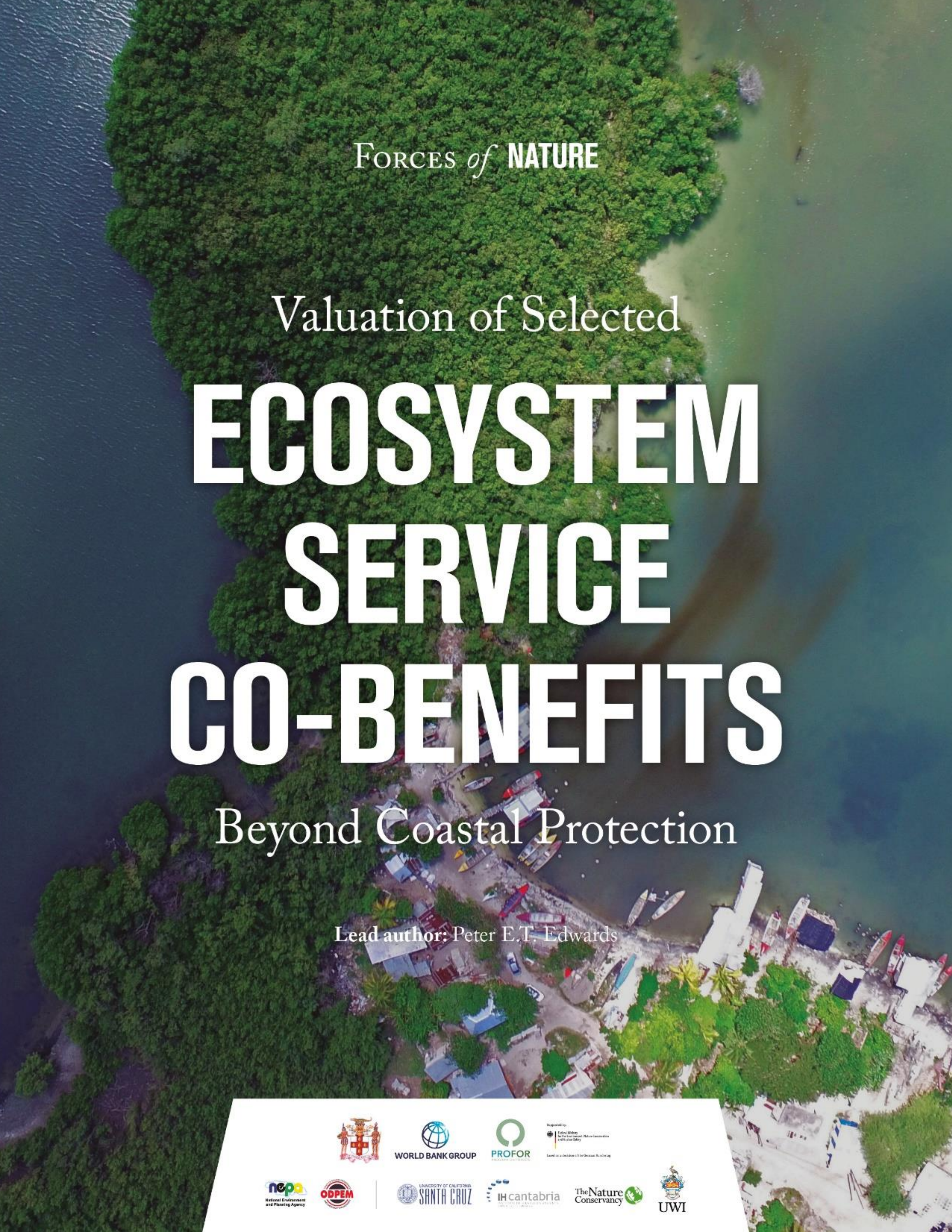

Forces *of* NATURE

Valuation of Selected ECOSYSTEM SERVICE CO-BENEFITS Beyond Coastal Protection

Lead author: Peter E.T. Edwards

Acknowledgements

The *"Valuation of Selected Ecosystem Service Co-Benefits Beyond Coastal Protection"* is one of the World Bank analytical products of the grant *"Assessment and Economic Valuation of Coastal Protection Services Provided by Mangroves in Jamaica"*, funded by the Program on Forests (PROFOR). This effort started in 2017 at the request of the Government of Jamaica through the National Environment and Planning Agency (NEPA), and the Office of Disaster Preparedness and Emergency Management (ODPEM). Numerous entities and professionals interested in the subject participated and an important group of collaborators made possible the materialization of this study. This analytical work is linked to the World Bank Jamaica Disaster Vulnerability Reduction Project (P146965).

The team especially wishes to thank the Program on Forests (PROFOR) for financing this product, and for the guidance provided by World Bank staff including Tahseen Sayed (Caribbean Country Director, LCC3C), Ozan Sevimli (Jamaica Country Manager, LCC3C), Sameh Naguib Wahba (Global Director, SURDR), Ming Zhang (Practice Manager, SLCUR), Valerie Hickey (Practice Manager, SLCEN), Werner Kornexl (Sr Natural Resources Mgmt. Spec, SEAE2), Garo Batmanian (Lead Environment Specialist, SENGL), Vanessa Velasco Bernal (co-Task Team Leader DVRP and Urban Development Specialist, SLCUR), Roland Bradshaw (Senior DRM Specialist, SLCUR), Eric Dickson (Senior Urban and DRM Specialist, SAF U2), Alvina Elisabeth Erman (Economist, GFDRR), and Laura Ivers (Senior Communications Officer, SENGL).

Leading Authors and Editors

The *"Valuation of Selected Ecosystem Service Co-Benefits Beyond Coastal Protection",* was supervised by a group of World Bank specialists in disaster risk management and natural resources comprised by Juliana Castaño-Isaza (Senior Consultant in Disaster Risk & Natural Resources Management, SLCUR) who provided overall leadership; and Simone Lee (Local Consultant, SLCUR), who coordinated this effort at the local level and provided invaluable technical inputs. Saurabh Dani (Task Team Leader DVRP, SLCUR) provided overall supervision and ensured alignment with the Jamaica Disaster Vulnerability Reduction Project.

The complete methodologies, and analytics were conducted by:
Peter E.T. Edwards, PhD

Government of Jamaica Leadership and Contribution

During the development of "Valuation of Selected Ecosystem Service Co-Benefits Beyond Coastal Protection", invaluable support and leadership were provided by Andrea Donaldson, Anthony McKenzie, Ainsworth Carroll, Monique Curtis, Gabrielle-Jae Watson, and Kellie Gough, from the National Environment and Planning Agency (NEPA); and Anna-Kay Spaulding, and Michele Edwards from the Office of Disaster Preparedness and Emergency Management (ODPEM).

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

Additional Support:

The team would like to recognize the support provided by Cecilia De Santis (WB), Marcela Nandllely González (WB), and Michelle Palmer (WB).

The development of this study benefited greatly from discussions with and advice received from the Caribbean Coastal Area Management Foundation (CCAM), and the Montego Bay Marine Park Trust (MBMPT).

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

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

Rights and Permissions:

Suggested Citation: Edwards, Peter E.T. "Valuation of Selected Ecosystem Service Co-Benefits Beyond Coastal Protection". Technical Report. World Bank, 2019.

Contents

List of Figures

List of Tables

Acronyms

AGRRA	Atlantic and Gulf Rapid Reef Assessment
ASA	Analytics and Advisory Services
BOD	Biological Oxygen Demand
CBA	Cost Benefit Analysis
CES	Cultural Ecosystem Services
COD	Chemical Oxygen Demand
DVRP	Disaster Vulnerability Reduction Project
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
GHC	Green House Gases
GSCC	Global Social Cost of Carbon
GOJ	Government of Jamaica
IPCC	Intergovernmental Panel on Climate Change
LULC	Land Use/Land Cover
NWC	National Works Agency
NPC	Net Present Value
PDF	Probability Density Function
PES	Payment for Ecosystem Services
PPCR	Pilot Program for Climate Resilience
PRTP	Utility Discount Rat
REDD	Reduced Emissions from Deforestation and Degradation
SCC	Social Cost of Carbon
SFCA	Special Fishery Conservation Areas
tCO_2	Tonnes of Carbon Dioxide
TNC	The Nature Conservancy
UCSC	University of California Santa Cruz
UNFCC	UN Framework Convention on Climate Change
UWI	University of West Indies
WB PROFOR	World Bank Program on Forests
WAVES	Wealth Accounting and Valuation of Ecosystem Services

Executive Summary

The economic values associated with wetland goods and services can be categorized into distinct components of the total economic value according to the type of use. Direct use values are derived from the uses made of a wetland's resources and services, for example wood for energy or building, water for irrigation and the natural environment for recreation. Indirect use values are associated with the indirect services provided by a wetland's natural functions, such as storm protection or nutrient retention. This analysis focused on ecosystems services beyond coastal protection. Two partner studies conducted by UWI and University of California Santa Cruz (UCSC) in collaboration with The Nature Conservancy (TNC) and the Environmental Hydraulics Institute of Cantabria (IHC), focussed on the coastal protection benefits well as the socioeconomic dependence on mangroves at the three study sites (Portland Cottage, Bogue Lagoon and Salt Marsh). This study examines other ecosystem services that mangroves provide; namely; carbon sequestration, fisheries benefit and other provisioning services of mangroves. An examination of other co-beneficial ecosystem services is conducted.

With respect to carbon sequestration, a benefit transfer approach was used based on a global soil carbon stock average of 386 $MgCHa^{-1}$ and a social cost of carbon (SCC) of \$48 T^{-1} C. Based on the areas of mangrove forest located at each site, the value of annual sequestration for Portland Cottage, Bogue Lagoon and Salt Marsh are respectively US\$4,709,818, \$1,226,554 and \$453,936 (JMD \$612,276,340, \$159,452,020 and \$59,011,680). Net Present Values calculated for a 100-year times span show estimated values for keeping carbon sequestered ranging from \$4.1M (Salt Marsh) to \$466M (Portland Bight).

UWI estimates of soil carbon stock for each location showed higher averages for carbon stock when compared to the global average. Using the site-specific values provided by the UWI team, the annual carbon sequestration values for Portland Bight, Bogue Lagoon and Salt Marsh are US\$12,483,701, \$3,831,391 and \$1,032,528 (or JM\$1,622,881,129, \$498,080,856 and \$134,228,640) respectively. It should be noted that carbon value estimates are influenced by the choice of discount rate and represent the avoided costs to society of not releasing this stored carbon to the atmosphere.

In regard to benefits to fisheries, mangroves are particularly effective as nursery grounds for juveniles of species that later move offshore or to adjacent habitats such as coral reefs. The estimates of mangrove derived fisheries value were based on a review of related literature value transfer approaches. Based on a comparison of a variety of studies that included a range of mangrove types and fisheries, the global median value of US \$77/ha/yr for (fin) fish, and US \$213/ha/yr for mixed species fisheries (Hutchinson et al 2014) was used for this analysis. For the

study sites using the average for mixed species fisheries, the estimated annual economic contribution of mangroves for Portland Bight, Bogue Lagoon and Salt Marsh was $54,145 (J$7,038,850), $14,101 (J$1,833,130) and $5,218 (J$678,340) respectively. The estimates indicate that the economic contributions from these sites are relatively modest in comparison to other systems. However, these are comparatively small areas and thus limited their ability to contribute more significantly to fishers' incomes. Site-specific fisheries dependent data was not able to be collected for this analysis. This in part due to a lack of systematic collection of catch (sales) data by the relevant government agency. In addition to artisanal fishery benefits provided by mangroves, there are potential economic benefits from the development of a high-end recreational fishery focused on catch and release based on species associated with mangroves. This type of activity could have the potential to contribute the local (site based) economy and builds individual and community resilience in the face of climate change. This would also support alternative livelihood strategies for mangrove dependent communities and in particular fishers.

There are additional economic benefits that are accrued from mangroves. Many of these benefits come from provisioning services (i.e. fisheries and, for mangroves, timber, honey and fuel wood), cultural services (tourism) and regulating services (shore protection). However for Jamaica one of the limitations for deriving these values is the lack of site-specific data regarding the market values attached to those services. Inability to access data from relevant government and municipal agencies was also a limiting factor for estimating the avoided costs of regulating water quality or sediment control. Additional limitations on how the site level data were collected did not allow for demonstration of pollution abatement services of mangroves. However related work on tourist economic values for preserving water quality indicate that if mangroves can be shown to serve this function there is a recreational benefit associated with this ecosystem service. Similarly with erosion control, there was not site level data that allowed for the estimation. A search of the literature showed values for erosion control at US$600 per household per year (Indonesia). Other studies showed that mangroves provide protective services to coastal infrastructure at values at US$480 per 75m width of mangrove-lined coastline. The UWI study showed long term erosion at several of the sites, often linked to anthropogenic impacts including loss of forest cover.

The social survey conducted by the UWI team also showed that people were generally aware of some of the roles that mangroves play in providing ecosystem services. Some survey respondents identified themselves as fishers and a small portion of these individuals indicated that they utilize the mangroves for fishing activity one to three times per week. Income on a weekly basis according to information sourced from 11 self-identified fishers at Portland Cottage showed that the income from the sale of fish ranged from J$3000 to J$40000 with an average income of J$12,091. However, most of these fishers reported a decreased in income in the last 5 years. Persons engaged in fishing were not surveyed at the Bogue site. While a comparatively lower number of persons at Salt Marsh meant the sample size was not large enough to draw any substantial conclusions on their dependence on mangrove fish catch. Mangrove restoration can enhance or increase economic value if it produces new ecosystem services that did not exist prior to restoration or if it increases the value of existing ecosystem goods and services or the value of other economic activities that depend on ecosystem conditions. Based on the findings outlined in this report in conjunction with the two complementary studies (UWI, TNC/USCB), confirm that most the elements for conducting a cost benefit analysis for Jamaican mangrove restoration exist. On the benefits side, the reasonably accurate estimates for carbon (presented here), good estimates for coastal hazard protection benefits as well as the implied fisheries and other ancillary benefits should provide enough information. Improving the quality of the ancillary benefits would require more robust estimates on nearshore fish populations with corresponding catch/effort data from fishers. Other required data would include; trends on water quality gradients (mangrove to reef) and rates of erosion prevention over time coupled with economic information on infrastructure and commercial property protected. Based on the analysis of some of the key ecosystem services (climate, fish and damage avoided) it is highly likely that a cost benefit ratio would favour mangrove restoration.

Mangrove restoration provides a natural experiment for tracking ecosystem service changes pre and post implementation. This is why it is important to gather data on a full suite of metrics including better quantification of key provisioning and regulating ecosystem services. With proper measurement it will increase the ability to make the connections between ecological functions and direct (or indirect) benefits to people. Indicators like forest products (honey, other) fisheries benefits (harvest, subsistence) and water quality improvement are a few of the parameters that require more updated methods of estimation. In the context of climate change and building resilience, monitoring the changes of key ecological and socioeconomic parameters will help improve data and allow for the tracking of these additional metrics.
The estimates presented in this report on the role of mangroves and their contribution to commercial fisheries also relied on global estimates from other studies. This analysis was limited to using the global averages because of the lack of data on these mangrove sites and particularly the lack of fisheries landing data that could assist in quantifying the role these mangroves play in supporting commercial fisheries from nearby fishing beaches. Data was not available for catch per unit effort, species targeted and sales from fishers who operate from beaches close to these sites. It was therefore difficult to make a direct link between fisheries catch and the potential beneficial role mangroves play, particularly as nursery areas for juvenile fish. This is a key component that was outside the control of this research effort.

Even with these limitations in mind, this analysis was able to identify additional benefits (beyond storm damage protection) and further highlights the major role that mangroves play in the lives of Jamaicans.

Introduction

The Government of Jamaica (GOJ) has received funding from the World Bank 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 (P146965)*. This effort is linked to the ongoing Jamaica Disaster Vulnerability Reduction Project (DVRP), which focuses on enhancing the climate and disaster resilience of key infrastructure and the country's disaster response capacity. The GOJ has received funding from the World Bank Program on Forests (PROFOR) to implement the this component of the larger Jamaica Disaster Vulnerability Reduction Project (DVRP), which focuses on enhancing the climate and disaster resilience of key infrastructure and the country's disaster response capacity. This report outlines Consultant Economist's (hereafter called the Economist) contextual understanding of the project, the approach and methodology to be utilised, the deliverables, work plan and next steps. This proposed activity will support complementary efforts currently underway by other project partners (University of the West Indies – UWI and The Nature Conservancy/University of California Santa Cruz –TNC-UCSC) including field data collection and analytical work targeting knowledge gaps in 1) Habitat Status, 2) Coastal Protection Ecosystem Services 3) Habitat Risk Assessment and 4) Cost Effectiveness Assessment. This analysis addresses a key sub component of the larger project by primarily supporting site level estimates of additional or co- beneficial ecosystem services in addition to coastal protection. The understanding being that additional ecosystem services (beyond coastal protection) contribute to coastal resilience (social and economic).

Context

Jamaica is ranked as one of the most at risk countries in the world with high percentages of GDP and population at risk to two or more hazards (World Bank, 2008). The country lies within a region of traditionally high hurricane activity and experiences frequent direct impacts and indirect storm damages. Climate change and climate variability are expected to increase the impact of some of the hazards that already cause significant damage. At the same time, human pressures on ecosystems such as mangrove forests and wetlands reduce their effectiveness in providing important social and economic benefits. The environmental degradation of mangroves is likely to result in impacts such as the loss of natural breakers of wave and wind energy, reduction in commercial and non-commercial fisheries (essential for livelihoods and food security), reduction of natural water filters, biodiversity loss, and loss of the ability to sequester atmospheric carbon. Combined these losses reduce Jamaica's climate change resilience and exacerbates for the ability to implement adaptation, mitigation and disaster risk management strategies.

Increasing the countries resilience to natural disasters will require a mix of conventional engineering solutions but equally important is the recognition that natural coastal infrastructure such as mangroves and related coastal ecosystems play this role. Justifying budget allocation for conserving these habitats can be supported by adding information that highlights the economic value of preserving and restoring these key ecosystems. Specifically data that shows the economic and social benefits of protecting coastal communities from natural hazards (tropical storms, coastal inundation, and shoreline erosion) and related fisheries and tourism benefits will help support conservation decision making. The main objective of this report is to, where feasible, estimate the economic values of additional ecosystem services of mangroves (beyond coastal protection) that support coastal resilience in three coastal mangrove sites in Jamaica.

Background

In identifying the ecosystem services provided by natural environments, a common practice is to adopt the broad definition of the Millennium Ecosystem Assessment (MEA 2005) that ''ecosystem services are the benefits people obtain from ecosystems.'' Broken down into the main categories, Supporting, Regulating, Provisioning and Cultural/Recreational.
A broader interpretation of ecosystem services equates ecosystem services with benefits. This analysis will include both intermediate and final services as benefits. The rationale being that supporting services, in economic terms, are akin to the infrastructure that provides the necessary conditions under which inputs can be usefully combined to provide intermediate and final goods and services of value to society (Polasky and Segerson, 2009). In other words, ''ecosystem services are the direct or indirect contributions that ecosystems make to the well-being of human populations''.

There are a number of different ways in which humans benefit from, or value, ecosystem goods and services. The first distinction is between the ''use values'' as opposed to ''nonuse values'' arising from these goods and services. Typically, use values involve some human ''interaction'' with the environment, whereas nonuse values do not. Direct-use values refer to both consumptive and non-consumptive uses that involve some form of direct physical interaction with environmental goods and services, such as recreational activities, resource harvesting, drinking clean water, breathing unpolluted air for example (Barbier et al 2011).

The fundamental challenge of valuing ecosystem services rests in providing an explicit description supported by accurate assessments of the links between the structure and functions of natural systems, the benefits (i.e., goods and services) derived by humanity, and their subsequent values. The conceptual diagram (Figure 1) shows how human drivers of ecosystem change affect important ecosystem processes and functions and in turn can impact economic value and human wellbeing.

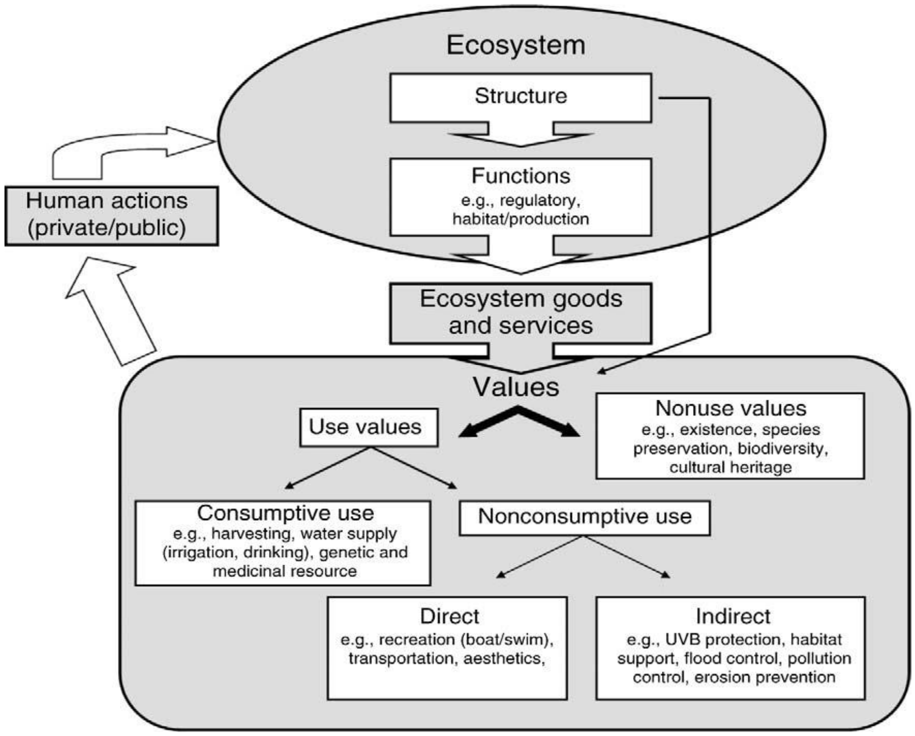

*Figure 1: Conceptual model of coastal ecosystem services (Adapted). This figure is adapted from NRC (2005). Economic valuation of ecosystem goods and services.*UVB is ultraviolet-B radiation from sunlight, which can cause skin cancer.*

Figure 2 is adapted from a study of ecosystem service valuation approaches and their traditional application to a variety coastal ecosystems including mangroves. Of the ecosystem services listed in Figure 2 there are some that are typically estimated given their value to coastal populations. These include; (1) dependency and use by local coastal communities for a variety of products, such as fuel wood, timber, raw materials, honey and resins, and crabs and shellfish [provisioning services]; (2) their role as nursery and breeding habitats for offshore fisheries; [supporting and provisioning services] and (3) their role as natural ''coastal storm barriers'' to periodic wind and wave or storm surge events, such as tropical storms, hurricanes and coastal floods [regulating services]. The other service of note is the carbon sequestration [regulating] services provided by mangroves.

Notable gaps in this list for include economic estimates for water purification services, tourism, recreation, education and research. For water purification, this may be related to the fact that estimates for that ecosystem service are largely in the realm of freshwater provisioning and the fact that mangroves typically thrive in high detritus and nutrient rich environments. The economic value of their role in nutrient uptake that in turn benefits associated ecosystems (seagrasses and coral reefs) may be instead reflected elsewhere (e.g. coral reef recreation values). Similarly tourism and recreation in mangrove areas may not be as globally developed as coastal (beach/coral reef) related tourism hence the paucity of studies given the relatively low demand for recreation in these environments. This study will take this into consideration as part of the overall analysis however the feasibility of producing reasonable estimates will have similar constraints to other global examples as represented in Figure 2.

;

TABLE 4. Ecosystem services, processes and functions, important controlling components, examples of values, and human drivers of ecosystem change for mangroves.

Ecosystem services	Ecosystem processes and functions	Important controlling components	Ecosystem service value examples	Human drivers of ecosystem change
Raw materials and food	generates biological productivity and diversity	vegetation type and density, habitat quality	US\$484–585·ha^{-1}·yr^{-1} capitalized value of collected products, Thailand (Barbier 2007)	mangrove disturbance, degradation, conversion; coastline disturbance; pollution; upstream soil loss; overharvesting of resources
Coastal protection	attenuates and/or dissipates waves and wind energy	tidal height, wave height and length, wind velocity, beach slope, tide height, vegetation type and density, distance from sea edge	US\$8966–10 821/ha capitalized value for storm protection, Thailand (Barbier 2007)	
Erosion control	provides sediment stabilization and soil retention in vegetation root structure	sea level rise, tidal stage, fluvial sediment deposition, subsidence, coastal geomorphology, vegetation type and density, distance from sea edge	US\$3679·ha^{-1}·yr^{-1} annualized replacement cost, Thailand (Sathirathai and Barbier 2001)	
Water purification	provides nutrient and pollution uptake, as well as particle retention and deposition	mangrove root length and density, mangrove quality and area	estimates unavailable	
Maintenance of fisheries	provides suitable reproductive habitat and nursery grounds, sheltered living space	mangrove species and density, habitat quality and area, primary productivity	US\$708-\$987/ha capitalized value of increased offshore fishery production, Thailand (Barbier 2007)	
Carbon sequestration	generates biological productivity, biogeochemical activity, sedimentation	vegetation type and density, fluvial sediment deposition, subsidence, coastal geomorphology	US\$30.50·ha^{-1}·yr^{-1}†	
Tourism, recreation, education, and research	provides unique and aesthetic landscape, suitable habitat for diverse fauna and flora	mangrove species and density, habitat quality and area, prey species availability, healthy predator populations	estimates unavailable	

† Based on Chumra et al. (2003) estimate of permanent carbon sequestration by global salt marshes of 2.1 Mg C·ha^{-1}·$yr^{-1}$and 23 September 2009 Carbon Emission Reduction (CER) price of the European Emission Trading System (ETS) of €12.38/Mg, which was converted to US\$2000.

Figure 2: Ecosystem functions and services of mangroves (Adapted). Table taken from taken from Barbier et al 2011 and related references[1].

The empirical studies conducted on wetland valuation vary widely in their use of valuation techniques, the actual products and services being valued, and the type and geographical location of the wetlands being considered. However in the case of wetland valuation, a standardized shadow price can be analyzed, such as the dollar value per year of 1 ha of wetland

[1] Chmura, G. L., S. C. Anisfeld, D. R. Cahoon, and J. C. Lynch. 2003. Global carbon sequestration in tidal, saline wetland soils. Global Biogeochemical Cycles 17:1111.

area (Brander et al, 2006). The economic values associated with wetland goods and services can be categorized into distinct components of the total economic value according to the type of use. Direct use values are derived from the uses made of a wetland's resources and services, for example wood for energy or building, water for irrigation and the natural environment for recreation. Indirect use values are associated with the indirect services provided by a wetland's natural functions, such as storm protection or nutrient retention. Non-use values of wetlands are unrelated to any direct, indirect or future use, but rather reflect the economic value that can be attached to the mere existence of a wetland (Pearce and Turner 1990). In addition to market and non-market valuation approaches other portions of value such as the value per tonne of carbon sequestered and stored. This will be discussed in more detail in a separate section.

The Brander *et al* (2006) study showed that the most significant ecosystem service associated with coastal wetlands is biodiversity. The study estimated biodiversity services of wetlands at US$17,000 per hectare per annum (Ha^{-1} yr^{-1}). Other valuable services were water quality, recreational fishing, flood protections and amenity values. It is important to note however that directly transferring the values from one study to a particular study site must be done with caution. The Brander *et al* study used a global data set and accounts for some geographic and socio-economic differences. The study show highest values for wetlands in Europe and lowest for South America, (where Jamaica was grouped). Thus the value per hectare reported must be understood within this context. Notwithstanding, there is clear evidence that the coastal wetlands of Jamaica provide services that annually contribute value.

There has been advances in the generation of mangrove and coastal ecosystem values, however a recent analysis showed that data on cultural ecosystem services (CES) has found to be lacking (Himes-Cornell et al 2018). This study suggested that mangrove valuation literature is not yet robust and more importantly lacks estimates of CES, such as spiritual and aesthetic value. These studies support the finding that most estimates are focused on small selection of ecosystem services based on the availability of benefit transfer values and the ability to easily measure values with market prices (Brander et al 2006, Barbier et al 2011, Himes-Cornell et al 2018). The focus on this narrow set of attributes results in very little data on ecosystem services that cannot be valued monetarily, but that are often equally important to local communities. The wider context of this analysis is that in the face of climate change and the (direct and indirect) dependence that people may have on mangroves ecosystems conserving mangroves should lead to increased resilience. In other words a simultaneous increase in ecological resilience and human/social resilience. This report will focus on ecosystems services other than coastal protection. Namely; carbon sequestration, fisheries benefits, water quality and discussions on a few other co-beneficial ecosystem services.

Identifying these additional ecosystem service benefits reinforces the argument for increased resources provided for mangrove restoration. Mangrove has the potential to contribute not only to short-term economic goals such as job creation, but can also provide long term economic gains while simultaneously restoring essential ecological functions and services. Investing in habitat restoration also opens the possibility for future economic activity. Improving the quantity and quality of ecosystem services should result in increased economic activities for example, sustainable fisheries, mangrove forest products and coastal tourism. Broader long-lasting benefits to local economies, such as higher property values and better water quality (Edwards at al 2013) will likely surpass the initial costs of restoration.

Overall Methodological Approach

This analysis where feasible incorporates site level information (social and biophysical) into the estimates of economic values. The aim is to provide complimentary social and economic information on the additional co-benefits of ecosystem services beyond coastal protection. The analyses for each of the key ecosystems relies heavily on literature and benefit transfer approaches. The general approach for the study is outlined below.

Literature Review

Literature review of relevant studies applicable to the project context. This includes economic and ecosystem service information. An examination of the relevant mangrove ecosystem service and economic valuation literature will be the basis for developing the methods to be applied to the ecosystem services of interest. This will include but not be limited to approaches such as benefit transfer methods, social cost of carbon, among others, when necessary. This review will draw on related efforts produced by the Bank including but not limited to the WAVES Guidelines of coastal protection (Beck and Lange, 2016).

Benefit Transfer

The benefit transfer method estimates economic values for ecosystem services by transferring available information from studies already completed in another location and/or context. For example, values for natural resources such as coral reef, seagrass, mangroves and fisheries may be estimated by applying measures of fishing values from a study conducted in another area. Empirical studies conducted on wetland valuation vary widely in their use of valuation techniques, the actual products and services being valued, and the type and geographical location of the wetlands being considered (Brander et al, 2006). Thus, the basic goal of benefit transfer is to estimate benefits for one context by adapting an estimate of benefits from some other context. Benefit transfer is often used when it is too expensive and/or there is too little time available to conduct an original valuation study, yet some measure of benefits is needed. It is important to note that benefit transfers can only be as accurate as the initial study (or studies).

As in the case of this study, this will be the primary approach given the timing and limited resources to conduct extensive primary research for example a comprehensive non-market (choice experiment) valuation survey.

As per standard practice for benefit transfer studies the output will provide rationale and criteria that will allow decision makers to decide on the most appropriate methodologies for each ecosystem service. Other standard practice of benefit transfer approaches includes presenting economic estimates that take into consideration and calibrate for factors such as; net present value, socio-political context, wealth/income measures and other market factors as applicable. Some of the basic steps are outlined below.

Step 1:
The first step is to identify existing studies or values that can be used for the transfer. As is with standard practice for this approach any data taken from studies will be representative of similar environments, social and economic contexts. It is expected that the studies will primarily be drawn from Caribbean and similar tropical locations[2].

Step 2:
The second step is to decide whether the existing values are transferable. The existing values or studies would be evaluated based on several criteria, including:

1. Is the service being valued comparable to the service valued in the existing study? Some factors that determine comparability are similar types of sites, similar quality of sites, and similar availability of substitutes.
2. Are characteristics of the relevant population comparable? For example, are demographics similar between the area where the existing study was conducted and the area being valued? If not, are data available to make adjustments?

Step 3:
The next step is to evaluate the quality of studies to be transferred. The better the quality of the initial study, the more accurate and useful the transferred value will be. This requires the professional judgment of the researcher. In this example, the researcher has decided that both studies are acceptable in terms of quality.

Step 4:

[2] Edwards, Peter (2013) Ecosystem Services of the Coral Spring and Mountain Spring Protected Area, Jamaica. Submitted to the Windsor Research Centre, Trelawny Jamaica.

The final step is to adjust the existing values to better reflect the values for the site under consideration, using whatever information is available and relevant. Supplemental data may also need to be collected in order to improve the transferability of the data. Where possible the integration of the biophysical data from UWI partners will be used as part of the analysis. These data are in general organized in the following groupings.

Incorporation of Partner Data: Ecological, Physical and Socio Economic

This report will use where appropriate, any data produced by the partners on the larger project (UWI and TNC). These data streams include:

<u>Ecological data:</u>

- Mangroves species composition, density & diversity
- Prop root/Aerial root network
- Mangrove trunk diameter
- Mangrove height and canopy width
- Fisheries production

<u>Geological/physical data:</u>

- Sediment retention and accretion in root system
- Sediment composition
- Carbon flux
- Wind speed before and inside mangrove
- Wave force before and inside mangrove
- Water quality

<u>Socio economic data:</u>

Quantitative surveys targeting households and commercial establishments to assess social vulnerability:

- Livelihoods dependent on fisheries
- Households dependency on fish for food
- Changes in mangrove forest
- Coastal flooding
- Potential for community engagement in mangrove restoration (jobs generation)

The site-based information in some instances can be used to scale up or impute estimated values from other locations that fit the (physical and socioeconomic) conditions of each of the sites. There are however limitations

Economic Value of Mangrove Carbon Sequestration

On average, mangroves contain three to four times the mass of carbon typically found in boreal, temperate, or upland tropical forests (Donato *et al* 201, Jardine et al 2014). Much of this carbon storage, however, is at risk of being lost, because mangroves are among the most threated and rapidly vanishing ecosystems globally, with habitat loss rates similar or greater to those in tropical forests (FAO, 2008).

In response to this trend, there has been an increased focus on the development and implementation of market-based mechanisms such as carbon offsets, to credit mangrove conservation for associated emissions reductions. This is largely modelled on the REDD (reduced emissions from deforestation and degradation) programs designed to protect tropical forests. The purpose of these programs is to provide market incentives to reduce emissions from deforestation by, for example, encouraging developing countries to reduce deforestation in return for compensation from developed countries committed to emission reductions (Angelsen 2008, Kindermann *et al* 2008).

Estimating Mangrove Carbon Stocks

Designing and evaluating market mechanisms for mangrove conservation requires several spatially explicit scientific inputs, including information on the mangrove area susceptible to deforestation, carbon in mangrove biomass and soils, annual carbon sequestration, the emissions profiles of mangroves converted to other uses, and the opportunity cost of protecting mangroves (Siikamäki *et al* 2013). Estimation of sequestered carbon is an important first step in this process.

A key challenge in assessing the carbon benefits from mangrove conservation is the lack of rigorous spatial estimates of mangrove soil carbon stocks. Unlike other tropical forests, for which the bulk of carbon storage is in biomass, mangrove carbon is primarily stored in the soil. For example, Donato *et al* (2011) estimate that soil carbon comprises 49–98% of carbon in mangrove forests. Mangrove carbon storage varies substantially over space; therefore, the benefits from mangrove conservation depend critically on the location of the mangroves conserved.

The data show that mangroves in North and Central America contain some of the most carbon-rich soils whereas mangroves in East Asia are among the most carbon-poor soils (Jardine et al 2014). Soils in South East Asia, where approximately 32.8% of the world's mangroves are located, have considerably greater carbon content than mangroves soils in East Asia but substantially less carbon content than mangrove soils in North and Central America (Jardine et al, 2014). (Jardine et al (2014) conducted a study where the estimated global mangrove carbon stored in soils was shown to be on average, 369 ± 6.8 Mg C ha^{-1} (in the top meter of soil). The study confirmed that due to regional differences, the amount of carbon per hectare in the world's most carbon-rich mangroves (the highest grid cell prediction is 703 ± 38 Mg C ha^{-1}) is roughly 2.6 ± 0.14 times the amount of carbon per hectare in the world's most carbon- poor mangroves (the lowest grid cell prediction is 272 ± 49 Mg C ha^{-1}). One Mega-gram (Mg) is equivalent to a Metric Ton. Jamaican mangroves are therefore likely to have a higher content than the global average.

A recent publication provides a standardized and comprehensive approach for site level estimates of coastal blue carbon (Hoyt et al 2014). This manual includes methods for estimating standing carbon, above and below ground, emissions fluxes for not only mangroves but tidal salt marshes and seagrass meadows as well. Given the relative small number of these types studies, the goal of the publication is to provide standardized methods for field measurements and analysis of blue carbon stocks and flux in coastal ecosystems. However in the absence this type of site level data, estimates of carbon stock are provided based on outputs from meta-analysis some of which are based on IPCC recommendations integrated into predictive algorithms and regressions.

The UN Framework Convention on Climate Change – UNFCC has a list of land use (LU) types including; Forest Land (FL), Cropland (CL), Grassland (GL), Wetland (WL), Settlements (SL) and Other Land (OL). This analysis focuses on Jamaica's MG (Mangrove Forest) specific to the three study sites. Each of which results in a combined area of 344.9 hectares. Of note, the most recent estimates for Jamaica's total mangrove forest areas is 9,715 Ha (5ht National Report 2019). The estimates of carbon sequestration and relevant economic values are based on the representative areas of these forest types. For the purpose of this analysis (and in the absence of site level data for the Jamaican mangroves), the suggested Global Tier 1 estimates for blue carbon stocks are used to calculate values for sequestered carbon. This study uses the global average for mangroves of 386 $MgCHa^{-1}$ assuming a carbon-rich soil depth of 1 meter (Donato et al 2011, Pendelton et al 2012, Hoyt et al 2014). It should be noted that this estimate is quite similar to the estimates from the Jardine et al (2014) meta-analysis. Table 1 below shows comparisons of carbon stock between mangroves, tidal salt marsh and seagrass beds.

Table 1 Global mean and range of values of soil organic carbon stocks (1m depth) for tropical coastal ecosystems and CO_2 equivalents. Adapted from Hoyt et al 2014

Ecosystem	Carbon Stock Mg/Ha	Range Mg/Ha	CO_2M equiv/Ha
Mangrove	386	55 – 1376	1415
Tidal salt marsh	255	16 – 623	935
Seagrass	108	10 – 829	396

In order to convert the sequestered carbon (per hectare) to some relative economic value we used the social cost of carbon as the main metric. We discuss how this cost per hectare of carbon sequestered is derived below.

Social Cost of Carbon

The social cost of carbon (SCC) may be interpreted as how much we should be willing to pay to reduce carbon dioxide emissions, or as the tax that we should impose on such emissions. The SCC is a concept that reflects the marginal external costs of emissions: it represents the monetized damage caused by each additional unit of car- bon dioxide, or the carbon equivalent of another greenhouse gas, emitted into the atmosphere (Kotchen 2017). In more technical terms, the social cost of carbon is defined as the incremental impact of emitting an additional ton of carbon dioxide, or the benefit of slightly reducing emissions. The social cost of carbon is the Pigou tax (Pigou 1920), that is, the amount GHG emissions should be taxed in order to maximize welfare (Tol 2018). Despite the widespread use of the SCC for evaluating climate-related policies, and the growing debate about its appropriate scope, there is surprisingly little research on the theoretical basis of the SCC and how it should be used for policy analysis. A recent study examined the theoretical implications and developed an approach that examined the SCC and provides suggests on whether countries should use a global or domestic SCC (Kotchen 2017). This study provided insight into the growing debate about whether countries should take account of the global benefits of reducing greenhouse-gas emissions when setting and evaluating domestic policy. The analysis was based on the global climate model called the C-DICE model[3] (Nordhaus 2015) and identified that there can be differences in the preferred SCC, depending on the particular economic conditions in each country (Kotchen 2017). This study for example was able to demonstrate how countries or regions would prefer a globally

[3] The Dynamic Integrated Climate-Economy model, referred to as the DICE model or Dice model, is a computer-based integrated assessment model developed by 2018 Nobel Laureate William Nordhaus that "integrates in an end-to-end fashion the economics, carbon cycle, climate science, and impacts in a highly aggregated model that allows a weighing of the costs and benefits of taking steps to slow greenhouse warming.

internalized shadow value on emissions that ranges from US$13 (Eurasia) to $91 (India) when the actual Global Social Cost of Carbon (GSCC) was estimated to be $40.

Discount and Pure Rate of Time Preference

Some of the controversy concerning the social cost of carbon arises from the complexity of its computation. Golosov et al. (2014) show that the social cost of carbon can be written as a function of total economic output, the pure rate of time preference, elasticity of damage with regard to the atmospheric concentration of carbon dioxide, and the rate of decay of carbon dioxide in the atmosphere. In economics, comparing impacts over time requires a discount rate. This rate determines the weight placed on impacts occurring at different times. For this analysis we will also present some estimates that take rate of time preference (discount rate) into consideration. To calculate the social cost of carbon, the atmospheric residence time of carbon dioxide must be estimated, along with an estimate of the impacts of climate change. The impact of the extra tonne of carbon dioxide in the atmosphere must then be converted to the equivalent impacts when the tonne of carbon dioxide was emitted. Since the social cost of carbon (SCC) is the marginal cost of emitting one extra tonne of carbon (as carbon dioxide) at any point in time. It is usually estimated as the net present value of climate change impacts over the next 100 years (or longer) of one additional tonne of carbon emitted to the atmosphere today. This estimate reflects the marginal economic effects of CO_2 emissions and derives from multiple studies researching the welfare effects of climate change in terms of crop damage, coastal protection costs, land value changes, and human health effects (Tol, 2012). An amount of CO_2 pollution is measured by the weight (mass) of the pollution. Some-times this is measured directly as the weight of the carbon dioxide molecules. This is called a tonne of carbon dioxide and is abbreviated "tCO_2". Alternatively, the pollution's weight can be measured by adding up only the weight of the carbon atoms in the pollution, ignoring the oxygen atoms. This is called a tonne of carbon and is abbreviated "tC". Estimates of the dollar cost of carbon dioxide pollution is given per tonne, either carbon, $X/tC, or carbon dioxide, $X/$tCO_2$. One tC is equivalent to 3.67 (44/12) tCO_2. The uncertainty about the social cost of carbon is fairly wide too and grows over time (Tol 2012). A component of this discount rate, the rate of pure time preference, measures the weight to attach to future levels of well-being solely because they are enjoyed later in time. The discount rate is critical when dealing with long time periods as with climate change. The higher the discount rate, the lower the concern for the future and the lower the social cost of carbon: As the uncertainty grows as we look further into the future, a lower discount rate implies a loss of confidence. A review of additional recent literature in this area found a wide range of estimates of the value of carbon stored, typically presented as a value per metric ton of carbon ($/tC). For the purposes of this report a median value of $48/tC is the SCC price estimated for Latin America and the Caribbean region (Kotchen et al 2014). Tol (2018) used probability density functions (PDF) based on three pure rate of time preferences (0%, 1% and 3%) to estimate price per metric tonne of carbon emissions. Mean estimates from this study are also applied to the three sites and total estimated mangrove cover for Jamaica and compared with the $48/tC value (Kotchen et al, 2014). Based on the PDF analyses, the Tol (2018) study estimated the mean social cost of carbon, at $677 per ton of carbon for a 0 percent PRTP, $360 per ton of carbon for a 1 percent PRTP and $44 per ton of carbon for a 3 percent PRTP. In other words, burning a barrel of oil emits 0.43 metric ton of carbon dioxide. A $28 per ton of carbon tax is thus equivalent to $3 per barrel, while a $677 per ton of carbon tax is equivalent to $79 per barrel.

Results: Carbon Sequestration Value

The analysis of the economic value of sequestered carbon for the project study sites are presented below in Table 2. The estimates below are based on an application of the Tier 1 approach as per suggested methodology (Kotchen 2017, Tol 2018). It should be noted that tier 1 assessments typically come with large error ranges for both above ground and soil carbon estimates (Hoyt et al 2014). The estimation approach outlined by Hoyt el (2014) was used for this analysis. The tier 1 assessment of a carbon stock within a project area is achieved by multiplying the area of an ecosystem by the mean carbon stock for that ecosystem type. The mean value of 386 MgC Ha^{-1} is therefore multiplied by the respective site areas to provide estimates of carbon stock. The areas for the study sites are; Portland Bight 254.2 Ha, Bogue 66.2 Ha and Salt Marsh 24.5 Ha. As part of this analysis we also estimate carbon sequestration values for the total estimated mangrove as per the LULC categorisation reported in the 5th National GHG report. This estimated area for Jamaica is 9,715Ha.

The basic calculations are as follows:
*Mean Carbon (MgC Ha^{-1}) * Area (Ha) = Mg (or T) of Blue Carbon in Study Site*
*Total Potential CO2 emissions per hectare ($MgCO_2$ Ha-1) = Mg C * 3.67*
*Carbon sequestration value = MgC * X$/MgC = X$*

Table 3 below shows the calculation of Net Present Value (NPV) of annually sequestering carbon at the rate estimated above for a 100 year time frame. This represents the value over time of keeping the mangrove forests intact. The sensitivity analysis compares discount rates ranging from 0.0% to 10%. It should be noted that for standard infrastructure development projects the typical discount rate used is 3%. For most carbon valuation studies the discount rate of interest is usually set at 1-1.4%. As discussed previously, part of the controversy with discount rates is that to account for intergenerational equity issues, discount rates for carbon should be set at zero given the longer time frames of climate and carbon cycling. However the resulting price estimates for carbon are typically quite large and as a result may have little real world policy application. However it can still be instructive to show the value over these longer time frames for trade off purposes. Based on the results of the sensitivity analysis we can examine the annual value of carbon sequestration as well as the future value of carbon over a 100 year life span. These estimates are based on the Kotchen (2017) value of US$48 per tonne of Carbon.

Incorporating UWI Site Specific Carbon Data

The previous analysis relied on the global average taken from the literature. The UWI team also conducted an analysis of carbon stock as outlined in the companion report (UWI, 2019). We also use the lower and upper bound of CMgHa-1 to assess the actual Social Cost of Carbon based on these estimates. The UWI component (Spence 2019) estimated carbon flux, standing biomass and soil organic carbon for the three locations. Using the mean bulk density value from a pedotransfer function (Grigal et al 1989) estimates were shown to be higher than the global average (386 $MgCHa^{-1}$). The average soil organic carbon stocks ($MgCHa^{-1}$) were 1023.12 (Portland Cottage), 1205.75 (Bogue) and 878 for Salt Marsh. These site specific averages were used to estimate SCC and are presented in Table 4 below.

Table 2 Annual Carbon sequestration values for mangrove study sites

	Portland Cottage	**Bogue Lagoon**	**Salt Marsh**	**Combined Sites**	**Jamaica Total**
Area (Ha)	**254.2**	**66.2**	**24.5**	**344.9**	**9,715**
Tonnes C Sequestered	98,121	25,553	9,457	133,131	3,749,990
Tonnes of CO_2 equivalent	359,778	93,695	34,676	488,148	13,749,965
Estimated Price T^{-1} C (Social Cost of Carbon)					
$48 (Latin America)	$4,709,818	$1,226,554	$453,936	$6,390,307	$179,999,520
Rate of time Preference					
0% PRTP = $677	$66,428,052	$17,299,516	$6,402,389	$90,129,958	$2,538,743,230
1% PRTP = $360	$35,323,632	$9,199,152	$3,404,520	$47,927,304	$1,349,996,400
3% PRTP = $44	$4,317,333	$1,124,341	$416,108	$5,857,782	$164,999,560
Jamaican Dollars – (US$1 = JM$130) Estimated Price T^{-1} C (Social Cost of Carbon)					
J$6,240 (Latin America)	$612,276,228	$159,451,968	$59,011,680	$830,739,936	$23,399,937,600
Rate of time Preference (Jamaican Dollars)					
0% PRTP = $88,010	$2,806,266,320	$730,821,520	$270,470,200	$3,807,558,040	$107,249,714,000
1% PRTP = $46,800	$1,186,285,308	$308,938,188	$114,335,130	$1,609,558,626	$45,337,379,100
3% PRTP = $5,720	$357,161,168	$93,013,648	$34,423,480	$484,598,296	$13,649,963,600

Table 3 Net present value (NPV) of annually sequestering carbon at various discount rates over 100 year period (SCC US$48 T-1C)

	Discount Rates				
	0.0%	**1.4%**	**3%**	**5%**	**10%**
SCC= US$48 T^{-1}C	**Net Present Values (100 Years)**				
Portland Cottage	$466,271,942	$248,002,288	$144,252,442	$88,994,496	$42,813,106
Bogue Lagoon	$121,428,806	$64,585,962	$37,566,922	$23,176,379	$11,149,597
Salt Marsh	$44,939,664	$23,902,660	$13,903,166	$8,577,361	$4,126,361
Combined Sites	$632,640,413	$336,490,909	$195,722,531	$120,748,237	$58,089,065
Jamaica Total	$17,819,952,480	$9,478,136,231	$5,513,030,978	$3,401,186,195	$1,636,228,655
SCC= J$6240 T^{-1}C	**Net Present Values (100 Years)**				
Portland Cottage	$60,615,352,460	$32,240,297,440	$18,752,817,460	$11,569,284,480	$5,565,703,780
Bogue Lagoon	$15,785,744,780	$8,396,175,060	$4,883,699,860	$3,012,929,270	$1,449,447,610
Salt Marsh	$5,842,156,320	$3,107,345,800	$1,807,411,580	$1,115,056,930	$536,426,930
Combined Sites	$82,243,253,690	$43,743,818,170	$25,443,929,030	$15,697,270,810	$7,551,578,450
Jamaica Total	$2,316,593,822,400	$1,232,157,710,030	$716,694,027,140	$442,154,205,350	$212,709,725,150

Table 4: Site specific carbon sequestration values for mangrove study sites

	Portland Cottage	**Bogue Lagoon**	**Salt Marsh**
Avg Soil Carbon Stock ($MgCHa^{-1}$)	**1023.12**	**1205.75**	**878**
Area (Ha)	**254.2**	**66.2**	**24.5**
Tonnes C Sequestered	260,077	79,821	21,511
Tonnes of CO_2 equivalent	953,616	292,676	78,874
Estimated Price T^{-1} C (Social Cost of Carbon)			
US$48	$12,483,701	$3,831,391	$1,032,528
JM$6,420	$1,622,881,129	$498,080,856	$134,228,640
Rate of time Preference			
0% PRTP = $677	$176,072,199	$54,038,580	$14,562,947
1% PRTP = $360	$93,627,757	$28,735,434	$7,743,960
3% PRTP = $44	$11,443,393	$3,512,109	$946,484
JM$ - Rate of time Preference			
0% PRTP = $88,010	$22,889,385,870	$7,025,015,400	$1,893,183,110
1% PRTP = $46,800	$12,171,608,410	$3,735,606,420	$1,006,714,800
3% PRTP = $5,720	$1,487,641,090	$456,574,170	$123,042,920

Table 5: Net present value (NPV) of annually sequestering carbon at various discount rates over 100 year period (SCC $48 T-1C)

	Discount Rates				
	0.0%	**1.4%**	**3%**	**5%**	**10%**
SCC= US$48 T^{-1}C	**Net Present Values (100 Years)**				
Portland Cottage	$1,235,886,399	$657,347,413	$382,351,188	$235,886,137	$113,479,132
Bogue Lagoon	$379,307,709	$201,747,459	$117,347,964	$72,396,161	$34,828,047
Salt Marsh	$102,220,272	$54,369,262	$31,624,300	$19,510,163	$9,385,869
SCC J$6,240 T^{-1}C	**Jamaican Dollars - Net Present Values (100 Years)**				
Portland Cottage	$160,665,231,870	$85,455,163,690	$49,705,654,440	$30,665,197,810	$14,752,287,160
Bogue Lagoon	$49,310,002,170	$26,227,169,670	$15,255,235,320	$9,411,500,930	$4,527,646,110
Salt Marsh	$13,288,635,360	$7,068,004,060	$4,111,159,000	$2,536,321,190	$1,220,162,970

Discussion: Carbon Values

Using a global soil carbon stock average of 386 $MgCHa^{-1}$ and a social cost of carbon (SCC) of \$48 T^{-1} C the value of annual sequestration for Portland Bight, Bogue Lagoon and Salt Marsh are respectively US\$4,709,818, \$1,226,554 and \$453,936 (JMD \$612,276,340, \$159,452,020 and \$59,011,680). Net Present Values calculated for a 100-year times span show estimated values for keeping carbon sequestered ranging from \$4.1M (Salt Marsh) to \$466M (Portland Bight).

However when estimates of soil carbon stock for each location were used with the same SCC the value of annual sequestration for Portland Bight, Bogue Lagoon and Salt Marsh are \$12,483,701, \$3,831,391 and \$1,032,528 (JM\$1,622,881,129, \$498,080,856 and \$134,228,640) respectively. The site-specific economic SCC values are higher than the global average. Similarly the Net Present Values for a 100 year time span at different discount rates are higher than the estimates using the global carbon stock average. As discussed previously, these value estimates are influenced by the choice of discount rate. It should again be noted that these values represent the avoided costs to society of not releasing this stored carbon to the atmosphere.

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

Economic Contribution to Nearshore Fisheries

Overview

Mangrove fisheries benefits are typically derived from two key ecological mechanisms. The first, is the high level of primary productivity from the mangrove trees and from other producers in the mangrove environment that supports secondary consumers. This high level of primary productivity forms the basis of food chains that support a range of commercially important species. The second is the physical structure (habitat) that they provide, creating attachment points for species that need a hard substrate to grow on, as well as shelter from predation and a benign physical environment. These two mechanisms combine to make mangroves particularly effective as nursery grounds for juveniles of species that later move offshore or to adjacent habitats such as coral reefs (Hutchinson et al 2014).

Many offshore species are found in mangroves during part of their life cycle, most commonly as juveniles. Indeed, juveniles of some species of penaeid prawn are found almost exclusively in mangroves. Many fish species are also found in mangroves as juveniles, and studies have demonstrated the movement of juveniles from mangroves to coral reefs and other offshore habitats (Kimirei et al. 2013). For Jamaica, studies showed that over 220 species of fish use mangroves to lay their eggs and feed (NEPA, 2013). This includes many commercial fish such as grunt, snapper, snook, tarpon, barracuda and mackerel. Furthermore, important reef cleaners such as the Rainbow Parrotfish (*Scarus guacamaia*), are highly dependent on mangroves for breeding.

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

Estimating the economic value of mangrove-associated fisheries is challenging, particularly at regional or global scales (Hutchinson et al 2014). Estimation of the proportional contribution to commercial (or subsistence) fish harvest is typically very data limited. The additional challenge these estimates is the underlying complexity and variability of the types of fisheries. Several studies are limited to individual target species or specific fishing methods and as a result capture only a part of the total fisheries value. Estimates for the economic contribution of mangrove habitat support to offshore fisheries can also vary spatially given differences between quality of the habitat at the seaward edge or ''fringe'' of the mangrove forests as compared to further inland (Aburto-Oropeza et al 2008).

Mangroves are important as breeding and nursery areas for fish and prawns that form the basis of major fisheries (Bann, 1997; Sasekumar et al., 1992). Annual commercial fish harvests from mangroves have been valued at from US$6,200 per km^2 in the United States to US$60 000 per km^2 in Indonesia (Bann, 1997).

Other studies have produced estimates with ranges between 5-25 per cent contribution of mangrove to offshore fishery (Spurgeon, 2002). Another study estimated a 31.7 % contribution of the local fishery landings the mangrove (Aburto-Oropreza, 2008), an equivalent of $15,000 dollars per acre. While another study on the contribution of Malaysian mangroves to nursery areas, coastal food chains and fisheries show that net fisheries contribution from 1 ha of mangrove forest amounted to US$846 yr^{-1} (Chong, 2007). The science underpinning our understanding of the role of mangroves has grown and show strong evidence that supports their effects in enhancing coastal and cross-shelf fisheries. These studies include examining correlations between catches of fish and mangrove area (Aburto-Oropeza et al. 2008), contribution to fish abundance (Laegdsgaard and Johnson 2001, Nagelkerken et al. 2001) as well as stable isotope studies that confirm fish movement between mangroves to coral reefs and other habitats as they mature (e.g. McMahon et al. 2011, Kimirei et al. 2013).

In the context of climate change and resilience (ecological and human), mangrove values for fisheries need to be viewed in a host of different contexts (Hutchinson et al, 2014). In many countries it is often the case that (subsistence) inshore fisheries are more valuable as a protein source in coastal communities where there is no agriculture, or where poverty prevents the purchase of other protein sources. It is therefore important to keep in mind that higher numbers of vulnerable populations engaging in low vales fisheries may have a more important localized social economic impact that higher value commercialized catch. Unfortunately, catch statistics for inshore, mixed-species fisheries are rarely recorded or reported. This makes it very difficult to assess the volume or value of fish caught and often results in undervaluation of this ecosystem service. Additional challenges for Jamaica is that the impact of overfishing is even more compounded in nearshore environments (FAO 2005; NEPA, 2011).

As mentioned previously other components of the broader project are focused on the disaster risk mitigation role of mangroves. There are additional protective roles that mangroves serve linked directly to fisheries. The provision of safe refuges for boats and fishing equipment in mangrove lagoons and forests during high energy events (storms and hurricanes) is an regulating ecosystem service that translates to avoided costs of damage. Storm refuge systems exist in many jurisdictions where special permission is granted to areas typically not permitted for boat owners to use mangrove safe areas

Methodology

The primary method utilized in for this component is a value transfer approach based on relevant global and Caribbean literature. The value transfer approach relies on linking the area of mangrove to its potential contribution to nearshore fisheries. These value transfers are based on studies that utilized a production function-based approach to derive estimates of fisheries value from mangroves. It is also dependent on objective measures of biophysical parameters that can then be tracked to corresponding changes in marketed output of the product. In this case, fish and seafood products.

In order to estimate the extent to which a given area of mangrove will benefit fisheries within and around it, it is necessary to understand the drivers of fish productivity and fishery value. As a habitat type, mangroves are highly variable and are located across a broad range of climate types from wet tropical to desert and temperate regions. Individual mangrove areas may have anything between one and 50 of the roughly 65 mangrove species, and the trees may be anything from small shrubs to 40m tall forests. It is important to note that environmental conditions are important. For example estuarine mangroves with abundant nutrients and fresh water input will be taller and more productive than mangroves on oceanic coral islands. Each individual mangrove forest is therefore unique, and this extensive variability makes predicting fish production a challenge. There are some common factors that influence production and fishery value in all mangroves. These can be demonstrated in the figure below (adapted from Hutchinson et al 2014) which describes a conceptual model of the drivers of mangrove fishery catch and value.

The conceptual diagram below is based on the assertion that environmental drivers determine the potential fishable biomass that might be present in natural conditions. This means that actual fishable biomass can be impacted from human impacts on the mangrove ecosystem and fish stocks. These impacts may however be mitigated by conservation and fishery management. The catch depends on the actual fishable biomass, and the socio-economic drivers that determine fishing effort.

In order to calculate reasonably accurate estimates of economic contribution of the fishery it will require data that allows for the prediction of potential fishable biomass (carrying capacity). Linking the environmental with the human impact drivers also requires data that could be obtained from monitoring. The link between ecosystem function and productivity and humans' dependence is manifested through the amount of fish harvested and sold (consumed). The economic contribution from the mangroves is then captured using this metric ($/kg of fish sold).

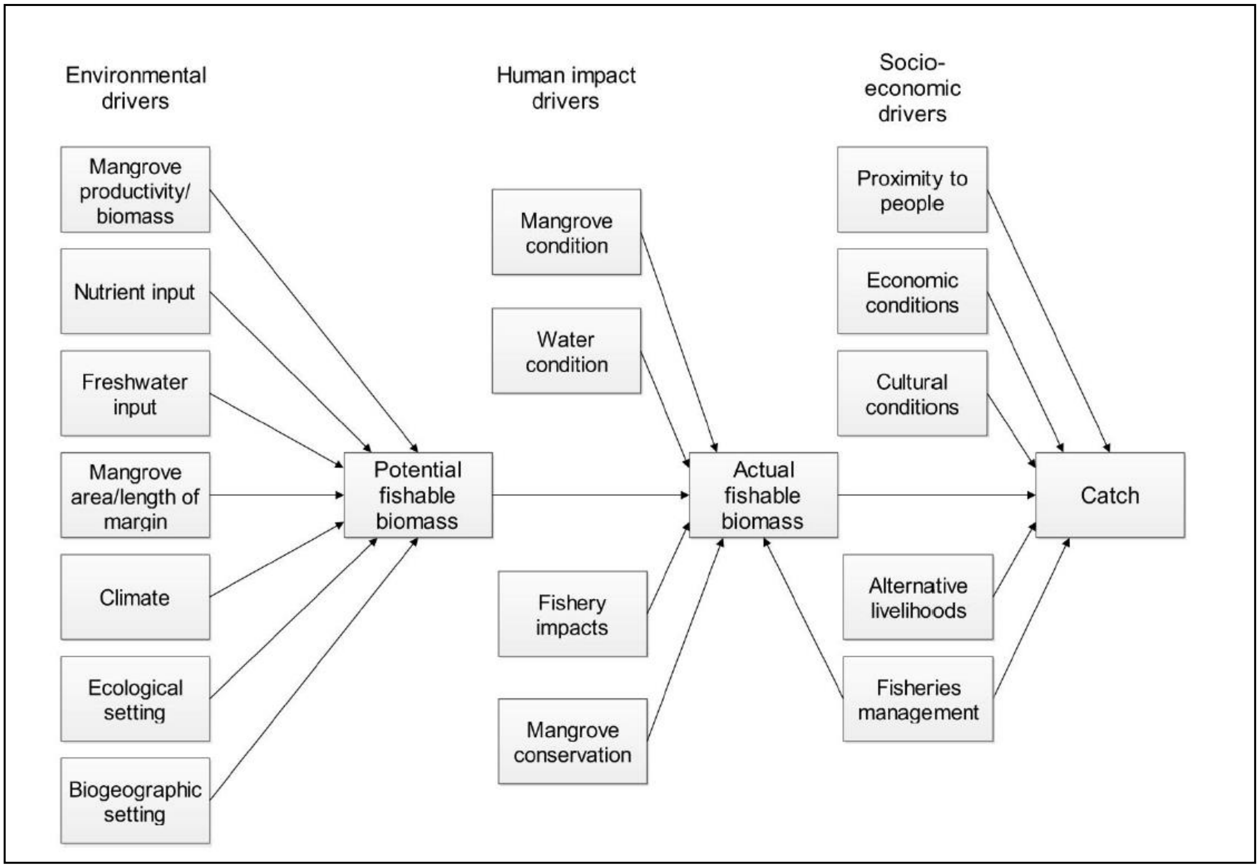

Figure 3: Conceptual Model of the drivers of mangrove fisher catch and value (from Hutchinson et al 2014)

Findings

The estimates of value per site outlined below are based on a review of related literature and subsequent benefit (value) transfer. There are studies with broad range estimates of mangrove-associated fisheries economic values often in excess of US$1000 per hectare per year. Based on a comparison of a variety of studies that included a range of mangrove types and fisheries, the global median value of US $77/ha/yr for (fin) fish, and US $213/ha/yr for mixed species fisheries (Hutchinson et al 2014) was used for this analysis. These median values are within the context of a wide variation value. For example, for mixed-species fisheries, the values ranged from $17.50 to $3,412 ha/yr. These median values are used as the value transfer estimates for the Jamaican mangrove sites.

Table 6: Estimated annual economic contribution of mangrove to small-scale mixed fisheries

	Portland Bight	Bogue Lagoon	Salt Marsh
	254.2	**66.2**	**24.5**
		$ Per Ha Per Annum	
Fin Fish (US$77/J$10,010)	$19,573 (J$2,544,490)	$5,097 (J$662,610)	$1,886 (J$245,180)
Mixed Fisheries ($213/J$27,690)	$54,145 (J$7,038,850)	$14,101 (J$1,833,130)	$5,218 (J$678,340)

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

The figure below illustrates the distribution of authorized fishing beaches along the coastline of Jamaica. When considering the three study sites there fishing beaches that may benefit from the presence of mangrove stands. The figures below illustrate the proximity of fishing beaches to each study site (CFRAMP 2000). The fishing activity from each beach may be in part be supported by the mangrove forests.

One fisheries management mechanism employed by the Fisheries Division was the declaration of seventeen marine areas as Special Fishery Conservation Areas (SCFA), also known as fish sanctuaries (MICAF, 2011). Each SFCA varies in size, ecosystems present, and management (see Figure 4 below). This management approach aims to protect and enhance the fish stock and to promote increased biodiversity in coastal and marine areas.

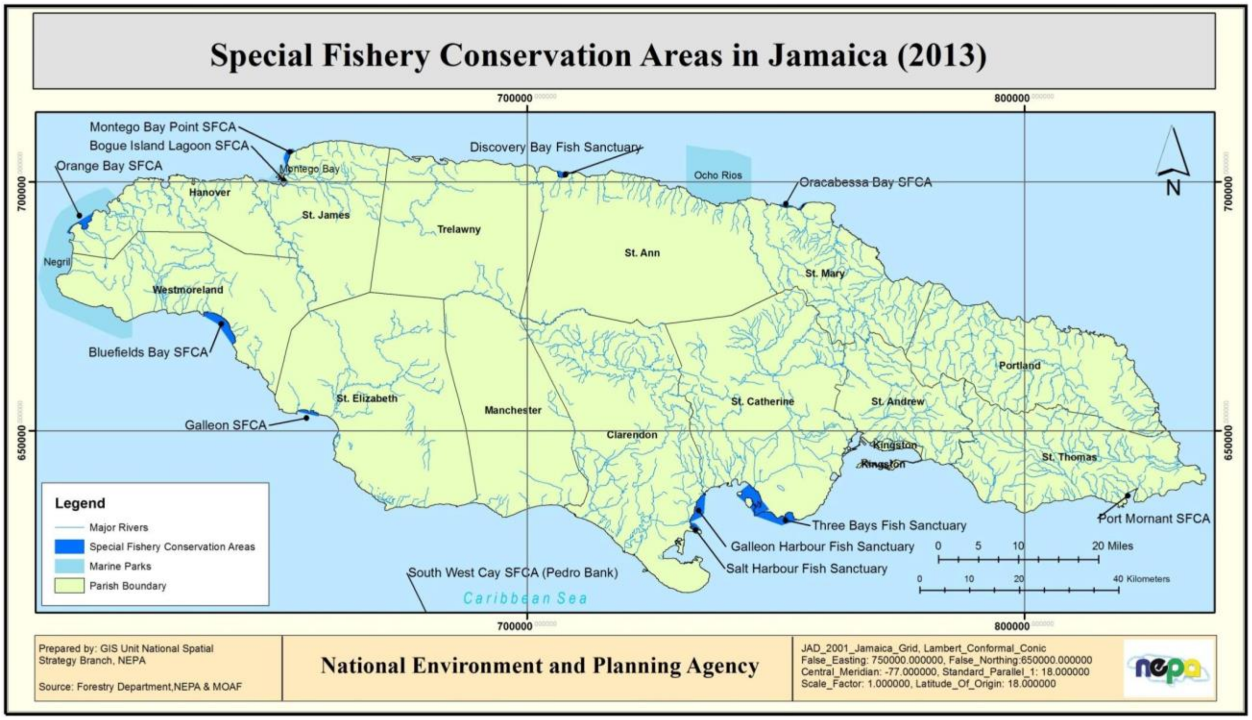

Figure 4: Map of Special Fishery Conservation Areas

An examination of the figure above shows that many of the SFCA include mangrove forests. In fact, these areas were selected based on a number of criteria including the presence of seagrass beds, a reef system and/or shallow waters abutting mangrove stands (MICAF, 2011) in their presence played an important role in site selection. It should be noted that there are currently two SFCAs established at two of the three study sites (Bogue and Portland Bight) and a third is proposed for Salt Marsh (MICAF, 2017).

Figure 5 shows the locations of the three project sites and their proximity to fishing beaches, protected areas and SFCAs.

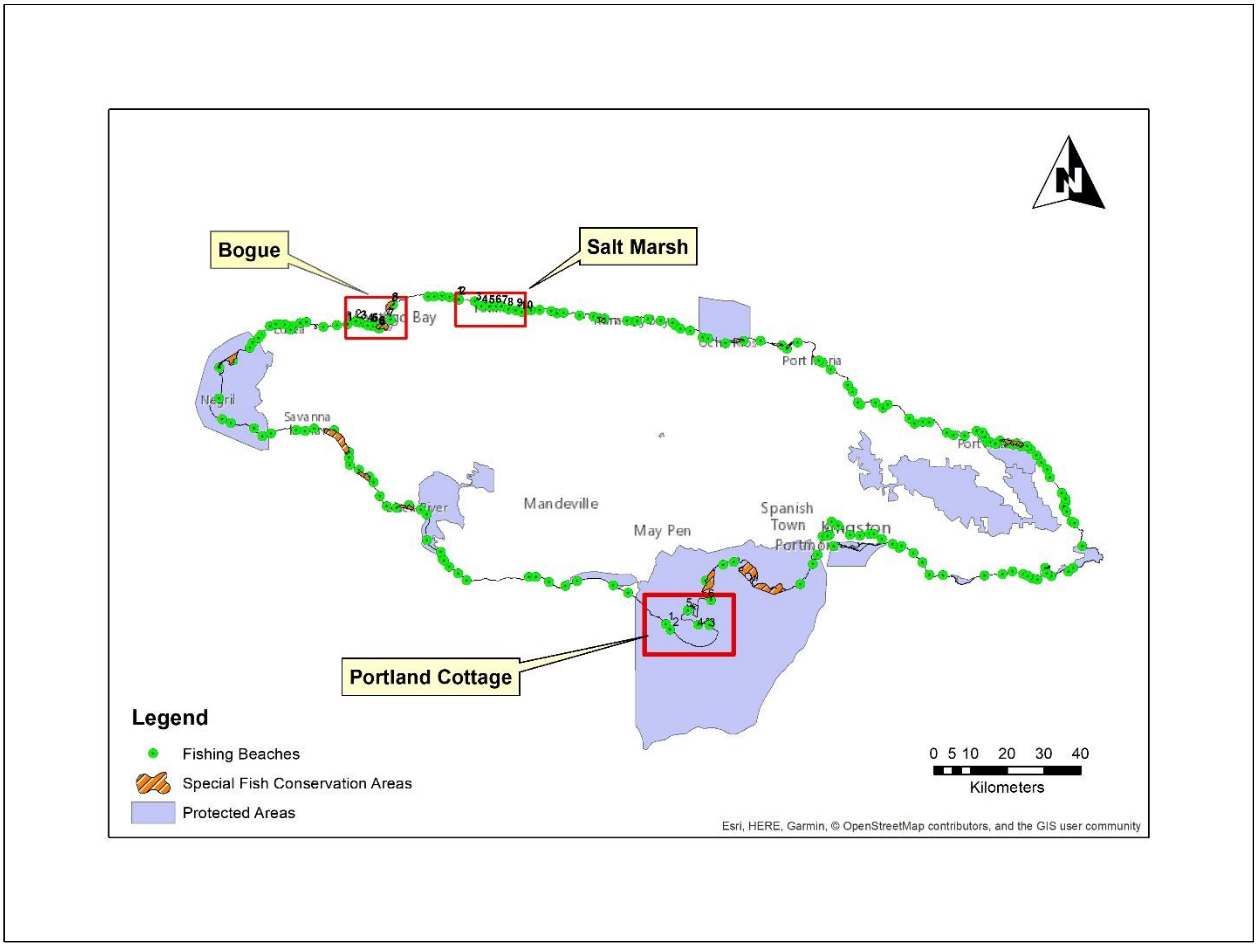

Figure 5: Island wide fishing beaches, project sites and Special Fish Conservation Areas

The figures below show the beaches that could potentially be benefiting from the fisheries provisioning services provided by the mangrove forests close by.

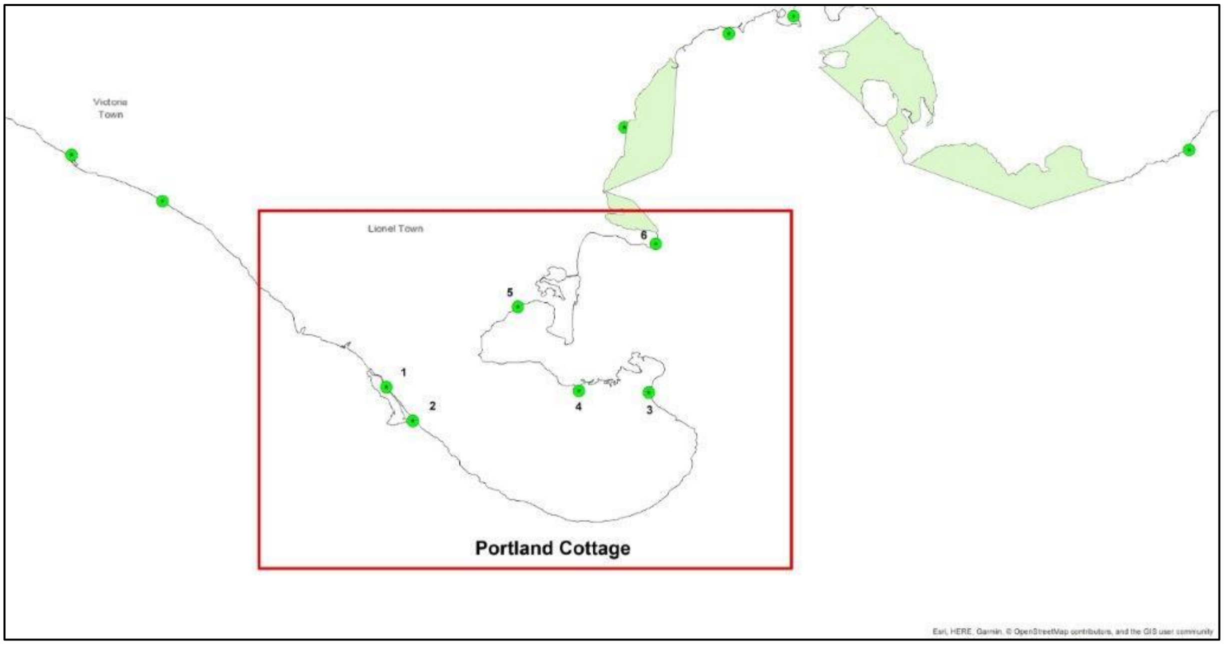

Figure 6: Portland Cottage and neighbouring fishing beaches. Key: 1. Rocky Point, 2. Jackson Bay, 3. Barnswell Dale, 4. Bournmouth, 5. Mitchell Town, 6. Welcome

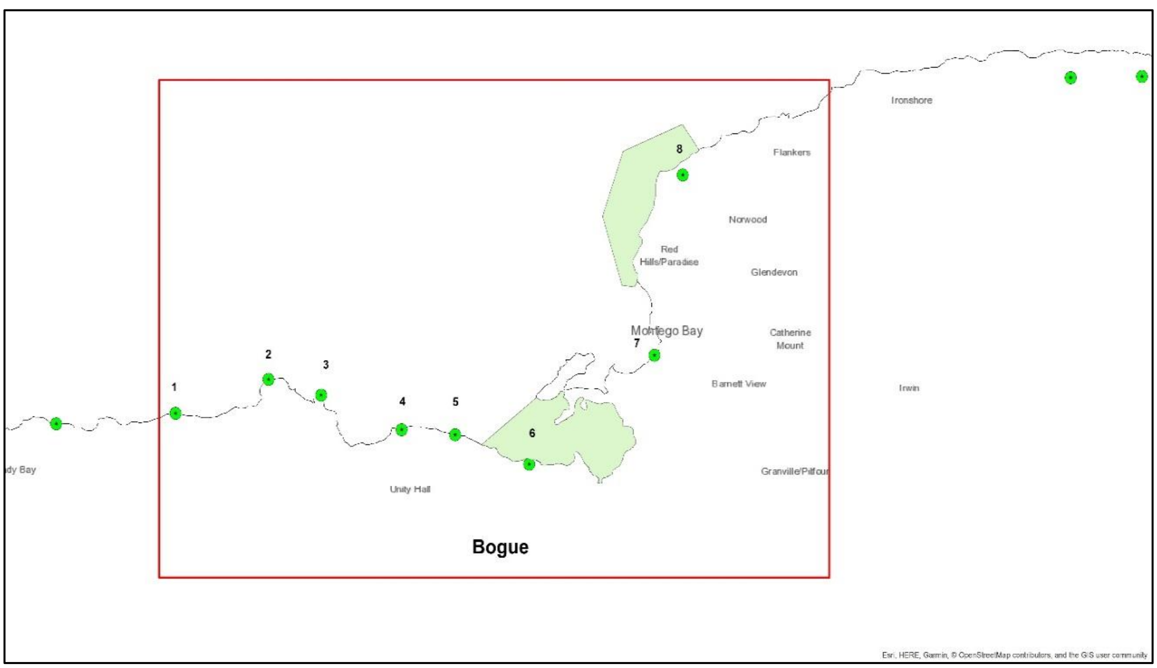

Figure 7: Bogue Lagoon and neighbouring fishing beaches. Key: 1. Hopewell, 2. Orchard, 3. Giggle, 4. Great River, 5. Spring Garden, 6. Reading, 7. Railway aka River Bay aka Montego Bay 8. Whitehouse

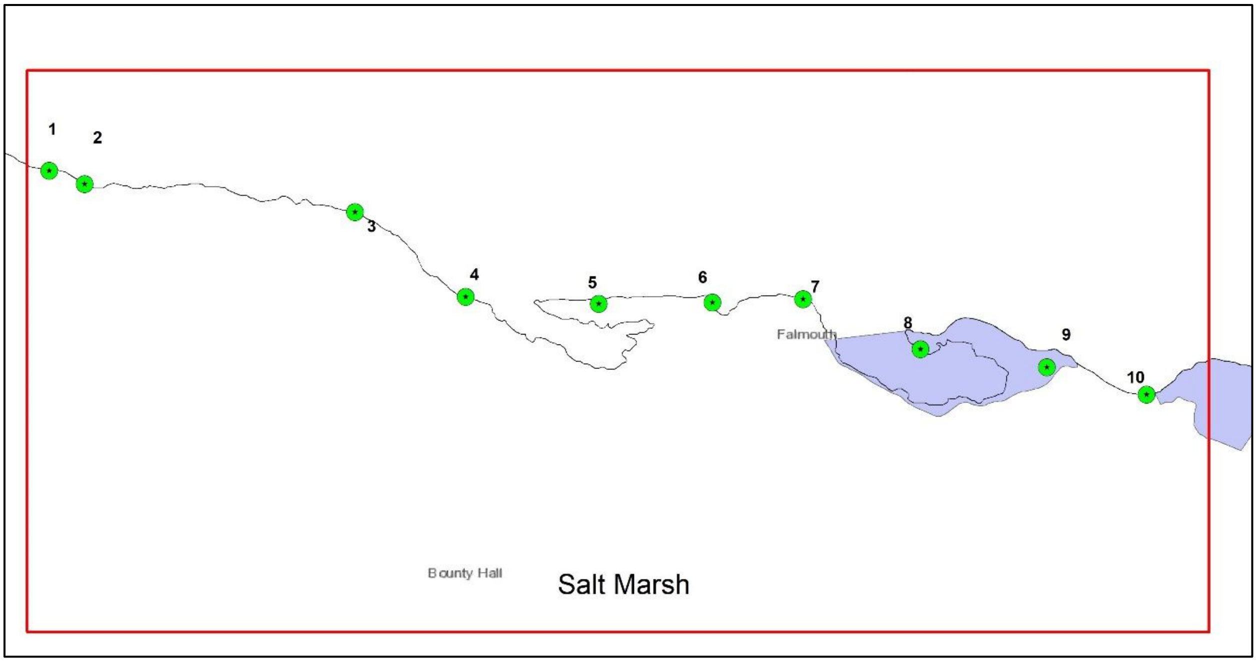

Figure 8: Salt Marsh and adjacent fishing beaches. Key: 1. Rosehall, 2. Success, 3. Grange Pen, 4. Gentles, 5. Salt Marsh, 6. Seaboard Street, 7 Charlotte Street (Victoria Park), 8. Rock, 9. Coopers (Good Hope), 10. Stewart Castle

To date there is limited data that indicates success (or lack thereof) of the SFCAs. Of those with publicly available data, the Oracabessa Bay SFCA has reported a 1,313.05% increase in fish biomass between 2011 and 2014 (NEPA, 2014). Similar data, if collected from other fish sanctuaries could be incorporated into the decision making process or validate the selection of these sites and the use of this approach as a fisheries management measure. The collection of this information along with data from fishers who may be experiencing improved fish catch per unit effort as a result of spillover effects from the SCFA is highly recommended. Another area for future investigation is examining the correlation of the size of the mangrove areas within these SCFAs and the comparative economic benefits to fishers. Establishing both ecological (fish biomass) and economic (fishery revenues) metrics is important to measure the effectiveness of this management approach. If it can be demonstrated that larger mangrove areas (fringe) corresponds with increased positive spillover effects and subsequent increases in fish catch it will support continued used of SFCAs that incorporate mangrove forests as a key component. This kind of information can also support arguments for mangrove restoration approaches.

Incorporating UWI Site-Specific Fisheries Data

At the three study sites, light traps were secured to red mangrove prop roots (in at least 1 m water depth) and used to collect fish larvae samples. Sampling was conducted during new moon phases. Fish larvae from these samples were identified, enumerated and then used to provide information on; richness, presence of commercially important species and their relative abundance.

The UWI ecological team noted some major limitations with this approach. Firstly they were unable to assess fish species composition over a standard 12 month period in part due to the requirement to set light traps a new moon cycle. They were also unable to sample in multiple locations at the same time. In addition, adult fish biomass is difficult to determine for mangrove areas without destructive sampling (pot/trap fishing). They did also note that adult fishes use the mangroves seasonally (for spawning) or diurnally (for feeding) but there are a few 'commercially important' adult species such as grunts, mojarras, sea breams, mullets and tarpons that are found permanently in mangrove areas in Jamaica. Based on some of the limitations cited above, adult fish species were not sampled. Summarized results are found below, but more details can be found in the full report (UWI, 2019).

Bogue Lagoon

Eleven fish families were identified in the Bogue Lagoon study location from the light trap assessment. 54% of the species belonged to the Gobiidae family other identified species included Atherinidae family accounting for 28 % of species. This family includes white fry/silverside which also fishers as bait. Other larval species identified at this site included Gray Snapper and School Master Snapper from the Lutjanidae family and Tetraodontidae (pufferfish family). The Snappers are commercially important species (UWI, 2019).

Portland Cottage

The light trap assessment for Portland Cottage yielded only one (1) family (Gerreidae) across two sampling locations at the site. This family of fish, also known as mojarra and include the Silver Jenny a common prey/bait fish used throughout the Caribbean and is not considered of high commercial value. Given the relative area and maturity of mangrove stands at this location, it is unclear why only one family of fish were detected at the site. The UWI led socioeconomic survey of surrounding communities examined the services that mangroves provided to the community. Only 37 (35.6%) of the sample were fishermen and of this number 24 responded to whether they fished in the mangroves. Of that amount, 13 (54.2%) stated that they fish in the mangrove mainly for home use and to a lesser extent commercial purposes. It should be noted that this area is protected and fishing should be off limits. However level of poverty and lack of other economic opportunities underscores the importance of these of mangroves to the livelihoods of these fishermen. The majority of these fishers reported using the mangrove areas for fishing 1 to 3 times per week. Among the fishes caught in the mangroves, which are for domestic consumption or sold are Grunt, Parrot, Sprat, Jack, Snapper and Doctor Fish. Snapper, Grunt and Parrot fish are primarily consumed in these communities. The sale of catch occurs only within in the community. A small number of respondents (11) reported weekly income from the sale of fish ranging from J$3000 ($US23) to J$40000 (US$308) with an average income of J$12090.90 (US$93). Most respondents reported experiencing a decline in income from the sale of fish the last 5 years. Subsistence extraction of oysters, fish bait and crabs was also reported for this site but no dollar values for these components were ascertained.

Salt Marsh

The light trap study conducted at Salt Marsh detected eleven fish families within the location. The results from the trap showed that over half of the species found, belonged to the Labridae family, which includes the Dwarf wrasse, 7% belonged to the Blennidae family (blennies), and 1% belonged to the Eleotridae family which includes Emerald sleeper. These species are not considered to have high commercial value. Also found were high a percentage of species belonging to the Clupeidae family (sardine, sprat, and small herring/ green fry) are a minor commercial fish species often harvested for use as bait.

Household survey at this site revealed a low percentage of fishers compared to the sample population (16.7%). Of the respondents who indicated that, they were fishers and even smaller sub sample indicated that they fished in the mangroves. These fishers also stated that fishing in the mangrove was mainly for domestic use and to a lesser extent commercial sale.

Larval contribution to commercial fisheries

Unfortunately, not much of the larval data collected at these sites can be used to extrapolate the contribution to fisheries. It was however notable that for some locations commercially relevant larval species included Snappers and Clupeid family (which are typically used as bait fish). The UWI ecology component also noted that adult fish use the mangroves seasonally (for spawning) or diurnally (for feeding) but also stated there are a few commercially important adult species such as grunts, mojarras, sea breams, mullets and tarpons that are found permanently in mangrove areas in Jamaica. In the absence of in water observations or samples caught with fish traps the UWI team was not able to report on adult fish species composition for this study.

Social Dependence

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

Other Potential Benefits: High end Recreational Fisheries

There is one mangrove ecosystem service that is currently underutilised. Recreational ecosystem services could support the development of a tourism product linked to catch and release high end recreational fishing in these mangrove areas. In general, recreational fishing is carried out for pleasure and while some cases it generates a small harvest, usually for personal consumption, in other cases the catch may not even be kept.

Among the highest value recreational targets are a range of fish species valued for their "fight" the challenge of catching them, as opposed to their nutritional value (Hutchinson et al 2014). Fish species, such as tarpon (*Megalops* spp.) and bonefish (*Albula* spp.) attract recreational fishermen who will spend money on transport, accommodation, food and guiding associated with these trips. With these factors in mind the value of recreational fisheries can be very high, and often higher than other mangrove-associated fisheries. For example, catch-and-release fishing for bonefish contributes around US$1 billion per year to Florida's economy (Ault et al. 2010). There is an opportunity for Jamaica to develop their recreational fishing industry and in particular the catch and release segment of sport fishers. Some Caribbean examples include bonefish, permit and tarpon fishing in Belize reportedly worth US $56.5 million 2007 (Fedler and Hayes 2008), and US $141 million to the Bahamas in 2008 (Fedler 2010). Assessing the feasibility of promoting a high-end catch and release fishery that is associated with mangroves will require data on their role in providing habitat for key species of interest. Two of the three study sites are already located on the north coast of Jamaica with established tourism infrastructure. As with SCFAs this tourism activity can also be incorporated into an overall mangrove restoration strategy given the potential economic and ecological benefits. Given the likely high overlap with this type of tourism activity with the skills associated with artisanal fishing as opposed to say crafts or other alternative livelihood activities requiring higher levels of capacity building and knowledge transfer. This kind of activity may therefore have a high potential for success as an alternative livelihood strategy for fishers.

Low Impact Mariculture

The implementation of low impact types of mariculture activities could be an additional area of benefit for vulnerable communities. It should be noted that this is not large-scale aquaculture t that may involve the destruction of existing mangrove stands for example shrimp farming. Instead mangroves are perfect locations for introducing low impact mariculture approaches. This may require the rejuvenation of previous Jamaican efforts to raise oysters (*Crassostrea rhizophorae* and *Isognomon alatus*) and other bivalves. These species occur naturally in the study sites and may already be subject to some level of harvest. The need to implement programs and frameworks to ensure that the fisheries sector is more resilient and adaptive to climate change has been an on-going initiative of many national economies and is considered necessary for Jamaica (Jones, 2017). Mangrove forests are excellent locations to support alternative livelihood strategies. One component of the Pilot Program for Climate Resilience (PPCR) is looking at the potential for sustainable and low impact aquaculture of oysters. The PPCR subcomponents have a focus on alternative livelihoods. Two of which are most applicable to mangrove forests, namely;

- Promoting Community-based Aquaculture – which involves the establishment of fish farm clusters in selected communities, contracting new fish farmers and providing inputs and farming materials by partnering with aquaculture/processing enterprises, and providing training. This subcomponent would support fisher folk, women and youth in targeted fishing communities to invest in aquaculture;
- Developing Coastal Mariculture/Polyculture – which are commercially viable and ecologically important with the aim of increasing marine-based sustainable livelihoods activities that keep the communities' seafaring traditions alive;

Discussion: Mangrove Fisheries Benefits

Jamaican wetlands and mangroves are decreasing in many coastal areas due to human activity and this has important implications on sustaining Jamaica's social and economic development (NEPA SOE Report 2013). For example, the loss of mangroves means major breeding grounds for fish, crabs, shrimps, prawns and other commercial and non-commercial marine life are no longer available. This in turn, reduces the possibilities of sustaining the livelihoods of over 23,000 licensed fisher folk as well as many more who fish informally (Jones, 2017).

Mangrove fisheries are particularly important in developing countries like Jamaica, as they provide a critical source of food and income for many who have few livelihood alternatives. These ecosystems support a broad range of fishing methods and result in the exploitation of a wide range of species. Mangrove forests also support inshore mixed species artisanal fisheries conducted with limited equipment, on foot or from open boats. This type of fishing is usually linked to small-scale commercial purposes and subsistence fisheries where the catch is primarily used to feed the fisher, family members and close community, with limited market transactions (Hutchinson et al 2014).

The estimates of economic contribution of mangroves to nearshore fisheries are modest. This is due to limitations based on the value transfer approach used. These modest estimates are also as a result of the relatively small areas (Ha) for these study sites as compared to other studies.

The lack of creel survey data from the responsible government agency presents significant limitations on the ability to extrapolate economic benefits for fish sales. The data on economic activity at the fishing beaches that may be cross-referenced with the location and potential beneficial influence from the mangroves at the study sites is not available. This type of data will be needed to improve the estimates of mangrove contribution to nearshore fisheries.

There are additional approaches not explored here that have the potential to provide additional economic information about key ecosystem services. These approaches require closer synergy between biophysical and social science methods. Improvements to bio-economic models will rely on more focused research that allows for explicit links between mangrove area, fish larvae population, in water fish census and fishing effort and catch. The conversion of catch per unit effort into economic value (revenues, profits etc.) can therefore be linked to the ecological productivity of a given mangrove site. This integrated research approach should result in bioeconomic models that are more representative of the site than the values taken from global extrapolations.

This information could be more beneficial if it was combined with biological data collected for corresponding adult species using appropriate (in water) 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[4] and others) and/or stationary counts (Bohnsack and Bannerot, 1986). Biological sampling of harvestable adults that utilise mangroves and associated ecosystems (seagrass beds and coral reefs) should produce data that can then be extrapolated into estimates potential catch. Improving these two types of information at the local scale would lead to better models for estimated the contribution of mangroves to nearshore fisheries. There studies that provide methodological approaches to generating data that can be incorporated in to bioeconomic modeling (UNEP, 2011; Hutchinson et al 2014). This combination of data sources can be used to develop more locally appropriate models of fish productivity.

These approaches will also rely on site-specific information on commercial or artisanal catch information. This is often difficult to acquire from the responsible government agencies. At even finer scale information related to subsistence and commercial harvest of mangrove crabs and other invertebrates such as oysters is often non-existent. In order to paint a complete and accurate local (or national) picture of biomass harvested from these mangrove systems resources will be required to collect and analyse this data. The development of site specific or Jamaica focused ecosystem models can therefore be used to develop production functions for

[4] Atlantic and Gulf Rapid Reef Assessment Program

predicting biomass and by extension potential contribution to commercial/subsistence fisheries. Based on the timing and resources allocated to this study it was not possible to develop such models using the larval fish (light trap) data for commercially important species data collected by the UWI ecology team.

Some of the early findings suggest that the Special Fishery Conservation Areas (SCFA) seem to be working (NEPA 2013). The next step from beyond identifying increases in biomass, would be to quantitatively confirm the impact of spill over effects on the catch of mangrove associated fish species.

There is a potential economic benefit from developing a high-end recreational fishery focused on catch and release based on species associated with mangroves. This type of activity could has the potential to contribute the local (site based) economy and builds individual and community resilience in the face of climate change. This would also supports alternative livelihood strategies for mangrove dependent communities and in particular fishers.

Other Market Based Values

This section will discuss other potential sources of economic benefits from mangroves. Brief considerations of market-based approaches include provisioning services as well as regulating services that can be easily observed or traded in the market. It should be noted that even where market transactions occur, the prices do not necessarily reflect the value of the particular good or service being provided by the mangroves and in fact may be underreporting the full value. As mentioned in earlier sections of this report, there other components of the larger study focused on applying a market-based approach to the economic benefits of avoided damages based on the services provided by mangroves. This will not be the focus in this report as it is covered elsewhere.

Economic Benefits of Honey Bees

Mangroves attract honeybees and facilitate apiculture activities for people living along the coastal zones (Siddiqi, l997). Mangroves apiculture activities accounts for about 90% of honey production among the mangrove communities in India (Krishnamurthy, l990). While in Bangladesh, an estimated 185 tons of honey and 44.4 tons of wax are harvested each year in the western part of the mangrove forest (Siddiqi, l997). Beekeeping is also a very benign way of obtaining a harvest from natural forests. Beekeeping is practised by a variety of different techniques that can be selected and adapted depending upon the situation of resource-poor community members who depend on mangrove forests.

In Tanzania, the black mangrove *Avicennia germinans* is also known as the honey mangrove. It has small white flowers that produce abundant nectar. There is little research on the relationship between bees and mangrove, however from observation of the type of pollen, nectar and scent, it appears that mangrove species are dependent upon bee pollination, and mangrove provides excellent forage for bees and significant honey crops (Ibrahim, 2016). In Florida the main species for pollen and nectar production are the black mangrove *Avicennia germinans*, buttonbush (*Conocarpus erectus*), and white mangrove (*Laguncularia racemosa*) (Stanford, 1983). As part of their regular husbandry techniques, beekeepers in Florida migrate their hives between the citrus growing areas in central Florida and the mangrove areas, with the mangrove honey season extending from mid May to early August. Average honey production from the mangrove is 35-40 kilogram per colony (Hamilton and Snedaker, 1984). In Cuba, there is a tradition of moving thousands of bee colonies to mangroves during their long blooming season.

Beekeeping provides one of the few sustainable ways to use mangroves and if done without harming the bees, it has no overall negative impact. Implementing beekeeping extension as part of local social development efforts can be used not only as a mechanism for providing alternative livelihoods but also as a way to protect the mangrove vegetation from deforestation. The promotion of honey bees has been cited as an integral part of the national strategy for the protection of Guyana's mangrove forests though the Guyana Mangrove Restoration Project (GMRP) implemented by the Ministry of Agriculture (http://www.mangrovesgy.org/home/). In addition to European honeybees, mangroves are also home to other pollinators (insect and animal) and serve as a natural reservoir for pollination services that provides an ecosystem service benefit to the agricultural sector.

The pollination services of bees are widely understood to be of immense value to natural and agricultural systems but putting a figure on this value is difficult. The only route towards valuing forest beekeeping is to measure the income earned from the sales of bee products. The paucity of robust quantitative data in about the value of forests for beekeeping and their contribution to livelihoods in financial terms, is one reason why beekeeping remains in the margins of development planning. This not true not only for Jamaica but globally. This analysis does not examine any local data regarding actual or potential yield from mangrove honey but highlights that this is another ecosystem service that has the potential to be monetized. More importantly developing a non-invasive approach that can be used to support local incomes can be part of an overall strategy to build resilience in the face of climate change. Therefore the application of a market price-based approach would be the best approach to estimate economic information on the ecosystem services provided by bees.

Other Market Replacement Estimates

In general the most feasible methods often applied to estimating economic information for coastal protection, water regulation and erosion control typically utilise the "cost of avoided damages" approach. Cost-based approaches are based on estimations of the costs that would be incurred if ecosystem service benefits needed to be recreated through artificial means (TEEB 2010). The damage cost avoided, replacement cost, and substitute cost methods are related methods that estimate values of ecosystem services based on either the costs of avoiding damages due to lost services, the cost of replacing ecosystem services, or the cost of providing substitute services. It should be noted that these methods **do not** provide strict measures of economic value, which are based on peoples' willingness to pay for a product or service. Instead, they assume that the costs of avoiding damages or replacing mangroves or their services. This is based on the assumption that, if people incur costs to avoid damages caused by lost ecosystem services, or to replace the services of mangroves, then those services must be worth at least what people paid to replace them. Thus, the methods are most appropriately applied in cases where damage avoidance or replacement expenditures have actually been, or will actually be, made.

As a reminder, this report complements another study (TNC/UCSC 2019) that applied a comprehensive damage avoidance framework used to examine the role mangroves play in protecting coastal infrastructure, lives and livelihoods. This analysis, <u>does not attempt to replicate the flood reduction benefits</u> of Jamaican mangroves but instead examines the literature for other ecosystem services that may can be estimated using that approach. For example regulating ecosystem services of mangroves that address water (quality and quantity) or sediment control (erosion reduction) can be estimated using damage or cost avoidance approach. It should be noted that while some of these regulating services can be linked to economic benefits, it is not always easy to make these linkages. As cited earlier in this report, these two types of regulating services have not been widely assessed in the literature. This is a gap that still needs to be addressed. A possible research approach for future work that could be applied to the Jamaican context is suggested later in this section.

The role that mangrove forests play in regulating water quality and quantity is examined. It should be noted that while some of these regulating services can be linked to economic benefits, it is not always easy to make these connections.

Economic Benefits of Water Regulation

Given data constraints and the paucity of published information, this section of the analysis will identify potential economic benefits and provide suggestions for improving the estimation of economically relevant data. This is again a literature-based review, examining some of the different ways to assess value this type of value. The likely approach is to derive estimates based on cost saving from avoiding water treatment and reducing nutrient loading into nearshore waters. As stated previously, there are a number of caveats about how this information (costs avoided) should be interpreted including the fact that these economic estimates typically undervalue the service (Desvouges et al, 1992).

Mangroves are natural filters that improve water quality through the control of sediments and the filtering of unwanted nutrients, such as sewage and some agricultural inputs, are being lost at a time when there are indications that nutrient levels in coastal marine areas are increasing (NEPA 2013). An assessment of marine water quality indicators across the island indicates that most of the coastal area is under threat and are not fully meeting all the established standards for various parameters (NEPA 2010). These elevated levels appear to be highest in areas near coastal townships and within the plume of waterways, gullies and rivers. Mangroves could play a role in reducing some of these deleterious impacts.

It is also notable that the study sites are located at the base of watershed areas that channel point and non-point sources of pollution into the receiving water bodies. Sewage generated in the Greater Montego Bay and Rose Hall area is treated at the Bogue Sewage Treatment Plant. At the same time, there is a considerable volume of untreated waste entering the marine environment via overland run off and upwelling in some areas. The Bogue Lagoon which receives effluent from the municipal sewage treatment facility has been shown to have signs of faecal stress (NEPA, 2013).

Site Level Water Quality Data

The UWI report provides details on in situ water quality parameters at the three sites. More details on the methods, parameter and sample locations are provided in the partner report. Brief summaries for each site are highlighted below.

Summary results for Portland Cottage showed slightly higher average water temperatures and salinities when compared to the Bogue and Salt Marsh sites. The results show that enrichment by evaporation is the primary driver of salinity which also determines plant community structure and productivity. However Total Dissolved Solids (TDS) is lower than the recommended minimum for brackish waters. Based on the two sample locations at this site, the data suggests that there is limited lithological control on water chemistry at these sites. Spectroscopic analysis of surface water samples from the two sampled sites at Bogue Lagoon revealed variable concentrations for a number of major elements (heavy metals). The values suggest that there is limited lithological control on water chemistry (UWI 2019, page 85) and like Portland Cottage, the mangroves may not be playing a significant role in regulating the nearshore water chemistry in the lagoon. Water quality samples were taken at two locations within the Salt Marsh location, Mean pH values for the sampled sites were strongly alkaline and are considered elevated and could potentially adverse impacts on a number of vital biotic and abiotic processes in this locality.

The summarized water quality information above is useful for establishing site level baseline information on selected water quality parameters. However because of the sample design (two random sites per location) the information cannot be used to comprehensively assess pollution abatement or other regulating services provided by these mangroves. The method utilized provides a static or snap shot of site level water quality. In order to demonstrate if the mangroves are providing regulating services then a sample approach that shows a gradient of water quality from inside the mangrove forest towards coastal waters should have been used.

As stated earlier, demonstrated benefits (including economic) of this particular ecosystem service (water quality regulation) is poorly studied, In the future recommended sampling approach should include transects with a series of water quality sampling sites that start within the landward side of the mangrove forest and head towards adjacent coastal water body. This approach should show if there are any changes across this gradient. It is also important to decide on what water quality parameters are relevant for the purpose of the study. In the case of water regulation services it may be useful to sample for heavy metals, pesticides or other pollutants. It should be noted that the selection of parameters for assessing nutrient abatement (N, P, K) need to be done with care. Mangroves soils and overlying waters tend to have naturally higher levels of organic matter (detritus) when compared to adjacent seagrass and coral reef ecosystems (Edwards, 2002). Higher concentrations of dissolved organic Carbon, Phosphorus or Nitrogen may be above recommended baselines for recreational coastal water quality and so these parameters may be the most appropriate for demonstrating nutrient abatement. It these site level mangrove nutrient water quality data are linked to larger coastal models (and water quality data) then perhaps mangrove nutrient abatement could be shown as contributing to offshore nutrient regulation. However in the absence of data showing the change in gradient from mangrove forest to open water this will be very difficult. A search of the literature for some examples of possible approaches that could be used to estimate or at minimum identifying economic benefits of water regulating ecosystem services provided by mangrove forests are discussed below.

Based on current research one of the more feasible approaches that has been shown is applying a variation of estimating the avoided cost of water treatment. For example estimated benefits of improved water quality by measuring the cost of controlling effluent emissions (sewage treatment plants). This approach has been more widely applied to more terrestrial or freshwater ecosystems as part of cost effectiveness analysis for potable water provision. A study in examining wastewater treatment efficiency in China showed that mangroves were able to reduce high levels of key water pollutants (Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD_5), Total Nitrogen, Total Phosphate and NH_3–N). The removal rates of organic matter and nutrients were positively correlated with plant growth (Yang, et al 2008). This study was incidentally conducted in a constructed mangrove wetland and the results might provide guidance in cost benefit considerations for restoration.

Mangroves also play a role in maintaining aquifers and preventing saltwater intrusion (Hilmi et al 2017). The mangrove ecosystem has ability to reduce seawater intrusion because mangrove can eliminate the effect of salinity, pH, pyrites and mitigate anaerobic conditions. Coastal aquifers are very vulnerable to seawater intrusion from overexploitation (high levels of extraction) from key stakeholders The mangrove soils play a storage function that results in maintaining the water table in coastal areas. In the face of climate change and sea level rise, conserving mangroves can contribute to water security. At the same time this water purification ecosystem service can be reflected in economic terms as the avoided costs of more expensive water provision (agriculture and domestic) by key user groups. This is however dependent on an ability to determine if users are accessing water from wells (the aquifer) and not from other upstream sources. The table below adapted from the National Water Commission's information on current rates for potable water and sewage rates. These figures are largely illustrative and provides context regarding cost per 1000 litres for fresh water. However in the absence of the volume of water protected by mangroves at each location and the amount of extraction estimation is not possible.

Table 7 Rates for Potable Water and Sewerage from the National Water Commission

CUSTOMER TYPE	USAGE (LITRES)	Water Rates Per 1,000 LITRES (J$)	Sewage Rates Per 1,000 LITRES (J$)
Residential	For up to 14,000	103.67	94.09
	For the next 13,000	182.80	165.90
	For the next 14,000	197.38	179.13
	For the next 14,000	251.93	228.64
	For the next 36,000	313.71	284.71
	Over 91,000	403.83	366.51
Commercial	All quantities	388.75	352.81
Condominium	All quantities	192.83	174.99
Primary School	All quantities	155.53	141.12

It should also be noted that the Bogue Lagoon and Salt Marsh mangrove sites are located on the north coast of the island of Jamaica. These mangroves are likely playing a role in maintaining coastal water quality. The loss or removal of mangroves could therefore negatively coastal water quality and in turn negatively impact the tourism industry. Based on the results of a choice experiment survey it was shown that tourists would have a welfare loss from reducing water quality from status quo "good" to "fair"(Edwards 2009). This study showed that aggregated per person consumer surplus for water quality would result in welfare loss of US$60.1M per annum. In another scenario when the attributes of water and beach quality were combined there was an aggregate loss in value of $198.4M (per annum) if quality changed from "good" to "poor". While it is recognized that it is difficult to attribute all the coastal water quality parameters mangroves role in water clarification, these north coast mangrove study sites do play some role in helping preserve water quality in tourist locations. Their loss would therefore contribute to reduced economic values to tourists.

Economic Benefits of Erosion Control

Like water quality benefits of mangroves, the literature examining economic benefits of erosion prevention is very limited. There are studies that describe ecological functions and processes around sediment dynamics, not much exists on the economic implications of this ecosystem service. While we utilize a cost-based (damage avoidance) framework to discuss this Jamaican case, future studies should use economic value or consumer surplus methods to improve the benefit estimates. Option and existence (non-market) values are based on the idea that natural systems like mangrove forests have some utility attached to them irrespective of whether they produce anything tangible. The value of the "utility" which people get from knowing that a particular natural place exists can therefore be estimated using appropriate non-market valuation approaches. Non market valuation studies must however be carefully designed. Most mangrove (and other ecosystems) non-market valuation studies typically bundle a broader suite of ecosystem services into their valuation context (willingness to pay for a bundle of services) making it difficult to disentangle these values. However a well-designed choice experiment survey with erosion control presented as an attribute along with others (fisheries, water regulation etc.) would allow for the estimation of implicit prices on this ecosystem service.

In order to value the type of ecosystem service, in this case erosion control, defining the type of production or utility that it is providing is a very important step (Ruitenbeek 1992). In the context of erosion (prevention), for example, the direct economic benefits of a remote mangrove system that might be uninhabited (e.g. an offshore island) would practically zero. By contrast, a mangrove system that protects agricultural lands behind it or hotels downstream, or protects public roads and other infrastructure could be credited with an erosion control benefit if the integrity of the road or agricultural production could be linked to the erosion protection provided by the mangrove forest.

For cost approaches the two commonly used methods involve estimating either the "avoided costs", or estimating the impacts on production if the particular service is lost. For estimating mangrove erosion control benefits, the avoided cost approach might involve estimating the construction and operating costs of a system of dams, weirs, artificial reefs, or other "engineered" solutions to avert erosion. The "production impact" approach involves estimating the value of lost production when erosion actually does occur. In cases where land is a traded commodity, this might involve estimating the land area lost due to erosion and valuing that loss at the current land price. In the case of these Jamaica mangrove sites, the land may not be traded, and therefore more appropriate techniques should value the production (of agriculture, for example) from adjacent or protected lands and then estimating the lost net output if erosion persists (Ruitenbeek, 1992).

Caribbean studies using cost based or benefit transfer approaches were not found. However a study in Indonesia, calculated the erosion control value of mangroves as being equivalent to US$600 per household per year (Ruitenbeek, 1992). Another study from Thailand and Vietnam calculated the expenditure which would be required to construct or maintaining protective coastal infrastructure, if the mangroves were removed (Suthawan, 1999). The study estimated avoided costs for coastline protection and stabilisation, by estimated expenditures on preventative methods to protect coastal infrastructure. The study estimated an annual value of US$480 per 75m-width of mangrove.

The analysis by the UWI team showed that for Portland Cottage there seems to be a net erosion of coastline (1961 to 2017). The net lateral seaward accretion rates are lower than long-term erosion. This might be linked a net loss in mangrove vegetation (forest cover) over this time period (UWI 2019 pg 107). The transportation of bauxite and alumina may play a role, or the kind of fishing and transportation activities that occur in the bay area, but it is impossible to determine the cause of the significant dieback. The UWI report also highlighted that, if the denudated areas continue to expand, and subsequently become, and remain, flooded as the peat stocks below them decay and collapse, then overtime the existing seaward fringes will become isolated. These mangrove forest at Portland Cottage are therefore offering reduced ecosystem services.

For Bogue Lagoon, sediment supply is apparently very low and no vertical accretion was observed. This site is bordered by industrial, commercial, residential properties and an established road network and has a history of geoengineering including land reclamation. The analysis by UWI showed that over a 56 year period the site has a net accretion rate. Notably the report suggested that the presence of the large constructed wetland for sewage treatment located just behind the mangrove fringe may be enhancing its growth. There are other sections of mangrove along the coastline experiencing net erosion including those along the main roads and major developments. This should be of concern as the mangroves are serving a role by providing natural buffers to erosional wave forces and cost saving for municipal maintenance. The reported anthropogenic activities including dumping of construction materials by private owners may also be contributing to the overall decline in mangrove forest cover.

For the Salt Marsh mangrove site, it appears that small scale urban sprawl may be affecting mangrove forest cover. The report also showed that generally in many sections along the coastline there is an alternating pattern of erosion and accretion. Possibly explained by the localized nearshore current regime. However anthropogenic activities are believed to be a major cause of some of the observed erosion at one of the sampled sites in an area not directly impacted by ocean currents.

In the absence of Caribbean/ Jamaican studies that made the link between erosion prevention and mangroves, a study of the role coral reefs play in mitigating beach erosion could provide insights on how this could be applied (Kushner et al 2011). This study used estimates from a previous contingent choice study (Edwards, 2009) that looked at Jamaican tourist's willingness to pay for improved coral reef and beach quality. The findings from this study (Edwards, 2009) were incorporated into an analysis that determined the welfare loss per meter loss of beach width. The study showed that at the end of 10 years, current erosion rates at the beaches in Negril, Montego Bay, and Ocho Rios would cause a US$19 million annual loss in value. If reefs degrade further, they estimated that the additional beach erosion would increase loss to US$33 million that year. A similar approach could be used to derive values for the mangroves erosion protection ecosystem services. As mentioned previously this approach would rely valuation estimates from a well-designed (national/international) economic valuation (attribute based, choice experiment) study that estimated WTP for Jamaican mangrove ecosystem services (fisheries, erosion control, water quality, carbon etc.).

Another potential way to estimate economic benefits from preventing coastal erosion is to assess the values of houses and key coastal infrastructure protected by existing mangroves. It would require up to date information on adjacent housing, costs to maintain road networks and other infrastructure. A useful proxy could be cost per mile to maintain National Works Agency NWA roads. The avoided costs of road maintenance and repair would be the main metric.

At a very basic level, the estimated (per hectare) coastal protection value for Jamaican mangroves estimated by the USCB partner study of US$2500 per Ha (per annum) could be compared to the annual rate of accretion or erosion. More accurate estimates to determine if each location is experiencing a net erosion would show a corresponding loss in economic value. While net accretion rates would demonstrate economic benefits which could include increase in per hectare value. This is a crude approach but most feasible given the limited availability of comprehensive data on land value, sale of properties and other commercial information for a hedonic analysis.

General Social Dependence on Mangroves

The UWI partner study also involved a rapid socioeconomic assessment that included household surveys of residents living close to these mangrove sites. The survey was used to collect general socioeconomic information as well as an assessment of respondents' general knowledge and awareness of the role and importance of mangroves. The survey was also used to assess respondents self-reported awareness (or lack thereof) of mangrove ecosystem services. Some of the findings from this assessment showed that for Portland Cottage respondents reported generally low levels of monthly income (median JM$18,000).

Of those who identified themselves as fishers who use the mangroves, the majority utilize the areas for fishing 1 to 3 times per week. Among the fishes caught in the mangroves, which are for domestic consumption or sold are Grunt, Parrot, Sprat, Jack, Snapper and Doctor Fish. Snapper, Grunt and Parrot fish are primarily consumed in these communities. Respondents also indicated that fish are sold only in the community. Income on a weekly basis according to information sourced from 11 self-identified fishers informed that the income from the sale of fish ranged from J$3000 to J$40000 with an average income of J$12,091. However, most of these fishers reported a decreased in income in the last 5 years. The majority of the respondents also indicated that in general the volume of fish has also decreased. Apart from fish, it was reported that oysters, shells and more importantly fish bait and crabs were also extracted. However, majority (91.5%) of the respondents stated that they did not earn any other income or livelihood from the mangrove (UWI 2019).

Bogue Lagoon has a different demographic profile given the nature of business and historical industrial development of the area. While information on average incomes were not forthcoming many respondents worked in a variety of commercial sectors. It is likely that most respondents did not live near the mangrove site. The survey was geared towards commercial establishments and as a result the findings were not able to be linked to the importance of mangroves to key stakeholders such as fishers. However respondents were able to recognize a number of benefits of mangroves including shoreline protection, providing habitat for wildlife and medicinal uses (UWI 2019 pg 61). As stated in the UWI report, perhaps the proximity of these business to the mangroves at Bogue may have reinforced the perceptions of the importance of mangroves to protect the coastline and their commercial operations. Unfortunately the survey was not able to capture any information from fishers who operate within or in the surrounding areas. This is a gap that should be addressed in future studies.

For Salt Marsh the survey was not able to capture a significant number of fisher folk who may be dependent on mangroves for economic sustenance. The small number of fishers surveyed (14) was not large enough to draw any substantial conclusions on their dependence on mangrove fish catch. Overall wider community members recognized mangrove ecosystem service benefits such as coastal protection and wildlife habitat. The study also suggested that these services may be particularly salient for those that may have been affected by coastal flooding or dependent on ecotourism activities in the Salt Marsh area. Residents were also able to recognize a general decrease in mangrove forest cover over the years due to cutting down of trees for housing development. It was encouraging to note that a majority of the surveyed respondents expressed a willingness to become involved in mangrove restoration activities. This was also observed in Portland Cottage and could be a useful entry point for blue/green infrastructure economic activities that provide alternative livelihoods for residents.

Economic Value of Restoring Mangroves

Mangrove restoration can enhance or increase economic value if it produces new ecosystem services that did not exist prior to restoration or if it increases the value of existing ecosystem goods and services or the value of other economic activities that depend on ecosystem conditions. If the total increased value exceeds the costs of restoration, then it can be considered that the restoration had net economic benefits to society (Pendleton 2010). Restoration decisions should informed by cost benefit analytical approaches. It is more often than not, easier to obtain pricing for the cost side of restoration activities, for example equipment, labour and materials to name a few. The benefit side of the equation often requires more effort, given that some of the values reside outside of formal markets (non-market values). The challenge with understanding, measuring, and monitoring the economic value of habitat restoration lies in the fact that economic values of estuary and coastal ecosystems, and thus the economic outcomes associated with restoration, are not always easy to quantify. Improving estimates of benefit will allow for the comparison of the costs of mangrove restoration thereby improving the overall Cost Benefit Analysis process.

Cost Benefit Analysis of Mangrove Restoration

The choice between mangrove restoration and decline can be prioritized by identifying where the greatest return in ecosystem services can be achieved relative to restoration dollars invested (TNC/USCB 2019). This is also why identifying or modelling how the ecosystems functions will change is a key component of this process. This best done within Cost Benefit Analysis (CBA) framework.

An additional challenge to valuing restoration is that it is limited to the change in ecosystem value that can be attributed to the restoration project or program. Therefore any baseline values for the previous degraded mangroves would not be considered. The overall net economic value of mangrove restoration is this change in value (pre to post restoration) minus the costs of restoration including any in-kind costs (e.g., the value of donated land).

It bears emphasising that there are pecuniary or localized economic impacts that can flow from mangrove restoration. The infusion of money into local economies from related expenditures can be used to estimate economic impacts of the restoration activity on local economies. The restoration of blue green habitat such as mangroves also can have high rates of employment per unit of money spent (e.g. Jobs per Million dollars). A study of economic impacts of coastal habitat restoration in the US showed that fisheries habitat restoration projects created, on average, 17 jobs per million (US) dollars spent (Edwards et al, 2013). It is however important to be reminded that measures of economic impact do not accurately reflect economic value and should not be considered a metric of value. In benefit-cost analysis, wages and project spending are accounted for as project costs. The economic impacts of blue-green or nature based coastal infrastructure development can be compared to the analysis applied to traditional (grey) infrastructure development efforts.

A further important unknown is whether trajectories for the recovery of ecosystem services coincide with those for biodiversity (Bullock 2011). This is crucial not only when considering the success of a restoration project, but also in calculating its cost effectiveness. The use of discounting also has major implications for the valuation of benefits in the future, as the exponential function often used short-changes the value of these services to following generations. If intergenerational equity is to be considered where the future of nature and human well-being is being considered, then this might lead to concerns that discounting is not appropriate in relation to ecological restoration projects. These uncertainties indicate a need for realistic approaches when using restoration to reverse environmental degradation and in forecasting benefits.

Payment for Ecosystem Services schemes (PES) might skew activities towards certain services and neglect other services and biodiversity; for example, where investors favour certain services over others (Koellner et al, 2010). The REDD+ mechanism has been criticised for its focus on enhancement of forest carbon stocks, as there is a possibility that other services and social issues could be adversely affected. Evidence also suggests that there is a trade-off between protecting biodiversity and reducing carbon emissions, indicating that REDD+ funds will need to be carefully targeted to ensure that both objectives are met (Venter et al, 2009). Potential negative social impacts include loss of livelihoods or access to lands undergoing restoration, a risk that is particularly high in areas where land tenure is insecure. These example highlight the need that for Jamaica, further research on the use of PES to fund restoration as well as how these PES markets function and their impacts on both people and biodiversity

Cost and Benefits of Restoring Jamaican Mangroves

Based on the findings outlined in this report in conjunction with the two complementary studies (UWI, TNC/USCB), confirm that most the elements for conducting a cost benefit analysis for Jamaican mangrove restoration exist. On the benefits side, the reasonably accurate estimates for carbon (presented here), good estimates for coastal hazard protection benefits as well as the implied fisheries and other ancillary benefits should provide enough information. Improving the quality of the ancillary benefits would require more robust estimates on nearshore fish populations with corresponding catch/effort data from fishers. Other required data would include; trends on water quality gradients (mangrove to reef) and rates of erosion prevention over time coupled with economic information on infrastructure and commercial property protected. Any restoration project design and implementation will have to account for a suite of costs including engineering design, ecological modelling, labour and materials (construction) and post restoration monitoring. Some of the information presented in the two related analyses.

As reported by the TNC/UCSC study mangrove restoration in Jamaica, and globally, is multiple orders of magnitude cheaper than coastal protection structures. In Jamaica, limited data indicate that sea-dykes and levees to protect the Kingston Harbor can cost over $11 Million per linear kilometer. This can be compared with other Caribbean locations where seawalls and levees can cost up to ~$6 Million per kilometer, whereas offshore breakwaters are much costlier at ~$20 Million per kilometer. Notable these projects are typically smaller than a few hundred meters. On balance, mangrove restoration is also typically cheaper per hectare than coral reef restoration.

There are typically four main factors that influence the costs of mangrove restoration projects; i) the costs of land and permitting; ii) the costs of obtaining and transporting the material; ii) the costs of designing and constructing the project, and; iv) the costs of monitoring and maintaining the project post-construction (TNC/UCSC 2019). Since mangrove restoration typically happens in the inter-tidal zone, the availability and price of land and the necessary permits. Another factor that influences costs is the restoration technique. However for Jamaica, some of these areas may be owned by the government while neighbouring plots are privately owned. Restoration is generally less expensive manually and in some cases, voluntary labor, while restoration projects that involve hydrological restoration can be more expensive due to the need for specialized equipment, labor and the purchase and transportation of sediment. Maintenance and monitoring is also an important cost component, though often not reported in restoration projects.

Costs of hard and engineered coastal structures like seawalls and levees are generally costlier even and often occupy a smaller physical footprint (area or length of coastline). Higher costs to maintain in terms of repairing damage or upgrading in response to changes in sea-level are also a reality.

On the benefits side of the analysis, it can be shown that given the application of appropriate discount rates, then it is highly likely that a cost benefit ratio would be in favour of the mangrove restoration option. The benefits that are typically easier to estimate tend to be the cost of avoided damages and carbon sequestration. However if policy makers desire to improve the accuracy of benefit estimates, they could request the inclusion of additional ecosystems services that may be more difficult to quantify and assign values (for example, water quality, forest products and erosion prevention). It is quite likely that the benefit estimates for cost hazard mitigation and carbon sequestration would outweigh the restoration cost, so it may not be necessary to be as precise with the additional benefits. However, restoration provides a natural experiment for tracking ecosystem service changes pre and post implementation and these additional metrics if measured properly will increase the ability to make the connections between ecological functions and direct (or indirect) benefits to people. Indicators like forest products (honey, other) fisheries benefits (harvest, subsistence) and water quality improvement are a few of the parameters that require more updated methods of estimation. In the context of climate change and building resilience, monitoring the changes of key ecological and socioeconomic parameters will help improve data and allow for the tracking of these additional metrics.

Of course there are other cost effectiveness metrics to consider. Namely is it more cost effective to conserve and restore mangrove habitats to provide a variety of ecosystem services? Or instead continue with business as usual (degradation) and in the event of extreme weather events bear the costs of disaster relief. This analysis does not address this but does provide additional information on benefits beyond disaster mitigation.

Study Limitations and Future Recommendations

Limitations on time and budget prevented a more detailed economic analysis of the key ecosystem service. The key elements of this analysis relied heavily on desktop research, literature reviews and basic value transfer approaches in order to provide a mixture of quantitative and qualitative information on the benefits of mangroves beyond coastal protection. Given these constraints, some caveats as well as recommendations for improving this kind of analysis for Jamaica are discussed below.

One of the more straightforward methodological approaches in terms of quantitative estimates were the carbon sequestration economic values associated with each study site. However, the estimates of carbon stock were not site based but instead the per hectare carbon stock were bases on global averages. While the complimentary (UWI, 2019) study did provide some estimates on flux, these values are not incorporated into this report. In the future, more complete analyses of carbon stock across the island will allow for more improved estimates of costs per hectare of sequestered carbon.

The estimates presented in this report on the role of mangroves and their contribution to commercial fisheries also relied on global estimates from other studies. This analysis was limited to using the global averages because of the lack of data on these mangrove sites and particularly the lack of fisheries landing data that could assist in quantifying the role these mangroves play in supporting commercial fisheries from nearby fishing beaches. Data was not available for catch per unit effort, species targeted and sales from fishers who operate from beaches close to these sites. It was therefore difficult to make a direct link between fisheries catch and the potential beneficial role mangroves play, particularly as nursery areas for juvenile fish. This is a key component that was outside the control of this research effort. In order to improve the collection of this type of data, it may require data collection at a national level led by the Fisheries Division. Other approaches could include a targeted (research) data collection exercise possibly funded by relevant Government agencies or international support. 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 used for other sites around the world (UNEP, 2011). Broadly speaking, even with the difficulties highlighted with assigning monetary values to mangrove fishery contribution, the information presented here can still be used to demonstrate the role mangroves play in providing a source of protein source, contributions to subsistence diets and/or supplementary income. As evidenced from the community surveys conducted by other project partners, many persons depend on these mangroves for subsistence level fishing and gathering of resources. Quantifying this level of dependency will be important as a part of a wider conservation and restoration strategy.

One of the biggest gaps of this report is the lack of enough information to properly inform the economic benefits of regulating coastal water quality and erosion control. This was due to a mixture of reasons. One overall factor was the general low level of access to government data derived or archived information. Notable gaps were with access to site level fishery information (catch, effort) that could have been used to improve the imputed value of contribution of the mangroves to fishing beaches in close proximity. Other government and municipal data gaps included information on costs to maintain road networks near to the sites and general data on prices of private and commercial real estate values adjacent to the study sites. Some of these limitations are linked to the short time frame and limited human and financial resources. However key ecosystem service outputs such as fisheries dependent data should be part of a more systematic approach to data collection as this metric can be used to improve the models used to estimate per hectare contribution of mangroves to nearshore fisheries.

Another suggestion for improving this type of analysis in the future is to include where appropriate physical information that can be used to link the ecological function of mangroves sand their role in regulating littoral transport of coastal sediment and coastline accretion. Making a tighter link between mangrove forests to coastal beach quality can then be extended to the economic benefits of the tourism product, which is largely based on sun, sea and (beach) sand. However, these connections are often not direct, so more relevant approaches should include site-specific examples where mangrove forests prevent or reduce the need for repairing infrastructure such as coastal roads. Beyond this the erosion services of mangroves may be best served with national level data sets or north coast versus south coast given the different geospatial contexts (tourism versus agriculture/housing) and larger role of modelling sediment transport and the role mangroves and associated nearshore ecosystems (seagrasses, coral reefs) play.

In general there is a need to inform policy makers, biophysical researchers and coastal resource managers of the appropriate use of economic valuation approaches. The World Resources Institute authored a publication (Waite et al, 2014) that provides a very good analysis that includes guidance for the appropriate use of economic valuation techniques. The key thing to note is that one size (approach) does not fit all. The size of the areas of concern can be a factor in the feasibility of assessing economic value. The type of ecosystem service as well can determine ease and feasibility. For example is much easier to derive recreational non-market economic values by estimating consumer surplus (willingness to pay) for preserving coastal beach and water quality. While that approach might not be suitable for assessing more esoteric or intermediate services such as carbon sequestration or water purification. The services of concern for mangroves tend to lie more in the intermediate or direct market value (wood, honey) realms. The economic estimation approaches rely heavily on well-collected physical and biological information that can be used to impute economic or other benefits. This means therefore that relevant government or natural resource management agencies and academic institutions will have to work closely to collect the type of data needed to improve modelling and predictions used to estimate benefits. Many of these suggestions were provided in earlier sections, including water and soil quality information that can be used to demonstrate abatement.

Conclusions

This rapid analysis has again confirmed the difficulty with calculating the economic value of the aesthetic and ethical benefits of ecosystems, or of the service some ecosystems provide through cycling nutrients (UNEP 2006). The temptation to provide estimates of the 'total' economic value of an ecosystem by summing different types of economic metrics (jobs, tourism sales, non market value, damage avoidance) must be resisted. Summing measures of economic activity that differ (for example summing avoided costs, tax revenues and non market values) produces numbers that vary considerably and could also result in double counting or in other instances underestimating benefits. I addition a singular focus on deriving monetary estimates could also underestimate the ecosystem's social benefits and overall importance. This means that it is not always wise to only depend on ecosystem valuations for policymaking and investment decisions. Instead these valuation estimates should be part of a suite of information used in the decision making process (World Bank, 2004).

However, if these limitations are taken into account, identifying various benefit streams including using economic valuation can help to demonstrate the major role that mangroves play in the lives of many people. Conceptually most of the benefits from these systems come from provisioning services (i.e. fisheries and, for mangroves, timber, honey and fuel wood), cultural services (tourism) and regulating services (shore protection). However for Jamaica one of the limitations for deriving these values are the lack of site specific data regarding the market values attached to those services. Suggestions for bridging these gaps were highlighted in the previous section of this report.

Of note, there is a need to examine the potential for capturing additional economic rent from currently un-realized (or underutilized) mangrove ecosystem services. The first area is the cultural/recreational service associated with high-end catch and release and other niche capture fisheries. The conditions that support tropical mangrove forests are often hot, humid and mosquito dominated environments. This may not be conducive to typically passive forms of tourism such as boat rides and snorkel tours. However, these types of environments may not deter high-end recreational fishers, who are often seeking unique experiences including the opportunity to "fight" with their catch. This type of activity also lends itself for easier transition for artisanal fishers as an alternative livelihood strategy.

Future work should also include a wider group of beneficiaries of mangrove ecosystem services. Some of whom may not even be aware that their economic activities are dependent of healthy mangrove stands. Broadening of the scope could lead to a better understanding of how the provision of ecosystem services varies at a range of scales in relation to ecosystem condition; for example, water provisioning is a complex process that can only be managed effectively at the catchment scale in relation to patterns of land use (Bullock et al 2011). Farmers and other industries who may be depend on fresh water from aquifers may be benefiting from this type of regulating ecosystem service. Identifying the costs associated with their needs will improve the description of the benefit streams from mangroves. This of course should be supported by scientific data (geological, hydrological) information from relevant research institutions and government agencies.

Identification of the benefits from restoration, in terms of both biodiversity conservation and provision of ecosystem services to people, requires an understanding of restoration outcomes.

Other studies have shown that the trajectories of ecosystem services and biodiversity in a restoration can vary both in shape and rate of change (Bullock et al 2011). Understanding the causes of these types of variation should be a future research priority for Jamaica and other small island states attempting to manage and conserve this ecosystem. Understanding the ecological and resultant economic variations can also contribute to the development of restoration as a predictive science.

References

Aburto-Oropeza, O., E. Ezcurra, G. Danemann, V. Valdez, J. Murray, and E. Sala. (2008). Mangroves in the Gulf of California increase fishery yields. Proceedings of the National Academy of Sciences USA 105:10456–10459

Angelsen, A. (2008) Moving ahead with REDD: issues, options and implications. Center for International Forestry Research, Bangor , Indonesia

Ault, J. S., R. Humston, M. F. Larkin, E. Perusquia, N. A. Farmer, J. Luo, N. Zurcher, S. G. Smith, L. R. Barbieri, and J. M. Posada. (2010). Population Dynamics and Resource Ecology of Atlantic Tarpon and Bonefish. Pages 217–258 Biology and Management of the World Tarpon and Bonefish Fisheries.

Bann, C., (1997). An Economic Analysis of Alternative Mangrove Management Strategies in Koh Kong Province, Cambodia. Research Report, Economy and Environment Program for South East Asia, Singapore.

Barbier et al (2011) The value of estuarine and coastal ecosystem services. Ecological Monographs, 81(2), 2011, pp. 169–193

Beck M.W. and G-M Lange (Editors) (2016). Wealth Accounting and the Valuation of Ecosystem Services Partnership (WAVES); Managing coasts with natural solutions: guidelines for measuring and valuing the coastal protection services of mangroves and coral reefs. Washington, D.C.,World Bank Group

Bohnsack, J.A. and Bannerot, S.P. (1986) A Stationary Visual Census Technique for Quantitatively Assessing Community Structure of Coral Reef Fishes. NOAA Technical Report NMFS, 41, 1-15.

Brander, L., R. Florax, and J. Vermaat (2006). The Empirics of Wetland Valuation: A Comprehensive Summary and a Meta-Analysis of the Literature. Environmental & Resource Economics 33: 223–250

Bullock, J.M., J. Aronson, A.C. Newton, R. F. Pywell and J. M. Rey-Benayas (2011) Restoration of ecosystem services and biodiversity: conflicts and opportunities. Trends in Ecology and Evolution. Vol 26(10):541-549

CFRAMP (2000). Jamaica National Marine Fisheries Atlas. CARICOM Fishery Report No. 4 : 53 p ISBN 976-8165-05-7

Chong V.C. (2007). Mangroves-Fisheries Linkages: The Malaysia Perspective. Bulletin of Marine Science 80(3):755-772

Desvouges W.H., M. C. Naughton and G.R. Parsons (1002) Benefit Transfer: Conceptual Problems in Estimating Water Quality Benefits Using Existing Studies. Water Resources Research, Vol. 28,(3):675 -683

Donato D C, Kauffman J B, Murdiyarso D, Kurnianto S, Stidham M and Kanninen M (2011). Mangroves among the most carbon-rich forests in the tropics Nat. Geosci. 4: 293–7

Edwards P.E.T. (2009). Measuring the Recreational Value of Changes in Coral Reef Ecosystem Quality in Jamaica: The Application of Two Stated Preference Methods". PhD Dissertation, University of Delaware, May 2009

Edwards, P.E.T. (2012). Ecosystem Service Valuation of Cockpit Country. For Windsor Research Centre, Sherwood Content PO, Trelawny, Jamaica

Edwards, P.E.T., Sutton-Grier A.E., Coyle, G., (2013) Investing in nature: Restoring coastal habitat blue infrastructure and green job creation. Marine Policy 38: 65-71

FAO (2005) Fishery Country Profile: Jamaica . October 2005.
http://www.fao.org/fishery/docs/DOCUMENT/fcp/en/FI_CP_JM.pdf
FAO (2008). The Impact of Beekeeping on Management and Conservation of Forests (FAO 2008) Chapter 7. FAO, Rome

FAO (2016). Mangrove carbon estimator and monitoring guide Jeremy S. Broadhead, Jacob J. Bukoski and Nikolai Beresnev. FAO, and IUCN, Bangkok

Fedler, A. J., and C. Hayes. (2008). Economic impact of recreational fishing for bonefish, permit and tarpon in Belize for 2007. Gainesville: Friends of Turneffe Atoll.

Fedler, T. (2010). The economic impact of flats fishing in The Bahamas. The Bahamian Flats Fishing Alliance.

Golosov, M., J. Hassler, P. Krusell, and A. Tsyvinski. (2014). Optimal taxes on fossil fuel in general equilibrium. Econometrica 82(1):41–88.

Government of Jamaica (2011). The Second national Communication of Jamaica to the UN Framework Convention on Climate Change (UNFCC). June 2011

Hamilton, L. S., & Snedaker, S. C. (1984). Handbook for Mangrove Are Management. IUCN/ UNESCO/UNEP, Honolulu: East-West Center.

Hilmi E., Kusmana C, Endang and Suhendang E (2017). Correlation Analysis between Seawater Intrusion and Mangrove Greenbelt. Indonesian Journal of Forestry Research Vol. 4, No. 2, October 2017, 151-168

Himes-Cornell A, Grose SO and Pendleton L (2018) Mangrove Ecosystem Service Values and Methodological Approaches to Valuation: Where Do We Stand? Front. Mar. Sci. 5:376.

Hoyt, S., J. Howard, K Isensee, E. Pidgeon and M. Telszewski (Eds) (2014). Coastal Blue Carbon methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrass meadows. The Blue Carbon Initiative, UNEP, UNESCO, CI
Hutchison, J; Spalding, M, and zu Ermgassen, P. (2014). The Role of Mangroves in Fisheries Enhancement. The Nature Conservancy and Wetlands International. 54 pages

Ibrahim A (2016) Assessment of Mangrove Phenology and the Role of Insect Pollinators in Fruit Production at Nyeke and Michamvi Mangrove Forests. PhD Thesis, University of Zanzibar. Tanzania.

Jamaica Meteorological Service (2008). Jamaica's Greenhouse Gas Emissions, 2000 – 2005 Final Report. Claude Davis & Associates, Owen Evelyn, Leslie Simpson and Ianthe Smith. February 2008

Jardine, S. L. and J. V. Siikamäki (2014). A global predictive model of carbon in mangrove soils Environmental Research Letters. 9 104013

Jones E (2017) Promoting Community-based Climate Resilience in the Fisheries Sector. Environmental and Social Management Framework. For The Fisheries Division, MICAF Jamaica

Kimirei, I. A., I. Nagelkerken, Y. D. Mgaya, and C. M. Huijbers. (2013). The Mangrove Nursery Paradigm Revisited: Otolith Stable Isotopes Support Nursery-to-Reef Movements by Indo-Pacific Fishes. PLoS ONE 8(6):e66320.

Kindermann, G., Obersteiner M., Sohngen B. et al . (2008) Global cost estimates of reducing carbon emissions through avoided deforestation. PNAS 105, 10302– 10307

Koellner, T. J. Sell and G. Navarro. (2010). Why and how much are firms willing to invest in ecosystem services from tropical forests? A comparison of international and Costa Rican firms. Ecol. Econ. 69, 2127–213967.

Kotchen M. J. (2017). Which Social Cost of Carbon? A Theoretical Perspective. JAERE, Volume 5, Number 3 http://dx.doi.org/10.1086/697241

Krishnamurthy, K. (1990). The apiary of the mangroves. In "Wetland Ecology and Management: Case Studies" (D. F. Whigham, D. Dykyjova and S. Hejny, eds), pp. 135-140. Kluwer Academic Press, Netherlands

Kushner, B., P., Edwards, L. Burke, and E. Cooper. (2011). Coastal Capital: Jamaica. Coral Reefs, Beach Erosion and Impacts to Tourism in Jamaica. Working Paper. Washington, DC: World Resources Institute. Available online at http://www.wri.org/coastal-capital.

Laegdsgaard, P., and C. Johnson (2001). Why do juvenile fish utilise mangrove habitats? Journal of Experimental Marine Biology and Ecology 257(2):229–253.

Lugendo, B. R., A. Pronker, I. Cornelissen, A. de Groene, I. Nagelkerken, M. Dorenbosch, G. van der Velde, and Y. D. Mgaya. (2005). Habitat utilisation by juveniles of commercially important fish species in a marine embayment in Zanzibar, Tanzania. Aquatic Living Resources 18(02):149–158.

McMahon, K. W., M. L. Berumen, I. Mateo, T. S. Elsdon, and S. R. Thorrold. (2011). Carbon isotopes in otolith amino acids identify residency of juvenile snapper (Family: Lutjanidae) in coastal nurseries. Coral Reefs 30(4):1135–1145.

MICAF, Ministry of Industry Commerce and Fisheries (2011). Special Fishery conservation areas (SFCS) http://moa.gov.jm/Fisheries/fish_sanctuary.php

MICAF, Ministry of Industry Commerce and Fisheries (2017). Special Fishery Conservation Areas. Summary Document. Prepared by J Squire

Mumby, P. J., A. J. Edwards, J. Ernesto Arias-Gonzalez, K. C. Lindeman, P. G. Blackwell, A. Gall, M. I. Gorczynska, A. R. Harborne, C. L. Pescod, H. Renken, C. C. C. Wabnitz, and G. Llewellyn. (2004). Mangroves enhance the biomass of coral reef fish communities in the Caribbean. Nature 427 (6974):533–536.

Nagelkerken, I., S. Kleijnen, T. Klop, R. A. C. J. van den Brand, E. C. de la Morinire, and G. van der Velde. (2001). Dependence of Caribbean reef fishes on mangroves and seagrass beds as nursery habitats: a comparison of fish faunas between bays with and without mangroves/seagrass beds. Marine Ecology Progress Series 214:225–235.

National Environment and Planning Agency (NEPA) (2011) State of the Environment Report 2010. National Environment and Planning Agency, Kingston, Jamaica ISBN 978-976-610-912-7

NEPA, (2013). State of the Environment Report 2013. National Environment and Planning Agency, Kingston, Jamaica ISBN 978-976-654-007-4

NEPA, (2014). Coral Reefs of Jamaica: An Evaluation of Ecosystem Health: 2013. Kingston, Jamaica. 15pp

Nordhaus, William (2014). Estimates of the social cost of carbon: Concepts and results from the DICE-2013R model and alternative approaches. Journal of the Association of Environmental and Resource Economists 1:273–312.

NRC [National Research Council] (2005). Valuing ecosystem services: toward better environmental decision-making. National Academies Press, Washington, D.C., USA

Laegdsgaard P. and C. R. Johnson (2001). Why do juvenile fish utilise mangrove habitats? Journal of Experimental Marine Biology and Ecology 257(2):229-253

Lopez and Nespa (2015). Carbon Storage: Utilizing Carbon-Based Modeling for Mangrove Restoration Efforts. Marismas Nacionales, Mexico. Pronatura Noroestes & Ecologists Without Borders.
Pendleton L, Donato D C, Murray B C, Crooks S, Jenkins W A, Sifleet S, Craft C, Fourqurean J W, Kauffman J B and Marbà N (2012). Estimating global 'blue carbon' emissions from conversion and degradation of vegetated coastal ecosystems. PloS One http://dx.doi.org/10.1371/journal.pone.0043542

Pierce D.W. and Turner R. K. (1990) The Economics of Natural Resources and the Environment. New York: Harvester Wheatsheaf, 378 pages

Pigou, A. C. (1920). The Economics of Welfare. London: MacMillan and Co.

Polasky, S., and K. Segerson. (2009). Integrating ecology and economics in the study of ecosystem services: some lessons learned. Annual Review of Resource Economics 1:409– 434.

Ruitenbeek, H. J. (1992). Mangrove Management: An Economic Analysis of Management Options with a Focus on Bintuni Bay, Irian Jaya. for the Environmental Management Development in Indonesia Project (EMDI)

Sasekumar, A., V. C. Chong M. U. Leh and R. D'Cruz (1992) Mangroves as a habitat for fish and prawns. Hydrobiologia Volume 247, Issue 1–3, pp 195–207

Siddiqi, N.A. (1997). Management of Resources in the Sunderbans Mangroves of Bangladesh. International News letter of coastal Management - Intercoast Network. Special edition, 1: 22-23.

Siikamäki, Juha, James N. Sanchirico, Sunny Jardine, David McLaughlin & Daniel Morris (2013) Blue Carbon: Coastal Ecosystems, Their Carbon Storage, and Potential for Reducing Emissions, Environment: Science and Policy for Sustainable Development, 55:6, 14-29, DOI: 10.1080/00139157.2013.843981

Spurgeon, J. (2002). Socio-economic Assessment and Economic Valuation of Egypt's Mangroves. Cairo: FAO
Suthawan, S. (1999). Economic valuation of mangroves and the roles of local communities in the conservation of natural resources: Case study of Surat Thani, South of Thailand. EEPSEA (Economy and Environment Program for Southeast Asia) Research Report.

TEEB (2010) The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB. Prepared by: Pavan Sukhdev, Heidi Wittmer, Christoph Schröter-Schlaack, Carsten Nesshöver, Joshua Bishop, Patrick ten Brink, Haripriya Gundimeda, Pushpam Kumar and Ben Simmons.

Tol, R. S. J. (2009). The economic effects of climate change. Journal of Economic Perspectives 23(2):29–51.

Tol, R. S. J. (2018) The Economic Impacts of Climate Change. Review of Environmental Economics and Policy, volume 12, issue 1, Winter 2018, pp. 4–25

Tol, R. S. J. (2012) On the Uncertainty About the Total Economic Impact of Climate Change. Environ Resource Econ. DOI 10.1007/s10640-012-9549-3

UNEP –WCMC (2006) In the front line. Shoreline protection and other ecosystem services from mangroves and coral reefs. UNEP-WCMC Biodiversity Series 24 by Wells, S., Ravilious, C., Corcoran, E.

UNEP (2011) Economic Analysis of Mangrove Forests: A case study in Gazi Bay, Kenya, UNEP, iii+42 pp.

Venter, O. W.F. Laurance, T. Iwamura T, K. A. Wilson, R.A. Fuller and H.P. Possingham (2009) Harnessing carbon payments to protect biodiversity. Science 326, (5958):1368.

Waite. R, Burke, L., Gray, E., van Beukering, P., Brander, L., McKenzie, E., Pendleton, L., Schuhmann, P., and

Tompkins, E. (2014). Coastal Capital: Ecosystem Valuation for Decision Making in the Caribbean.

World Bank (2004) Assessing the Economic Value of Ecosystem Conservation. Environment Department Paper No. 101. Authors; Stefano Pagiola, Konrad von Ritter, Joshua Bishop in collaboration with TNC and IUCN.

Yang Q., Tam N. F., Wong Y. S., Luan T. G., Su W. S., Lan C. Y., Shin P. K. and Cheung S. G. (2008). Potential use of mangroves as constructed wetland for municipal sewage treatment in Futian, Shenzhen, China. Marine Pollution Bulletin. Vol 57(6-12):735-43.