in the coastal zone. This includes the economic benefits of reducing soil erosion on household stock and municipal infrastructure such as roads and bridges. Additional information that would be needed is access to high resolution areal imagery remote sensing data, information on property values as well as the cost of capital infrastructure projects such as road repairs, seawall construction to name a few. Data that includes root density, hydrodynamic conditions and other factors can be used to improve

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<sup>38</sup> Bohnsack and Bannerot (1986)

<sup>39</sup> Hutchinson (2014)

<sup>40</sup> UNEP (2011)

site level predictive models and generate more specific rates of erosion or accretion. Models with predictive power can thus be linked to market based economic information such as the cost of construction of coastal protection systems or benefits of avoided damage to personal or commercial property. A range of market comparison methods can be used to provide economic information that outlines savings (personal or municipal) when natural infrastructure mechanisms are used in lieu of maintenance costs for the upkeep of hard or grey infrastructure.

### **Water Quality**

This particular regulating ecosystem service of mangroves continues to present a challenge with respect to converting it into monetizable units that can be directly linked to the ecosystem. Mangroves role in water purification can be reasonably linked to the protection of seagrass beds, coral reefs and contributing to maintaining navigable waters by reducing siltation. However, the direct economic contribution of specific areas of mangroves cannot always be linked to a particular economic activity (tourism, fishing etc.).

Linking water regulating ecosystem services of mangroves to specific economic values is made more challenging due to continuing measurement limitations (what water quality parameters to measure, location etc.). In addition, there is generally lack data availability on these key parameters among other limitations all with serve to limit application of valuation methods beyond (damage avoidance) market-based and benefit transfer studies<sup>41</sup>.

Nevertheless, there are still pieces of information that can improve the state of the literature on applying water quality economic values to mangrove ecosystem services. The collection of data on the role that mangroves play in regulating the flow of heavy metals or other toxins into coastal waters would be potentially useful. This information could be linked to benefits to human health and seafood safety. Both of which could potentially have economic values associated with them. Another area of potential investigation is the role that mangrove ecosystems play supporting fresh water and underground aquifers by preventing saltwater intrusion. There are studies that have examined the ability of mangroves to reduce saltwater intrusion<sup>42</sup>. These studies showed that the level of saltwater intrusion increased when coastal mangrove forests were degraded. Similar studies could be applied to the Jamaican context and this information could be then used as part of a market-based approach that compares the avoided costs of desalination or lost potable water sources to benefits of maintaining mangroves.

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<sup>41</sup> Barbier et. al. (2011)

<sup>42</sup> Hilmi et. al. (2017)

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## **Appendices**

Appendix 1: Socio-economic Survey Instrument

**QUESTIONNAIRE**

**Name of Community:** \_\_\_\_\_

**Questionnaire ID**

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

**SECTION A- DEMOGRAPHICS**

1. Gender
  1. Male
  2. Female
2. Please state age \_\_\_\_\_
3. Highest level of educational attainment:
  1. No schooling
  2. Primary/preparatory
  3. All age/Elementary
  4. Junior Secondary
  5. New Secondary
  6. Secondary High
  7. Vocational High
  8. University
  9. Community College
  10. Other tertiary
  11. Other, please state \_\_\_\_\_
4. Relationship status:
  1. Single
  2. Common law union
  3. Married
  4. Divorce
  5. Widow
  6. Other \_\_\_\_\_
5. How many persons live in the household? \_\_\_\_\_
6. How long have you resided in the area? \_\_\_\_\_
7. What is the main income source for the household?
  1. Paid government employee
  2. Paid private employee
  3. Unpaid employee in agriculture or any other business
  4. Self-employed with paid employees
  5. Self-employed without paid employees
  6. Remittances
  7. Other, please state \_\_\_\_\_

8. Have you receive any remittances in the last 6 months?
  1. Yes
  2. No
9. If yes, from where did you receive it?
  1. Abroad, please state where \_\_\_\_\_
  2. Same community
  3. Outside of your community, please state where \_\_\_\_\_
  4. Please fill out table on each person living in the household
10. Do you or anyone in the household currently receive any Social Welfare benefits or pension?
  1. Yes
  2. No
11. If yes, what benefits or pensions? Tick all that apply.
  1. Employment related pension
  2. National Insurance
  3. PATH Program
  4. Other Public Assistance/Poor
  5. Other (Specify) \_\_\_\_\_
  6. Not Stated
12. Please fill out the necessary information for all members of your household

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

13. Was the household able to save from their last month's income?
  1. Yes
  2. No
14. Do you have any form of savings in the bank, credit union or any other financial institution?  
Please tick all that apply




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



#### **SECTION B HOUSING CHARACTERISTICS**

20. Does any member of your household own, rent or lease this dwelling?
1. Owned
  2. Rented
  3. Leased
  4. Squatted
  5. Rent-free
  6. Other, please state \_\_\_\_\_
21. What about the land- is it owned, leased etc. by any member of the household?
1. Owned
  2. Rented
  3. Leased
  4. Squatted
  5. Rent-free
  6. Other, please state \_\_\_\_\_
22. How many rooms does the household occupy?

23. How many rooms are used for mainly sleeping?
24. What does the household used most for lighting?
1. Kerosene
  2. Shared electricity
  3. Owned electricity
  4. Candle
  5. Other, please state \_\_\_\_\_
25. How does this household obtain water for domestic purposes? Tick all that apply
1. Public piped into dwelling
  2. Public piped into yard
  3. Private piped into dwelling
  4. Private catchment, not piped
  5. Public standpipe
  6. Public catchment
  7. Spring or river
  8. Trucked water/water truck
  9. Other, please state \_\_\_\_\_
26. Which kind of fuel does this household use most for cooking?
1. Wood
  2. LPG
  3. Charcoal
  4. Kerosene
  5. Biogas
  6. Solar energy
  7. Electric
  8. Other, please state \_\_\_\_\_

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

OUTER MATERIALS		ROOF MATERIALS		OTHER PARTS OF THE HOME	
Concrete and blocks		Metal sheeting		Landline	
Stone and brick		Shingle (Fiber glass)		Mobile/Cell phone	
Concrete and wood		Tile (clay)		Radio	
Wood and brick		Tile (other)		Television	
wood		Concrete		Personal computer/laptop	
Other, please state		Other material (specify: _____)			

OTHER PARTS OF THE HOME		OTHER PARTS OF THE HOME		Notes:
Kitchen attached to the house		Inside toilet		
Kitchen unattached from the house		Outside toilet/latrine		
Bathroom attached to the house				
Bathroom unattached from the house				

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

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

### Section C- Commercial Demographics

29. Gender

1. Male
2. Female

30. Please state age \_\_\_\_\_

31. Highest level of educational attainment:

1. No schooling
2. Primary
3. Secondary
4. Tertiary
5. Other, please state \_\_\_\_\_

32. How would you describe your role or function in the business?

1. Owner



2. Manager
3. Other, please state \_\_\_\_\_
33. How many employees work in the establishment? \_\_\_\_\_
34. How long has the business been in operation within the community? \_\_\_\_\_
35. What type of business form do you have?
  1. Sole proprietorship
  2. Partnership
  3. Corporation
36. Which of the options below best describes the industry or activities in which your business operates?
  1. Wholesale
  2. Craft
  3. Hotels/guest house
  4. Restaurants
  5. Industrial sales and equipment
  6. Call Center
  7. Other, please state \_\_\_\_\_
37. What would be the value of your business if sold today? \$ \_\_\_\_\_
38. How did you arrive at this value?
  1. Formal Appraisal
  2. Estimate by Owner
  3. Other, please state \_\_\_\_\_
39. What is your business's most recent annual sales turnover?
  1. Less than or equal to US\$100 000
  2. US\$100 000 - 600 000
  3. US\$600 001 - 1 000 000
  4. US\$1 000 001 - 1 400 000
  5. US\$1 400 001 - 1 800 000
  6. US\$1 800 001 - 2 200 000
  7. US\$2 200 001 - 2 600 000
  8. US\$2 600 001 - 3 000 000
  9. Greater than US\$3 000 000

#### **Section D - Fishing and other livelihoods**

40. Do you or any member of your household consume fish as a protein source?
  1. Yes
  2. No
41. If yes, where do you purchase fish? Tick all that apply
  1. In the town
  2. At the jetty as soon as the fishers come in

3. At the supermarket
4. I receive from family and friends at no charge
5. I catch my own fish
42. What type of fish do you buy for consumption?
  1. Snapper
  2. Parrot
  3. Grunt
  4. Other, please state
43. Do you or anyone in your household fish within the community? **If no, skip to Section E**
  1. Yes
  2. No
44. If yes, where exactly is your main fishing spot/area?
45. How long have you been fishing in this area?
46. What types of fish do you catch there?
47. Do you fish within the mangrove area?
  1. Yes
  2. No
48. How often do you fish there?
  1. Daily
  2. 2X per week
  3. 3X per week
  4. More than 3X per week
49. What types of fish do you catch in those areas? \_\_\_\_\_
50. Besides fish, do you extract any other product from the sea within these mangrove areas?
  1. Oysters
  2. Shells
  3. Shrimps
  4. Fish bait
  5. Crabs
  6. Other, please state \_\_\_\_\_
51. What is the purpose of the fish catch? Tick all that apply
  1. Home used
  2. Commercial use
52. If for commercial use, which fish do you sell commercially? \_\_\_\_\_
53. Where/ to whom do you sell your fish? Tick all that apply
  1. Supermarkets
  2. Hotels/resorts
  3. Restaurants
  4. Shops

5. Community members
6. Other, please state \_\_\_\_\_
54. What is your estimated income from these fish on a weekly basis? \_\_\_\_\_
55. How has your income from fishery changed over the past 5 years?
  1. Decreased
  2. Same
  3. Increased
  4. Don't know
56. How has the number of your fish catch changed over the past 5 years?
  1. Decreased
  2. Same
  3. Increased
  4. Don't know
57. Are there any areas that you are prohibited from fishing?
  1. Yes
  2. No
58. If yes, please state where \_\_\_\_\_

#### **SECTION E- MANGROVE KNOWLEDGE, USES AND IMPORTANCE**

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

	Very Important	important	Neither important or unimportant	Not important	N/A
Aesthetic (Visual) appeal					
Fish Habitat					
Medicinal value					
Source of food					
Shoreline protection (from erosion or storm surges)					
Source of wood (fuel)					
Source of wood (building material)					
Supporting offshore or nearshore fisheries production					
Water quality					
Wildlife habitat					
Carbon store					
Cultural value					

Other, Please state \_\_\_\_\_

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

1. No
2. Yes

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

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

62. How many years have you been earning an income from mangrove?

63. How has your income from mangrove forest changed over the past 5 years?

1. Decreased
2. Same
3. Increased
4. Don't know

64. How do you think your income from mangrove forest will change in the next 5 years?

1. Decreased
2. Same
3. Increased
4. Don't know

65. Which species of mangrove is/are widely used by you for income generating activities? Tick all that apply.

1. White
2. Red
3. Black
4. Button

66. How many times have you cut down/ gather these mangroves for use in the past month?

1. None
2. 1 to 5X
3. 6 to 10X
4. 11 to 15X
5. Greater than 15X

67. Was mangrove removed for the establishment of your home/ business?

1. Yes
2. No

3. Don't know

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

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

**SECTION F- FLOOD RISK AND COPING CAPACITY**

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

1. Yes
2. No

70. If yes, how many times in the past year, have the community flooded?

1. Once a year
2. Two times per year
3. Three times per year
4. Four times per year
5. Five times per year
6. Greater than 5 times per year

71. When was the last time you were affected in anyway by a flood? \_\_\_\_\_

72. Did this flooding affect your property? If no, skip to question 70

1. Yes
2. No

73. Did the water enter your house?

1. Water did not enter house



2. Water was under the floor boards
  3. Water was above floor boards
  4. Water was above skirting boards
74. In what other ways, did the last flood affect you? Tick all that apply
1. Could not attend work
  2. Children could not attend school
  3. Injury to yourself/family members
  4. Destroy livelihood equipment (e.g. boats)
  5. Destroy crops and livestock
  6. Had to relocate permanently
  7. Had to relocate temporarily
  8. Other, please state \_\_\_\_\_
75. Was your house insured against flood damage?
1. Yes
  2. No
  3. Unsure
76. Do you have any flood defenses in place at your property? Tick all that apply
1. Sandbags
  2. Non-return valves
  3. Placed home on concrete blocks/stilts
  4. Disconnected drainage
  5. Floor / door modification
  6. Bolted down manholes
  7. Other.....
  8. None
77. Did these help to prevent water entering your house?
1. Yes
  2. No
  3. Unsure
78. What were the main factors that helped you to recover from the flood? Tick all that apply
1. Savings
  2. Remittances
  3. Borrowing money from friends and/or relatives
  4. Crediting goods from shops or supermarkets
  5. Government assistance
  6. Sold assets
  7. Move to safer place
  8. Other, please state \_\_\_\_\_
79. How long did it take you to recover from the impact of the last flood?
1. Less than 1 month
  2. 1 to 4 months
  3. 5 to 8 months

4. 9 months to 1 year
  5. Over 1 year
  6. I have not recovered.
80. Apart from the last date you experience flood, were there other dates on which you have suffered flooding? Please list
81. What actions have you taken to minimize the impact of future flood events on your household?  
Tick all that apply
1. I have not done anything
  2. Relocated
  3. Flood proof home (barriers, raise house)
  4. Took out Flood insurance
  5. Other, please state \_\_\_\_\_

#### **SECTION G- MANGROVE MANAGEMENT AND RESTORATIVE EFFORTS**

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

87. How well are mangroves managed in your area?

1. Excellently
2. Adequately
3. Could be better
4. Not very well managed
5. No management

88. Who are currently responsible for the management of mangroves in your area?

1. Government
2. Community members
3. Private organisation, Please state which \_\_\_\_\_
4. Non-governmental organisation, please state which \_\_\_\_\_
5. Other, please state \_\_\_\_\_
6. No one
7. Don't know

89. How can we ensure mangroves are better protected and maintained in your community? Tick all that apply

1. Engaging community members
2. Fines or penalties for damaging mangroves
3. Community education
4. On ground works (fencing, groynes)
5. Planting/Replanting mangroves
6. Long-term monitoring programs
7. Restoration and rehabilitation programs
8. Policies for mangrove protection
9. Enact laws for mangrove protection
10. More research on local mangroves
11. Educating local government
12. Other, please state \_\_\_\_\_

90. Are you aware of any initiatives designed to improve the condition of/restore mangroves in your area?

1. Yes
2. No

91. Are you currently involved in mangrove restorative activities?

1. Yes
2. No

92. If yes, what some of these activities you participated in? Tick all that apply

1. Planting/Replanting mangroves
2. Community education
3. Research
4. Other, please state \_\_\_\_\_

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

1. Yes
2. No

## Appendix 2: Screenshots of Socio-economic survey using ODK

1	type	name	label
2	select_one community	community	Name of community:
3	text	other_community	other community:
4	select_one building_type	building_type	Type of building:
5	begin_group	household_survey	Questions for Households
6	note	demographics	Demographic Characteristics
7	select_one gender	gender	1. Gender of respondent:
8	integer	age	2. Age of respondent
9	select_one education	education	3. Highest level of educational attainment:

A2.1: Designing the survey in excel using excel form programming for subsequent upload to ODK

disaster\_man...

Experience with flooding

**69. If yes, how many times, IN THE PAST YEAR, has the community flooded?**

☐ no flood in the past year

☐ Once

☐ Two times

☐ Three times

☐ Four times

☐ Five times

☐ Greater than 5 times

A2.2: Visualizing the questions in ODK on mobile device

## Appendix 3: Vegetation assessment data sheet

Date	Time	Habitat type: Fringe, Basin, Scruch, Overwash	1. Establish six plots of 10X10m2 along transect. 2. Measure stem diameter at 1.3m and 1.5m 3. Categorized stem diameters in five groups: 0–10 mm, 10–25 mm, 25–100 mm, 100–200 mm and 200 mm. 4. For each category, select one rep. tree and measure diameter at 0.1 m, 0.5 m, 1.0 m,1.5 m and 2.0 m. 5. Note whether tree is small, avg or large. Measure roots, stem and branches of representative tree. 6. Establish three subplots of 0.5X0.5m2 OR 1X1m2, representing a sparse, average and dense pneumatophore cover. 7. Count total number of pneumatophores in each subplot. 8. Measure Height and diameter for 20 pnematorphores randomly per subplot . For red mangroves prop , measure diameter at 0.1 m& 0.5m per subplot																		Comments											
Researcher (s)		Ecological condition Intact, Degraded, Deforested																														
Location		Disturbance evidence																														
Latitude	Longitude	Cyclone: Not evident, Light, Moderate, Severe																														
Directions to plot			Timber harvest: Not evident, Low (<30%); Medium (30-70%); High (>70%)																													
1m x1m subplot -Pneumatophores ( sparse, average, dense) or Prop roots																																
1	SPARSE - TOTAL NO. OF ROOTS IN PLOT:																															
2																																
3																																
4																																
5																																
6																																
7																																



## Appendix 4: Reconnaissance data sheet

### **Reconnaissance Data sheet for Transect/ Vegetation plot placement**

Date\_\_\_\_\_

Time\_\_\_\_\_

Site \_\_\_\_\_

Researchers\_\_\_\_\_

Name of Transect/ Transect No.\_\_\_\_\_

#### **Transect/Plot position**

Description	GPS Coordinates -N	GPS Coordinates -W

#### **Sketch of zonation pattern with distance**

#### **Other Notes**

---

Field Personnel: \_\_\_\_\_

Notes:





**nepa**  
National Environment  
and Planning Agency



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