UNIVERSITY OF CAPE COAST

ASSESSMENT OF COASTAL ECOSYSTEMS IN THE GREATER CAPE THREE POINTS AREA TOWARDS ITS DESIGNATION AS MARINE PROTECTED AREA IN GHANA

ALBERTA JONAH

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BY

ALBERTA JONAH

Thesis submitted to the Department of Fisheries and Aquatic Sciences of the School of Biological Studies, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfillment of the requirements for the award of Doctor of Philosophy degree in Integrated Coastal Zone Management

JULY 2020

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature……………………… Date: …………………………

Name: ……………………………………….……

Supervisors' Signature

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature……………………….. Date ………………

Name: ……………………………………

Co-Supervisor's Signature……………………………… Date ……..………

Name: …………………………………

ABSTRACT

Coastal ecosystems sustain local and national fisheries livelihoods through a range of ecosystem services (ES) they provide. Five of these coastal ecosystems, located in two communities within the Greater Cape Three Points (GCTP) area—Princess Town (PT) and Cape Three Points (C3P)—were assessed to develop a scheme for establishing Marine Protected Area (MPA). To conduct an integrated assessment, the study employed the Community Participatory Mapping and Assessment of ecosystems and their services method. This was complimented with Field Ecological Assessment, Economic Valuation of ES, Cost-Benefit Analysis of fishing and Risk Assessment of the ecosystems using InVEST HRA model, V.3.7. The study revealed that the coastal water bodies provide nursery for important fish species (*Sardinella maderensis, Pseudotolithus senegalensis and Tilapia spp*.) in the Ghanaian fishery. Physico-chemical parameters measured for the Nyan estuary and Enhuli lagoon for a one year period (November, 2017 – November, 2018) indicted that both water bodies were in generally good condition to support aquatic life. ES prioritized by the Princess Town community were valued at US$ 2,917.41 $ha^{-1}yr^{-1}$ for a total area of 239.3 ha, whilst those prioritized by the Cape Three Points community were valued at US$ 22,566.84 $ha^{-1}yr^{-1}$ for a total area of 17.6 ha. The study established that the ecosystems assessed in the GCTP area were cumulatively at low – to – medium risk to a combination of anthropogenic pressures exerted on them. The study developed a proposed MPA map plan for the GCTP area. The plan proposed a network of multiple-use MPAs with special dedicated zones for regulation of activities with different levels of restrictions to enhance ecosystem conservation for the sustenance of fisheries livelihoods and also create the opportunity for developing ecotourism in the area.

KEY WORDS

Ecosystem Services

Marine Protected Areas

Ecosystem Risk Assessment

Zoning

Valuation

Coastal Ecosystems

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DEDICATION

To Lt. Cdr. William K.N. Sagoe, Mr. & Mrs. Albert & Elizabeth Jonah, Ms. Naana A. Jonah and Mr. Erik K. Yarboi.

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CHAPTER ONE

INTRODUCTION

Evidence of the deplorable state of Ghana's fisheries sector as presented in scientific research, and also observed by local fishers and other stakeholders, fosters the need for robust protection of key coastal and marine ecosystems which provide services that support the sector (Food and Agriculture Organization [FAO], 2016; Segbefia & Aryee, 2017; Zaney, 2018). Establishment and management of Marine Protected Areas (MPAs) has received increasing attention from policy makers worldwide as a mechanism for sustainable resource use, ecosystem protection and biodiversity conservation (Chircop et al., 2010; European Environment Agency, 2018; Institute for European Environmental Policy & Natural Resources Defense Council, 2008; Ministry of Fisheries and Aquaculture Development [MOFAD], 2015; Ruskule, Vinogradovs, & Pecina, 2018; Sanders, Gréboval, & Hjort, 2013).

Ghana's commitment to designate critical areas of its coastal and marine environments as Marine Protected Areas (MPAs) to ensure sustainable management of the country's fisheries resources and marine ecosystems is laudable to that effect. This requires well-informed management plans based on integrated assessments of these ecosystems, covering ecological, socio-cultural and economic aspects. The study sought to address the challenge of conducting a comprehensive integrated assessment of marine and coastal areas for the designation of MPAs, to identify sensitive areas for protection and suggest the type of protection to be assigned to an area.

Background to the Study

The coastal and marine regions of Ghana are rich in ecosystems and biodiversity assets relevant for local economic development and human well-being. Particularly, the coastal areas of the Western Region of Ghana support some of the most critical biodiversity in the country (deGraft-Johnson, Nunoo, & Amankwa, 2010). There are several key ecosystems which are unique in terms of supporting biodiversity and providing ecosystem goods and services critical for economic and social development of the area (Ateweberhan, Gough, Fennelly, & Frejaville, 2012). The dependence of local communities on biodiversity in the region is noteworthy. The Region, is densely populated with major industrial, agricultural, mining, subsistence farming and fisheries activities and has great potential for tourism development with the availability of beaches, cliffs, lagoons, wildlife, cultural and historical sites and coastal landscape (Ateweberhan et al., 2012).

This rich coastal area is however, facing several environmental challenges including overfishing, coastal deforestation, coastal erosion, pollution and rapid population growth as revealed in previous studies (Coastal Resources Center & Friends of the Nation, 2011; deGraft-Johnson et al., 2010). A specific study conducted by Ateweberhan et al. in 2012, indicated that the near shore rocky areas of Western Ghana are faced with overfishing and calls for the establishment of Marine Protected Areas as part of restoration measures for important ecosystems or species. These measures will also support livelihoods and human well-being (Ateweberhan et al., 2012). Others assessed conditions of ecosystems in the region and indicated management concerns for selected critical ecosystems in the region (Coastal Resources

Center & Friends of the Nation, 2011; deGraft-Johnson et al., 2010). Establishing Marine Protected Areas (MPAs) is as a useful tool for managing special ecosystems or species, maintaining livelihoods, facilitating restoration, or controlling access to important coastal and marine areas.

Ghana considers establishing MPAs in critical areas of its coastal and marine zones as one of the strategies for the sustainable development of its fisheries resources. This is stipulated in Key issue four (4) of the National Fisheries Management Plan of Ghana, which addresses the issue of protecting marine ecosystems to conserve biodiversity (MOFAD, 2015). Particularly, Strategic Action 4.2 of the plan focuses on the "creation of Marine Protected Areas to protect nursery areas and spawning grounds, mainly in estuaries and mangrove areas". In light of this, regional and institutional stakeholder consultation for sensitization on the MPA policy, MPA objectives setting and MPA site identification are ongoing along the coast to enhance the process. Some coastal ecosystems in the Western Region of Ghana were earmarked for different levels of protection during the nationwide stakeholder consultation on the selection of areas to be designated as Marine Protected Areas to sustain Ghana's fisheries (Nunoo, 2018).

In view of these developments, this study explores operationalization of the Integrated Ecosystem Assessment methodology, using different tools to identify critical areas for protection in selected coastal ecosystems in the Western Region of Ghana, to serve as an exploratory or decision-making tool for establishing MPAs in the Ghanaian context.

Statement of the Problem

Protected areas have generally been used as conservation approaches towards biodiversity protection and maintenance in terrestrial systems in Ghana. These comprise forest reserves, wildlife conservation areas, and Ramsar sites. There are 280 forest reserves in Ghana under the management of the Forest Services Division (Forestry Commission) (Attuaquayefio & Fobil, 2005). Twenty-one (21) legally-constituted wildlife conservation areas, as well as five (5) Ramsar sites are under the management of the Wildlife Division (IUCN/PACO, 2010). The Forestry Commission has also established thirty (30) Forest Reserves as Globally Significant Biodiversity Areas (GSBAs) because of their importance as ecosystems for globally-significant biodiversity (Attuaquayefio & Fobil, 2005). However, it is of concern to note that the coverage of Protected Areas in Ghana does not extend to the coastal and marine areas of the country.

There is no designated Marine Protected Area (MPA) for conservation of coastal and marine biodiversity that support the well-being of coastal communities (Coastal Resources Center & Friends of the Nation, 2011). Thus, Ghana has not been able to contribute to achieving the global MPA target – the Convention on Biological Diversity (CBD)'s Aichi Biodiversity Target 11 (CBD, 2010). The lack of guidelines developed for national designation of MPAs and implementation; limited participation of local stakeholders who are mostly direct users of the resources; limited understanding of ecosystem values and functioning; and lack of scientific studies to inform policies needed for site identification, size determination, designating zones, monitoring and development of institutional structures constitute the myriad of challenges confronting Ghana in successful implementation of MPAs.

Incorporating a coordinated Ecosystem Assessment (EA) within a comprehensive MPA framework provides a platform to address these challenges (Agardy et al., 2011; FAO Fisheries Department, 2003; Mapping and Assessment of Ecosystems and their Services [MAES], 2014; Millennium Ecosystem Assessment [MEA], 2003). EA allows for an interdisciplinary and participatory process of gathering information to assess the condition of ecosystems (in biophysical, socio-cultural and economic terms), investigate the natural and anthropogenic pressures exerted on them, and, determine response mechanisms (Ahmed, 2011).

An effective EA for an MPA design necessitates a systematic involvement of local communities – comprising of inhabitants close by or relying on the resources to be protected, and all people interested in or are affected by the MPA designation (OSPAR, 2008). From Ghana's experience, inadequate community participation in siting and managing coastal ecosystems have contributed to the limited success of conservation of these ecosystems (Coastal Resource Center [CRC], 2013; Kumi et al., 2015; Opoku, 2013). It is one thing to propose management measures such as MPAs in national policies and another to effectively design, site, monitor and enforce them. Community participation is essential if marine conservation and sustainable use objectives are to be met. Studies on community participatory approaches for assessing ecosystem services towards the establishment of MPAs is lacking in Ghana. How should a community participatory mapping process about MPAs be organized? Who should be involved in participatory mapping? What needs to be known about the system-to-be-governed and the particular ecological, social and cultural context in which the MPA is to be introduced? These are issues that require a robust EA process to address them.

Effective design and implementation of MPA is essentially dependent on quality and reliable data acquired from all relevant channels via an integrated ecosystem assessment. Data on coastal and marine resources in Ghana, including socio-economic data, ecological data and areas of anthropogenic pressures among other relevant data which form the basis for a comprehensive and effective design of MPAs in Ghana are deficient and uncoordinated. To compound this challenge, is the lack of an existing coordinated approach to synthesize the various data in a comprehensive decision making tool for MPA designation and zoning. These challenges present the need for committed and coordinated efforts to be made to address the data needs in coastal and marine management in the country and develop a national, context-specific framework for design and implementation of Marine Protected Areas in Ghana.

A generally accepted framework for designing and implementing MPAs in Ghana on a national scale, which is adaptable to local contexts based on peculiarities of issues on the local scale is lacking. Such a framework, when implemented efficiently, will enhance integration of the appropriate stakeholders in the management. There is therefore the need to develop a system that harnesses the opportunities to establish MPAs, the experiences of which would serve as a template to be piggybacked for not only Ghana but other suitable areas in the sub-region. This study contributes to the development of an integrated approach for MPA site identification and zoning, community stakeholder participation in the MPA designation process and provides baseline data for monitoring the success of MPA implementation in the Greater Cape Three Points area.

Aim of the Study

The aim of the was to assess ecosystems in the Greater Cape Three Points area to identify critical areas for conservation and explore the management options available for potential creation of Marine Protected Areas based on a comprehensive assessment. The study thus highlighted areas where management decisions may have possible impacts on biodiversity and wildlife, and also brought to bear, the pressures exerted by anthropogenic activities and their degree of intensity on the ecosystems. This information was provided relative to biodiversity assets and possible impacts on them to allow for full consideration of those impacts.

Research Questions

The study sought to answer the following question:

1. What is the current state of coastal ecosystems in the GCTP area?
2. Which ecosystem services are critical to the inhabitants of the area to be highlighted in the MPA designation plan?
3. What is the economic value of these critical ecosystem services to the inhabitants of the area?
4. What are the anthropogenic pressures exerted on the ecosystems which may hinder their proper functioning?
5. What level of risk do these anthropogenic pressures pose on the ecosystems?

6. What will be an appropriate conservation plan for the area to protect ecosystems and sustain the well-being of people?

Research Objectives

General objective

The general objective of the study was to propose a conservation management plan for selected ecosystems in the Greater Cape Three Points area, based on an integrated ecosystem assessment.

Specific objectives

To achieve the main objective of the study, the following specific objectives were addressed:

1. Conduct ecological assessment on the current status of selected ecosystems in the GCTP area, namely, lagoon, estuary, rocky bay, sandy beach and mangroves.
2. Map critical ecosystem services of socio-cultural importance provided by the selected ecosystems.
3. Conduct economic valuation of the ecosystem services.
4. Assess anthropogenic threats posed to the ecosystems.
5. Develop a conservation plan to designate critical areas for management consideration in the GCTP area.

Significance of the Study

This research will benefit coastal and marine managers, as well as policy makers in the areas of socio-economic development and conservation. The results obtained from the study will contribute to scientific knowledge relevant for informing decision making on the type of MPA to be established, the critical ecosystems or species to protect and the social and cultural factors to consider in implementing MPAs in the Western Region of Ghana. It will also provide the platform for sensitizing the communities about the Ecosystem Based Management concept and facilitate their appreciation of ecosystem functioning, continual supply of ecosystem services via effective management of ecosystems and the effects of destructive anthropogenic practices. It will further demonstrate how community involvement in the MPA designation process can be achieved. The study will also serve as a baseline for future monitoring and evaluation of management interventions towards improving Ghanaian fisheries resources. It will form a basis for future scientific studies in other comparable West African countries.

Delimitation of the Study

This study was conducted in support of national efforts to design and implement functional MPAs along the coastal areas of Ghana for the effective management of the fisheries sector and support Ghana's grand coastal development agenda (MOFAD, 2015; Nunoo, 2018). It focused on operationalizing a methodological tool for assessing coastal ecosystems in support of decision-making on the design and implementation of Marine Protected Areas in Ghana. Coastal ecosystems, rather than offshore marine ecosystems were considered for this study, with the basis that coastal ecosystems play diverse but important roles for the sustenance of marine fisheries via the provisioning of ecosystem, food and nurseries for most fish species.

Mapping and assessing the ecosystems and the services they provide informed the basis for investigating anthropogenic pressures that impact or threaten the proper functioning of these ecosystems. Climatic related or natural environmental pressures were thus not considered in this study, even though the study acknowledged that pressures or drivers of change in ecosystems are not limited to anthropogenic pressures only. Anthropogenic pressures in the study area were identified through field observations and key informants, and the ones selected for the assessment were collectively selected by the communities in a participatory mapping exercise.

Valuation techniques in general and stated preference methods specifically are affected by uncertainty, stemming from gaps in knowledge about ecosystem dynamics, human preferences and technical issues in the valuation process. There is a need to include uncertainty issues in valuation studies and to acknowledge the limitations of valuation techniques in situations of radical uncertainty or ignorance about regime shifts.

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Following the Coastal Resources Center (CRC) and Friends of the Nation (FON)'s categorization of the "Greater Cape Three Points (GCTP)" as a critical management or conservation site in their 2011 report, the GCTP was selected as the area to conduct this study. CRC & FON (2011) described the GCTP as an area in the Ahanta West district which comprises of the various coastal ecosystems within Cape Three Points, Princess Town and Miemia. For the purpose of this study, the GCTP area was restricted to coastal ecosystems within Cape Three Points and Princess Town communities, excluding Miemia due to limited resources and difficult accessibility at the time of the study. The ecosystems considered for the study were limited to rocky bay, estuary, mangrove forest, sandy beach and lagoon.

The Ecosystem-Based Management approach applied in this study was considered within a single sector, fishing, rather than a full cross-sectoral EBM that involves coordination of assessments across different sectors like, shipping, energy, and Oil and Gas exploration. The scope of the study did not extend to cover connectivity with external activities beyond the study area. The study was conducted on a local scale and thus replication in other places should take the scale into consideration and be mindful of the socio-cultural and economic dynamics of that area.

Limitations of the Study

In applying the Ecosystem – Based Management Approach for establishing MPA in the Greater Cape Three Points area, the study assumed that certain areas were more important than others for achieving certain goals and that this relative importance can drive the establishment of spatially explicit rules and regulations. In view of that, the focus on critical areas in the Greater Cape Three Points area were restricted to the areas of importance to the study. It was this relative importance that determined the spatially explicit conclusions drawn for the study. The study assumed that ecosystem services prioritized by community members in the two communities under study represent the most important ecosystem services that support fisheries livelihoods in the area. Thus, other ecosystem services which could be critical in the analysis of the MPA design, but were not considered by the communities, were excluded.

Economic values estimated for the ecosystems under study may not portray the absolute values of the ecosystems. Valuation was affected by ambiguity, stemming from gaps in knowledge about ecosystem dynamics and human preferences. Where no market prices existed for certain ecosystem services, respondents involved in the valuation exercise either over-quoted, under-quoted or quoted no amount at all to represent the value they place on those ecosystem services. Also, the economic valuation is limited by the uncertain that the estimated value would be maintained at the same level in future since the valuation does not include the sustainability of resource use. Economic valuation of ecosystems performed in this study was therefore done primarily to capture useful information about changes to livelihoods that may result from ecosystem management actions, and not to state the absolute economic value of the study area. The study cautions therefore that, trade-off decisions made between ecosystem conservation and undertaking economic development should not be limited to the economic value stated for the ecosystems in this study. Other non-monetary values derived from the ecosystems must be duly accounted for to balance conservation adequately with development objectives. These limitations of monetary valuation of ecosystems and the services they provide must be critically taken into account in decision making because ecosystems approach critical thresholds and changes to them may be irreversible or reversible only at prohibitive cost. Policy should therefore be guided by the 'safe-minimum-standard' and 'precautionary approach' principles.

Due to limited information about the effects of anthropogenic pressures on coastal habitats in the locality, such information for the habitat risk assessment were based on literature reported from other areas. The study thus assumed that ecosystems around the world respond in similar ways to any given stressor. Also, the cumulative risk of pressures on the habitats understudied may have been over- or under-estimated due to limited knowledge on the interaction of multiple pressures on coastal ecosystems. The study assumed additivity, rather than synergism or antagonism, as the type of interaction that will occur when an ecosystem is exposed to multiple pressures.

Since no nationally approved indicators for measuring healthy environmental status of coastal ecosystems exist in Ghana, the study deplored acceptable criteria and baseline for the assessment. Indicators developed for assessing each of the ecosystems' suitability for conservation and assignment of zones to each ecosystem, were based on the results of the ecosystem assessment performed in the study area. This limits the outcome of the proposed conservation to the study area and the scope of assessment. Thus, replicability of such an approach should be circumspect about employing similar assessment categories.

Limited data on the ecological status of the ecosystems, coupled with little data on the socio-cultural and economic profile of the communities in terms of fishing posed a challenge in conducting a data-rich assessment. Time was a major limiting factor for the limited scope set for the study. The scope of the study was also reduced due to poor accessibility to some communities. Sampling was hindered in certain periods due to heavy rains and some traditional norms. Most community members demanded financial motivation for cooperation, limiting the number of respondents to only those who were willing to engage freely.

Organization of the Study

Chapter One gives an introduction to the study and outlines the aim and objectives for the study.

Chapter Two discusses available literature for assessing ecosystems for conservation.

Chapter Three explains the materials and methods employed in conducting the integrated assessment.

Chapter Four presents the results obtained from the integrated assessment.

Chapter Five discusses the results, highlighting major findings and explaining trends observed from the assessment.

Chapter Six provides a summary and conclusion on the study conducted. It also gives a set of recommendations for further action in the area of conservation.

CHAPTER TWO

LITERATURE REVIEW

This Chapter reviewed various literature to explain what Ecosystem-Based approach to management is and how it is applied to the designation of Marine Protected Areas (MPAs). It also discussed Marine Protected Areas in general and reviewed literature on various MPAs established around the world.

The "Ecosystem- Based Approach" to Coastal and Marine Ecosystems Management

The Millennium Ecosystem Assessment (MEA) in 2005 recommended the adoption of Ecosystem-Based Management (EBM) approaches as a paradigm for improving the conditions of ecosystems (Agardy et al., 2011; MEA, 2005). This was based on a global assessment conducted on ecosystems around the world, which revealed the rapid rate of deterioration of most of the ecosystems assessed. Different terms have been used to express the concept of management approaches with an 'ecosystem' focus. These include: Ecosystem-Based Approach (EBA), Ecosystem Approach (EA) and Ecosystem-Based Management (EBM). Farmer et al. (2012) elaborated that these terms are considered synonymous based on the component of their definitions (Farmer, A., Mee. L., Langmead, O., Cooper, P., Kannen, A., Kershaw, P. and Cherrier, 2012).

During the Joint Ministerial Meeting of the HELSINKI and OSPAR Commissions held in 2003 the term, 'Ecosystem Approach to Management (EAM)' was defined as: "the comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity" (HELSINKI & OSPAR, 2003).

The Convention for Biological Diversity (CBD) also defined the 'Ecosystem Approach to Management (EAM)' as: "a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. It is based on the application of appropriate scientific methodologies focused on levels of biological organization which encompass the essential processes, functions and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of ecosystems" (CBD, 2004).

The United Nations Environment Program (UNEP) referred to the term, 'Ecosystem Approach (EA)' and defines it as "a strategy for the integrated management of land, water and living resources that provides sustainable delivery of ecosystem services in an equitable way" (Agardy et al., 2011). In this management approach, "the associated human population and economic or social systems are seen as integral parts of the ecosystem. Most importantly, ecosystem-based management is concerned with the processes of change within living systems and sustaining the services that healthy ecosystems produce" (Agardy et al., 2011).

A scientific consensus prepared by scientists and policy experts in the United States of America referred to the term 'Ecosystem-Based Management (EBM)' and defined it as "an integrated approach to management that considers the entire ecosystem, including humans. The goal of ecosystem-based management is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need. Ecosystem-based management differs from current approaches that usually focus on a single species, sector, activity or concern; it considers the cumulative impacts of different sectors" (McLeod et al., 2005).

The various definitions of the "Ecosystem" approach above have certain common components:

1. Integrated approach, where the entire ecosystem, including human, biotic and abiotic components, should be considered in management actions and measures for managing resources.
2. Concerned with the sustainable delivery of ecosystem services (resources) that support human activities.
3. Management approach with an environmental concern.

Noteworthy about the Ecosystem-Based Management (EBM) approach is that instead of dealing with single issues, species, or ES in isolation, it considers holistically, the interactions within an ecosystem (Katsanevakis et al., 2011). It encompasses the identification and measurement of the social, economic and long-term or short-term environmental impacts of a development (Beaumont, et al., 2007). Application of the ecosystem approach enhances the achievement of equilibrium between the three pillars of sustainable development; conservation, sustainable use, and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources (CBD, 2000; Duran, Artene, Gogan, & Duran, 2015).

Conceptual Framework for Establishing Ecosystem-Based Marine Protected Areas

The Ecosystem-Based Management approach is basically hinged on three main concepts, namely, the Ecosystem Services (ES) concept (MEA, 2005), the Drivers-Pressures-State or Condition-Impact-Response (DPSIR) concept (Kristensen, 2004); and the Economics of Ecosystems and Biodiversity's (TEEB) concept for "making nature's values visible" (The Economics of Ecosystems and Biodiversity [TEEB], 2010).

The ES concept

The ES concept opines that socio-economic development and the long-term well-being of people is heavily dependent on Ecosystem Services (ES) delivered by healthy ecosystems' functioning. Thus, goods and services provided by ecosystems in coastal areas depict the livelihoods peculiar to those areas (Agardy et al., 2011).The ES concept is applied to understand the range of benefits people gain from the natural functions of ecosystems and assess the values they place on these benefits to facilitate the selection of appropriate management options for human well-being (Everard & Waters, 2013; Kreye, Pienaar, Boughton, & Wiggins, 2016). It provides a framework for classifying the various services supplied by an ecosystem, which are then mapped, modelled and assessed to analyze their state and the effects of anthropogenic stressors on them (Czúcz et al., 2018).

The DPSIR concept

The DPSIR analytical framework is employed to provide an understanding of how human actions are connected in various ways to impact on the environment. The framework is employed in the assessment of ecosystems, where, various pressures and their effects on the condition of ecosystems are analysed, so that policymakers can design suitable responses. ‘Drivers’ refer to human demand for ES and other natural resources which induce ‘Pressures’ that affect ecosystem conditions – “State”. The ‘Impacts’ identified informs the creation of policy Responses which are expected to change the drivers and the way they are managed to cope with negative impacts (Mapping and Assessment of Ecosystems and their Services [MAES]., 2016). As people benefit from ES for their development, they exert pressures that impact the ecosystem. These pressures can cause direct or indirect changes in different aspects of an ecosystem, thereby threatening the continuous supply of ecosystem goods and services (MEA, 2003). Indirect drivers, including technology, individual or social preferences and population impacts can lead to changes in factors directly affecting ecosystems, such as the overexploitation of fisheries or the application of fertilizers to increase food production (MEA, 2003).

The TEEB concept

The TEEB concept facilitates the mainstreaming of biodiversity values and ecosystem services into decision-making at all levels through a valuation approach developed to reveal their economic values to enhance trade-offs in decision-making (Department for Environment Food and Rural Affairs [DEFRA], 2007). Valuation is vital in generating markets for the conservation of biodiversity and ecosystem services. The TEEB follows three approaches in analyzing and structuring valuation of biodiversity—and ecosystem services—according to the situation (TEEB, 2010) as follows:

a. "Recognizing value" approach is used where the value of ecosystems, landscapes, and biodiversity is appreciated by communities, due to their spiritual and cultural values of nature, thus fostering conservation and sustainable use. In this case, monetary valuation of biodiversity and ES may not be necessary (TEEB, 2010).
b. Where the full costs and benefits of using an ecosystem for a development project need to be known by policy makers or businesses before taking action, costs or values of the ecosystem, which go beyond those costs which enter markets in the form of private goods are demonstrated. In such instances, the "Demonstration value" approach is sort after. This approach refers to economic or monetary valuation of natural areas which are compared against an intended project (TEEB, 2010).
c. The final approach, "Capturing value", refers to a mechanism which integrates the values of ecosystems into decision-making through incentives and price signals. This approach captures the demonstrated values of ecosystems and biodiversity in monetary terms in markets (TEEB, 2010).

TEEB's valuation methodology is based on the Total Economic Value (TEV) framework. TEV refers to the sum of the values (direct, indirect, option, and existence values) of all service flows generated by natural resources both now and in the future, expressed in money or any market-based unit of measurement (Brander, Gómez-Baggethun, Martín-López, & Verma, 2010).

Figure 1 shows a schematic diagram for the proposition of adopting Ecosystem-Based Management (EBM) approach for the establishment of

MPAs for sustainable development: Healthy ecosystem functioning (A) is necessary for the supply of Ecosystem Services (B) that provide benefits to support human activities and uses (C). This translates to the economic, cultural and ecological values that support human well-being (D), captured as total economic values of ecosystems and biodiversity (E). However, these human activities and uses—Drivers—exert various Pressures (F) and Impacts (G) the health of ecosystems and their functioning (A) by compromising their State, risking the continuous supply of services. Effective management of activities using the EBM approach in the establishment of a Marine Protected Area is the Response required to balance the demand for ecosystem services with the supply of these services (H), to ensure continued supply of ecosystem services (I_1), reduce the pressures on them (I_2) and enhance the well-being of people (I_3), reduce pressures on.

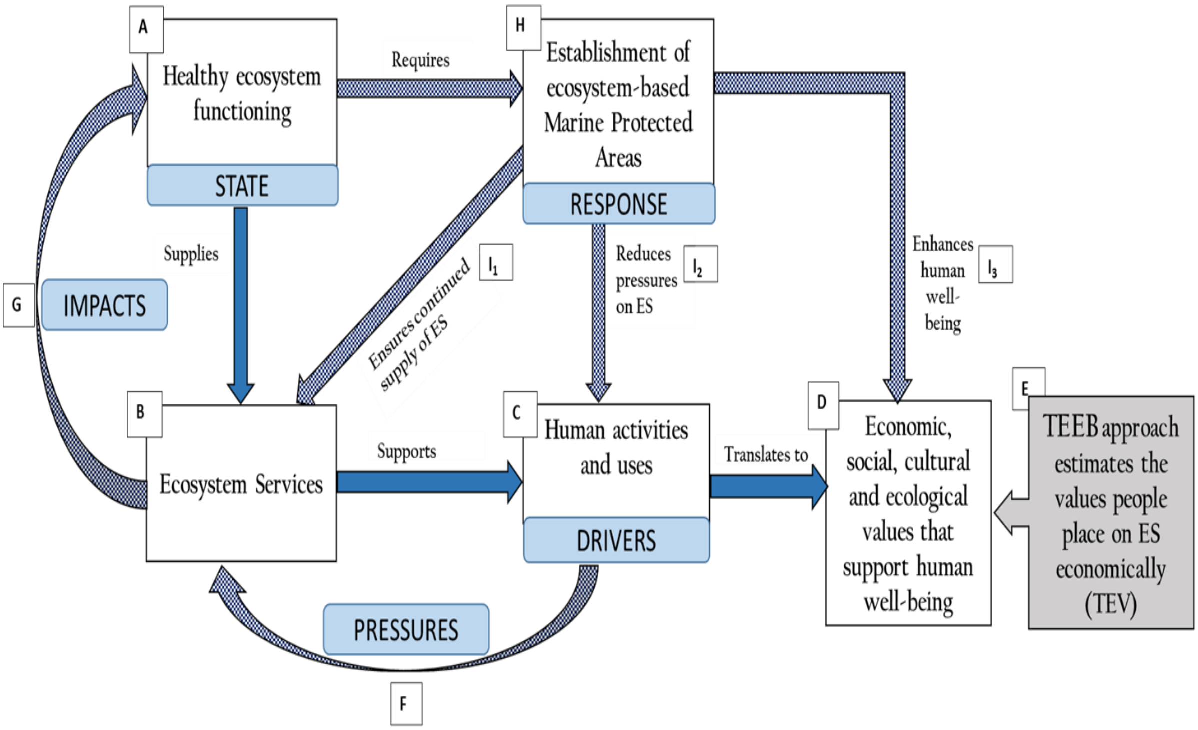


Figure 1: Conceptual Framework for establishing an Ecosystem-Based Marine Protected Area. Adopted from (Kristensen, 2004; Millennium Ecosystem Assessment, 2005; TEEB, 2010).

Operationalizing the Ecosystem-Based Approach

Application of the EBM approach to coastal and marine management is widely accepted as it offers an avenue to plan and manage ecosystems in a way that accounts for the multiple needs of current society without jeopardizing the chances for future generations to benefit from the full range of goods and services provided by the ecosystem (Arkema, Abramson, & Dewsbury, 2006; Dell'Apa, Fullerton, Schwing, & Brady, 2015; Ruckelshaus, Klinger, Knowlton, & DeMaster, 2008).

Nonetheless, in a study conducted by Link & Browman (2017) to review global efforts to operationalize and implement Ecosystem-Based Management, they brought to light the fact that implementation of a truly multi-sectoral EBM is limited. This is attributed to the multi-faceted dimensions of the approach, lack of consensus on a clear-cut tool / method to operationalize EBM, and the multiplicity of competing interests, diminishing political will to enact EBM in practice (Link & Browman, 2017). This revelation is not surprising since coastal and marine issues differ from place to place over varying scales, and depending on the purpose or objective for setting up a management scheme, coastal and marine managers may choose to focus on certain aspects of the system or management design, rather than considering everything in totality. Based on good knowledge and understanding of ecological and social systems, managers may prioritize the management of most critical elements (Agardy et al., 2011).

It is however important to note the core elements of the EBM approach to ensure that a selected management approach is "Ecosystem-Based". The core elements, as summarized by Agardy et al. (2011) include: Recognition of connections among systems and between ecosystems and people; Application of the Ecosystem Services (ES) perspective; Cumulative impact assessment of various activities affecting the ecosystem; Balance of multiple objectives related to different benefits and ecosystem services; and Adoption of adaptive management to enhance change, learning and policy adaptation throughout the management process.

The Food and Agriculture Organization has developed a scheme for operationalizing the Ecosystem-Based Approach to Fisheries Management (EBAFM). The scheme commences with 'scoping' to identify the fishery, geographic area and stakeholders, as well as to determine the broad issues for the fishery – covering economic, social and ecological components of sustainable development (FAO Fisheries Department, 2003). The information compiled are then analyzed to understand the environmental impacts of the fishery in terms of effect on ecosystem and direct and indirect impact on biota other than the target species (FAO Fisheries Department, 2003). Following this step, objectives are set for the fishery based on priority ranking of the various issues identified (FAO Fisheries Department, 2003). Indicators and reference points for each operational objective are developed to provide a framework for evaluating the management rules and assess the performance of the fishery in achieving its objectives. Rules are then set to determine the management action to be applied under different conditions to achieve each objective. An example is the use of Total Allowable Catches (TACs) to manage sardine and anchovy fisheries (FAO Fisheries Department, 2003). The final step involves the design of a monitoring, assessment and review strategy for appraisal of the success of the management measures in attaining the objectives is appraised. The entire process is conducted in consultation with stakeholders, with their participation enhanced to ensure they obtain ownership of the plan and its implementation (FAO Fisheries Department, 2003).

Conducting an Integrated Ecosystem Assessment towards the Application of an Ecosystem-Based Management Approach

Ecosystem Assessment constitutes an interdisciplinary and participatory process of gathering information to assess the condition of an ecosystem (in biophysical, socio-cultural and economic terms), investigate the natural and anthropogenic pressures exerted on it, and, determine response mechanisms (Ahmed, 2011). The Mapping and Assessment of Ecosystems and their Services (MAES) working group have developed a comprehensive analytical framework for conducting ecosystem assessment to enhance Ecosystem-Based Management as follows:

(i) Mapping of the concerned ecosystem and the services it supplies;

(ii) Assessment of the condition of the ecosystem;

(iii) Quantification of the services provided by the ecosystem; and

(iv) Compilation of the results into an integrated ecosystem assessment to guide decision making.

MAES was deployed by the European Union (EU) in connection with the EU Biodiversity Strategy 2020 that was launched in response to the findings of the Millennium Ecosystem Assessment (MEA). The framework applies the Ecosystem Services (ES) concept and helps to provide a comprehensive evaluation of the best available information for guiding decisions on complex public issues, including the designation of MPAs (Maes et al., 2018). A successful application of the ES approach commences with 'categorization' of the ecosystem service provided by the said ecosystem for easy and transparent communication (Maes et al., 2013; Ruskule et al., 2018).

Various approaches to categorize ecosystem services have been developed based on an array of criteria including: spatial character and scale, service flow, service beneficiary, or whether the use of a service by one individual or group affects the use by others (Ruskule et al., 2018). The Common International Classification of Ecosystem Services (CICES) provides a classification scheme that facilitates the measurement, accounting for, and assessing ecosystem services.

Table 1 – *Description of the Various Categories of Ecosystem Services*

Category of Ecosystem Service	**Description**
Provisioning services	The products obtained from ecosystems, including food, fibre, fuel, genetic resources, bio-chemicals, natural medicines, pharmaceuticals, ornamental resources and fresh water.
Regulating and Maintenance services	This category comprises all the ways in which ecosystems control or modify biotic or abiotic parameters that define the environment of people
Cultural services	The non-material benefits related to culture, that people obtain from ecosystems. These include, spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences.
Supporting services	The services that are necessary for the production of all other ecosystem services (examples include, soil formation, photosynthesis, primary production, nutrient cycling and water cycling).

Source: Haines-Young & Potschin (2018)

Ecosystem mapping

The MAES framework prioritizes the use of 'maps' to serve as a communication tool to facilitate stakeholder dialogue and easy identification of locations where critical ecosystem services are produced or used (Maes et al., 2018). Mapping of the main ecosystems and the ecosystem services present, including those services produced or consumed elsewhere is vital in ecosystem assessment (Brūniņa, Konstantinova, & Aija, 2016). Ecosystem mapping involves the spatial allocation of ecosystems based on an agreed ecosystem typology (such as terrestrial ecosystem, freshwater ecosystems and marine ecosystems) according to the mapping scale and purpose, and, the quantification of their condition and services they supply (Ruskule et al., 2018). The conservation status of ecosystems and species, and the ecological and environmental status of ecosystems should be included (Maes et al., 2013). The benefits of carrying out this important activity includes: provision of baseline data against which net future gains or losses are measured; data integration into spatial development process; and to understand and communicate ways in which the natural environment contributes to people's well-being (Burgess, Darrah, Knight, Danks, & MacArthur Foundation, 2016; Maes et al., 2013; Ruskule et al., 2018)

Indicators, proxies or surrogates and models are examples of techniques used to map ES (Burgess et al., 2016). Indicators are generally developed for mapping each of these service categories. Indicators for mapping ecosystem services are referred to as the information used to communicate the characteristics and trends of ecosystem services (Brown et al., 2014). For example, in mapping provisioning services, indicators for food production, such as fish landing stocks and other primary data are generally used because food production and market data are readily available (Brown et al., 2014; Maes et al., 2013). Where such statistics are not available, usually in the case of mapping regulating, cultural and supporting services, proxies are used to represent the capacity of the ecosystem to provide the ES intended to be mapped (Burkhard & Maes, 2017; Maes et al., 2013). This approach uses existing spatial data on ecosystems and land use/land cover (LU/LC) to demonstrate ecosystems' capacity to provide ES in a spatial manner (Burkhard & Maes, 2017).

Models can also be developed in mapping ES. Models are able to calculate ES values, given other input variables. Biological or ecological models and derived indicators (for example, InVEST or ARIES) are examples of tools that may be adapted to map ecosystem services (Burkhard & Maes, 2017; Maes et al., 2013).

Table 2 – *Summary of the Types of Information Required for Mapping Ecosystems and their Services and the Various Sources for Obtaining the Data.*

Information Required	**Data Source**				
	Remote Sensing	Natural Resource and Biodiversity Inventories	Socio-economic Data	Indigenous and Traditional Knowledge	Case Studies of Ecosystem Response to Drivers
Spatial extent and condition of ecosystem		X		X	
Quality, quantity, and spatial distributions of services provided by system		X			
Human populations residing in and deriving livelihoods from system			X		X
Trends in ecosystem conditions and services	X	X		X	X
Response of ecosystem condition and services to drivers				X	X

Source: Adapted from DeFries & Pagiola (2005).

Remote sensing is the science of obtaining information about objects or areas from a distance, typically from aircrafts or satellites, without being in direct physical contact (Burgess et al., 2016). These data are generally digital and consequently amenable to computer-based analysis for classifying land cover types and assessing trends (DeFries & Pagiola, 2005). It is a primary data source for mapping the extent and condition of ecosystems over large areas (DeFries & Pagiola, 2005). Remotely sensed data is usually calibrated and validated with in situ data (ground-based data).

Another source of data for mapping is from inventories of natural resources and biodiversity conducted at different levels – local, national and global. This provides information on the locations and amounts of important ecosystem services. Globally, the International Union for Conservation of Nature (IUCN) produces an inventory of a comprehensive list of threatened species, published in the ‘Red Data Books’ and the ‘Red Lists of Threatened Species’ since the 1960s. It provides information about range, population size, ecosystem and ecology, use and/or trade, threats, and conservation actions that will help inform necessary conservation decisions (IUCN, 2018). Taking local inventories of natural resources and biodiversity is a vital source for mapping ecosystems and their services, since most ES are provided locally. Local inventories offer primary data that can directly inform land use policies and trade-offs among ecosystem services (DeFries & Pagiola, 2005). For regulating and cultural services, primary data are not usually available and thereby, proxies are resorted to in mapping them (Maes et al., 2013).

Data on the populations living within ecosystems should be captured when conducting ecosystem mapping (MEA, 2005). Information on the distributions of human populations within ecosystems is relevant for analyzing the linkages between people and the ecosystem services provided in the area. This can be obtained from demographic and socioeconomic data collected through population censuses and surveys (DeFries & Pagiola, 2005).

Indigenous and Traditional knowledge is particularly useful for acquiring important data on ecosystem conditions and trends. Participatory approaches are employed for obtaining such data. Local stakeholders can be involved in creating maps and focusing priority areas. Expert judgement of these stakeholder are sought to identify criteria to be used to map locations of supply, delivery and valuation of ecosystem services (Burgess et al., 2016; DeFries & Pagiola, 2005). Indigenous and traditional knowledge can be also used to generate information on drivers of change to ecosystems and the sources of these drivers.

Case studies are valuable for providing comprehensive analyses of ecosystem – and ecosystem services' - response to drivers in specific locations. This can be used to fill gaps generated by lack of more comprehensive data when necessary (DeFries & Pagiola, 2005). Evidence generated from a sufficient number of case studies allows general principles to emerge about ecosystem responses to drivers (DeFries & Pagiola, 2005).

Assessment of ecosystem condition

The capacity of ecosystems to supply service is dependent on the natural condition of the ecosystem as well as the anthropogenic pressures to which it is exposed. The assessment produces spatial maps of the impact of multiple pressures on the ecosystem. This information is relevant for assessing the ability of the ecosystems to supply ecosystem services. MAES, in their 2016 Technical Report, discussed the approaches for conducting such an assessment as:

a. The indirect approach – based on evaluation and mapping of the **pressures** acting on ecosystems (MAES, 2016). The main pressures that alter ecosystems are ecosystem change, climate change, overexploitation, invasive alien species, pollution and nutrient enrichment.

b. The direct approach – assessments of **ecosystem condition**, biodiversity and environmental quality (MAES, 2016). Direct assessment of ecosystem condition is an approach that can be used to complement the pressures mapping approach. It involves the use of indicators such as water quality, distribution and conservation status of ecosystems and species and soil quality, to illustrate the cumulative effect of pressures on ecosystems over time (MAES, 2016). These two approaches are applied to evaluate ecosystem condition.

Various tools that can be employed for assessing ecosystems and their services include TESSA toolkit, ValuES, InVEST, Co$ting Nature, ARIES, MIMES, LUCI, GISCAME and ESP Mapping Tool. Application of such tools provide a way for scientists and practitioners to effectively map and assess ecosystems (and ecosystem services) (Burgess et al., 2016).

Quantification of the services provided by ecosystems

Quantification is a tool used to obtain more detailed values for goods and services provided by ecosystems, in terms of their quantity. Ecosystem values are measures of the worth of ecosystem services to people (Brown et al., 2014). Ecosystem services can be valued in terms of: how many people will be affected in the absence of certain services, how many jobs will be lost, and, how many economic agents will suffer losses (Stegarescu, Do, & Partidario, 2014). The values obtained from quantification is vital for communicating the importance of ES and also for measuring ES trade-offs

(Kelleher & Kenchington, 1992). These values can be expressed as: **economic** (monetary) values **and non-economic** (non-monetary) values (DEFRA, 2007).

Economic valuation

This involves assigning monetary value to environmental factors (Burkhard & Maes, 2017). It deals with how people's well-being is affected by their conceptions (preferences) about what plays a role in their well-being based on the economic values placed on ecosystem goods and services (Barbier et al., 2011; Costanza et al., 1997; Liekens, De Nocker, Broekx, Aertsens, & Markandya, 2013; Swedish Environmental Protection Agency [SEPA], 2018). It forms the basis for considering socio-economic trade-offs between costs and benefits of an environmental action, or to determine what a reasonable level of an environment tax or subsidy might be (SEPA, 2018). The economic value of goods and services provided by ecosystems is compared with economic values of activities that may compromise them. This enhances selection of choices between the conservation and restoration of some ecosystems and the continuation and expansion of human activities in others. The methods for conducting economic valuation fall under two main groups as summarized in Table 3. The 'value transfer' method can also be used sometimes to generate approximate valuation of an ecosystem service, where a generalized value is given to an ecosystem (or ecosystem services) based on a study done in another geographical place, provided the necessary uncertainties related to the peculiarities of the two geographic locations are properly addressed (Barbier et al., 2011; SEPA, 2018).

Monetary valuation of ES may not fully represent the value of ecosystem services, and may place the economic values associated with conservation lower than alternative anthropogenic uses in the short term, which can suggest outright conversion decisions to be made (Schröter et al., 2014). It is therefore important to also assess the values of ES from a non-monetary perspective, such as globally significant biodiversity values, irreplaceable cultural values or relational values (Chan et al., 2016). Also, certain ES (such as cultural heritage) are difficult to assess in monetary terms and may be better evaluated using non-monetary measures. It is important to keep these risks and limitations in mind and to be strategic about when and how to undertake an ES assessment. In particular, it is important to identify situations when conservation strategies and arguments based on biodiversity or other cultural or social values may be more effective than assessing economic values.

Table 3 – *Methods for Conducting Economic Valuation*

Scenario valuation methods (Stated Preferences) – methods which involve the use of hypothetical scenarios in describing alternatives in a social survey (De Groot, Wilson, & Boumans, 2002).	**Market data methods (Revealed Preferences)** – methods based on studying the relationships between ecosystems and actual behaviours, prices, and production (SEPA, 2018).
The replacement cost method – used in this approach to estimate the cost of replacing ecosystem service with man-made equivalent. For instance, natural waste treatment by marshes which can be (partly) replaced with costly artificial treatment systems (De Groot et al., 2002).	Direct Market valuation method – the exchange value that ecosystem services have in trade or on the market. It is mainly applicable to provisioning services (ecosystem products / goods and some cultural services (eg. recreation) (De Groot et al., 2002).
The damage avoided cost method – used as a proxy to express the avoided costs that would have been incurred by the society in the absence of those services (example is flood protection provided by mangroves which avoids property damage) (De Groot et al., 2002)	Production function method – estimates the value of ecosystem services by identifying the contribution of an ecosystem service to the production of, for example, fish or timber (SEPA, 2018).
The contingent valuation method – estimates an ES based on how much a person would be willing to pay to prevent loss of, or enhance an ES. People might be asked to state how much they are willing to pay to increase the level of water quality in a stream, lake or river so that they might enjoy activities like swimming, boating, or fishing (De Groot et al., 2002; SEPA, 2018).	Hedonic Pricing method – uses the role of the natural environment in pricing of properties to reveal the value of certain cultural services. (De Groot et al., 2002; Liekens et al., 2010; Marine and Coastal Biodiversity Management in Pacific Island Counties, 2017).
	Travel cost method – used to estimate the value of ecosystems or sites that are used for recreation (cultural services). The travel expenses and time that people spend to visit a site represent the "price" of access to the site (De Groot et al., 2002). The environmental quality influences the choice of destinations for outdoor activities (SEPA, 2018).

Non-economic valuation

Non-economic valuation approaches can be used to examine the importance, preferences, needs or demands expressed by people towards nature, and articulate plural values through different qualitative and quantitative measures other than money (Kelemen, García-Llorente, Pataki, Martín-López, & Gómez-Baggethun, 2016). It explores the beliefs, motivations and sociodemographic factors that influence individual and social choices in ES management, enhancing the identification of potential intervention Points to address unsustainable practices. It captures the socio-cultural values of the ecosystem as expressed by the people. Non-monetary valuation methods are summarized under four categories by SEPA (2018) as follows:

1. Qualitative valuation method – Provides an in-depth understanding of the value people place on ecosystem services without necessarily linking it to any particular measurement. It addresses issues like: what the public thinks about a certain environmental issue; and how an area is used and how people feel about the area. Methods that can be used to capture values in this approach include in-depth ecological surveys; contact with interested parties via focus group discussions, in-depth interviews, and questionnaire studies; and description of values based on stories or historical events.
2. Semi-quantitative valuation method – Based on quantifying values by assigning them points. This is often done as a desktop study, but scoring can be derived from information based on discussions with stakeholders and other experts, for example, or field studies of species compositions and the use of an area. Likert scale can be used in this way to conduct the scoring, based on a framework that explains what each score means to

enhance transparent analysis. This method allows for ranking of the importance of various ecosystem services to people or the degree of impact (in terms of who is affected the most and the least) on different categories of people by a particular project.

3. Quantitative valuation method (physical units) – uses one or more indicators to describe the value of an ecosystem service. It is based on the premise that some measurable aspects of the environment, or our use of it, can reasonably reflect the contributions of different ecosystem services to human well-being. For instance, the number of visits to an area that is used for recreation can be an indicator of recreational value of that area; carbon dioxide absorption from a wooded area can be used as an indicator to express the contribution of the area to global climate regulation; the amount of dead hardwood could be an indicator of the availability of ecosystem for the white-backed woodpecker. Modelling can be useful in quantitative valuation to describe for example, the amount of air pollution a particular activity generates, or, how different environmental quality levels affect the occurrence of different species.

Selection of which of the non-economic methods to use in valuation of ES is based on: the capabilities of the researcher and the sociocultural context of the communities involved; the institutions and the value-systems held by stakeholders; the institutions and the value-systems held by stakeholders; the needs and purposes of the decision-makers and of the concerned project; the commitment and capacity of the researchers and practitioners who carry out the valuation process; and the main characteristics of the decision making process affected (Kelemen et al., 2016).

Community Participation in Ecosystem Assessment for Conservation Management

The importance of fostering community participation at the local level in the design and implementation of conservation management approaches have been echoed by various authors and institutions in the field of conservation (Beaumont, 1997; Davis et al., 2014; Kelleher & Kenchington, 1992; OSPAR, 2008; Paudyal, Baral, Burkhard, Bhandari, & Keenan, 2015). Community participation in conducting ecosystem assessment facilitates the incorporation of traditional knowledge, which is useful for assessing trends in ecosystem condition over a long period of time (Uprety, Asselin, Bergeron, Doyon, & Boucher, 2012). Complementing formal science with traditional knowledge provides an array of benefits (Ericksen & Woodley, 2005; Moller, Berkes, Lyver, & Kislalioglu, 2004). Ericksen & Woodley, (2005) highlight the substantial insight provided by traditional ecological knowledge on locally important resources and management practices in the locality under assessment. Such knowledge is relevant for arriving at holistic solutions which address not only ecological concerns, but socio-cultural ones as well. Combination of knowledge from both sources provides rich source of information at different spatial and temporal scales (Moller et al., 2004).

Community participation also helps to boost communities' awareness and visibility of the conservation measure, presenting an avenue for communicating its objectives and dealing with trepidations that may arise in relation to restrictions imposed by it. This enhances understanding and support for the conservation measure's objective and promotes communication with community members (Davis et al., 2014).

Decision Support Tools for Conducting an Integrated Ecosystem Assessment

Decision support tools enhance managers to evaluate the impacts of human activities on ecosystems and to assess trade-offs among different activities and ecosystem services (Ocean Research Advisory Panel, 2013). They incorporate ecology, economics and geography to support decision making (Bagstad, Semmens, Waage, & Winthrop, 2013). Varying from simple spreadsheet models to complex software packages, these tools enhance duplication and quantification of ecosystem services analyses in both private and public sector decision making (Bagstad et al., 2013). A study conducted by Bagstad et al. (2013) reviewed the different decision support tools available and categorized under the various stages of the ecosystem services assessment process as:

1. Tools for conducting Ecosystem Services impact screening – ESR, Co$ting Nature
2. Tools for conducting Land/Seascape-scale modeling and mapping – ARIES, EcoAIM, EcoServ, Envision, EPM, InVEST, LUCI, MIMES, SolVES, InFOREST
3. Tools for conducting site-scale modeling – EcoMetrix, LUCI
4. Tools for conducting non-monetary valuation – EcoAIM, ESValue, SolVES
5. Tools for conducting monetary valuation – Benefit Transfer and use Estimating Model toolkit, Ecosystem Valuation Toolkit, NAIS (Bagstad et al., 2013).

Each tool has its strengths and weaknesses and based on the objective of the assessment to be conducted, the researcher or decision-maker selects the most appropriate tool. An appropriate tool is one that enhances an ecosystem service assessment that is quantifiable, replicable, credible, flexible and affordable. Bagstad et al. (2013), in their review of available decision-support tools, reported on a number of criteria for selecting the most appropriate tool in conducting an effective ecosystem services assessment. These include: Quantification and uncertainty; Time requirements; Capacity for independent application; Level of development and documentation; Scalability; Generalizability; Nonmonetary and cultural perspectives; and Affordability constitute the evaluative criteria for tool selection (Bagstad et al., 2013).

Establishing Marine Protected Areas as part of an Ecosystem-Based Approach to Fisheries Management

Adopting EBM approach in fisheries management facilitates the 'precautionary approach' principle, which considers the exploration of possible detrimental outcomes in fisheries systems and develops appropriate contingency and mitigation measures to curb them. Creation of MPAs is part of the precautionary approaches of an Ecosystem-based management system to secure ecosystem integrity in the absence of scientific certainty (Hoyt, 2009; Agardy et al., 2011). MPAs are established to act as a buffer against such uncertainty, providing a sort of 'conservation insurance' (FAO, 2011). Marine Protected Area (MPA) is an example of spatial management tools that can support Ecosystem-Based Approach to Fisheries Management (EBAFM). However, EBAFM can in turn be used as a management approach to implementing an MPA (FAO, 2011).

What are Marine Protected Areas (MPAs)?

Marine Protected Areas (MPAs) are established by countries and regional bodies as a useful tool for regulating different human uses in a coastal marine ecosystem through legal or other effective means, to achieve the long-term conservation of ecosystems with their associated services and cultural values (Agardy et al., 2011; Dudley, 2008). MPAs range from small, highly specialized areas to large, complex, multi-use areas (Agardy et al., 2011). Examples of MPAs include, marine reserves, marine sanctuaries, national parks and wildlife refuges (OceanTracks, 2017). MPAs are differentiated according to the types of activities that are permitted within the boundaries of the protected area or how long the area will be protected as captured in Table 4.

Table 4 – *Types of MPAs*

MPA type according to types of activities that are permitted within the boundaries of the protected area	**MPAs type according to how long the area will be protected**
1.Multiple use – MPAs that allows extractive uses like fishing with some restrictions.	1.Permanent – MPAs with indefinite protection, aborted only on future legislative requirement.
2.No-take – MPAs that allow people to use the area but prohibit extraction or any destruction to the area.	2.Conditional – MPAs which have the potential to continue into the future, but reviewed periodically to see if it meets its objectives.
3.No impact – MPAs that allow people to use the area but extraction, disposal of possible pollutants, the installation of materials and disruption to the environment of any kind is not permitted.	3.Temporary – MPAs designed to meet short-term conservation goals.
4.No access – MPAs that restrict all access to the area.	4.Year-round – MPAs that are in effect throughout the year.

Source: OceanTracks (2017)

The International Union for Conservation of Nature (IUCN) categorizes protected areas into six (6) main types as follows:

1a. Strict nature reserve – Strictly protected area for biodiversity and possibly, geological or geomorphological features, where human visitation, use and impacts are controlled and limited to ensure protection of the conservation values.

1b. Wilderness area – Large, uninhabited, unmodified or slightly modified areas which have retained their natural character and influence, protected and managed to preserve their natural condition.

2. National park – Large natural or near-natural areas protecting large-scale ecological processes with characteristic species and ecosystems which allows for environmentally and culturally compatible spiritual, scientific, educational, recreational and visitation activities.
3. Natural monument or feature – Areas set aside to protect a specific natural monument (for example, a landform, sea mount, marine cavern, cave or ancient groove).
4. Ecosystem/species management area – Areas set aside to protect particular species or ecosystems.
5. Protected landscape or seascape – Areas that have become distinctly valuable as a result of humans' interaction with nature over time, and safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.
6. Protected areas with sustainable use of natural resources – Areas which are large and mainly in a natural condition with low-level, non-industrial

natural resource use under sustainable natural resource management systems to promote conservation (Dudley, 2008; IUCN, 2019).

MPAs can be used as component of a wider EBM approach, to effectively restore and maintain healthy coastal and marine ecosystems by controlling anthropogenic activities that threaten their functioning or physically damage the environment. By this, MPAs contribute to the holistic protection of critical coastal and marine ecosystems and resources, and also offer social and economic opportunities for current and future generations (National Marine Protected Areas Centre, 2015; Salm & Clark, 2000).

Legal Frameworks and Contemporary Ocean Policies for Establishing Coastal and Marine Protected Areas

National policies on fisheries management and biodiversity conservation, of which the establishment of MPAs is a vital tool, are usually hinged on international instruments and agreements in the form of multi-lateral and bilateral treaties which provide the overall context to enhance sustainable marine conservation (International Union for Conservation of Nature [IUCN], 2004). Member states which are signatories to these international legislative instruments are required to pass enabling legislation to align their national laws to the provisions or agreements in the international law for conservation of coastal and marine ecosystems and biodiversity (FAO, 2011). International instruments set in place to enhance the establishment and management of MPAs include:

1. The United Nations Convention on Biological Diversity, 1992 – the most significant international legal instrument that addresses the establishment of protected areas. The convention defines the term “protected area”

in Article 2 as "a geographically defined area, which is designated or regulated and managed to achieve specific conservation objectives" (United Nations [UN], 1992). The Convention enjoins each contracting party in Article 8, to establish a system of protected areas or areas where special measures need to be taken to conserve biological diversity. It also outlines the provisions for establishing and managing such protected areas in Articles 9 – 14 (UN, 1992).

2. Sustainable Development Goals / Global Goals (SDGs), 2015 – Seventeen goals adopted by all United Nations Member States as a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030 (United Nations Development Program, [UNDP] 2019). Goal 14 is dedicated to the conservation and sustainable use of the oceans, seas, and marine resources. Targets 14.2 and 14.5 particularly address protection, conservation, and management of coastal ecosystems and resources (Neumann, Ott, & Kenchington, 2017). The UNDP supports countries to achieve these goals through partnerships with governments, private sector, civil society and citizens to create integrated solutions through projects and initiatives to address the goals (UNDP, 2019).

3. The United Nations Convention on the Conservation of Migratory Species of Wild Animals (the Bonn Convention), 1979 – provides a global platform for the conservation and sustainable use of migratory animals and their ecosystems. In order to protect endangered migratory species, the parties to the Convention are enjoined to conserve or restore the ecosystems of endangered species; prevent, remove, compensate for or

minimise the adverse effects of activities or obstacles that impede the migration of the species; and prevent, reduce or control factors that are endangering or are likely to further endanger the species (Article 5) (UN, 1979).

4. The World Heritage Convention, 1972 – convention concerning the protection of World cultural and natural heritage, which was adopted by the General Conference of UNESCO in 1972, enjoins contracting parties to protect and manage world heritage properties with the most important properties for the conservation of biological diversity. Legislative and regulatory measures at national and local levels are to be developed to assure the survival of the property and protect it against development and change that might negatively impact the outstanding universal value, or the integrity and/or authenticity of the property (Provision II.F). The World Heritage Committee has adopted specific guidelines to evaluate cultural and natural properties to be nominated for inscription on the World Heritage List. Cultural and natural properties identified and defined by the World Heritage Committee include: Cultural Landscapes, Historic Towns and Town Centres, Heritage Canals and Heritage Routes (United Nations Edeucation Scientific and Cultural Organization [UNESCO], 1972).
5. The Ramsar Convention on Wetlands of International Importance especially as Waterfowl Ecosystem, 1971 – promotes the conservation and sustainable use of wetlands. This Convention enjoins contracting parties in Article 4, to promote the conservation of wetlands and waterfowl by establishing nature reserves on wetlands, and provide adequately for their wardening (UNESCO, 1971).

6. The United Nations Convention on the Law of the Sea 1982 – legal framework for marine and maritime activities. This convention establishes rules governing all uses of the world's oceans and their resources (Division for Ocean Affairs and the Law of the Sea, 2018). It addressed issues related to delimitation, environmental control, marine scientific research, economic and commercial activities, transfer of technology and the settlement of disputes relating to ocean matters (Division for Ocean Affairs and the Law of the Sea, 2018). Particularly, article 61 in part 5 of the convention enjoins coastal states to design effective conservation and management measures to maintain or restore populations of harvested species at levels which can produce the maximum sustainable yield, to ensure that living resources in their exclusive economic zone are not endangered by over-exploitation. Other provisions related to determining harvesting capacity, licensing, compliance, regional cooperation for management of migratory species, amongst other related topic are captured in part 5 of the convention (United Nations Convention on the Law of the Sea [UNCLOS], 1982).
7. UNESCO's Man and Biosphere (MAB) programme, 1971 (Biosphere Reserves) – an Intergovernmental Scientific Programme that created the concept of biosphere reserves established to set up a network of protected areas with the aim of reconciling conservation and sustainable use with socio-economic development and maintenance of cultural values (UNESCO, 2017). The MAB provides a framework to support national governments in the planning and implementation of research and training programmes. Participating countries are to establish MAB National

Committees that ensure maximum national participation in the international programme, and also define and implement each country's activities (UNESCO, 2018).

National legislation for the establishment of MPAs are developed with a view to coordinating with international, regional, bilateral and other instruments and frameworks addressing MPAs, fisheries management and biodiversity conservation (FAO, 2011). In Ghana, a number of legislative instruments are in force to make provision for the protection of coastal and marine environment and conservation of biodiversity thereof. These include:

1. Constitution of the Republic of Ghana, (Amendment) Act, 1996 – Ghana's supreme law which spells out the nation's fundamental political principles and outlines the fundamental rights and duties of citizens. The amendment Act is based on the original constitution which entered into force in 1992. Chapter 21 of the constitution is dedicated to utilization and management of Lands and Natural Resources. Particularly, Article 269 mandates Parliament to provide for the establishment of Natural Resources Commissions, including the Fisheries Commission, under an Act of Parliament to be **responsible for regulation and management of the utilization of natural resources** and co-ordinate policies related to them (Government of Ghana, 1996).
2. The Fisheries Act, 2002 (Act 625) – provides regulations for the exploitation and management of fisheries resources to develop a sustainable fisheries industry in Ghana. Part 3 of the Fisheries Act, 2002 addresses the topic of Fisheries Management and Development. It enjoins the Fisheries Commission in Article 42, to **prepare a fishery plan** for the

management and development of fisheries. The Fisheries Commission was established by the Fisheries Commission Act, 1993 (Act 457) to manage the utilization of fishery resources and other related issues in Ghana. Article 91 of Part 3 of the Fisheries Act, 2002 also charges the Minister responsible for fisheries to **establish marine reserves** for conservation purposes (Dovlo, 2018; Government of Ghana, 2002).

3. The Fisheries Management Plan of Ghana, 2015 – developed by the Fisheries Commission based on its mandate according to section 42 of the Fisheries Act, 2002, to set out formal harvest strategy for Ghana's fishery and provide direction for the formulation of management actions. The plan includes actions for protecting marine ecosystem to conserve biodiversity in Key issue 4 and explicitly states the **creation of marine ecosystem protection areas** to protect nursery areas and spawning grounds mainly in estuaries and mangrove areas (MOFAD, 2015).
4. The Water Resources Commission Act, 1996 (Act 522) – Article 31 of the Act reserves authority for the Minister to declare an area or part of that area within a water resource as a protected catchment area upon satisfaction that special measures are necessary for the protection of the water resource. The Act refers to water resources to include river, spring, stream or natural lake or part of a swamp, and **defines protected catchment area** as "any area declared by the Minister to be preserved for the protection of water resources in or derived from the area" (Water Resources Commission, 2019).
5. The Environmental Protection Act, 1994 (Act 490) – establishes the Environmental Protection Agency, an agency of the Ministry of

Environment, Science, Technology and Innovation, as a regulatory body to advise the Ministry on the formulation of policies on all aspects of the environment, **make recommendations for the protection of the environment**, and also, promote effective planning in the management of the environment as part of its core functions (Environmental Protection Act, 1994).

6. The Petroleum (Exploration and Production) Act, 2016 (Act 919) – an Act developed to regulate petroleum activities to provide for and ensure safe, secure, sustainable and efficient petroleum activities. The Act demands all petroleum activities conducted in an area to be preceded by an integrated Impact Assessment (IA) to **facilitate the inclusion of environmental factors into petroleum exploration activities** and enhance sustainable development – Article 82. It also provides the requirements for conducting such an assessment in Article 7, to include impact of the petroleum activities on the environment, trade, agriculture, fisheries, shipping, maritime and other industries, as prescribed in the Environmental Protection Agency Act, 1994 (Act 490), for appropriate measures to be taken to safeguard the environment (Government of Ghana, 2016).

Review of Contextual Approaches for Establishing Marine Protected Areas around the World

MPAs have been designated in various places worldwide with a limited number of success stories in their setting up, implementation and management (Agardy et al., 2003; MEA, 2005). This is due to diverse challenges, most significantly related to limited or no information on some phases of the design and implementation process needed for a holistic development. Limited knowledge on the status of coastal ecosystems and their full values, as well as limited education on ecology and marine systems are factors that lead to conservation or management failures (MEA, 2005; Ban, Hansen, Jones, & Vincent, 2009). Again, conventional top-down methods employed in keeping resource use to sustainable limits and the lack of legislation covering traditional use in most coastal areas have contributed to the failure of most conservation efforts (MEA, 2005; Salm, Clark, & Siirila, 2000). Other conservation efforts have not succeeded because of failure of management designs to address multiple threats to coastal and marine areas. Since the threats to these areas are multiple and cumulative over time, protected areas that address only one of the threats usually fail to conserve the ecosystems and the services they provide (Agardy et al., 2011; MEA, 2005).

Success stories of functioning MPAs around the globe however exist and lessons can be drawn from these examples in planning, designating and implementing robust and sustainable MPAs. It is in the interest of policy makers and implementers of the MPA strategy to note the conditions for success or failure of MPAs in coastal communities to avoid the failures that have been experienced in other places.

The Americas

Case one: Gladden Spit and Silk Cayes Marine Reserve (GSSCMR) – Belize

Background

Gladden Spit and Silk Cayes Marine Reserve form part of Belize Barrier Reef System, which stretches for more than 1000 kilometers along the coasts of Belize, Guatemala, Honduras and Mexico. The reserve holds an important spawning aggregation site for over twenty-five species of fish, which spawn at various times of the year. Fishers from Belize have traditionally exploited a variety of traditional spawning sites throughout Belize since the 1920s. These spawning sites attract whale shark (*Rhincodon typus*) populations during spawning time to feed on freshly released spawn from other fish species. The aggregation of whale sharks in the area also boosts shark tourism (Sobel & Dahlgren, 2004).

The Problem

Scientific investigations carried out within the general reef area demonstrated that fishing levels were unsustainable. Fishing during the spawning season by even a limited number of traditional hand-line fishermen could remove more than 10 percent of the spawning population, and spear fishing over the rest of the year removed a further 14 percent of the population. Fisheries models indicated that fishing levels in the area were unsustainable with a threat of extinction of populations if not managed (Sobel & Dahlgren, 2004).

Configuration

Given the critical nature of the area for fisheries and international shark tourism, the Friends of Nature (FoN), a community-based organization, fostered dialogue among the communities towards the designation of the area as a reserve in 2000 (Sobel & Dahlgren, 2004). The reserve covers a total area of 25,992 acres, of which 378 acres, is designated as a no-take, and the rest designated as General Use Zone. It was designated a Marine Reserve in 2003, principally for the protection of Gladden Spit spawning aggregation site, the congregating whale sharks, and the tourism value of the Silk Cayes (Belize

Fisheries Department, 2012). Recognizing its international importance as a spawning site and also, its economic value to the whale shark tourism industry, traditional fishers agreed to revere fishing restrictions at the site and work closely with scientists (Sobel & Dahlgren, 2004). FoN has developed a draft management plan with communities via public consultations (Belize Fisheries Department, 2012; Sobel & Dahlgren, 2004). The reserve issues special licenses for boats and guides within the whale shark zone, in addition to strict carrying capacity limits (Sobel & Dahlgren, 2004).

Outcome

The reserve is managed under a co-management arrangement between the FoN – now Southern Environmental Association (SEA) and the Fisheries Department of the Government of Belize (Belize Fisheries Department, 2012). The SEA board of directors is composed of local community leaders, and all decisions regarding the reserve operation are based on thorough discussion and consensus amongst the communities. SEA is responsible for the day-to-day management of the reserve, including activities such as patrols and fee collections (Belize Fisheries Department, 2012). A number of local and international organizations have assisted SEA with institutional strengthening, community consultations, planning and reserve management. The coalition of National and International NGOs have jointly advocated for new legislation to protect Nassau grouper spawning aggregation sites, and in November 2002, two new laws were enacted (Sobel & Dahlgren, 2004). Together, these laws provide protection for aggregating finfish and serve as a model for other countries. It also provides collaboration between conservation groups, the commercial fishing industry, and the government of Belize (Sobel & Dahlgren, 2004).

Case two: Florida Keys National Marine Sanctuary (FKNMS) – Florida

Background

FKNMS is one of the fifteen (15) MPAs that make up the National Marine Sanctuary System in the United States of America. It is administered by National Oceanic and Atmospheric Administration (NOAA), a federal agency, and jointly managed with the state of Florida. FKNMS protects 2,900 square nautical miles of waters surrounding the Florida Keys, from south of Miami westward to encompass the Dry Tortugas, excluding Dry Tortugas National Park. Within the boundaries of the sanctuary lie the world's third largest barrier reef, extensive seagrass beds, mangrove-fringed islands, more than 6,000 species of marine life and protects pieces of America's history such as shipwrecks and other archaeological treasures (National Oceanic and Atmospheric Administration [NOAA], 2011). The Sanctuary provides habitat for the Florida manatee (*Trichechus manatus*), a threatened species under the Endangered Species Act (ESA) (NOAA, 2011).

The Problem

Warning signs about the fragile and finite nature of marine resources in the Florida Keys necessitated the establishment of John Pennekamp Coral Reef State Park off Key Largo in 1960 (NOAA, 2011). Persisting environmental degradation prompted the eventual designation of Key Largo National Marine Sanctuary in 1975 and the Looe Key National Marine sanctuary in 1981(NOAA, 2011). Regardless of these efforts made by the United States government to address the various direct, *in situ* impacts to coral reef resources and depletion of reef populations, various challenges persisted. Oil drilling proposals, reports of deteriorating water quality and evidence of declines in the health of the coral reef ecosystem, coupled with several large vessel groundings in the Keys led to the signing into law, the bill establishing the Florida Key National Marine Sanctuary in 1990 (Salm et al., 2000). This expanded protection of the area to an area of 2800 square nautical miles for conservation and included the previously protected areas. It encompasses 220 miles of coral reef tract that parallels the island chain of the Florida Keys (Salm et al., 2000).

Configuration

National marine sanctuaries are typically designated by the Secretary of Commerce through an administrative process established by the National Marine Sanctuary Act (NMSA). However, recognizing the importance of the Florida Keys ecosystem, and the degradation of the ecosystem due to direct and indirect physical impacts, Congress passed the Florida Keys National Marine Sanctuary and Protection Act (FKNMSPA) in 1990, designating the FKNMS to be managed as a national marine sanctuary under the NMSA (NOAA, 2011). After the initial six-year FKNMS planning process, a comprehensive management plan for the Sanctuary, the 1996 Florida Keys National Marine Sanctuary Management Plan, was implemented in July, 1997 (NOAA, 2011).

With the designation of the FKNMS in 1990, several protective measures were implemented. The sanctuary uses an ecosystem approach to comprehensively address the variety of impacts, pressures and threats to the Florida Keys marine ecosystem (NOAA, 2011).

Outcome

Accomplishments of the Sanctuary includes the establishment of an authority under the FKNMSPA and the implementation of the management plan in 1997 to identify the best and most practical projects and programs to protect the Sanctuary's natural and cultural resources while allowing commercial and recreational activities (NOAA, 2011). The Sanctuary has integrated the administrative functions of two former sanctuaries – at Key Largo and Looe Key – into a single headquarters umbrella with two regional offices. This integration streamlined delivery of human resources, community relations, and policy development (NOAA, 2011). The plan uses authorities from various state and federal agencies and coordinates the resources of many partners (NOAA, 2011).

Case three: Ria Lagartos and Ria Celestun Biosphere Reserves (RLRCBR) - Mexico

Background

In 1979, the Mexican Federal Government designated 59,130 hectares of the pristine coastal ecosystems of Ria Lagartos and Ria Celestun at the northern coast of the state of Yucatan, bordering the Gulf of Mexico as wildlife reserve, with the objective to protect the feeding and nesting ecosystems of flamingos found in Mexico. These estuarine wetland protected areas have now gained status as a Biosphere reserve (Salm et al., 2000; United Nations Educational Scientific and Cultural Organization [UNESCO], 2011).

The Problem

The principal impacts and threats facing Ria Lagartos are the loss of vegetation and ecosystem fragmentation caused by poorly planned cattle ranching and the expansion of salt mining, loss of aquatic species due to overfishing, and pollution caused by ranching practices and inadequate waste management. At Ria Celestun, the major threats to the health of the wetland system are vegetation loss caused by poorly planned development due to increasing population, the loss of aquatic species due to overfishing, altered ground-water flows and salinity caused by the poorly planned construction of highways and bridges, and pollution caused by inadequate waste management and the lack of sanitary facilities in urban areas. Local communities are growing, mainly due to inland migrations, and putting a strain on the available resource base (The Nature Conservancy, 2008).

Configuration

The Parks in Peril (PiP) project was launched to initiate management activities in both reserves, focusing on procuring field, communications and computer equipment; channeling resources for basic research; completing a threats analysis, monitoring programs, and land tenure updates; developing financing strategies; and building the capacity of both reserve and Pronatura Península de Yucatán (PPY) staff to carry out site conservation activities. PiP was a project created by The Nature Conservancy (TNC) in 1990, largely funded by the United States Agency for International Development (USAID), to create local capacity for conservation in threatened, high-biodiversity landscapes throughout Latin America and the Caribbean (The Nature Conservancy, 2008).

Support and information generated from the project was used in developing management plans for both reserves. In particular, the PiP consolidation products were fundamental to the development of the Ría

Celestún Management Plan, and have contributed to the channeling of research efforts and forging strategic alliances with research institutes and universities. The threats analysis has been one of the critical tools for designing a strategy for Ria Lagartos and has been the cornerstone for the Ria Celestun's strategy. The primary partners involved in conservation management in the reserves include the Non-Governmental Organization, PPY and the Ría Celestún and Ría Lagartos Biosphere Reserve Management through the National Commission for Natural Protected Areas (CONANP) (Salm et al., 2000).

Outcome

Ecotourism is an option considered within the management plan of the Ria Celestun Biosphere Reserve. The Federation of boat operators from Celestun has been playing a very important role both in promoting tourism development and keeping strict rules to navigate along the estuary in order to prevent flamingo flocks from being disturbed. Training of nature guides have been an important component in developing community based tourism in the Celestun coastal area, within an integrated management plan that provides trainees with the means for applying their new knowledge. Even local investors are interested in supporting the training of more Natural Guides to support management of the reserves. In 1997, the RARE Center, together with local NGOs, initiated the Nature Guide Training Programme on the Yucatan Peninsula, and trained the first nature guides from Celestun (Salm et al., 2000). Since the course, some of the Nature Guides have participated in various workshops organized locally to promote community participation in coastal management strategies. The guides learnt about the natural history of their region, nature interpretation, learned how to use field guides and binoculars, and other skills such as group management and clear communication. Both reserves gained status as Biosphere Reserves in 2004 (Salm et al., 2000).

Australia

Case four: Great Barrier Reef Marine Park (GBRMP) – Australia

Background

The GBRMP is the largest marine park in the World, with 3,000 separate reef systems, 760 fringe reefs, 600 tropical islands and an estimated 300 coral cays. It covers an area of 344,400 km^2 along the northeastern coastline of Australia (World Wildlife Fund [WWF], 2018). The nearshore areas of the reef till today, has been used by the Australian Aboriginal people for their subsistence, culture and lifestyle (Sobel & Dahlgren, 2004). The GBR also provides employment for many through the tourism, fishing and shipping industries managed on an ecologically sustainable basis (WWF, 2018).

The Problem

Increasing density of human use of the GBR became a concern during the late 1960s and 1970s. The concern was particularly attributed to oil drilling and limestone mining, increased land clearing and development along the adjacent coast, as well as accelerated fishing, recreation and tourism (Intergovernmental Ocenographic Commission - United Nations Educational, Scientific and Cultural Organization [IOC-UNESCO], 2019; Port Douglas, 2019; Salm & Clark, 2000).

Configuration

To address the human use concerns, the Federal parliament acted to establish the GBR marine park in 1975, to provide for multiple use consistent with established requirements for nature conservation. Zoning plans were used to provide a basic framework for management of the Marine Park. The Great Barrier Reef Marine Park Act, 1975 empowered the GBR Marine Park Authority, an independent statutory authority, to manage the entire area. Public involvement is a cornerstone of the Marine Park. A formally constituted Consultative Committee was established by the act and advises the authority and the responsible federal and state ministers. The act also requires the authority to seek public input into the development of zoning plans. Specialist advisory committees are also established where appropriate, to advice on strategies, or address critical issues, or to develop more detailed plans for management of intensively used areas. The Act banned oil drilling and mining as unacceptable threats to the coral ecosystem (IOC-UNESCO, 2019; Port Douglas, 2019; Salm & Clark, 2000).

Outcome

The establishment of an independent statutory Authority with strong legislative mandate to exclusively manage the protected area, has proven to be an important factor in the success of the GBR Marine Park. The authority adopts a holistic approach to ecosystem management by establishing formal complementary management arrangements amongst all relevant levels of government and stakeholders, creating processes for reaching agreement of proposed restrictions. This has fostered support of affected communities, since they are involved in the decision making process. The use of holistically developed zoning plans (the Great Barrier Reef Marine Park Zoning Plan 2003 and Regulations and the Marine Parks Zoning Plan 2004) enhances clear and conscience management of the protected area (Salm et al., 2000; Sobel & Dahlgren, 2004)

Africa

Case five: Chumbe Island Coral Park (CHICOP) – Zanzibar, Tanzania

Background

CHICOP is a privately created and managed protected area covering the whole of Chumbe Island and the fringing reef on its Western side, established in Zanzibar-Tanzania. It was the first, and remains up to date, the only functioning marine park in Tanzania (Chumbe Island Coral Park [CHICOP], 2017; Salm et al., 2000).

The Problem

The coral park was developed in 1991 for the conservation and sustainable management of uninhabited Chumbe Island off Zanzibar, one of the last pristine coral islands in the region. The Government of Zanzibar approved the project as a tourism investment based on the provisions of the Zanzibar Investment Protection Act 1986.

Configuration

With the help of volunteers and some limited donor funds, baseline surveys and species lists on the island's flora and fauna were conducted (Salm et al., 2000). After commissioning the ecological baseline surveys and thus establishing the conservation value of the island, CHICOP negotiated for conservation of the island and the Chumbe Reef Sanctuary was gazette as a protected area in 1994. Simultaneously, CHICOP was given management contracts for the whole of the island and the reef sanctuary (CHICOP, 2017; Salm et al., 2000). A management plan which guides the project's operation was produced in 1995 (Salm et al., 2000). The resort includes a fully protected Coral Reef Sanctuary and Forest Reserve that harbor rare wildlife, a Visitor and Education centre, small eco-lodge, nature walks and historical monuments (CHICOP, 2017). Though privately funded, the project is non-commercial (CHICOP, 2017). Profits from ecotourism are to be re-invested in conservation area management and free excursions for local schoolchildren. Conservation management was built up through capacity building and raising of awareness of local fishers (training of rangers and their interaction with fishers) and government officials (through an Advisory Committee), close monitoring and review (CHICOP, 2017; Salm & Clark, 2000). The hands-on approach to capacity building and monitoring through inexpensive on-the-job-training of local fishers by volunteers has produced very competent and committed park rangers. The rangers interact with fishers by stressing the role of the protected area as a breeding ground for fish. This has proved to be very successful. Village fishers now generally respect the park boundaries and report that catches outside the boundaries have increased since the establishment of the sanctuary (CHICOP, 2017; Salm & Clark, 2000).

Outcome

As a result of successful management, the coral reef has become one of the most pristine in the region, with 370 species of fish and over 200 species of scleractinian coral, at least 90% of all recorded in East Africa (Salm & Clark, 2000). The project has helped to raise conservation awareness and understanding of the legal and institutional requirements among government officials (Salm et al., 2000). Seven government departments were involved in negotiating the project in the initial phase, and this has improved political support and prepared the ground for improvements in the legal framework. It is a noted example of Payment for Ecosystem Services within the context of coral reefs ecosystem and commercial viability of tourism based on marine conservation (CHICOP, 2017).

Asia

Case six: Negombo Lagoon – Sri Lanka

Background

Negombo Lagoon is a large, productive estuarine lagoon in Negombo, south-west Sri Lanka, and covers an area of approximately $32km^2$. The lagoon supports many fishing households and is of international significance for biodiversity and a refuge for migratory birds. The lagoon is connected to the Indian Ocean by means of a narrow inlet near the Town of Negombo. It is part of a much larger Muthurajawela marsh – Negombo lagoon coastal wetland with a total area of 6,232 ha. The Muthurajawela marsh is 3,068 ha in extent and extend southwards from the 3,164 ha lagoon (DEFRA, 2007).

The Problem

The lagoon is faced by various environmental and socioeconomic problems including over-exploitation of marine and brackish water fisheries resource, alteration of sedimentation patterns and key hydrological characteristics due to change in land use in the catchment area, and, illegal encroachment in the wetland area due to rapid population increase (Prakash, Weerasingha & Supun, Aruna & Withanage, Amila & Kumsuminda, 2017; Salm et al., 2000).

Configuration

An ecosystem-based approach was used to integrate environmental considerations into a Master Plan. The plan was prepared by a consultant team based on biological, geo-physical and socioeconomic resource information and consensus building among stakeholders (Salm et al., 2000). Support was provided by the Netherlands government during a period of over seven years. The foundation of the Master Plan was zoning, which addressed the issues of development needs, conservation importance and equity (Samarakoon, 2005). For planning purposes, four zones (conservation zone, Buffer zone, Mixed Urban zone and Residential zone) were delineated for the lagoon and surrounding area endorsed by stakeholder workshops (Salm et al., 2000)

The Master Plan received Cabinet approval in 1991 and a Master Plan Implementation Steering Committee (MPISC) was established. The MPISC was instrumental in ensuring community participation during the entire planning process. The workshops resulted in a common vision on the ways to tackle the main coastal zone management issues, obstruction of lagoon-water exchange due to heavy siltation, and destruction of fisheries nursery areas (Salm et al., 2000).

Outcome

The management plan enhanced exercise of practicality, legitimacy, and equity; strong scientific and technical foundation based on ecosystem structure and functioning; community and stakeholder involvement and empowerment; and high level political commitment and inter-agency coordination. The plan offers a platform for Integrated Coastal Zone Management conservation in the Muthurajawela Marsh – Negombo lagoon estuarine system (Samarakoon, 2005). The Negombo lagoon has now been declared as a Fishery Management Area, under Section 31 of the Fisheries and Aquatic Resources Act, No.2 of 1996, by the Minister of Fisheries and Aquatic Resources in the Republic of Sri Lanka in 2005 (DEFRA, 2007).

CHAPTER THREE

MATERIALS AND METHODS

The materials and methods employed for assessing selected ecosystems in the GCTP area for possible designation as Marine Protected Areas are explained in this Chapter. The chapter commences with a description of the research design, followed by the study area. Subsequently, the materials and methods employed in conducting the socio-cultural, ecological and economic assessments within two communities of the GCTP area are explained.

Research Design

The study employed an integrated assessment approach, following the principles of applying the Ecosystem-Based Management (EBM) concept to management of coastal and marine ecosystems. Ecological assessments of each ecosystem were complimented with socio-cultural, and economic assessments in a Mapping, Assessment and Quantification process, following MAES, 2016. This facilitated the combination of direct scientific assessment of the ecosystems with perspectives from direct beneficiaries of ES, to afford managers a holistic insight into the array of issues that feed into a comprehensive management approach which addresses social, economic and ecological concerns. Results of the assessments were synthesized into a set of indicators for developing a set of criteria for verifying each ecosystem's suitability for assignment of conservation status. A proposed zoning plan for the study area was then developed based on the cumulative assessment of each of the ecosystems understudied.

Study Area

The Greater Cape Three Points (GCTP) area in the Ahanta West district of the Western Region of Ghana was considered for this study, based on initial studies carried out to identify the area as important for biodiversity and critical for the fisheries industry in Ghana (Ateweberhan et al., 2012; Coastal Resources Center & Friends of the Nation, 2011; deGraft-Johnson et al., 2010). It forms part of the areas proposed for protection in the national MPA draft (Nunoo, 2018). The area hosts a suite of critical ecosystems consisting of estuaries, lagoons, mangroves, sandy beaches and headlands that provide nurseries for many species that support Ghana's fisheries sector (Coastal Resources Center & Friends of the Nation, 2011). The area further provides the critical oceanographic conditions (temperature and food) for the post spawning life cycle of the round sardinella (*S. aurita*), an importance species in Ghana's artisanal fishery (Castro, Skrobe, Asare, & Kankam, 2017). The area also serves as a migratory route of this fish species to their spawning grounds and other countries within the sub- region (Brainerd, 1994). The stretch of sandy beach is a major nursing ground for marine turtles from August to March. Dolphins and whales inhabit the area as well, between October and December. The area also provides feeding grounds and habitat for many birds (Quartey, 2014).

Fishing and farming are the main traditional occupations in the area. The area portrays high levels of overfishing due to the near-complete removal of top predatory fish, resulting in the release of prey species and high dominance of a few abundant species as observed in scientific research (Ateweberhan et al., 2012). The continuous decline in fish catch has influenced many fishermen to either branch completely or combine their occupation with farming, intensifying the need for people to acquire huge areas of land for oil palm or rubber plantations (Coastal Resources Center & & Friends of the Nation, 2010).

The area has become more popular with the discovery of offshore oil in Ghana, as the first location for the commercial exploration of oil in the country. This has increased the potential for industrial and other related development, as prospective investors aggressively purchase lands, escalating the pressure exerted on the coastline in the near future (Coastal Resources Center & Friends of the Nation, 2010). Exploitation of the offshore oil and gas fields in the area also poses threats of oil pollution that could affect biodiversity. Other major issues of concern in this coastal area as identified by Coastal Resources Center & Friends of the Nation (2010) include, incidence of sand winning and sea erosion, destruction of mangroves, poor sanitary facilities and lack of basic amenities and rising social problems due to emerging oil and gas sector.

The study area, for the purpose of this study was restricted to the coastal ecosystems within Princess Town and Cape Three Points communities in the GCTP area, which lie between coordinates 4°48´13.3´´N; 2°8´23.4´´W and 4°45´9.4´´N; 2°5´15.9´´W (17.7 km^2) and extends up to one kilometer from the shoreline.

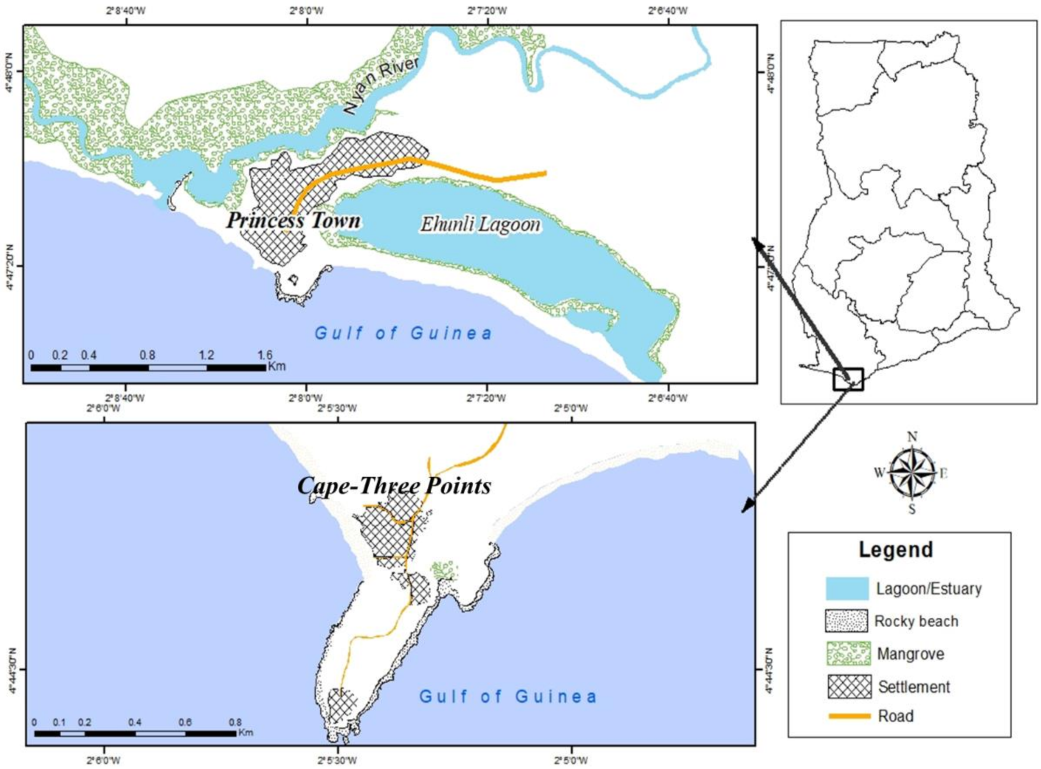


Figure 2: Map of study area.

Following the priority coastal ecosystems considered for conservation under Ghana's Fisheries Management Plan, 2015-2019, the following ecosystems were selected in the two communities for assessment, to understand their ecological, spatio-temporal and socio-economic values for managing fisheries in the area:

Princes Town

1. Nyan river estuary

The Nyan estuary (Figure 3) at Princess Town lies between coordinates 4^0 47' 46'' N, 2^0 08' 28'' W and 4^0 47' 57'' N, 2^0 08' 02'' W.

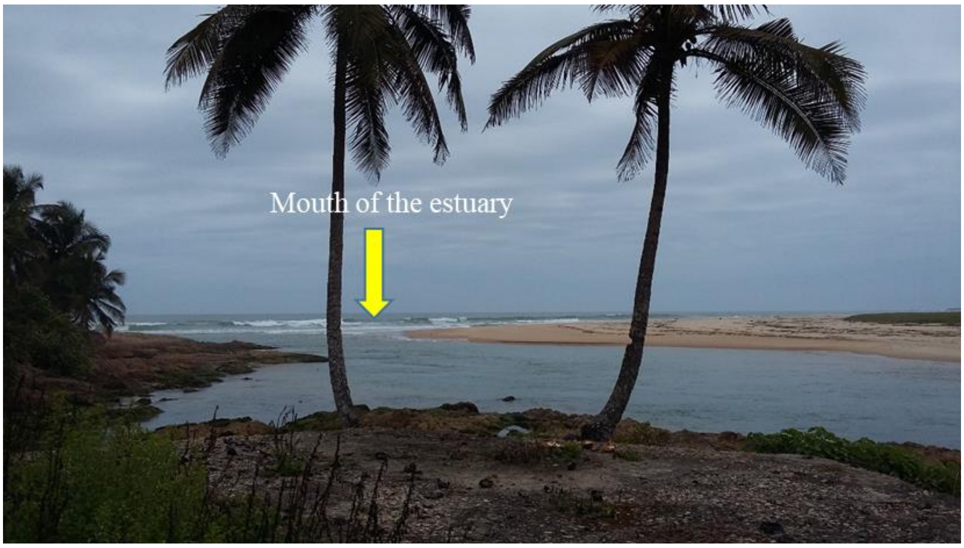


Figure 3: Picture showing Nyan estuary at Princess Town.

2. Ehunli lagoon

The Ehunli lagoon (Figure 4) is a close lagoon adjacent to the Nyan estuary at Princess Town. It lies between the coordinates 4^0 47' 44'' N, 2^0 07' 50'' W and 4^0 47' 06'' N, 2^0 06' 41'' W.

Figure 4: Picture showing Enhuli lagoon at Princess Town.

Cape Three Points

3. Rocky bay

The rocky bay (Figure 5) located at Cape Three Points, lies between coordinates $4^0$44'40"N, $2^0$05'17"W and 4^0 44' 37" N, 2^0 05' 14" W. It contains round boulders that are completely submerged at high tide and exposed at low tide and hosts a variety of algae and invertebrates, attracting a number of predator fish species.

Figure 5: *Picture showing rocky bay at Cape Three Points.*

4. Mangrove forests bordering each of the three water bodies.
5. Sandy beach

The sandy beach (Figure 6) investigated in the study area is found in Cape Three Points within the coordinates, 4^0 44' 40" N, 2^0 05' 26" W and 4^0 44' 55" N, 2^0 05' 33" W.

Figure 6: Sandy beach at Cape Three Points.

Sampling Procedure and Data Collection Methods

Ecological assessment of ecosystems in the study area

An ecological assessment of the ecosystems under study was conducted to investigate the "ecological value" or importance of the ecosystem, and to characterize current status for monitoring and projecting substantial changes (De Groot, Wilson, & Boumans, 2002; Ward, Tarte, Hegerl, & Short, 2002). Particularly, the ecological assessment formed the basis for scoring each ecosystem's degree of exposure to a stressor and consequence of the exposure.

The study combined indicators selected from the three categories of indicators - physical, chemical and biological indicators to conduct the assessment (Wicks, Longstaff, Fertig, & Dennison, 2010). Temperature, pH, salinity and turbidity were physical indicators used to describe the physical components of the ecosystem. Chemical indicators, represented by concentration levels of nutrients (phosphate and nitrate) in the ecosystem, were used to describe the chemical components of the ecosystem. Species diversity and conservation status of finfish and shellfish sampled in the study area were the biological indicators used to express ecosystem function of the area. Finally, carbon stocks of mangrove forests in the study area was also determined to express the regulation function of the ecosystem in terms of carbon storage.

Determination of physicochemical parameters

Five sampling stations each were demarcated along the lagoon and estuary with the aid of a boat, aerial photos and GPS device. The stations were spread about 100m apart from each other across the length of each of the water bodies in order to obtain samples that are representative enough of the system. For the estuary, Station 1 was situated at the mouth (close to where the river enters the sea) and for the lagoon, station 1 was situated at the point where the lagoon begins within the community. For each station, three samples were collected from the edges and the mid portion of the water as replicates to describe conditions in that station. For each sampling station, Temperature, salinity, pH and turbidity of the water were measured along 3 random Points using the Horiba U50 Series multi-parameter water quality probe. Sampling was done for a period of one year, from November, 2017 – November, 2018.

Figure 7: Measuring water quality parameters on the Nyan estuary.

The probe was immersed to a depth of 30 - 40 cm. Two measurements were taken of each parameter at the sampling point after which the average was calculated for each sampling station.

Water samples were also collected at each sampling point in plastic containers and stored on ice for transportation to the laboratory to conduct nutrient analysis. Using the chemicals, NITRAVER 5 PWD PLWS 10 ml and PHOSVER 3 PWD PLWS 10 ml, the nitrate and phosphate levels of the water bodies were estimated following protocols for using the pocket calorimeter, DR900.

Determination of biological parameters

Rocky shore fauna (Rocky bay)

Gastropods, bivalves, urchins and other rocky shore fauna were randomly sampled, identified and counted quarterly, using a 0.25 m^2 quadrat and transect in a stratified random sampling method within one hectre of sampling area at low tide for a period of one year (November, 2017 – November, 2018).

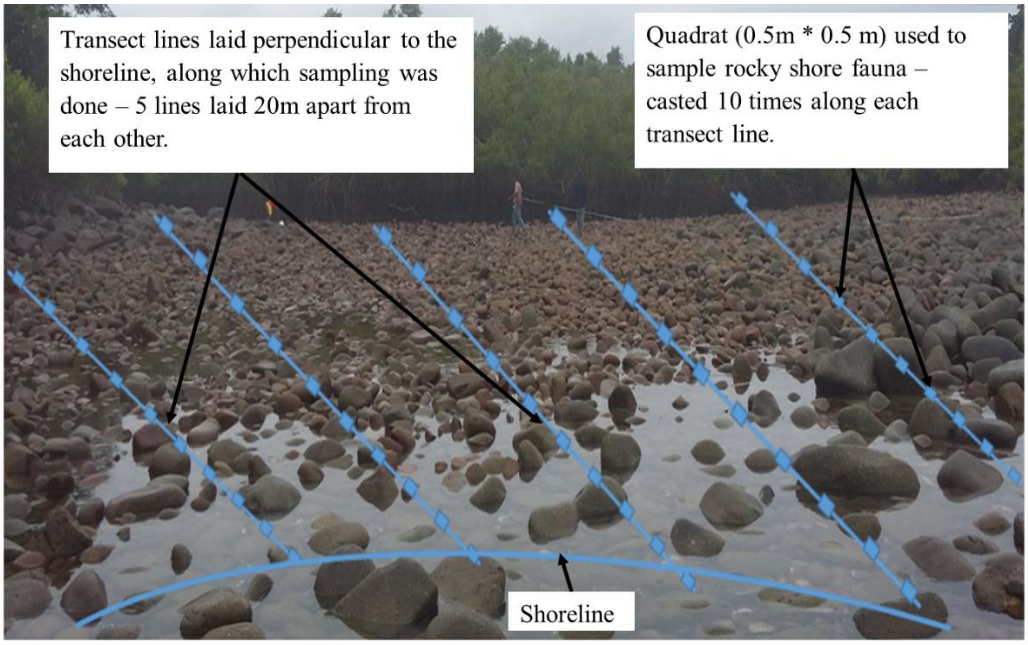


Figure 8: Sampling design for collecting rocky shore fauna data.

Samples of the various species encountered on the field during the sampling exercise were stored in containers, duly labelled and sent to the laboratory for due identification following Edmunds & Agyei-Henaku, 1978. Species encountered during each sampling session were listed and their frequencies recorded in a quarterly period.

Finfish (Ehunli lagoon and Nyan estuary)

Fishes were sampled monthly from the two water bodies using a cast net, from November, 2017 to November, 2018. Samples were kept on ice to minimize post mortem decomposition and taken to the laboratory for further analysis.

In the laboratory, each specimen was identified using FAO's Species Identification Guide for Fishery purposes (Volumes 2, 3 and 4) (Carpenter & De Angelis, 2016). The total lengths (TL) and weight of each species were also measured.

Mangroves

Mangrove data were collected between February 2018 and March 2018 for carbon assessment in the study area. A global positioning system (GPS) was used to determine the coordinates of the sites, plots and soil sampling locations.

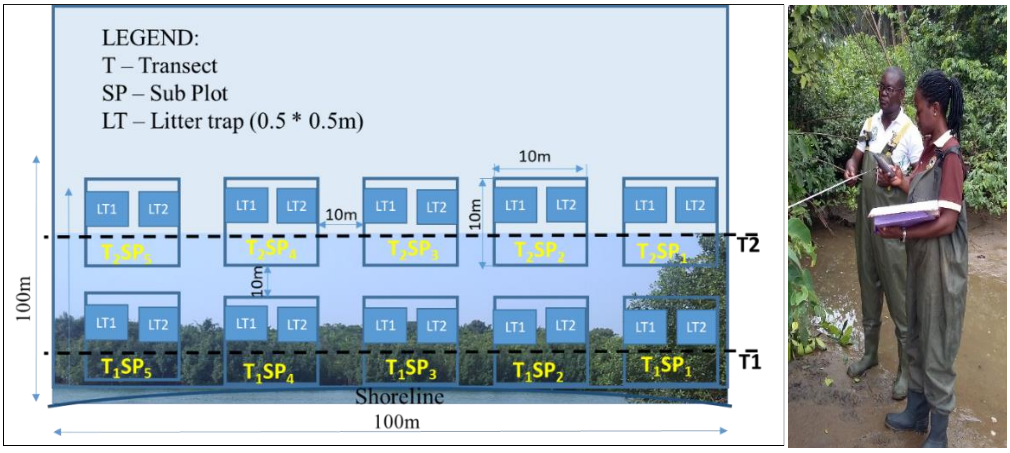


Figure 9: Sampling design for carbon assessment of mangrove ecosystems.

A sampling design adapted from Kauffman and Donato (2012) was used to describe forest composition, biomass and ecosystem carbon pools. Stratified systematic sampling was used where parallel transects were laid perpendicular to the water's edge. A rectangular plot design was adopted unlike circular plots proposed by Kauffman and Donato (2012) in order to reduce heavy disturbances of the mangrove seedlings and sediments. One hectare (10,000 m^2) sampling plots were demarcated for each of the mangrove ecosystems under study in the study area. Within each plot, ten (10) subplots, of an area of 100 m^2 (10m by 10 m) each were demarcated using a measuring tape and ribbons. The subplots were spaced 10 m perpendicular to the shoreline and 5 m parallel to the shoreline from each other. The rationale for this design was to provide a basis to assess stock-change estimates across the mangrove forests.

Two litter traps (0.5m x 0.5m) each were placed on two trees randomly in the subplots to directly collect litter that fall from the trees for analysis.

Soil samples were obtained at random locations within each subplot to analyze soil carbon stocks.

In order to quantify the total carbon stocks in the study area, the mangrove ecosystem was divided into aboveground and below-ground components (Donato et al., 2011). Carbon stocks of four (4) different carbon pools of the mangrove system were estimated:

- Above ground living biomass (mangrove trees)
- Above ground dead biomass (leaf litter)
- Below ground biomass (roots and rhizomes)
- Soil

Above ground living biomass and carbon stocks

Mangrove trees with stems ≥ 2 cm within the sampling plots were sampled. The different species found within the plot were identified, counted and recorded. Diameter at breast height (DBH) of each tree was measured using a tape measure and Vernier calipers where appropriate and also recorded. The biomass of live trees and their equivalent below-ground biomass were calculated using published allometric equations following Komiyama, Sasitorn, & Shogo, (2005). Using conversion factors, the relative organic carbon stocks of the aboveground and belowground carbon pools were also estimated.

Above ground dead biomass

Mangrove leaves trapped in the litter traps were collected into a plastic bags and transported to the laboratory for biomass and organic carbon estimation using equations following Howard, Hoyt, Isensee, Telszewski, & Pidgeon, (2014). In the laboratory, the composite sample (comprising of litter collected from each sub-plot) was weighed and its fresh weight was recorded. A sub-sample from the composite sample was recorded and its fresh weight was weighed. The sub-sample was dried at a temperature of 105 degrees Celsius for 24 hours and its dry weight was recorded.

Soil biomass

To accurately measure the soil carbon pool, three parameters were quantified: 1) soil depth; 2) soil bulk density; and 3) organic carbon concentration. For the purpose of this study, the mangrove soils were sampled in the top 100 cm depth. A corer was designed and manufactured locally following protocols from Kauffman and Donato (2012), with openings at 10cm intervals along the entire length of the corer. To obtain the soil samples, the corer was steadily inserted vertically into the soil until the top of the sampler was at a level with the soil surface. At a depth of 100 cm, the corer was twisted in a clockwise direction a few times to cut through any remaining fine roots. The corer was pulled gently out of the soil while continuing to twist it, in order to retrieve the soil sample. Soil subsamples of 20 cm^3 each were obtained at 20 cm and 90 cm length of the corer to represent two depth classes of the soil profile (0 - 30 cm and 80 - 100cm) using a cut-off polyethylene syringe (Kauffman & Donato, 2012). The samples were placed in labeled zip lock bags and transferred to the laboratory for analyses of soil carbon content. In the laboratory, the soil samples were dispensed onto a pre-weighed Petri dish and oven-dried to a constant mass at 105°C to determine the bulk density of the samples. The Loss on Ignition (LOI) method was used to determine soil organic matter (Salehi, Beni, Harchegani, Borujeni, & Motaghian, 2011). Following this method, soil samples were subjected to combustion at a high temperature of 550°C for 4hrs.

Socio-cultural valuation of ES

Community members in the two communities (Princess Town and Cape Three Points) were actively engaged in a participatory mapping and assessment of Ecosystem Services (ES) provided by ecosystems in the study area (Paudyal et al., 2015). This was done to involve local community members who are dependent on coastal resources and are important stakeholders in the use and management of the resources. As a way of raising public awareness on services provided by ecosystems in the area and their value for their well-being, community members were involved to enhance effective sustainable measures (Bureau of Fisheries and Aquatic Resources of the Department of Agriculture, 2001).

Following the Direct Field Observation method (Kawulich, 2005), a reconnaissance survey was initially conducted to observe the fisheries related activities in the study area, the ecosystem services provided by ecosystems in the area that support fisheries livelihoods, and the anthropogenic pressures exerted on these ecosystems. Key informants (the Chief, Chief fisherman, Tourism manager, Assemblyman and youth leader) of each of the two communities were contacted and briefed about the purpose of the study (Kumar, 1989; McKenna, Iwasaki, Stewart, & Main, 2011). They were then engaged in interviews on fisheries in their communities, state of the ecosystems in the area and identification of the various anthropogenic pressures on them following an interview guide (refer to Appendix A).

Based on observations made from the reconnaissance surveys and literature (Barbier, 2017; Sousa, Sousa, Alves, & Lillebø, 2016; United Nation Environment Program [UNEP], 2006), ES provided by the selected ecosystems that support fisheries in the area were identified and listed. The Common International Classification of Ecosystem Services (CICES) scheme was used to classify the services for easy and clearer assessment. These observations formed the basis for conducting the participatory mapping and assessment.

Subsequently, community stakeholders were duly sensitized about the mapping and assessment exercise in a preliminary community durbar, where the purpose for the study and requirements from the communities were explained. Consent of the participants involved in the mapping and assessment exercise was sought to use their information given for academic research purposes. The community stakeholders were then engaged in collectively selecting top 5 most important ecosystem services that support fishing activities as observed in the area according to their perceptions. They were then guided through participatory mapping of the location of these ecosystem services and significant changes that have occurred in the ecosystems that has affected the trends in ecosystem services supply in the area. Community stakeholders were also requested to prioritize 4 anthropogenic pressures on ecosystems that threaten their ability to provide ecosystem services and map the sources of these pressures.

To enhance communication of the concepts and interpretation of the ES, a photo collage was designed in which the list of ESs identified were set along with photos and examples of how they could contribute to well-being. Specific photos of the study area were used if available, to help in communicating better to the participants. The accuracy and reliability of outputs of this mapping and assessment approach is dependent on the degree to which local communities understood the functioning of the ecosystems and the services they provide.

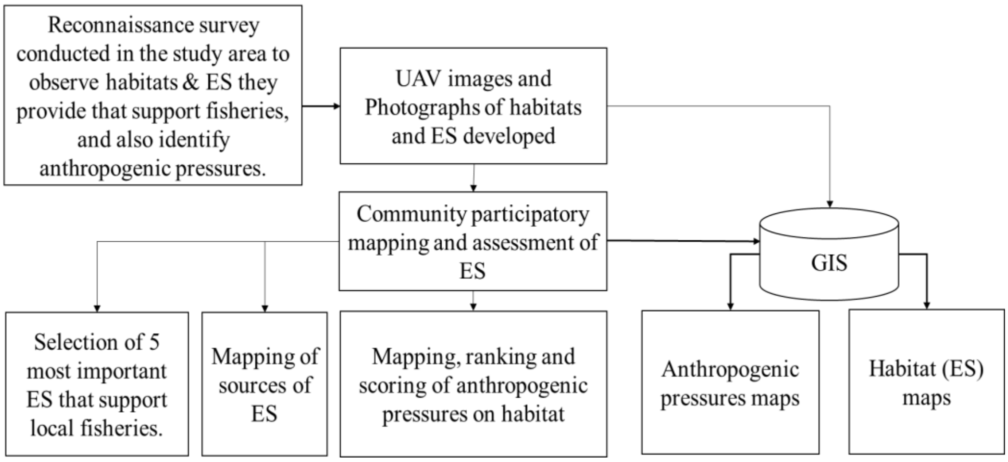


Figure 10: Framework for conducting socio-cultural assessment of ecosystem services provided by ecosystems in the study area. Adapted from Paudyal et al., (2015).

Stakeholder identification and selection

For the purpose of this study, only individuals with a connection to fisheries in the community were selected to participate in the mapping and assessment exercise to investigate the values they place on the ES provided in the study area. Adopting the purposive, snowballing method (Naderifar, Goli, & Ghaljaie, 2017), these key informants assisted in identifying people engaged in fisheries activities in the communities, who were then invited for the participatory assessment. A total of 100 people (55 in Princess Town and 45 in Cape Three Point) agreed to participate in the study. Following the Focus Group Discussion (FGD) method, which involves assembling people from similar backgrounds or experiences together to discuss a specific topic, local resource users (consisting of shellfish collectors, fishermen and fish processors) in both communities were put in groups, each containing a maximum of seven (7) individuals for each category of local resource users. (Oversees Development Institute, 2009; van Eeuwijk & Angehrn, 2017).

Selection of five most important ecosystem services that support local fisheries

A non-monetary, qualitative valuation of ES method, as adopted by (Paudyal et al., 2015), was employed to rank and select 5 most important ES provided by each ecosystem that support fisheries according to the perception of the community members who use the resources. Base maps of the ecosystems under study, produced from UAV images of the study area, obtained from the Center for Coastal Management of the University of Cape Coast were used for the participatory assessment. The images were captured during the reconnaissance survey in November, 2017. The image map for Princess Town and Cape Three Points were printed in color at a scale of 1: 2,250 and 1: 1,800 respectively. Participants were guided in identifying physical features on the base maps to facilitate interpretation of the maps.

All ES for each ecosystem were displayed in groups according to the ES categories – Provisioning, Regulating and Maintenance, and Cultural services. Paper stickers with numbers on them were pasted beside each ES for easy identification of the ES.

Figure 11: Display of ecosystem maps and ES photographs.

The ES categories were explained to the participants. Also, each ES was explained with reference to how they contribute to the fisheries sector. To ensure participants understood the concepts, they were encouraged to ask questions and also summarize the explanations given them in their own words.

Figure 13: Participants observing and selecting 5 ES of importance to fisheries and ranking the ES individually.

The reasons for the choices and ranking made were discussed in groups and presented by each group for discussion to ascertain the community's collective decision on which ES are critical for fisheries in the communities.

Figure 14: Participants discussing the reasons for their ranking in their focus groups.

Mapping out ES for each ecosystem

Presence of the 5 selected ES in each of the ecosystems under study was also determined using the participatory method. Participants in the focus groups were asked to indicate the various ecosystems that provide each of the

ES they selected and rank them with scores ranging from 1 (low provision of the ES) to 3 (high provision of the ES).

Assessment of anthropogenic pressures in the study area

Anthropogenic pressures on the ecosystems in the study area identified initially by the key informants in the communities were presented to the 7 FGs in each community. The participants were requested to rank them in order of importance collectively. Top 4 pressures were then selected to represent critical pressures in each of the communities in the study area. Each FG was also presented with base maps of each ecosystem and were guided in identifying physical features on the base maps to facilitate interpretation of the maps. The groups were then requested to mark the locations of each of the stressors on the maps using a set of symbols and colors to indicate the type and rank of the pressure. The maps were converted into digital format and were geo-referenced to serve as a basis for mapping pressures on the ecosystems under study.

Figure 15: Participant indicating location of pressures.

Economic valuation of ES

Community participants also provided data for the economic valuation of selected ES. Economic valuation of ES is widely advocated as being useful to support ecosystem management decision-making. Data provided included unit price of fish, unit cost of harvesting a kilogram of fish, quantity of fish harvested daily, number of fishing trips made daily, tour revenue generated annually and number of tourists recorded annually. The data were used to estimate the market price of the services as an indication of the economic value placed by the community on those services. By means of an open-ended questionnaire, data was captured for estimating the Total Economic Value (TEV) of ecosystems in the study area (refer to Appendix 2). TEV provides a holistic measure of the economic value of ecosystems, made up of use and non-use values which can be further sub-classified if appropriate (Pearce, Atkinson, & Mourato, 2006; TEEB, 2010). The TEV method was adopted on the assumption that making nature's values visible facilitates mainstreaming the values of biodiversity and ecosystem services into decision-making at all levels. This is assumed to help decision-makers recognize the wide range of benefits provided by ecosystems and biodiversity, demonstrate their values in economic terms and, where appropriate, suggest how to capture those values in decision-making.

Furthermore, a Cost-Benefit Analysis (CBA) of fishing in the GCTP area was performed to examine the profitability of fishing activities (Aheto, 2011). The CBA method employed for this study was the Net Present Value (NPV). NPV is a discounted cash flow technique that takes into account the time value of money. In this study, NPV greater than zero inferred profitability. The NPV method was applied with the assumption that the discount rate remains unchanged during the project period. It was also assumed that investment is made once cash flow is recovered.

Figure 16: Obtaining data on operation costs and income generated from fishing activities.

The methods employed for conducting the economic valuation, as well as the sources of data obtained for the valuation are summarized in Table 5.

Table 5 – *Methods for Economic Valuation of Ecosystem Services*

ES Category	**ES**	**Data Source**	**Valuation Method**
Provisioning	Food: Finfish, Shellfish (Direct Use Value - DUV)	Primary data on price of products harvested, quantities harvested and cost of harvesting obtained through field surveys using questionnaires	Market price [Economic value = A *(B - C)], where A = Annual gross harvested / cultivated amount (kg/yr), B = unit price of good ($ / kg), C = unit cost for harvesting / cultivating the good ($ / kg) (Costanza et al., 1997; De Groot et al., 2002; DEFRA, 2007; Merriman & Murata, 2016)
Regulating and Maintenance	Carbon storage and	Primary data obtained from field carbon	Market price [Economic value = A * B], where A = Total amount of carbon

ES Category	ES	Data Source	Valuation Method
	cycling (Indirect Use Value – IUV)	stock assessment. Market price of carbon obtained from EU ETS – World Bank, 2019	stored in the site (area of mangrove * carbon storage of mangrove), B = unit price of carbon ($27/t$CO_2$e) (Merriman & Murata, 2016)
Cultural	Tourism (Direct use value)	Primary data on number of tourist visits and amount paid, obtained from tourism office in the communities	Tour revenue generated annually ($) (Price of tours * Number of tourists) (DEFRA, 2007; Merriman & Murata, 2016)
Cultural	Spiritual (Existence value)	Primary data obtained through field surveys using interview and questionnaire schedules to estimate the average amount the community is willing to pay yearly for the protection of places of spiritual importance	Stated preference method (amount willing to be paid for protection of water bodies for spiritual purposes) ($) (Aheto, 2011; Barbier, Acreman, & Knowler, 1997; Liekens et al., 2010)
Cultural	Aesthetics (Existence value)	Primary data obtained through field surveys using interview and questionnaire schedules to estimate the average amount the community is willing to pay yearly to manage places of aesthetic value to the community.	Stated preference method (amount willing to be paid for maintenance of places with aesthetic value) ($) (Aheto, 2011; Barbier et al., 1997; Liekens et al., 2010).

No standardized method exists in the community for the pricing of fish which is usually sold locally within the community or to middle men to be transported to larger markets. For the purpose of this study, a special bucket was used to standardize the weight and price of products harvested. To harmonize the quantities of fish harvested from the lagoon and estuary monthly, the average weight of fish harvested from each system once monthly for a 12 month-period was determined. The estuary yielded an average of 1.4 kg/trip/month and the lagoon yielded 2.1 kg/trip/month. These standardized quantities were then multiplied by the highest number of trips recorded for the fishermen per month in the survey (28 trips), to determine the monthly output.

Data Analysis

Spatial multi-criteria analysis, which involves modelling problems geographically, using computer processing, and predicting outcomes, interpreting and understanding change and detecting important patterns, was employed in analyzing field data obtained for the integrated ecosystem assessment. Data collected for each assessment type were however analysed independently using various methods to interpret and synchronize all the data collected.

Ecological assessment

Physicochemical parameters

Descriptive statistics were used to analyze the physicochemical data obtained from the field. Univariate analysis, consisting of frequency distribution, mean and standard deviation were used to understand the trends in the data. Microsoft Office (Excel) was used to perform these analysis and plot graphs and tables to demonstrate the trends for each of the parameters for interpretation and determination of level of anthropogenic pressures for performing the ecosystem risk assessment.

Biological parameters

Rocky shore fauna

The Margalef index was used to determine species richness of the rocky bay. Species richness, defined as the number of species present in a sample / ecological community (Dellasala, Goldstein, & Veech, 2018), was calculated using the equation:

Species richness, $d = [(S-1) / (\ln N)]$ (3.1)

where, S is number of species in the sample, and N is the number of individuals in the sample.

The Shannon-Wiener index was also used to determine the species diversity of the rocky bay. Species diversity, which is a function of species richness, the number of species in a given locality and species evenness (Baillie & Upham, 2012), was calculated using the equation:

Species diversity, $H' = [-\sum_{t=1}^{S} Pi(\ln Pi)]$ (3.2)

where, S is the number of species in the community and P_i is the proportion of individuals belonging to species i in the community.

The evenness or equitability component of diversity, which expresses how evenly the individuals in the community are distributed over the different species (Heip, Herman, & Soetaert, 1998), was calculated from Pielou's index (J) given as:

$$J' = H'/H_{max} \quad (3.3)$$

where H' is the number derived from the Shannon diversity index and H_{max} is the maximum possible value of H' (if every species was equally likely)

Each of the species encountered in the sampling were checked against the IUCN Red List of Threatened Species categories (IUCN, 2018) to verify their conservation status.

Finfish

Fish samples were analysed for species richness, diversity and evenness with formulae 3.1, 3.2 and 3.3.

Each of the species encountered in the sampling were checked against the IUCN Red List of Threatened Species categories to verify their conservation status. Also, length-frequency distribution of 5 most important fish sampled in the study area was generated to describe the modal sizes of the species encountered. The 5 most important species in the study area were determined using the following criteria: most abundant species; endangered / threatened species; the highest priced species encountered in the field samples; and the species that occurred throughout the sampling period.

Mangroves

Mangrove tree population parameters:

The species frequency and relative frequency of the mangrove trees sampled were calculated to understand the population dynamics of each forest.

The frequency of each species, i, F_i, was calculated as:

$$F_i = \frac{\text{Number of individuals of species } i}{\text{Total Number of individuals of all species}} \quad (3.4)$$

The relative frequency, R_f of each species, i, was as:

$$R_f = \frac{\text{Frequency of species } i}{\sum \text{Frequencies of all species}} X\ 100 \quad (3.5)$$

Biomass and Carbon Stocks:

Aboveground living biomass (mangrove trees) -

Estimates of aboveground living biomass (*Wtop*) and belowground biomass (W_R) were calculated using the allometric equations for mangroves developed by Komiyama *et al.* (2005) for Southeast Asian mangroves**.** The following common allometric equations were used:

Above-ground biomass, Wtop = $0.251pD^{2.46}$ (3.6)

where Wtop is above-ground biomass, *p* is specific wood density and D is diameter at breast height. The biomass of trees in each subplot were summed to obtain the total biomass in Mg per plot (1 Mg = 1 metric ton). Biomass was then converted to the equivalent amount of carbon by multiplying the aboveground biomass by a factor of 0.46 (Howard et al., 2014)

Below-ground biomass, $W_R = 0.199p^{0.899}D^{2.22}$ (3.7)

Where WR is below-ground biomass, *p* is specific wood density and D is diameter at breast height. The belowground biomass values of trees in each subplot were summed to obtain the total biomass in Mg per plot (1 Mg = 1 metric tonne). Biomass was converted to the equivalent amount of carbon by multiplying the aboveground biomass by a factor of 0.39 (Howard et al., 2014)

Aboveground dead biomass – leaf litter, LL (kg) =

$$\frac{\text{dry mass of subsample (g)}}{\text{wet mass of the subsample (g)}} X \text{ wet mass of all the litter in the sample plot (kg)} \qquad (3.8)$$

Carbon in the leaf litter component per area (kg C/m) was estimated as (Kauffman & Donato, 2012):

(Average biomass of the litter * Carbon conversion factor (0.45)) / Area of the plot (m^2). (3.9)

Soil:

The dry bulk density, D_{bd} (gcm^{-3}) of the soil samples were estimated as: oven-dry sample mass (g) / sample volume (m^3) (Kauffman & Donato, 2012)

$$D_{bd} = \frac{\text{oven−dry sample mass (g)}}{\text{sample volume (m3)}} \quad (3.10)$$

Loss on ignition (%LOI) (Kauffman & Donato, 2012) was estimated as:

$$\%LOI = \frac{\text{dry mass before soil combustion (mg)} - \text{dry mass after combustion (mg)}}{\text{dry mass before soil combustion (mg)}} X\ 100 \quad (3.11)$$

The soil organic carbon content (%C_{org}) (Kauffman & Donato, 2012) was estimated as:

$$\%Corg = 0.415 * \%LOI + 2.89 \quad (3.12)$$

Soil carbon, SC (Mgha^{-1}) was finally calculated as: bulk density (gcm^{-3}) * Soil depth interval (cm) * %C_{org} (expressed as a whole number)

$$SC = D_{bd}\ X \text{ Soil depth interval } X\ \%C_{org(expresed\ as\ whole\ number)} \quad (3.13)$$

Total Carbon Stocks of mangrove ecosystem –

The total carbon stock (or density) of the mangrove system was determined by adding all of the component pools according to protocols by (Kauffman & Donato, 2012).

Total carbon stock (Mg ha-1) of plots = $C_{treeAG} + C_{treeBG} + C_{ll} + C_{soil}$ (3.14)

Where C_{treeAG} = above-ground carbon pools of trees; C_{treeBG} = below-ground tree carbon pool; C_{ll} = Leaf litter carbon pool and C_{soil} is the total soil carbon pool (Howard et al., 2014).

The carbon dioxide equivalent was used as a proxy for carbon sequestered by the mangroves under study. Carbon sequestration is the long-term storage of CO_2 or other forms of carbon to mitigate or defer global warming and avoid dangerous climate change.

Total potential CO_2 sequestered per hectare (Mg CO_2/ha) = Total carbon stock multiplied by conversion factor of 3.67 (Howard et al., 2014). (3.15)

Socio-cultural assessment

Results of the ecosystem services and anthropogenic pressure mapping exercise performed by the communities, harmonized with GPS coordinates of observed pressures taken during the field visit were used to generate pressure maps via QGIS 3.0 software in a spatial data exploration analysis. The base maps on which the markings were made were converted into digital format and geo-referenced to use as a basis for generating the pressure maps. Results from the community ranking and scoring of pressures exerted on ecosystems were combined with data obtained from the ecological assessment in a scoring criteria to determine exposure and consequence scores to be used in the ecosystem risk assessment.

Economic valuation of ecosystem services

Total Economic Value was estimated as DUV + IUV + OV + EV (Barbier et al., 1997; TEEB, 2010) (3.16)

where, DUV is Direct Use Value, defined as the economic or social value of the goods or benefits obtained from the services provided by an ecosystem that are directly used by a person.

IUV (Indirect Use Value) relates to the change in the value of production or consumption of an economic activity or property that an environmental function is protecting or supporting.

OV (Option Value) is the value which arises because an individual may be uncertain about his or her future demand for a resource and/or its availability in the ecosystem in the future. Option value was not estimated in this study since the participants could not quantify futuristic services and was thus omitted from the TEV.

EV (Existence Value) relates to the intrinsic value people place on an ecosystem, not because they currently use them, but because they derive some satisfaction from its existence and wish to see them preserved ‘in their own right’.

BV (Bequest Value) results from individuals placing a high value on the conservation of ecosystems for future generations to use.

NPV was calculated following the equation:

$$NPV = \sum_{t=1}^{n}(B_t - C_t)/(1+r)^i \quad (3.17)$$

Where: r is the discount rate, t is the number of time periods, B_t is the benefits derived from fishing during a single period, t, C_t is the operational cost of fishing during a single period, t and i is the lifespan of a fishing vessel estimated to be 10 year.

The present value was discounted based on Ghana Commercial Bank’s interest rate value for December, 2018 at 26.86% (Bank of Ghana, 2019).

The cost items used in calculating the total cost for harvesting was limited to Equipment cost, which was calculated as purchase cost divided by the expected lifetime of the equipment, plus typical annual repair/maintenance cost (Merriman & Murata, 2016).

Integrated Habitat Risk Assessment

The Habitat Risk Assessment (HRA) model of InVEST Software version 3.7 was used to assess risk posed to the selected ecosystems by human activities in a spatial analysis, following the methodology applied by Cabral et al., (2015). This was generated to prioritize areas for conservation and inform the design and configuration of spatial plans. The model was applied on the assumption that ecosystems are impacted by anthropogenic pressures that pose varying levels of risks on the ecosystems' ability to continually provide ecosystem services. This involved the combination of information about exposure of the ecosystems to each of the stressors selected in the participatory mapping exercise, with information about the consequence of that exposure for each ecosystem. Given the limited information on the effect of anthropogenic pressures on habitats, it was assumed that the ecosystems understudied respond to pressures in similar ways to how other ecosystems around the world respond to such pressures according to available literature documented for those areas. Thus, where local data was absent, data from other areas where literature was available was used.

Criteria used to assess the exposure of each ecosystem to a stressor, following Tallis et al. (2016), were:

- Temporal overlap – refers to the duration of time that the ecosystem and the stressor experience spatial overlap.
- Intensity – based on how intensive the ecosystem is exposed to the stressor. Stressors that occur the whole year have higher intensity than the ones that occur only for a few months in the year.
- Management effectiveness – based on the management strategies that reduce or enhance exposure of ecosystem to stressors. Low score is allocated when management is effective and high score allocated when management is not effective.

Criteria used to assess the consequence of exposure to a stressor were:

- Change in area – refers to the percentage change in areal extent of a ecosystem when exposed to a stressor.
- Natural disturbance – refers to the degree to which a ecosystem is resilient to anthropogenic stresses due to its naturally frequent perturbation.
- Natural mortality – refers to the rate of recovery of a ecosystem from disturbance. Ecosystems with high natural mortality rates are generally more productive and more capable of recovery.
- Recruitment rate – the process by which young individuals (e.g., fish and coral larvae, algae propagules) undergo larval settlement and become part of the adult population.

The likelihood of exposure (E) of a ecosystem to a stressor and the consequence (C) of this exposure was compiled using community responses generated from the community members during the participatory mapping exercise by assigning a score (0 – 3) to a set of criteria for each attribute as demonstrated in Table 3 following Cabral et al., 2015 and Tallis et al., 2016. This was validated through observation from the reconnaissance studies, ecological assessment, drone imagery of the study area and literature. Criteria were selected based on their applicability to the study area and availability of data as shown in Table 6.

Table 6 – *Criteria for scoring Exposure and Consequence*

Criteria	Score			
	0	1	2	3
Exposure				
Temporal overlap	No score	Ecosystem and stressor co-occur for 0-4 months of the year	Ecosystem and stressor co-occur for 4-8 months of the year	Ecosystem and stressor co-occur for 8-12 months of the year
Intensity	No score	Low	Medium	High
Management	No score	Very effective	Somewhat effective	Not effective
Consequence of exposure				
Change in area	No score	Low loss (0–20%)	Medium loss (20–50%)	High loss (50–100%)
Natural disturbance	No score	Low (daily to weekly)	Several times per year	Annually or less often
Recovery / Ecosystem resilience attributes				
Natural mortality	No score	High mortality (80% or higher)	Moderate mortality (20-50%)	High (annually or less often)
Recruitment rate	No score	High mortality (Every 2+ yrs)	Medium (Every 1-2 yrs)	High (annual or more)

Source: Tallis et al. (2016)

The overall exposure E and consequence C scores assigned for each ecosystem were calculated as weighted averages of the exposure values and consequence value assigned in the scoring exercise, following Tallis et al., 2016:

$$E = \frac{\sum_{i=1}^{N} \frac{e_i}{d_i . w_i}}{\sum_{i=1}^{N} \frac{1}{d_i . w_i}} \tag{3.18}$$

$$C = \frac{\sum_{i=1}^{N} \frac{c_i}{d_i . w_i}}{\sum_{i=1}^{N} \frac{1}{d_i . w_i}} \tag{3.19}$$

Where, d_i represents the data quality rating for criterion i, w_i represents the importance weighing for criterion i and N is the number of criteria evaluated for each ecosystem. The level of risk of each ecosystem *i*, caused by pressure *j*, R_{ij}, was generated using the Euclidean distance equation (Tallis et al., 2016):

$$R_{ij} = \sqrt{(E-1)^2 + (C-1)^2} \quad (3.20)$$

The final outputs from the model were:

1. A map depicting each ecosystem's cumulative risk from all the stressors considered. A ecosystem's risk is classified as HIGH if its cumulative risk score is 66%-100% of the total possible cumulative risk score, MEDIUM if its cumulative risk score is 33%-66% of the total possible cumulative risk score, LOW if its cumulative risk score is 0-33% of the total possible risk score or NO RISK if there's no stressor on the ecosystem cell.
2. A map depicting the cumulative risk of the entire ecosystem considering the average index of risk across all the ecosystems. The risk categorization follows the ecosystem risk categorization above.

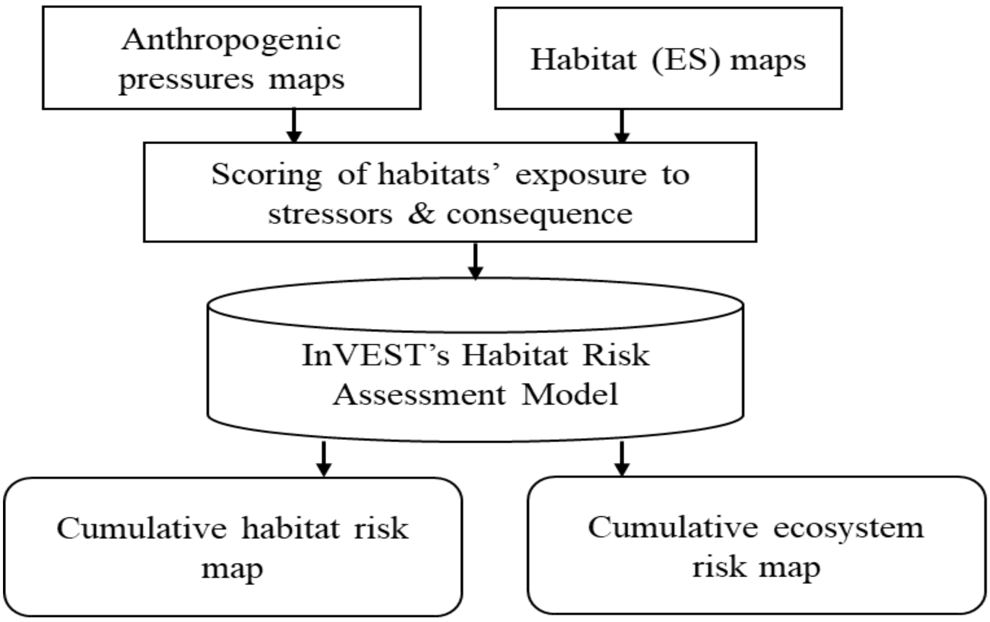


Figure 17: Framework for conducting Ecosystem Risk Assessment. Adapted from (Cabral et al., 2015; Tallis et al., 2016).

Synthesis of Assessment Categories for Conservation Consideration

A multi-criteria analysis approach was applied to synthesize the various assessments performed in the study area. Based on all the categories of assessments conducted, indicators were set to determine each of the ecosystems' suitability for conservation and the kind of conservation status to be accorded to it. This formed the basis for developing a zoning scheme for a proposed multi-use MPA in the study area. Two conservation zones were considered for the ecosystems in the study area – General use zone and Sanctuary zone (Great Barrier Reef Marine Park Authority, 2018; Habtemariam & Fang, 2016; Parks and Wildlife Service, 2017; Ramsar Convention Secretariat, 2010). Table 7 summarizes the indicators set for each assessment category.

Table 7 – *Indicators for Determining Conservation Suitability for each Ecosystem*

Assessment category	**Scores**					
	0 (No)	**1** (Yes) / (Very low)	**2** (Low)	**3** (Moderate)	**4** (High)	**5** (Very high)
Ecological Decomposition and nutrient supply	No	Yes	N/A	N/A	N/A	N/A
Species diversity	N/A	0 – 1	1.1 - 1.5	1.6 - 2.0	2.1 - 3.0	3.1 - 4.0
Ecological Percentage of species threatened (%)	N/A	1 – 20	21 – 40	41 – 50	51 – 80	81 – 100
Presence of ecosystem that provide nursery	No	Yes	N/A	N/A	N/A	N/A

Assessment category	Scores					
	0 (No)	**1** (Yes) / (Very low)	**2** (Low)	**3** (Moderate)	**4** (High)	**5** (Very high)
Socio - economic						
Source of livelihood	No	Yes	N/A	N/A	N/A	N/A
Fishing value (USD)	N/A	1 – 100	101 – 200	201 – 300	301 – 400	401 – 500
Cultural						
Place of spiritual value	No	Yes	N/A	N/A	N/A	N/A
Recreational						
Place of tourism value	No	Yes	N/A	N/A	N/A	N/A
Place for community recreation	No	Yes	N/A	N/A	N/A	N/A
Risk value						
Level of risk to pressures in the area	N/A	0 - 0.57	0.58 - 1.13	1.14 - 1.7	1.71 - 2.27	2.28 - 2.83
Management						
Level of management	N/A	None	Not effective	Somewhat effective	Effective	Very effective

N/A = Not Applied

For categories with more than one component, scores for the different components under that category were summed to obtain the total value of that category before assigning the value to a particular ecosystem. A combination of criteria were selected to assess each ecosystem's suitability for assignment of a particular conservation status. Table 8 presents the criteria of combinations used in assessing each ecosystem's suitability for a particular conservation zone type. Ecosystems with the highest score for the combination of criteria for each zone type were considered suitable for that zone.

Table 8 – *Criteria for Determining Conservation Status for the Ecosystems*

Zoning type	**Criteria combinations**
General Use Zone (GUZ)	1. Ecological value
	2. Socio-economic value
	3. Level of risk to pressures
	4. Recreational value
Sanctuary Zone (SZ)	1. Ecological value
	2. Cultural / Spiritual value
	3. Existing management

CHAPTER FOUR

RESULTS

Results obtained from conducting an integrated assessment of ecosystems in the study area for designing a conservation management plan are presented in this chapter. The chapter commences with a description of each of the ecosystems considered for the study. It also presents the ES selected by the communities which represents the most important ES that support their livelihoods. Furthermore, the economic value of the ecosystem services are presented, followed by the list of anthropogenic pressures exerted on the ecosystems as selected by the communities. Results of the Habitat Risk Assessment of each of the ecosystems understudied are presented, and finally, a suitability criteria for developing a zoning plan is presented.

Description of the Ecosystems Understudied

Nyan estuary

Physicochemical parameters recorded for the estuary are presented in Table 9. Details of the estimates are captured in Appendix C1.

Table 9 – *Physicochemical Parameters of the Nyan Estuary (Nov, 2017 – Nov, 2018)*

Parameters	Nyan Estuary	
	Range	Mean (± S.E.)
Temperature (^{o}C)	27.13 – 31.22	28.45 ± 0.34
pH	7.10 – 8.46	7.84 ± 0.14
Salinity (ppt‰)	20.2 – 28.6	16.49 ± 3.63
Nitrate	0.00 – 3.65	1.06 ± 0.26
Phosphate	0.05 – 1.61	0.43 ± 0.15

Fish sampled in the estuary from November, 2017 – November, 2018, consisted of 27 species from 13 different families (Appendix D1), with species diversity and evenness of 2.1 and 0.65 respectively (Appendix D1). Figure 18 illustrates the composition of species by numbers encountered in the Nyan estuary and their percentages. Flagfin mojarra (*Eucinistomus melanopterus)* occurred most in the samples, making up 47% of all the samples.

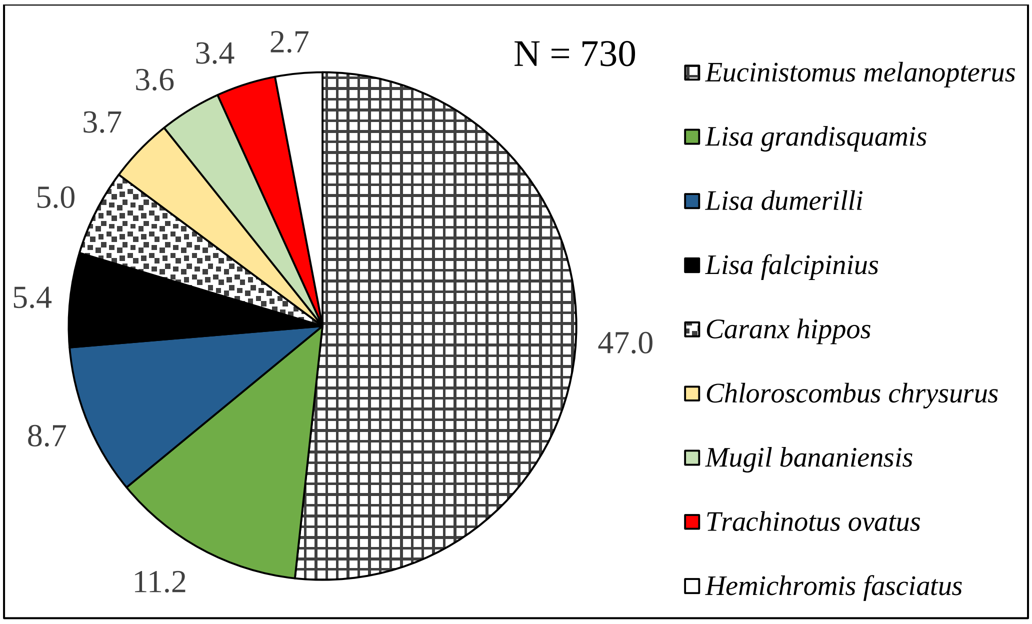


Figure 18: Species composition by numbers of fish sampled from the Nyan estuary and their percentage of occurrence.

Various species of grey mullet were encountered throughout the sampling period and are thus they were considered as socially important fishery resources in the area, since they are available to the community for harvesting throughout the year (Peh et al., 2017). Four (4) important species, comprising: most abundant species among the samples (*Eucinostomus melanopterus*) – 47%; threatened species among the samples (*Pseudotolithus senegalensis*) – 0.7%; the highest priced species among the samples (*Lutjanus goreensis*) – 2.1%; and the species that occurred throughout the sampling period (*Lisa grandisquamis*) – 11.2%; were identified. The modal length ranges recorded for each of the 4 important species were compared with their reported lengths at first sexual maturity as obtained from literature, to determine the general sizes of fish harvested in the estuary (Table 10).

Table 10 - *Modal Sizes of Important Fish Species Encountered in the Estuary*

Species	Number sampled - N	Length range recorded / Mean length ±S.E.(cm)	Modal length range (cm)	Length at first sexual maturity (cm) reported for the species
Eucinostomus melanopterus (flagfin majorra)	327	7.8 – 13.1 9.8±0.05	10.0 – 10.9	11 (Henrique de Amorim Xavier et al., 2012)
Pseudotolithus senegalensis (cassava croaker)	5	16.4 – 21.1 17.9±0.87	16.0 – 16.9	24 (Sossoukpe, Nunoo, & Adite, 2013)
Lutjanus goreensis (snapper)	14	7.9 – 17.1 11.9±0.75	10.0 – 11.9	34 (Fakoya & Anetekha, 2019)
Lisa grandisquamis (large-scaled mullet)	78	11.1 – 21.9 15.9±0.26	16.0 – 16.9	15 (www.fishbase.org)

Per the IUCN Red List of threatened species, four "Near threatened" species, namely: *Galeoides decadactylus* (thread fin), *Albula vulpes* (bone fish), *Brachydeuterus auritus* (bigeye grunt) *and Epinephelus aeneus* (white grouper) were encountered in the samples obtained from the estuary. Likewise, one "Endangered" species, *Pseudotolithus senegalensis* (cassava croaker) was encountered in the samples obtained from the Nyan estuary.

Length-frequency distribution of the 4 important species identified are presented in Figure 19.

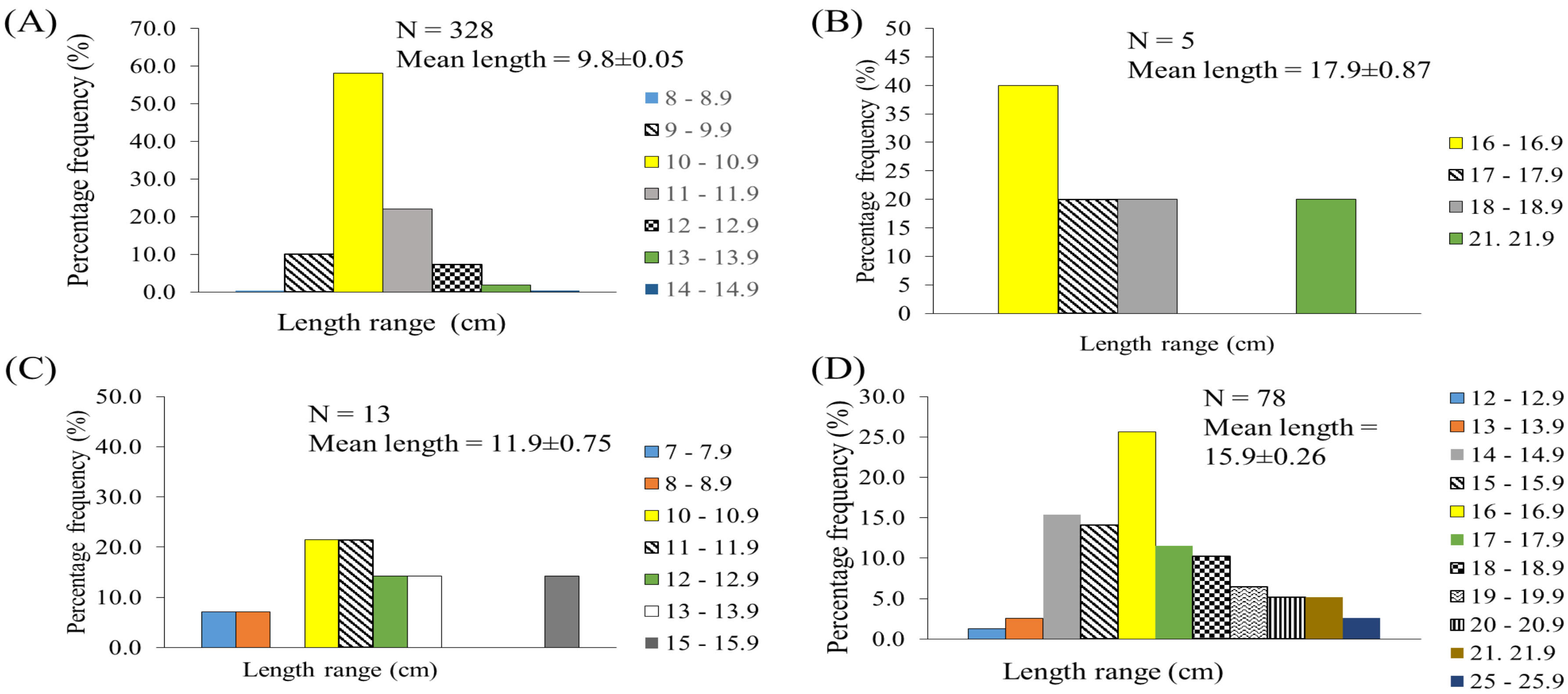


Figure 19: Length-frequency distribution of 4 most important fish species sampled from the Nyan estuary: (A) - *Eucinostomus melanopterus*; (B) - *Pseudotolithus senegalensis*; (C) - *Lutjanus goreensis*; (D) - *Lisa grandisquamis*.

Ehunli lagoon

Physico-chemical parameters recorded for the lagoon are presented in Table 11. Details of the estimates are captured in Appendix C2.

Table 11 – *Physical Parameters of the Ehunli Lagoon (Nov, 2017 – Nov, 2018)*

Parameters	Ehunli lagoon	
	Range	Mean (± S.E.)
Temperature (^{o} C)	26.18 – 32.34	30.75 ± 0.49
pH	7.20 – 8.49	7.92 ± 0.12
Salinity (ppt‰)	21.50 – 37.33	27.20 ± 1.47
Nitrate	0.49 – 2.20	1.26 ± 0.13
Phosphate	0.03 – 0.94	0.24 ± 0.08

A total of 22 fish species belonging to 11 families (Appendix D2) were recorded from the lagoon, with species diversity and evenness of 1.7 and 0.56 respectively (Appendix D2). Figure 20 displays the various species encountered in the Enhuli lagoon by numbers, and their percentages of occurrence. The flat sardinella (*Sardinella maderensis*) dominated the samples with a composition of 49.7%.

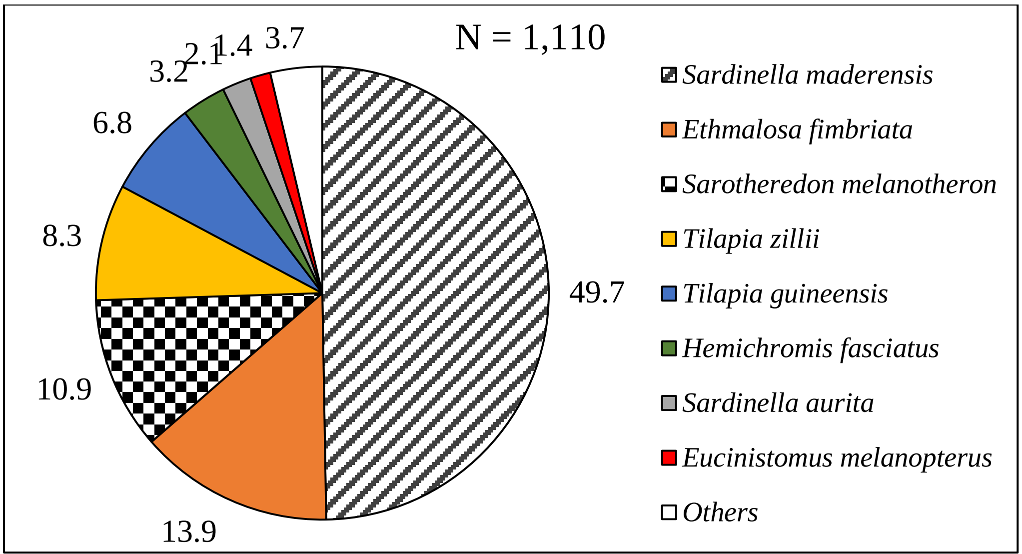


Figure 20: Species composition by numbers of fish sampled from the Enhuli lagoon and their percentage of occurrence.

Four (4) important species identified from the lagoon samples were: *Sardinella maderensis* – most abundant species and threatened species among the samples; *Tilapia zillii* – the highest priced species; and *Ethmalosa fimbriata* – the species that occurred throughout the sampling period. The modal length range recorded for each of the 4 important species were compared with their reported lengths at first sexual maturity as obtained from literature, to determine the general sizes of fish harvested in the lagoon (Table 12).

Table 12 - *Modal Sizes of Important Fish Species Encountered in the Lagoon*

Species	Number measured - N	Length range recorded (cm) / Mean length ±S.E.(cm)	Modal length range (cm)	Length at first sexual maturity (cm) reported for the species
Sardinella maderensis (common sardinella)	545	8.8 – 28.2 13.0±0.1	11.0 – 11.9	15.6 (Osei, 2015)
Ethmalosa fimbriata (bonga shad)	154	10.6 – 17.9 14.3±0.1	12.0 – 12.9	15.0 (Baldé, Döring, Ekau, Diouf, & Brehmer, 2019)
Tilapia zillii (red-belly tilapia)	87	7.4 – 54 10.3±0.5	9.0 – 9.9	7.0 (www.fishbase .sinica.edu.tw)

Investigating the international conservation status of each of the species encountered in the sampling period, it was discovered that two (2) "Near threatened" species, namely: *Galeoides decadactylus* (thread fin) and *Albula vulpes* (bone fish); and one "Vulnerable" species, *Sardinella maderensis* (common sardinella), make use of the lagoon ecosystem. Monkey sighting is an activity that attracts visitors to the lagoon. Monkeys residing in the mangroves bordering the lagoon support tourism, where fishermen rent their fishing vessels to tourists to view monkeys along the serene lagoon. Similarly to the bird watching activity in the estuary, this provides diversification of income for some fishermen.

Length-frequency distribution of the 4 important species identified are presented in Figure 21.

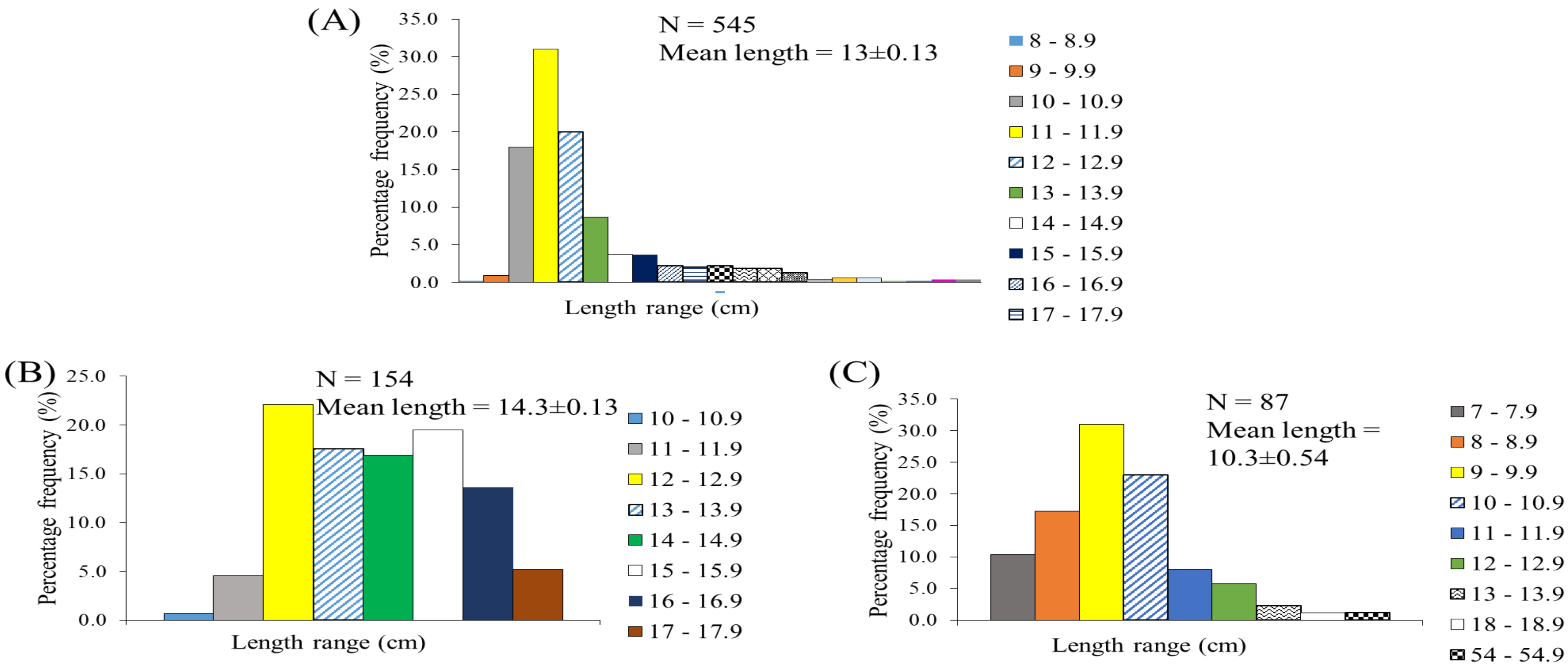


Figure 21: Length-frequency distribution of important fish species sampled from the Ehunli lagoon: (A) - *Sardinella maderensis*; (B) - *Ethmalosa fimbriata*; (C) - *Tilapia zillii*.

Rocky bay

Rocky shore species sampled comprised of 16 species, with species diversity and evenness of 1.4 and 0.51 respectively (Appendix D3). Figure 22 displays the various species encountered in the bay. *Nerita senegalensis* (black nerite) had the highest composition of 55.3% in the samples.

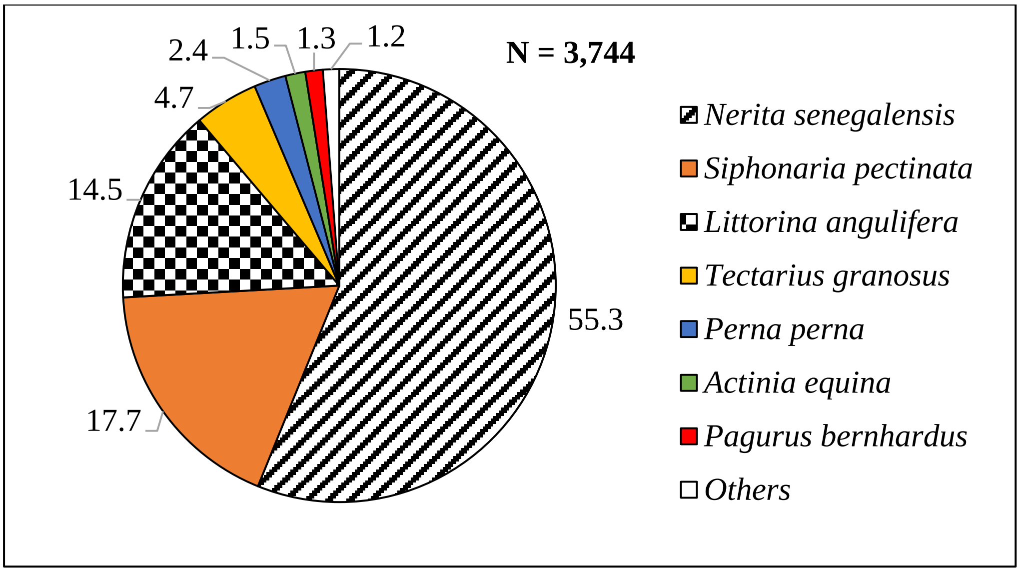


Figure 22: Species composition of fish sampled from the Rocky bay and their percentage of occurrence.

None of the species encountered were evaluated in the IUCN List of endangered species (IUCN, 2018). This is because according to the IUCN list, they are data deficient species (IUCN, 2018). The bay serves as a nursery for various fish species, as fingerlings were observed in various parts of the bay during the sampling period.

Sandy beach

The beach primarily serves as a landing site where fish captured offshore are landed, sorted and distributed for sale. Fish smoking sheds have been built close to the beach, where some of the fish landed is smoked to add value before sale. The beach also serves as a "garage" for keeping vessels when they are not in use. The beach is a recreational ground for fishermen and the community in general, where at any point in time, community members can be seen resting, having social gatherings or playing games. It is also a vital location for the mending of fishing nets and sometimes building of fishing vessels.

Mangroves

Species composition of mangrove trees sampled in the study area

Two species of mangrove (*Rhizophora mangle* and *Laguncularia racemosa*) were recorded within the study site. *Rhizophora mangle* dominated the sampling site with 640 trees/ha recorded for the lagoon system (Appendix E2), 300 trees/ha recorded for the estuary system (Appendix E1) and 570 trees/ha recorded for the rocky bay system (Appendix E3). No *Laguncularia racemosa* was recorded for the lagoon system (Appendix E2), however, the estuary system recorded 110 trees/ha (Appendix E1) and the rocky bay system recorded 190 trees/ha (Appendix E3). Nortey et al. (2016) recorded mangroves bordering the Nyan estuary as comprising of three species; *Rhizophora mangle, Avicennia germinans and Laguncularia racemose.* In this study however, two species were encountered; *Rhizophora mangle and Laguncularia racemosa.* This could be due to differences in sampling area extent. Sampling of mangrove trees to determine carbon stocks in this study was restricted to the banks of the estuary.

The structural attributes of mangrove forest stands surrounding the three coastal water bodies under study, sampled within one hectare for each system are shown in Figure 23:

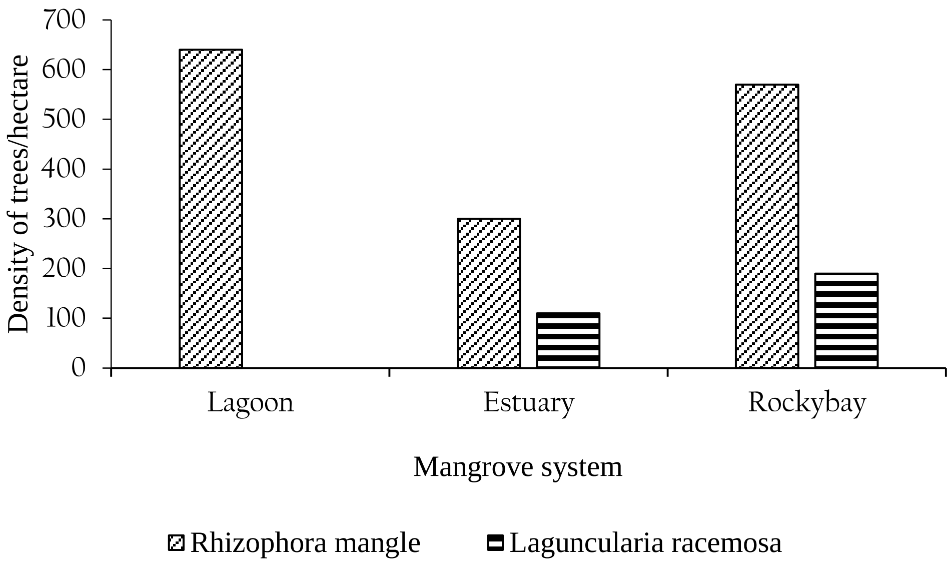
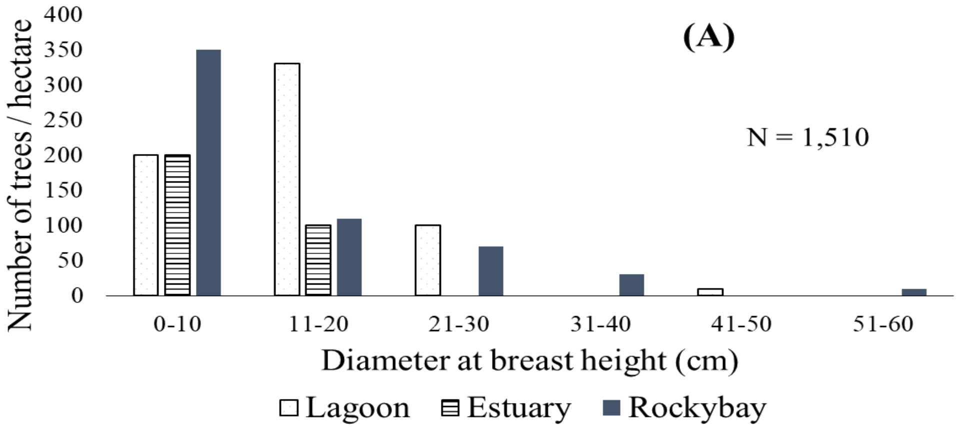


Figure 23: Density of trees per species in each mangrove system (February – March, 2018).

Size composition of the mangrove trees sampled is presented in Figure 24. Mean diameter at breast height (dbh) of the mangrove species recorded in the study area is presented in Figure 25. *Rhizophora mangle* trees in the lagoon system recorded the highest mean dbh of 13.86 ±1.05 (standard error) cm (Appendix E2), followed by the rocky bay system at 12.51±1.36 (standard error) cm (Appendix E3), and estuary system at 9.68±0.58 (standard error) cm (Appendix E1). Comparing with the maximum dbh for mature trees reported at 10 cm from literature (Kauffman & Donato, 2012), it was concluded that *R.mangle* trees of the lagoon mangrove system were averagely mature whilst those of the estuary mangrove system were averagely smaller trees. Also, *Laguncularia racemosa* trees in the rocky bay system recorded the highest dbh of 6.13±1.27 (standard error) cm, followed by the estuary system at 4.65±0.52 cm (Appendix D), depicting mature trees of *L.racemosa* in the rocky bay mangrove system and averagely smaller tree sizes of that species in the estuary mangrove system.



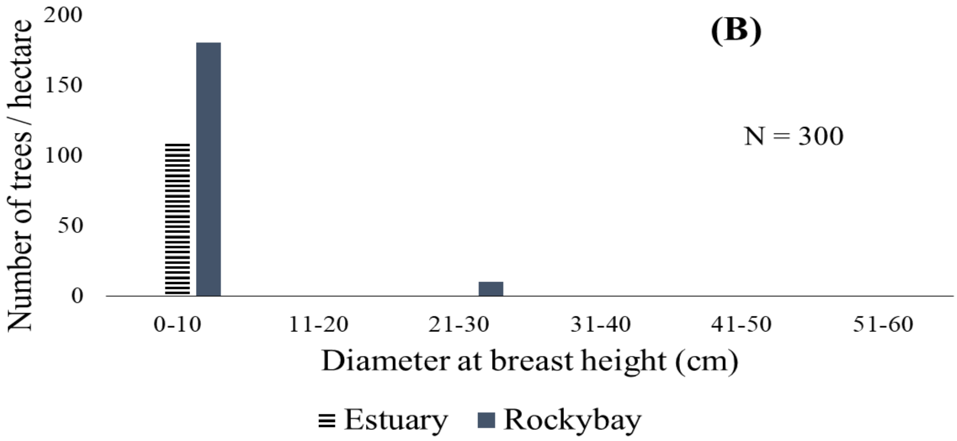


Figure 24: Frequency of mangrove diameters in the 3 mangrove systems: (A) - *Rhizophora mangle* and (B) - *Laguncularia racemose*.

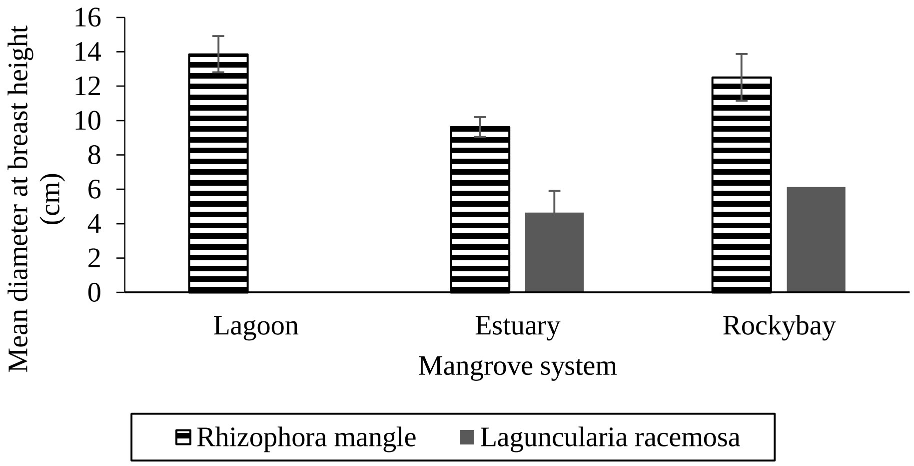


Figure 25: Mean diameter at breast height (dbh) of mangrove species. Bars are standard error bars. February – March, 2018

Litterfall

Biomass and carbon stocks of leaf litter produced by mangroves in the study area are presented in Figures 26 & 27.

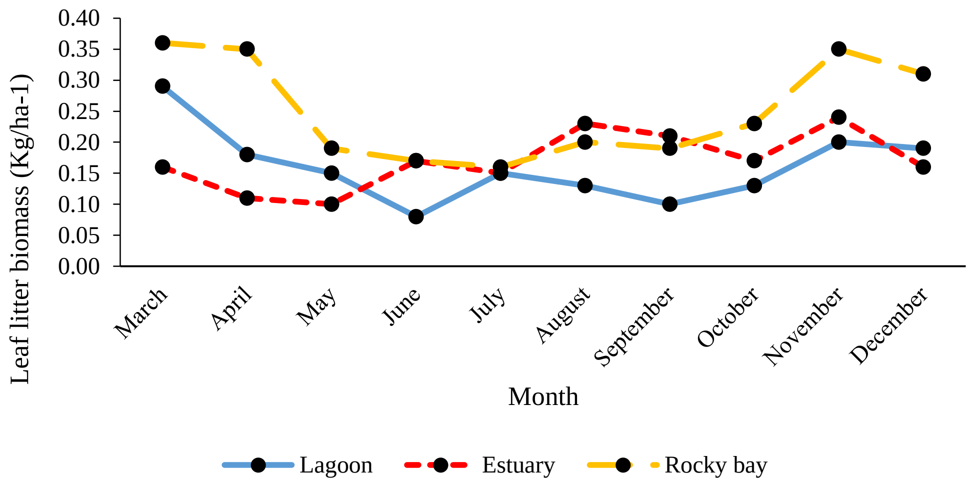


Figure 26: Monthly variations of Carbon stocks in leaf litter sampled.

Leaf litter fall was highest in March for both lagoon (0.29 kg/ha^{-1}) and rocky bay system (0.36 kg/ha^{-1}), and highest in November for the estuary system (0.24 kg/ha^{-1}) (Appendices E4, E5 and E6). The lagoon recorded its lowest leaf litter fall in September (0.10 kg/ha^{-1}), the rocky bay in July (0.16 kg/ha^{-1}), and the estuary in May (0.43 kg/ha^{-1}) (Appendices E4, E5 and E6).

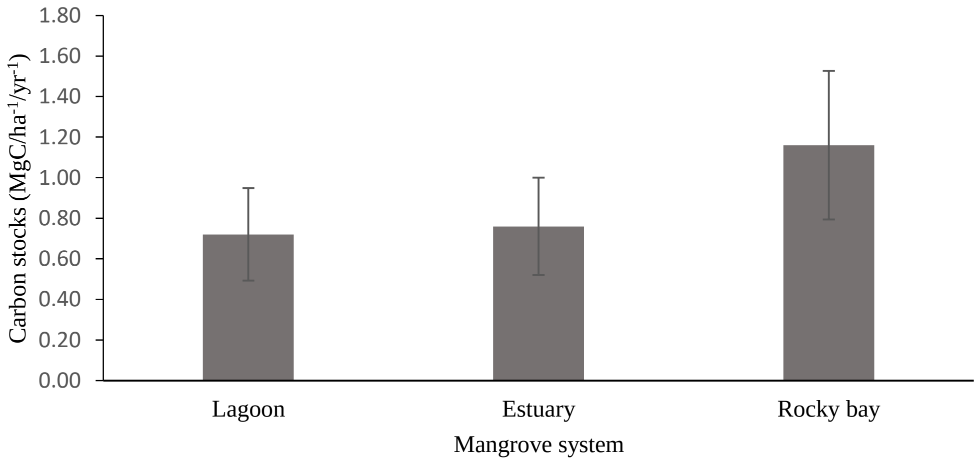


Figure 27: Average carbon stocks of leaf litter produced by each mangrove system per hectare over 10 months. The bars represent standard error bars.

The average carbon stocks of mangrove leaf litter produced in the study area by the lagoon system was 0.72 ± 0.23 MgC/ha/yr estuary system was 0.76 ± 0.24 MgC/ha/yr; and rocky bay system was 1.16 ± 0.37 MgC/ha/yr.

Carbon Stored and Sequestered in the Mangroves

Total carbon stored and sequestered in the three mangrove systems studied (Appendix E10) are presented in Table 13.

Table 13: *Total carbon stored and sequestered in the 3 mangrove systems under study.*

Mangrove system	**Carbon stored (MgC/ha)**	**Carbon sequestered ($MgCO_2e/ha$)**
Estuary	2,920.83	10,719.446
Lagoon	4,077.4	14,964.058
Rockybay	3,963.09	14,544.54

The lagoon mangrove system recorded the highest amount of carbon at 4,077.4 MgC/ha (carbon dioxide equivalent of 14,964.06 $MgCO_2e/ha$), followed by the rocky bay mangrove system at 3963.09 MgC/ha (carbon dioxide equivalent of 14,544.54 $MgCO_2e/ha$), and the estuarine mangrove system at 2920.83 MgC/ha (carbon dioxide equivalent of 10,719.44 $MgCO_2e/ha$) (Refer to Appendix E10 for details of estimates).

The amount of carbon contained in the various carbon pools assessed are presented in Figure 28. Soil pool contained the highest amount of carbon in all 3 systems (Appendix E10) and litter contained the least amount of carbon in all three systems.

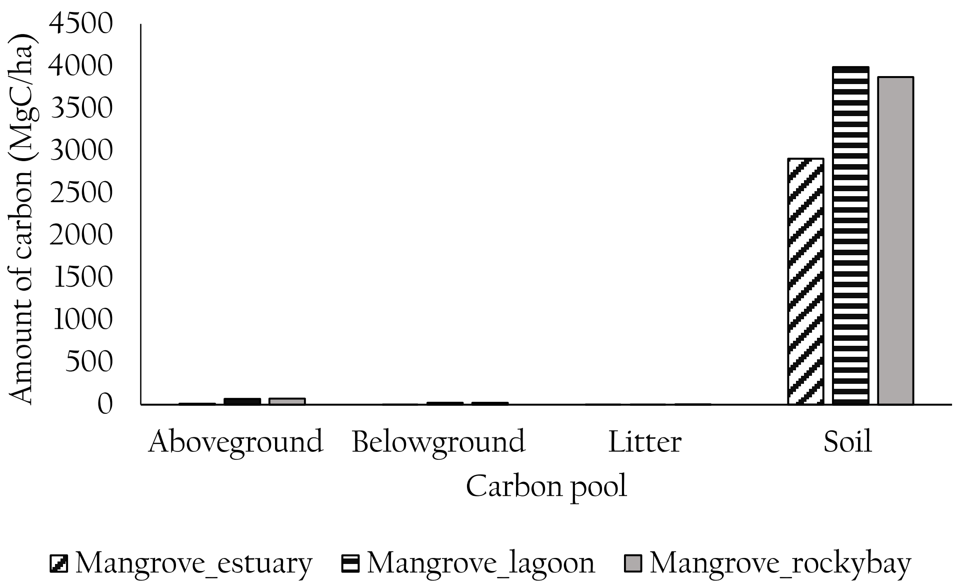


Figure 28: Amount of carbon stored in the 4 carbon pools assessed for each mangrove system.

Top Five Priority ES That Support Fisheries in the Study Area.

Prioritized ES according to the 2 communities are presented in Figure 30, in order of importance, from 1 (highest importance) to 5 (least importance). The list of ES observed which support fisheries livelihoods during the reconnaissance survey, from which the communities prioritized is captured in Appendix H. Princess Town community selected food as the topmost priority, followed by nursery, spiritual service, climate regulation and tourism (Appendix G1). Cape Three Points community also selected food as the ES of topmost priority, followed by nursery, then, decomposition and fixing, aesthetics and landing site (Appendix G2). Figure 29 also captures the sources of the prioritized ES and their levels of supply of the ES, from 1 (low supply) to 3 (high supply).

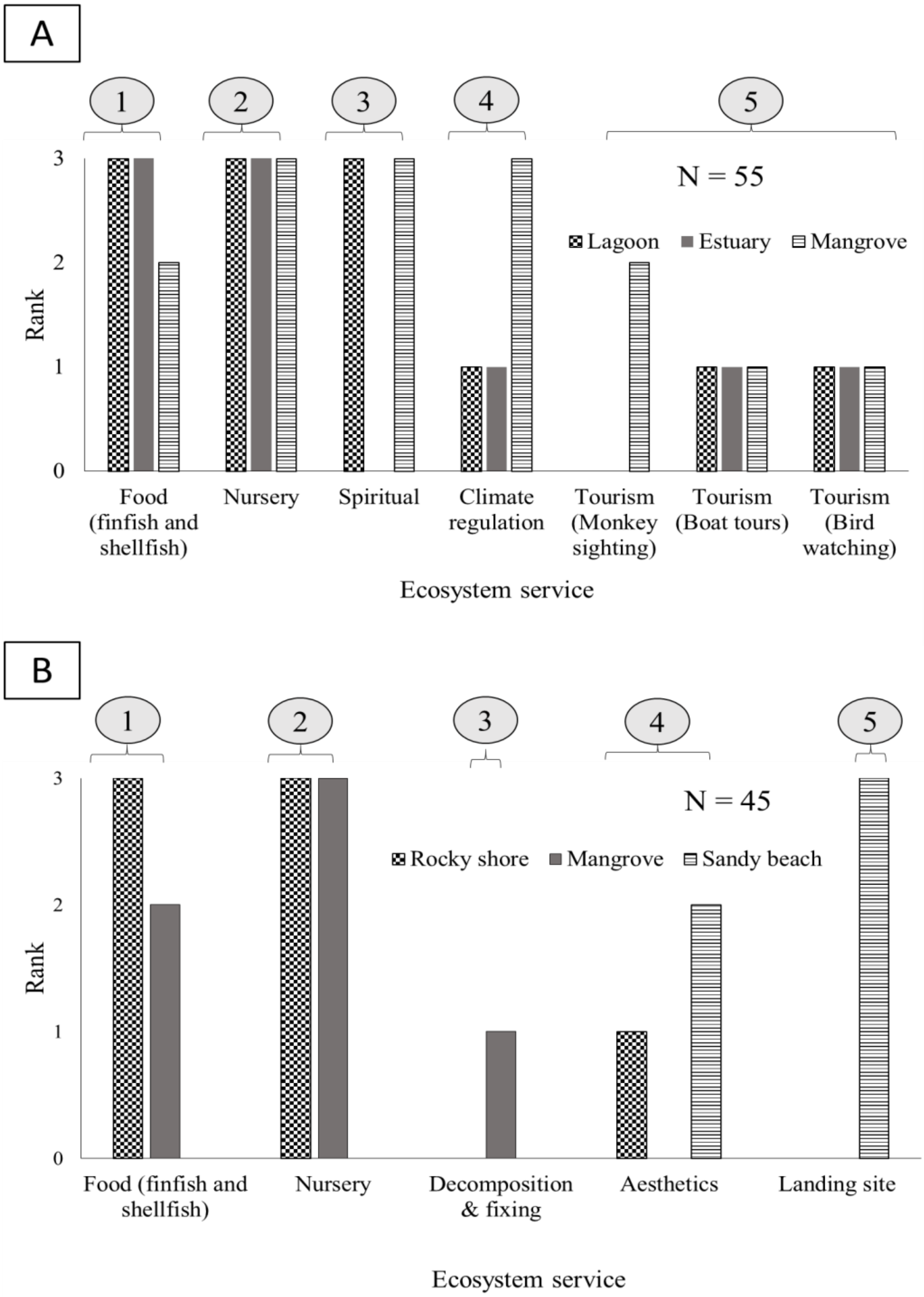


Figure 29: ES selected, ranked and mapped out by the two communities: (A) – Princess Town community, (B) – Cape Three Points community.

Economic Values of Selected Ecosystem Services in the Study Area

Princess Town

Fishing

At Princess Town, fifty-five (55) community members who extract fishery resources directly from the estuary and lagoon were engaged in this survey (Appendix F1). Figure 30 shows the demographic characteristics of respondents to the survey in Princess Town. Female respondents were solely involved in shellfish harvesting whilst male respondents were generally involved in fishing and also shellfish harvesting.

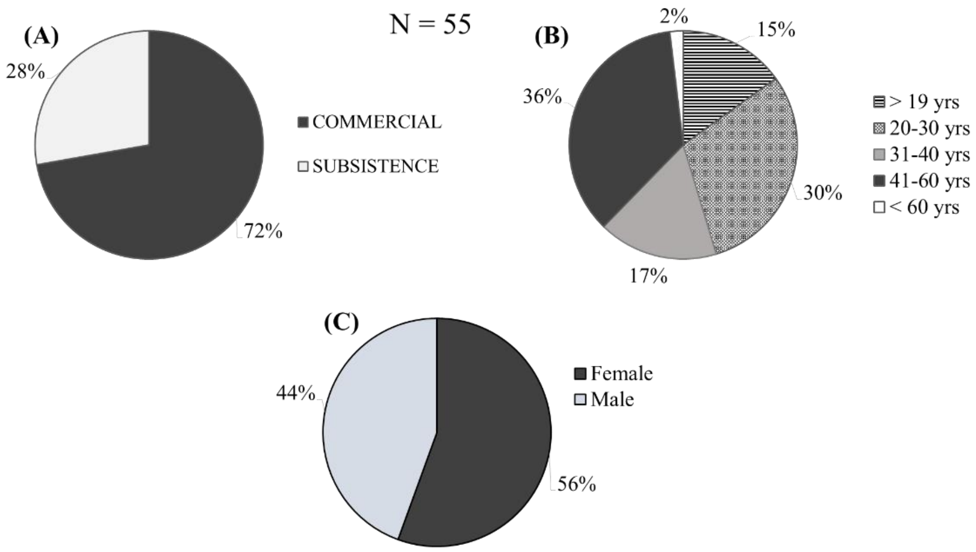


Figure 30: Demographic characteristics of respondents – (A) shows purpose for harvesting fish in the estuary or lagoon; (B) shows age distribution of respondents; (C) show the gender composition of respondents.

According to Figure 30A, seventy-two percent (72%) of the respondents fish for commercial purposes whilst twenty-eight percent fish for subsistence. The highest percentage of respondents were within the age class of 41 – 60 years (Figure 30B). Females represented 56% of the respondents at Princess Town (Figure 30C). Summary of the economic value, as well as the Net Present Value (NPV) of the inshore multi-species fishery of Princess

Town is presented in Table 14. Details of the estimation is captured in Appendices F1 and F3. Values were converted in dollar equivalent at conversion rate of Gh¢1 = US$0.18 (Bank of Ghana, 2019).

Table 14 – *Economic Value of Fish in Princess Town*

	Economic value of fish /kg/ind.yr. (US$)	Av. Price / kg (US$)	Total operational cost / yr (US$)	Net benefits (US$)	NPV (US$)
Estuary	68.83	0.49	161.67	232	8.18
Lagoon	189.02	0.49	161.67	352.97	22.26
Shellfish	547.38	0.23	1.40	410.4	322.04

Place of spiritual value

Community members engaged in the survey valued the spiritual service provided by the Enhuli lagoon at an average of US$186.35 annually (Appendix F1).

Tourism

Economic value of tourism, a diversification of fishing for community members was estimated at US$1,989/yr (Appendix I). A classical tour package at Princess Town cost US$30.6 for non-Ghanaians. This package comprises of accommodation, lagoon tour, estuary tour and beach hike to Miemia. Tourism records revealed that tourist visits (all non-Ghanaians) have reduced drastically in recent years as presented in Figure 31.

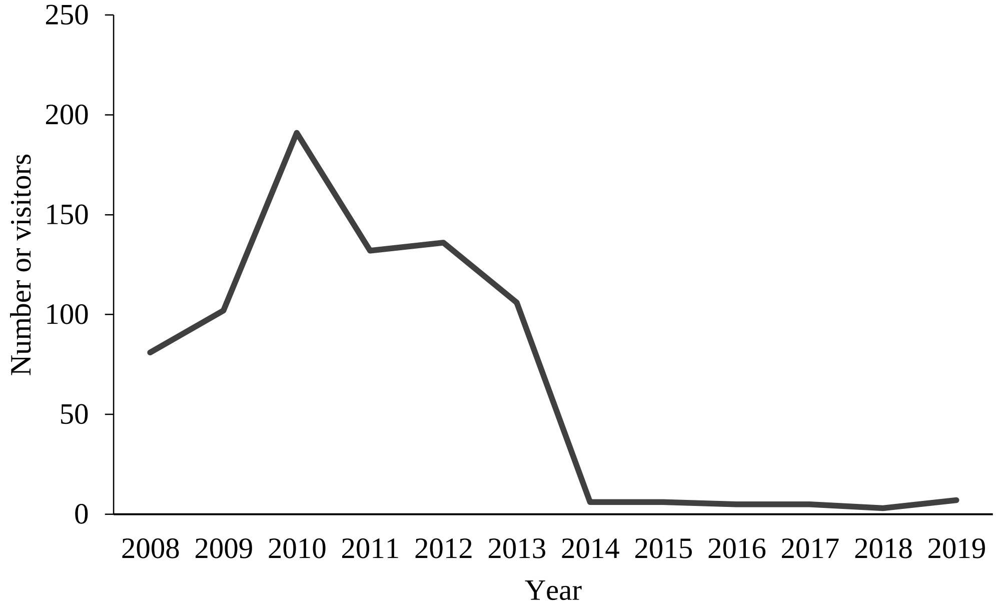


Figure 31: Number of tourists visiting Princess Town over a decade obtained from Tourism office in Princess Town in February, 2019.

Climate regulation

The market value of carbon sequestered by the Ehunli lagoon mangrove system was estimated at US$404,030.7 /Mg$CO_2$e/ha/yr and US$289,425.15 /MgCO_2e/ha/yr for the Nyan estuary mangrove system (Appendix E10).

Cape Three Points

In Cape Three Points, fishing is seldom done within the rocky bay ecosystem considered. However, since the rocky bay and the mangrove forest play an important role in providing ecosystem and food to fish in the area, fishermen engaged in small-scale fishing offshore were included in the survey to provide information on the market value of the fish they catch as proxy for the value of the ecosystems. Figure 32 shows the composition of respondents of the survey in Cape Three Points. The respondents indicated that the shellfish they collect from the mangroves in the area are for subsistence purposes only and thus were not included in the survey. Forty-five (45) community members were engaged in the survey (Appendix F2).

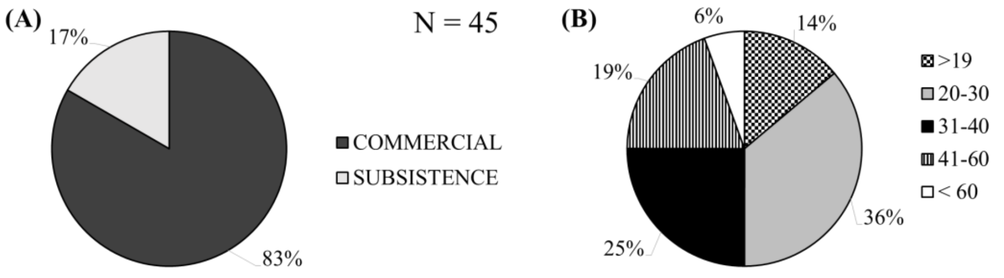


Figure 32: Demographic characteristics of respondents – (A) shows purpose for harvesting fish in the estuary or lagoon; (B) shows age distribution of respondents.

According to Figure 32A, eighty-three percent (83%) of the respondents at Cape Three Points engage in fishing for commercial purposes and 17% engage in it solely for subsistence. The modal age class of the respondents was 20 – 30 years (Figure 32B). The economic value of fishing performed off the bay was estimated at US$473.79/ kg/ind.yr (Appendix F3). The average price of fish was estimated at US$0.75 /kg (Appendix F2). The total annual cost of operation and the net benefits of fishing were estimated at US$161.67 and US$429.76 respectively (Appendix F2). The NPV of fishing was also estimated at US$2.59. Values were converted from Gh¢ to US$ equivalent at a conversion rate of Gh¢1 = US$0.18 (Bank of Ghana, 2019) (Appendix F3).

Aesthetic value

Community members engaged in the survey valued the aesthetic service provided by the beach and rocky bay at an average of US$1,650.90 annually (Appendix F2).

Decomposition and fixing

The market value of carbon sequestered by the rocky bay mangrove system was estimated at US\$392,701.5 /$MgCO_2e$/ha/yr (Appendix E10).

Total Economic Value of ecosystems in the Greater Cape Three Points Area

The study site covered a total area of 265.8 ha, valued at US\$1,095,086.68/ yr (US\$ 698,135.94/ yr for Princess Town and US\$ 396,950.78 for Cape Three Points) for the provisioning of those ES prioritized by the communities. Figure 33 summarizes the values assigned by both communities.

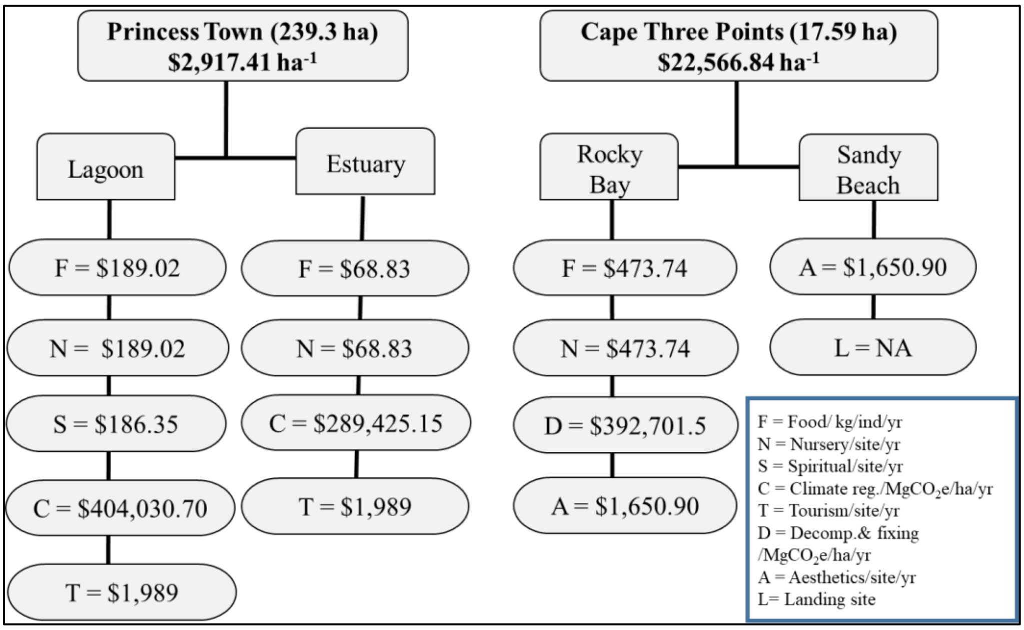


Figure 33: Economic Values of Priority ES in the GCTP Area

Anthropogenic pressures perceived as critical for impacting ecosystems in the study area

The list of pressures listed by the key participants during the reconnaissance survey are captured in Table 15, part A. Top 4 prioritized pressures according to the communities are also captured in Table 15, part B.

Table 15 – *List of Pressures Identified in the Study Area*

Princess Town		**Cape Three Points**	
Pressures listed by key informants (part A)	Selection made by community as top critical pressures (part B)	Pressures listed by key informants (part A)	Selection made by community as top critical pressures (part B)
Overexploitation	✓	Coastal deforestation	
Rainfall / storms		Open defaecation	✓
Coastal development		Coastal development	
Fertilizer input	✓	Marine debris	✓
Plastic pollution	✓	Solid waste disposal	✓
Mining		Sargassum (brown algae)	
Destructive fishing methods (dynamite fishing)		Destructive fishing methods (dynamite fishing & light fishing)	✓
Sewage			
Coastal deforestation	✓		
Sargassum (brown algae)			

From the prioritization and mapping exercise, pressures on ecosystems in Princess Town, as selected collectively by the community were pollution by plastics, coastal deforestation, fertilizer input and overfishing (Appendix H1). In Cape Three Points, pressures selected were open defaecation, marine debris, waste disposal and dynamite fishing (Appendix H2). Figure 34 display maps of each of the pressures selected, overlaid on the ecosystems under study.

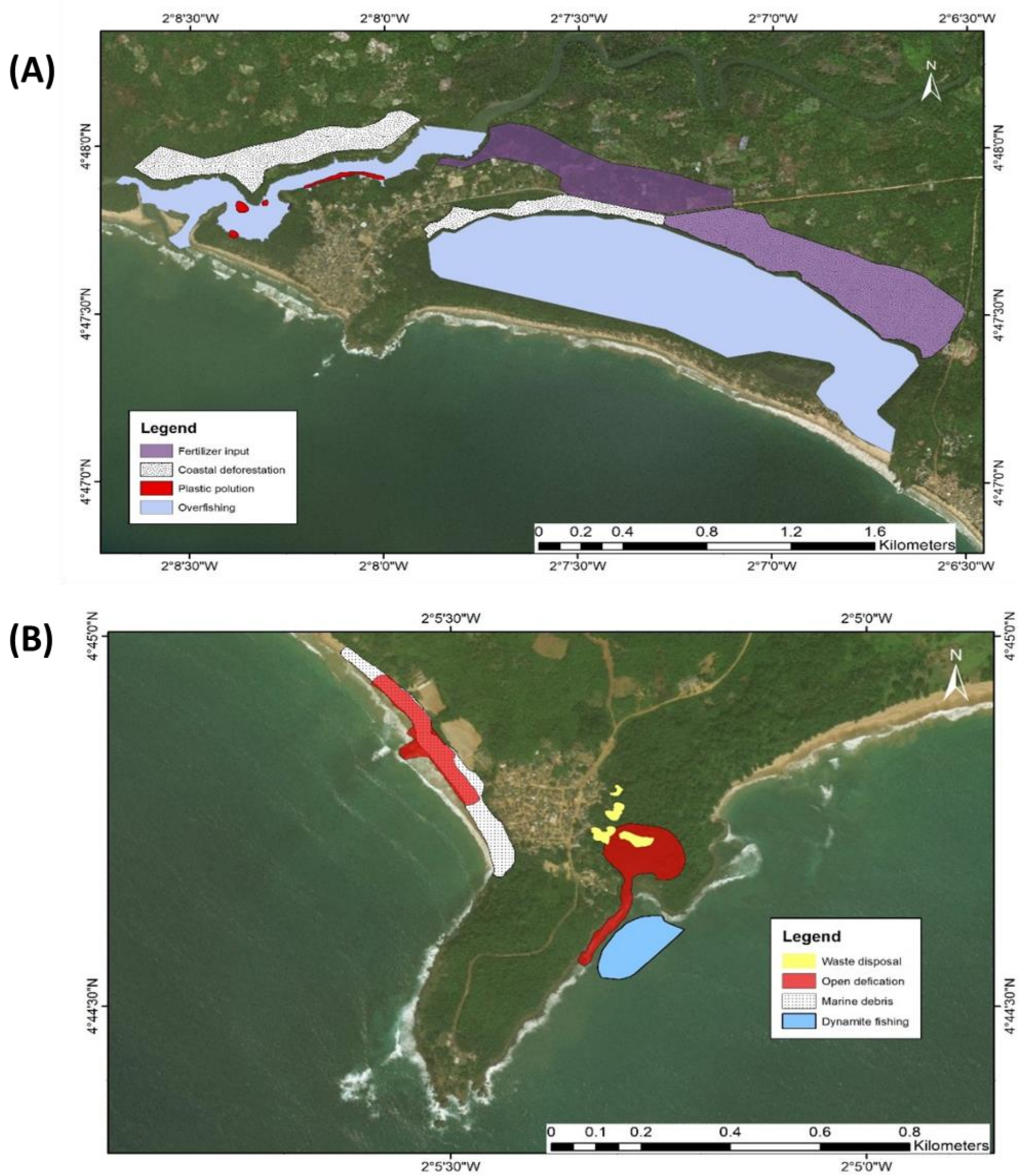


Figure 34: Map showing location of anthropogenic pressures selected in Princess Town (A) and Cape Three Points (B).

Habitat Risk Assessment

Scores generated for each ecosystem's exposure to the set of pressures (E) and the consequence of their exposure (C), are summarized in Tables 16 & 17. Using the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) Habitat Risk Assessment (HRA) model to assess the risk posed on each ecosystem by the set of pressures, cumulative risk maps for each ecosystem category and the entire ecosystem were generated. Table 18 presents a summary of the mean risk scores and the percentage level of risk generated by the model for each ecosystem category. Figures 35 & 36 display the cumulative risk of each ecosystem from all the stressors that interact with it. Figure 37 also displays the cumulative risk of the two areas to all the pressures selected for the study.

Table 16 – *Scores of Ecosystems' Exposure to Pressures and Consequence of the Exposures in Princess Town*

	Ecosystem											
	Estuary				**Lagoon**				**Mangrove**			
Criteria	**PP**	**FL**	**CD**	**OF**	**PP**	**FL**	**CD**	**OF**	**PP**	**FL**	**CD**	**OF**
Exposure of ecosystem to pressures												
Temporal overlap	3[b,c]	1[a,c,e]	2[a,b]	3[a,b]	2[b,c]	3[a,c,e]	1[a,b]	2[a,b]	2[b,c]	2[a,c,e]	1[a,b]	3[a,b]
Management effectiveness	3[a,b]	3[a,b]	3[a,b]	3[a,b]	2[a,b]	3[a,b]	2[a,b]	2[a,b]	2[a,b]	3[a,b]	3[a,b]	3[a,b]
Intensity	2[a,b,e]	2[a,c,e]	2[a,b,c,d]	3[a,b]	1[a,b,e]	1[a,c,e]	1[a,b,c,d]	3[a,b]	1[a,b,e]	2[a,c,e]	2[a,b,c,d]	2[a,b]
Consequence of exposure												
Frequency of disturbance	2[b,e]	2[b,e]	3[b,e]	2[b,e]	3[b,e]	3[b,e]	3[b,e]	3[b,e]	3[b,e]	3[b,e]	3[b,e]	3[b,e]
Change in area	1[e]	1[e]	2[e]	1[e]	1[e]	1[e]	1[e]	2[e]	1[e]	1[e]	2[e]	1[e]

Pressures: PP = Plastic pollution; FL Fertilizer input; CD = Coastal deforestation; OF = Overfishing;
Scoring components: [a] Community score; [b] Researcher's observation; [c] Ecological assessment; [d] Drone imagery of the study area;

[e] Literature

Table 17 – *Scores of Ecosystems' Exposure to Pressures and Consequence of the Exposures in Cape Three Points.*

	Ecosystem											
	Rocky bay				**Mangrove**				**Sandy beach**			
Criteria	**DF**	**MD**	**OD**	**WD**	**DF**	**MD**	**OD**	**WD**	**DF**	**MD**	**OD**	**WD**
Exposure of ecosystem to pressures												
Temporal overlap	2[a,b]	3[a,b]	3[a,b]	3[a,b]	2[a,b]	1[a,b]	3[a,b]	3[a,b]	1[a,b]	3[a,b]	3[a,b]	2[a,b]
Management effectiveness	3[a,b]	3[a,b]	3[a,b]	3[a,b]	3[a,b]	2[a,b]	3[a,b]	3[a,b]	3[a,b]	2[a,b]	3[a,b]	3[a,b]
Intensity	2[a,b]	1[b,d]	3[b,d]	3[b,d]	2[a,b]	1[b,d]	3[b,d]	2	1[a,b]	2[b,d]	3[b,d]	1[b,d]
Consequence of exposure												
Frequency of disturbance	1[b,e]	1[b,e]	1[b,e]	3[b,e]	3[b,e]	1[b,e]	3[b,e]	3[b,e]	1[b,e]	2[b,e]	2[b,e]	2[b,e]
Change in area	1[e]	1[e]	1[e]	2[e]	1[e]	1[e]	1[e]	1[e]	1[e]	2[e]	1[e]	1[e]

Pressures: DF = Dynamite fishing; MD = Marine Debris; WD = Waste Disposal; OD = Open defaecation;
Scoring components: [a] Community score; [b] Researcher's observation; [c] Ecological assessment; [d] Drone imagery of the study area; [e] Literature

Table 18 – *Mean Risk Scores and Percentage Level of Risk of Each Ecosystem*

Ecosystem	**Pressure**	**Mean risk**	**Risk (%high)**	**Risk (%medium)**	**Risk (%low)**
Cape Three Points					
Mangrove	All pressures	1.0	0	59.9	40.1
	DF	0.0	0	0.2	99.8
	MD	0.2	0	0	100
	OD	2.1	77.2	22.8	0
	WD	1.8	6.8	93.2	0
Rocky bay	All stressors	1.3	0	100	0
	DF	0.8	0	45.3	54.7
	MD	0.5	0	0	100
	OD	2.1	73.8	26.2	0
	WD	1.9	30.8	69.2	0
Sandy beach	All stressors	1.1	0	100	0
	DF	0	0	0	100
	MD	1.8	0	100	0
	OD	2.1	82.9	17.1	0
	WD	0.6	0	0	100
Princess Town					
Estuary	All stressors	1.5	0	100	0
	CD	1.6	0.0	100	0
	FL	0.6	0	23.5	76.5
	OF	2.3	100	0	0
	PP	1.4	0	78.5	21.5
Lagoon	All stressors	0.9	0	25.5	74.5
	CD	0.9	0	34.2	65.8
	FL	0.6	0	21.6	78.4
Lagoon	OF	1.9	0	100	0
	PP	0.1	0	0	100
Mangrove	All stressors	1.1	0	64.7	35.3
	CD	1.5	0	84.4	15.6
	FL	0.4	0	16.6	83.4
	OF	1.9	39.3	60.7	0
	PP	0.5	0	14.2	85.8

Pressures: PP = Plastic pollution; DF = Dynamite fishing; FL = Fertilizer input; CD = Coastal deforestation; OD = Open defaecation; MD = Marine debris; WD = Waste disposal; OF = Overfishing

Source: InVEST 3.7 - HRA

The maximum risk score for an individual ecosystem – pressure combination is 2.83 (100%). Areas where low risk is accorded depict areas where risk score falls within 0-33% of the total possible cumulative risk score in that area. Medium risk areas refer to areas where risk score falls within 33%-66% of the total possible cumulative risk score in that area. No ecosystem is at high risk of the stressors assessed in the study area since no risk score beyond 66% of the possible cumulative risk score was recorded.

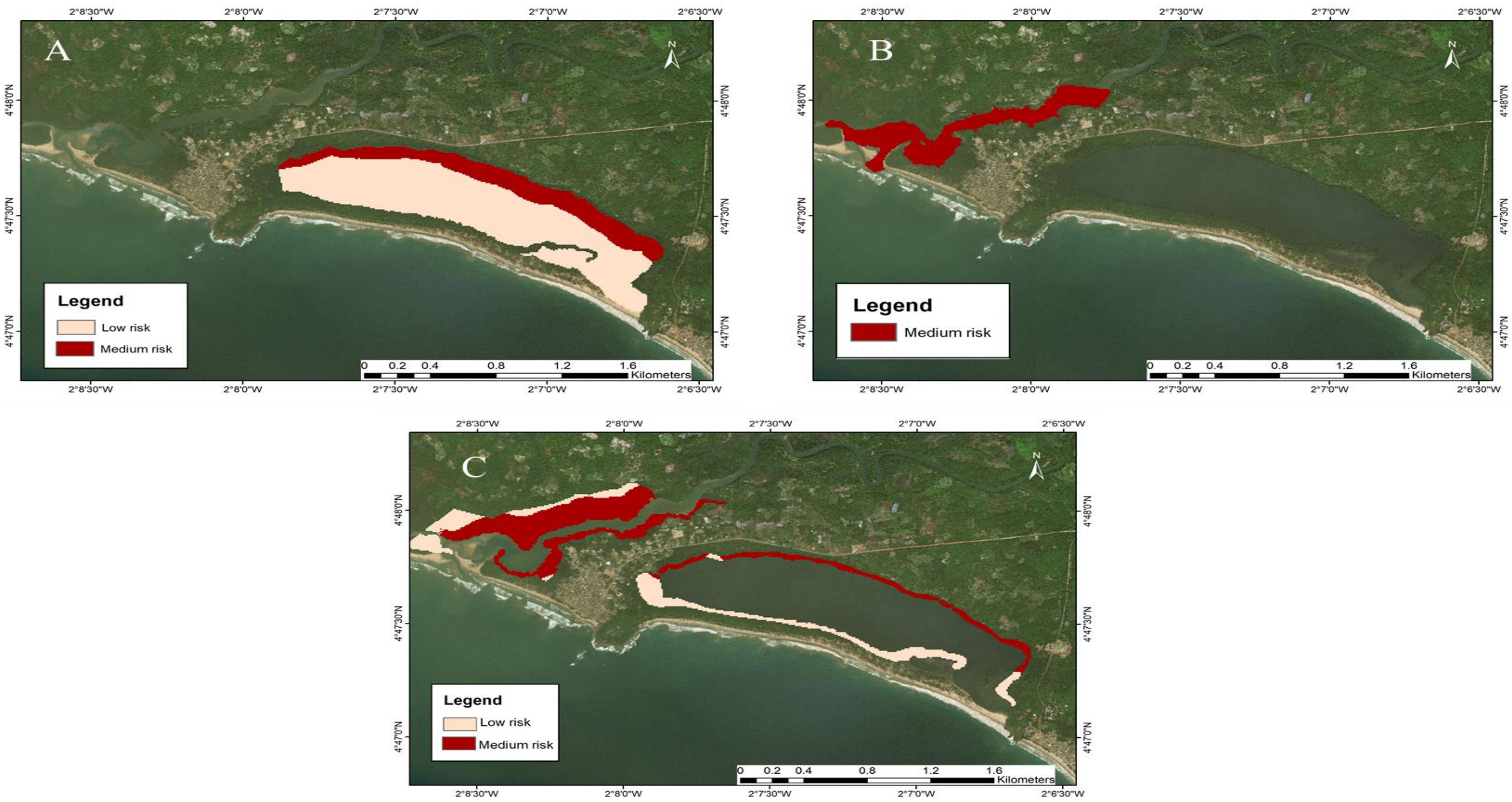


Figure 35: Cumulative risk maps of ecosystems—Lagoon (A), Estuary (B) and Mangrove (C)—to a combination of all selected pressures assessed at Princess Town. Source: InVEST 3.7 – HRA

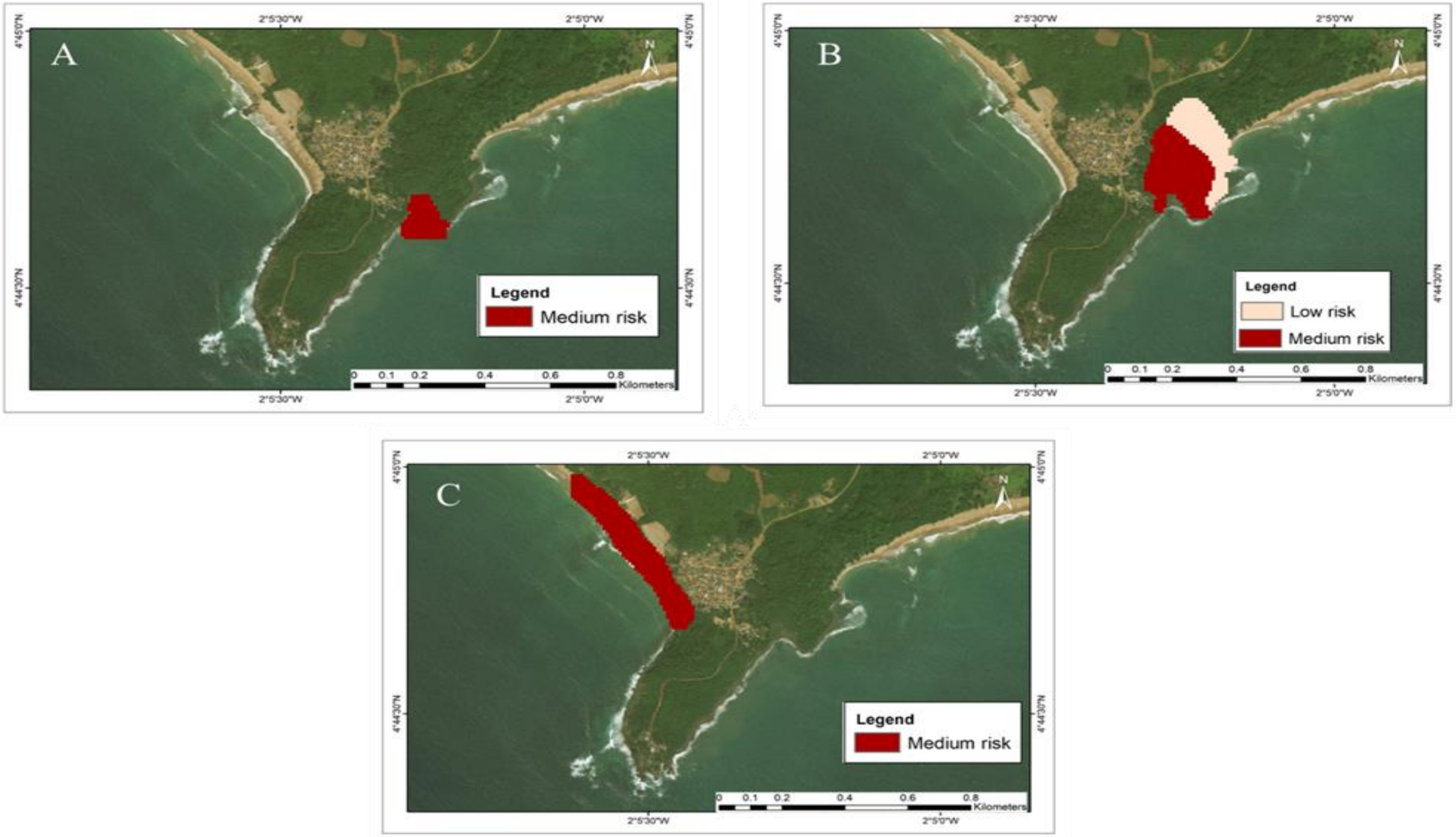


Figure 36: Cumulative risk maps of ecosystems— Rocky bay (A), Mangrove (B) and Sandy beach (C)—to a combination of all selected pressures assessed at Cape Three Points. Source: InVEST 3.7 – HRA

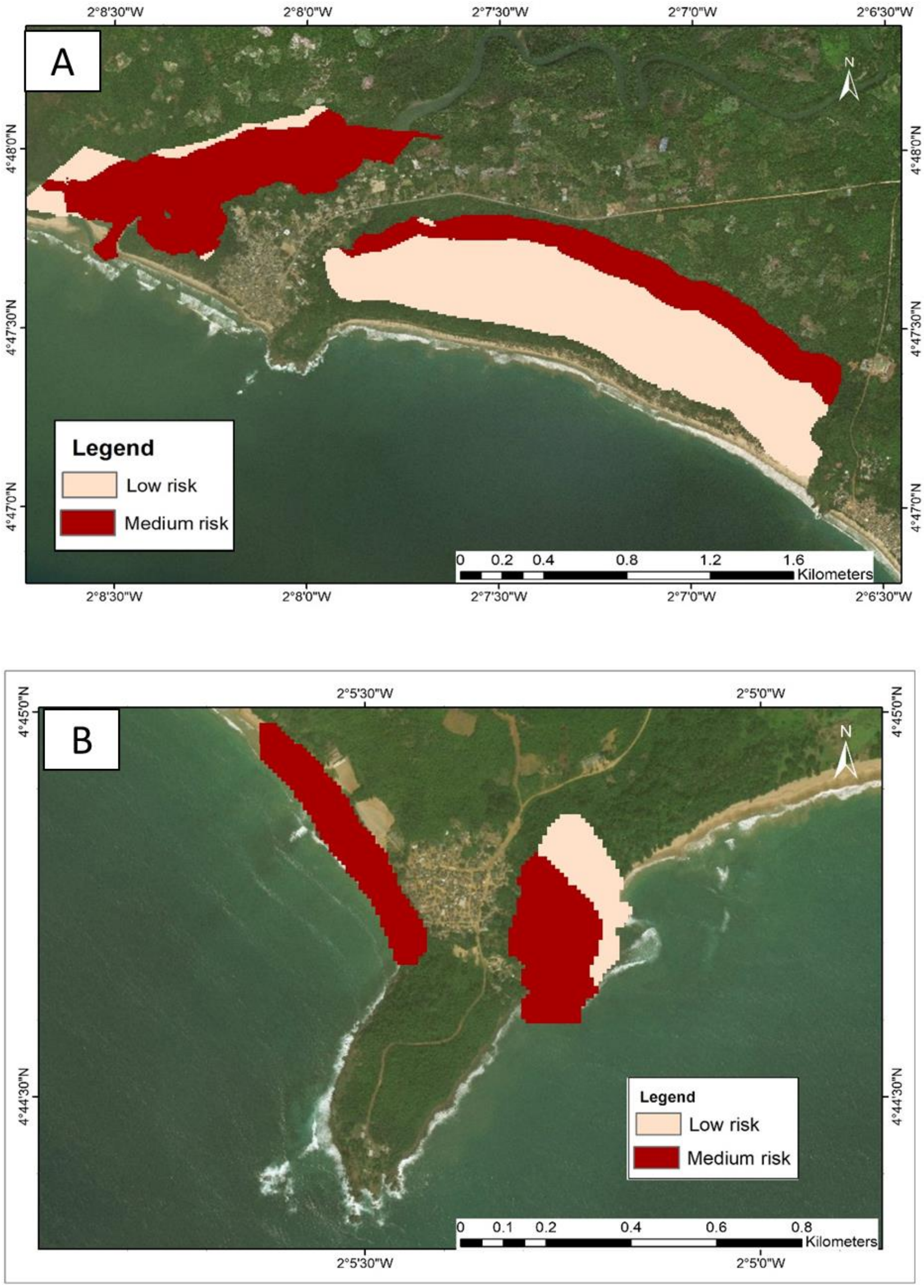


Figure 37: Cumulative risk map of Princess Town (A) and Cape Three Points (B) to a combination of all pressures. Source: InVEST 3.7 – HRA

Developing Zoning Scheme for Multi-use MPA

Based on the set of criteria developed for verifying each ecosystem's suitability for designation as a special zone, scores were assigned to each ecosystem. Table 19 displays the scores awarded to each ecosystem. Table 20 summarizes the total score of each ecosystem and shows the ecosystem suitable for each of the proposed zones.

A map showing the different zones proposed for the ecosystems in the GCTP area is displayed in Figure 38.

Table 19 – *Scores Awarded for Special Zone Designation Based on the Different Ecosystem Suitability Criteria*

Ecosystem	**Categories**																	
	Ecological					**Socio - economic**			**Cultural**		**Recreational**			**Risk**		**Management**	
	E1	E2	E3	E4	**total**	SE1	SE2	**total**	C1	**total**	R1	R2	**total**	Ri1	**total**	M1	**total**
Princess Town																	
Lagoon	1	3	1	1	**6**	1	2	**3**	1	**1**	1	1	**2**	2	**2**	3	**3**
Estuary	1	4	1	1	**7**	1	1	**2**	0	**0**	1	1	**2**	3	**3**	1	**1**
Cape Three Points																	
Rocky bay	1	2	0	1	**4**	0	0	**0**	0	**0**	0	1	**1**	3	**3**	0	**0**
Sandy beach	0	0	0	0	**0**	1	0	**1**	0	**0**	0	1	**1**	2	**2**	0	**0**

Sub components for Ecological – E1 = Decomposition & nutrient supply; E2 = Fish species diversity; E3 = Percentage of ecosystem threatened; E4 = Presence of ecosystem that provides nursery
Sub components for Socio-economic – SE1 = Source of livelihood; SE2 = Fishing value
Sub components for Cultural – C1 = Place of Spiritual value
Sub components for Recreational – R1 = Place of tourism value; R2 = Place for community recreation
Sub components for Risk – Ri1= Level of risk to pressures in the area
Sub components for Management – M1 = Level of management

Table 20 – *Ecosystem Suitability for the Proposed Zones (General Use and Sanctuary Zones). Highest score depicts the most suitable ecosystem for each proposed zone.*

Ecosystem	**Proposed zones**	
	General Use Zone	**Sanctuary zone**
Princess Town		
Lagoon	13	9
Estuary	14	7
Cape Three Points		
Rocky bay	6	3
Sandy beach	3	0

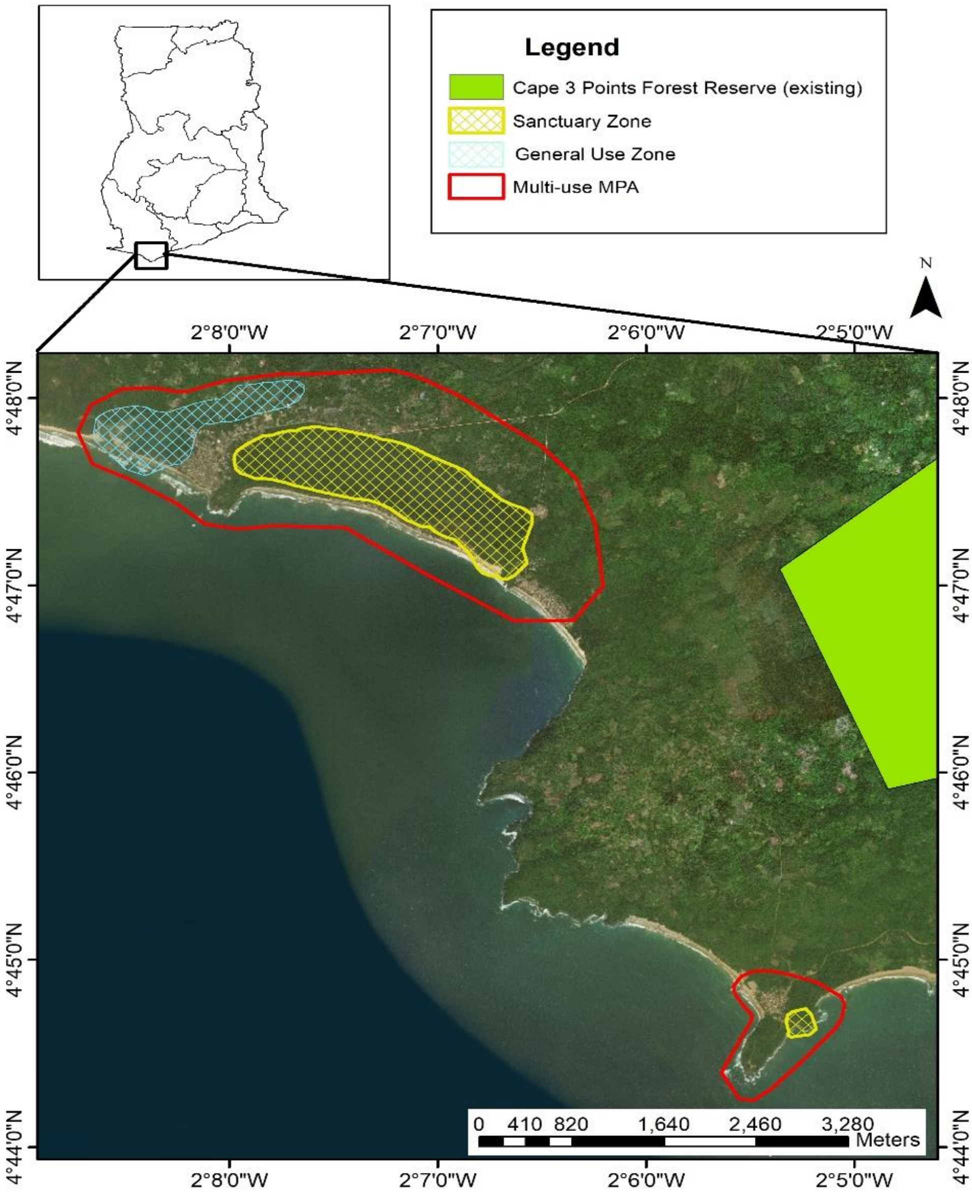


Figure 38: Proposed zoning plan for the Greater Cape Three Points area.

CHAPTER FIVE

DISCUSSION

Results obtained from the integrated assessment conducted on selected ecosystems in the Greater Cape Three Points Area are discussed in this chapter. The discussion is based on the conceptual framework for establishing MPAs as adopted by the study. An appropriate conservation plan for the area according to the assessment conducted is also discussed, followed by a final discussion on the zoning plan designed for the area.

Drivers of Change – Demand for Ecosystem Services in the Study Area.

Contribution of the coastal ecosystems to the local economy was demonstrated in the socio-economic valuation assessment. Fishing and its related activities, as well as tourism in the area are dependent on the presence and functioning of the ecosystems. Top 5 Ecosystem Services (ES) prioritized by each of the two communities that support fisheries related livelihoods in the study area depicted the values they placed on the ecosystems for their well-being:

Priority 1

The two communities studied both selected food (finfish and shellfish) provisioning as the topmost ES priority (Appendix G1). The reason given for this choice was that fish generates income for most people in the community, and also helps in meeting their dietary needs. Both communities ranked the water bodies highest and the mangroves bordering them, medium, for the provisioning of fishery resources. This demonstrates the importance of the water bodies and their surrounding mangroves to the communities, and also primarily indicates that the community would be interested in a conservation action that will boost their fish yields, but not hinder them from harvesting since it provided an important source of their sustenance and commercial activities. From the economic assessment conducted in this study, fishing as a commercial activity was estimated to yield an average of US$ 68.83/kg per individual per annum from the Nyan estuary, US$189.02/kg per individual per annum from the Enhuli lagoon and US$ 473.79 /kg per individual per annum from the near shore areas of Cape Three Points (Appendix F3). Commercial shellfish collection from mangroves in the area was also estimated to yield an average of US$ 547.38 /kg per individual per annum (Appendix F3). Comparing with the daily minimum wage in Ghana set at GH¢ 10.26 (US$ 1.84)— GH¢ 3,450.6 (US$ 621.1) per year—for 2019 (WageIndicator, 2019), it was inferred that an individual at Princess Town obtained an average income of approximately 21% of the national yearly minimum wage for harvesting one kilogram of fish per annum from the estuary and lagoon. Shellfish harvesting in Princess Town was also estimated to generate an income of approximately 88% of the national yearly minimum wage for an individual harvesting one kilogram of shellfish per annum. Fishing at the nearshore waters of Cape Three Points also yielded approximately 76% of the national yearly minimum wage for harvesting one kilogram of fish per annum. The net present values estimated for fishing and shellfish collection in the communities were positive, indicating profitability for the people engaged in these activities for their livelihoods (Kenton, 2019). It was observed that shellfish harvesting yielded higher income as compared to fish obtained from coastal water bodies in the area. This could be due to the fact that the cost incurred in harvesting a kilogram of shellfish was relatively low as compared to that of catching fish, and also, shellfish collectors indicated that they engaged in the activity all year round and collected as much as they could.

The economic survey recorded more female respondents (56%) who generally engaged in shellfish collection than males (44%) who generally engaged in fishing. This suggests that the coastal ecosystems provide an important social service, generating livelihoods particularly for women in the community, making them critical ecosystems for achieving Target 8 of the Convention on Biological Diversity’s strategic plan for biodiversity, 2011 – 2020 (promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all) (CBD, 2010). The study thus affirmed that the coastal ecosystems provide an important income generating source for the two communities as indicated by the participants in the economic survey and also noted by other valuation studies on similar ecosystems. (Brown et al., 2014; Cavanagh et al., 2016; Pierre Failler, Élise Pètre, Thomas Binet, & Jean-Philippe Maréchal, 2014).

The survey also revealed that besides economic gains, fishery resources harvested in the area were vital for the diet of the people. Twenty-eight percent (28%) of the 55 respondents from Princess Town stated that they obtained fishery products from the area purposely for subsistence. Harvesting these wild goods act as an important safety net (Peh et al., 2017). The respondents indicated that it would cost them between Gh¢ 2-10 (US$ 0.36–1.8) to purchase alternative protein for their daily meals in times they are not able to catch fish. Seventeen percent (17%) of the 36 respondents surveyed from Cape Three Points also harvested fishery products solely for subsistence and indicated that it would cost them between Gh¢ 10-100 (US$ 1.8-18) monthly to purchase alternative protein for their meals in times they are not able to catch fish.

Priority 2

Nursery grounds provision for fish species was the second service prioritized by both communities. Reason given for this choice according to the consensus reached by the participants was that shallow waters are vital for food provisioning, protection and ecosystem for juvenile fish which becomes adults for them to harvest. This was evidenced by the field ecological assessment performed by the study. Length-frequency distribution of fish sampled in the lagoon and estuary confirmed the nursery function they provide. Comparing the modal lengths of important fish species sampled with their reported lengths at first sexual maturity, it can be concluded that juveniles of those important fish species reside in the coastal water bodies, making them critical ecosystem for fisheries. The nursery role of coastal ecosystems have been discussed in many studies (Maes et al., 2013; Nagelkerken et al., 2000; Ogden & Gladfelter, 1983). Many of the marine fishery species exploited spend at least some part of their life histories in near-shore coastal habitats (MEA, 2005) All the ecosystems understudied, with the exception of the sandy beach, were ranked highest (3) for provisioning of nursery service by both communities. This choice buttressed the importance of fish provisioning for the communities and also, the communities' understanding of the importance of coastal ecosystems for the continuous provisioning of fish which was their topmost priority.

Priority 3

The third most important ES selected by the Princes Town community was the “spiritual” service provided by the Enhuli lagoon. The reason given for this choice was that the culture of the people is strongly tied with the deity of the lagoon which is important for their well-being. The community members stated an average amount of US$186.35 yearly as the amount they were willing to pay for effective management of the lagoon to continually provide the spiritual service it provides. This choice suggested that formal conservation plans would have to consider the existing local management arrangements in place for the lagoon.

The Cape Three Points community placed no value on spiritual service in their selection even though some portions of the rocky beach in the area was said to be of spiritual importance. They however, selected decomposition and fixing of nutrients by mangrove trees as their third choice. The choice was based on the reason that mangrove litter provide food for certain organisms which in turn provide food for the fish they harvest, as reported in the study by (Kamruzzaman et al., 2019).

Priority 4

Climate regulation was selected by the Princess Town community as the fourth most important ES, and mangroves were ranked the highest ecosystem for provision of this service. The choice was based on the reason that the presence of mangrove trees is important for supplying oxygen for sustaining life. The market value of carbon sequestered by mangrove forests bordering the lagoon, estuary and rocky bay depict the worth of the mangrove trees in the prevention of CO_2 emission. Carbon sequestration was valued at

US\$392,701.5 /MgCO_2e/ha/yr for the rocky bay mangrove system, US\$404,030.7 /MgCO_2e/ha/yr for the lagoon mangrove system and US\$289,425.15 /MgCO_2e/ha/yr for the estuary mangrove system.

Cape Three Point community's fourth choice of ES was aesthetics, indicated to be provided by the rocky bay (ranked low) and the sandy beach (ranked medium). Justification given for this choice was that the beauty of the coastal ecosystems provide a sense of relaxation. The community members engaged in the assessment indicated that they were willing to pay an average of US\$1,650.90 yearly to maintain this service.

Fifth priority

Tourism was the final ES selected by the Princess Town community. The lagoon, estuary and mangroves were all indicated as sources of this important cultural service. The community's reason for selecting this service was that tourism, which is supported by biodiversity and aesthetics of the area provides an important source of income to the community. Bird watching and monkey sighting has been developed as a touristic attraction in the area as visitors engage in sailing along the estuary and lagoon to view the variety of bird, monkeys and other animals which use the coastal ecosystems as feeding grounds or ecosystem. Fishermen rent out their fishing vessels to tourists at a fee between US\$ 9 and US\$ 18 per day for these activities. This provides diversification of livelihoods for fishermen. Tourism activities in Princess Town were estimated to yield a yearly income of US\$ 1,989 (Appendix I) for the tourism industry. This choice suggested that conservation efforts would be appreciated by this community if it includes a plan for enhancing tourism-related activities.

Landing site (spatial service) was Cape Three Points community's final important ES selected, and the sandy beach was indicated as the source of this service. Landing, sorting and even smoking of fish, as well as mending of fishing nets and building of canoes are all activities in connection with fishing that are performed at the Cape Three Points sandy beach by virtue of its existence. The beach was said to provide a place for recreation as well, where fishermen and other community members indulge in various recreational activities. This choice highlighted the importance of considering the connectivity of this ecosystem in a conservation plan.

State of the Ecosystems which Supply the Prioritized ES

Mangroves

The mangroves assessed in the area were considered nearly pristine, since exploitation rates are low due to no market demand placed on them (Nortey, Aheto, Blay, Jonah, & Asare, 2016), certain areas were observed to have experienced significant cutting for other purposes. The 3 mangrove systems understudied were generally in good condition and were estimated to sequester high amounts of carbon, emphasizing their important role as carbon sinks (Kauffman & Donato, 2012). Carbon stock assessment of mangrove forests bordering the three water bodies understudied estimated that the mangrove forests store a total carbon of 3,653.77 ± 367.95 MgC/ha, which is regarded relatively high in comparison with average carbon contained in tropical mangroves recorded at 1,023 MgC/ha (Donato et al., 2011). The carbon storage function performed by the mangrove is vital for providing a pH buffer against ocean acidification. Increase in carbon dioxide concentrations on surface waters increases the acidity of the water, affecting biological activity which could have substantial direct and indirect effects on marine organisms and the ecosystems they live in (The Royal Society, 2005). Kamruzzaman et al.(2019) indicated that decomposition of mangrove leaf litter contribute substantial quantities of organic matter in coastal ecosystems via nutrients released in the process. These nutrients are absorbed by the trees for growth and also contributes to the complex marine food web (Donato et al., 2011; Kamruzzaman et al., 2019). As mangrove litter (leaves, seeds and seedlings) fall, they enter the surrounding water body which are grazed by some small animals. The litter is further broken down by bacteria and fungi and decaying pieces of debris are eaten by detritivores (e.g. crabs) which in turn provide food for larger fish and other animals (Kamruzzaman et al., 2019; Stewart & Fairfull, 2008).

Comparing the amount of carbon sequestered by mangroves in the study area (Appendix E10) to magroves of the Indo-Pacific region which are recorded to be among the highest carbon pools of any forest type—ranging between 2,074 and 4,621 MgCO_2e/ha (Kauffman & Donato, 2012)—the importance of protecting these mangroves to prevent indiscriminate cutting cannot be overemphasized. Even though the area assessed is relatively smaller, the high levels of carbon stocks recorded signifies the climate mitigation potential of the mangrove ecosystems. The communities attributed important ecosystem services (food, nursery, climate regulation, decomposition and fixing, tourism and spiritual well-being) to the mangroves in the area. The mangroves provide key socio-economic benefits to the community members (especially women and children who make their livelihoods from shellfish harvesting). Periwinkles, crabs, clams and oysters are among the commercially important resources harvested from the mangroves. During the FGDs, members of the communities also indicated mangroves to be one of the important coastal features that regulate storms and prevent flooding during. Mangroves bordering the Enhuli lagoon are protected by traditional rules because of its spiritual value and for that reason, monkeys reside permanently in the trees, creating an opportunity for monkey sighting to be developed as a touristic activity in the area. It therefore suggested that conservation plans in the area would be efficient if it prioritizes protection of mangroves for the provision of these vital ES.

Estuary

The estuary recorded the highest species diversity but yielded a lower quantity and weight for fish sampled within the sampling period. This could be related to the fishing pressure exerted on the estuary. Physico-chemical parameters investigated in the estuary suggested that it was in generally good condition for supporting aquatic life. The mean temperature value of 28.45 ± 0.34°C (Table 9) recorded for the sampling period fall within the normal temperature range for tropical coastal waters, following the report of Alabaster and Lloyd (1982) that temperature of natural inland waters in the tropics generally varies between 25°C and 35°C. The Nyan estuary was slightly alkaline within the period of study, as expected for saline areas of estuaries (Fisher, 1993). The range of pH levels recorded in the sampling period is considered suitable for aquatic life as it fell within the reported range of 6.5–8.5 preferred by most marine organisms (Fisher, 1993; Pillay, 2004). Nitrate and phosphate levels of the estuary recorded during the sampling period—used as an indicator to investigate nutrient load in the estuary—were close to the optimum limits of 0.1 mg/L and 1.0 mg/L recommended for phosphate for nitrate respectively, as the suitable levels in estuaries and other coastal ecosystems that prevents algal blooms (NOAA/EPA Team, 1988). While high nutrient levels suggest the potential for explosive algal growth, low levels do not necessarily mean the estuary is receiving less nutrient input (Fisher, 1993). Large quantities of nutrients may flow into the estuary and be quickly taken up by phytoplankton. Phosphorus may also bind with the sediment and remove this nutrient from the water (Fisher, 1993). In this regard, although water nutrient concentration is low, the quantity of nutrients tied up in the biomass and sediment is high. Change in any of these factors, due to such events as upwelling, change in PH, or seasonal turnover, could increase the concentration of nutrients in the water (Fisher, 1993). Regular estuary monitoring can provide further data for determining appropriate management measures for nutrient load in the estuary. Salinity levels of the Nyan estuary ranged between 20.2–28.6‰, which influenced the composition of species recorded during the sampling period. A study conducted by Dzakpasu (2012), to measure the extent of seawater penetration in the Nyan estuary demonstrated that seawater penetrates as far as 12.27 km at high tide and 8.31 km at low tide (Dzakpasu, 2012). This implies that estuarine fish species can be found at such distances.

Lagoon

The lagoon recorded relatively lower species diversity as opposed to the estuary (since it's a close system), but yielded a higher quantity and weight for fish sampled within the sampling period. This higher quantities of fish caught from the lagoon could be attributed to the management regime in place which enhances biodiversity conservation to an extent. The lagoon was also considered to be in generally good condition per the physico-chemical parameters investigated. Mean temperature recorded for the lagoon within the sampling period was 30.75 ± 1.69°C (Table 11), which also falls within normal temperature range for tropical coastal waters (Alabaster & Lloyd, 1982). The pH levels recorded for the lagoon for the sampling period ranged between 7.20 and 8.49 (Table 11) and is considered suitable for aquatic life as it fell within the reported range of 6.5–8.5 preferred by most marine organisms (Fisher, 1993; Pillay, 2004). Mean nitrate and phosphate levels recorded for the sampling period, 1.26 ± 0.48 and 0.24 ± 0.28 respectively (Table 11) were above the recommended limits but not at alarming levels.

The lagoon is managed locally by a set of traditional rules (taboos) governing use and accessibility. These taboos place a ban on the use of explosives in fishing; the use of motorized vessels in fishing; fishing on Thursdays; fishing between the time a community member dies and the time he/she is buried; and cutting of mangrove trees surrounding the lagoon. There are rules also set for the use of certain products harvested from the lagoon, since those products are perceived by the community as “spiritual food”. For instance, shrimps and bloody cockles obtained from the lagoon are to be used for subsistence purposes only, restricting the volumes that may otherwise be harvested. These taboos provide a means of conserving the lagoon. Ming’ate & Karigu (2018) and Verschuuren (2006) reported on the importance of spiritual values of ecosystems in management and conservation strategies. When these traditional rules are accorded legal status, they will contribute to effective conservation of the lagoon.

Traditionally, the sand bar of the lagoon is breached (artificial opening of the lagoon) every four years, an activity that forms part of the community's celebration of the local "Kundum" festival. Generally, sandbar breaching promotes water exchange between the lagoon and the ocean (Conde et al., 2015). However, scientists who have analyzed the impacts of artificial openings of coastal lagoons have indicated that particular caution should be taken in conducting this management practice (Conde et al., 2015). The most evident effects of artificial openings are observed on water abiotic variables (Conde et al., 2015). Discharge of ocean water into the lagoon creates steep salinity gradients, as well as nutrients and chlorophyll changes (Conde et al., 2015). Effects of artificial openings of coastal lagoons on fish assemblages are dual, some being beneficial for some coastal species but detrimental for others. Since the effects that may probably occur on other ecosystem components as a result of the change in the lagoon's natural functioning are complex and unknown, it is important to proceed with such activities cautiously. Conde et al. (2015), in their report on solutions for sustainable coastal lagoon management, demonstrated a multidimensional decision-making model for artificial opening, to help those who have to make the decision about when, where, and how it can be done in the best way possible, based on relevant information obtained via research. A formal conservation measure for the Enhuli lagoon will have to address this issue comprehensively.

Sandy beach

Like many beaches along the coast of Ghana, the Cape Three Points sandy beach was observed to be periodically littered by the influx of *Sargassum* (brown algae). For the 12-month field sampling period (November, 2017–November, 2018), *Sargassum* was observed consistently at the beach between March, 2017 and November, 2017. The *Sargassum* are able to cover the entire beach, depriving fishermen access to the sea, as they are unable to launch their vessels through it. They attract tiny insects as they decay on the beach and these insects sting and also occasionally enter the nostrils of users of the beach. The decaying brown algae also produce an offensive smell, which the community members attribute to frequent headaches suffered by most of them in the area. Another challenge attributed to the influx of *Sargassum* is lower fish catch, as fishermen explain that the high densities of *Sargassum* washed ashore by the sea reduces their fishing grounds and also have the potential of entangling the fishes. There is currently no management in place for curbing this menace.

Marine debris is also one of the features that characterized the sandy beach. Solid waste comprising of plastic bags, styrofoam, pvc pipes, gallons, plastic cups, rubber slippers, nylon chords, coconut husk, paper cartons, shoes, plastic buckets, used diapers and glass bottles flood the beach. Cleaning of waste at the beach is said to be under the management of Zoil Services Limited, however, community members noted that the frequency of their service has been "drastically reduced", thereby limiting daily cleaning by community members themselves only to the places used by the community. A more comprehensive management approach should be instituted for curbing these challenges of the sandy beach.

Rocky bay

The bay contains boulders which are mostly submerged by the sea and completely exposed at low tide. Presence of the boulders serve as an important ecosystem for a number of rocky shore fauna and flora which are critical for sustaining fishery livelihoods in the area. Dominance of the black nerite, gastropods in the bay, may influence the abundance of algae as they graze on algae cover in the rocky shore ecosystem and control algae blooms (Cubit, 1984). Species diversity of shellfish recorded for the bay was relatively low with none of the species listed on the IUCN Red list of threatened species. Fishing directly in the bay is limited by the rocks, but just at the mouth of the bay, fishermen harvest by hook and line mostly for subsistence purposes. Commercial fishing in the area is mostly done offshore.

Anthropogenic Pressures and their Impacts on the Coastal Ecosystems

Habitat Risk Assessment (HRA) conducted to determine the influence of multiple human activities on the ecosystems understudied indicated that both Princess Town and Cape Three Points were cumulatively at **medium risk** to a combination of all the pressures assessed. Individually, the ecosystems investigated within each community were at different levels of risk to each or a combination of all the anthropogenic pressure(s) assessed. This highlights areas of concern to be considered in developing appropriate conservation measures for the GCTP area.

Mangroves

Mangroves in the GCTP area were classified as having **low–to–medium risk** cumulatively for the combination of all pressures examined. However, mangroves in Cape Three Points were particularly at high risk to open defaecation and waste disposal in certain areas, whilst those at Princess Town were at high risk to overfishing in certain parts. The effects of these pressures can be detrimental to the health of the mangrove ecosystem which is important for fisheries. The dumping of waste in mangroves introduce plastics on the mudflat which obstruct the establishment of seeds and growth of mangrove seedlings (FAO, 2002). Ganesan & Pandey (2018) noted that one of the main causes of the Mumbai floods in 2005 was plastics accumulation in mangroves, which hindered regular water flow. Waste material get entangled among the network of root structures and obstruct tidal flow into and from the mangrove swamp, which adversely affect the feeding sites of many animals (Ganesan & Pandey, 2018). Ecosystems available to crabs, molluscs, birds and mud skippers are reduced due to the occurrence of plastics. In addition, fish and other aquatic organisms are known to ingest plastic unknowingly as food and introduce it up the food chain (Ganesan & Pandey, 2018). Open defaecation has adverse effects on the ecosystem via the introduction of toxins, bacteria and microbes which contaminates fish stocks. It contributes to nutrient load which eventually end up in aquatic systems and trigger eutrophication that leads to anaerobic conditions of water bodies. It also leads to visual and olfactory pollution which reduces the dignity of the community members (Mensah & Enu-Kwesi, 2018).

Estuary

The HRA ranked the Nyan estuary at Princess Town cumulatively at **medium risk** for combination of all the pressures considered. Coastal deforestation and overfishing individually posed high risks on the estuary. Coastal deforestation can lead to increased muddiness and increased flooding in estuaries, which in turn reduces primary productivity and impacts the tourism industry with the inherent loss of aesthetics (Wolanski, 2007). The mud also affects the biological properties of the water and the benthic food chains in river deltas (Wolanski, 2007).

Open access fishing with no regulation set in place to manage exploitation was suggested by the community to be the cause of high fishing pressure in the estuary. Fishermen from the community and its surroundings engage in fishing all year round, employing some destructive fishing methods occasionally (such as dynamite fishing) to enhance their catch. Participants also noted that restrictions on resource extraction in the Enhuli lagoon diverts exploitation pressures to the estuary, accounting for smaller sizes and quantities of catch in recent times in the estuary. Overfishing can impact entire ecosystems by changing the size of remaining fish, their reproduction and the speed at which they mature (World Wildlife Fund [WWF], 2019). An imbalance is created when too many fish are extracted from the ecosystem. This can erode the food web and lead to a loss of other important aquatic life (WWF, 2019).

Lagoon

The Enhuli lagoon was cumulatively at **low–to–medium risk** for the combination of all the pressures considered. The lagoon was not at high risk for any of the pressures considered for the study. This could be attributed to the traditional management system in place fueled by the spiritual value placed on the lagoon which goes to a large extent to conserve it. That notwithstanding, the traditional rules established are not legally binding and compliance depends largely on an individual's belief system and the level of power of the traditional authority. The lagoon is not entirely immune to the anthropogenic pressures examined, as it showed varying percentages of medium risk to each of the pressures. Strengthening the management of the lagoon to maintain its pristine nature through the codification of customary law is key to conserve it as an important socio-cultural ecosystem for the Princess Town community (Kahler, 2019).

Rocky bay

The rocky bay at Cape Three Points was cumulatively at **medium risk** for combination of all the pressures considered. Per individual pressures, the rocky bay was at high risk for open defaecation and waste disposal as it was in the case of the mangroves bordering it. Community members at Cape Three Points indicated that the rocky bay provides aesthetic services in addition to providing food and nursery services. It was however ranked 1 (low) and this could be attributed to the rampant defaecation and disposal of waste in the area. Dynamite fishing shatters coral reefs, destroying coastal habitats which in turn reduces fish catches and affect food security. It also contributes to beach erosion because when reefs are destroyed protection of beaches from the sea is hindered (Guard & Masaiganah, 1997).

Sandy beach

Sandy beach at Cape Three Points was also ranked cumulatively at **medium risk** for the combination of all the pressures considered. Open defaecation however posed a high risk to the beach. The stretch of sandy beach is dotted with rocks, some of which serve as a place of convenience for females in the community. Since the community spends much time at the beach, constant exposure to the faecal matter is detrimental to their health. Fish is usually sorted and processed at the beach and this exposes the fish to contaminants, reducing its quality for consumption.

Establishing Marine Protected Area as a Response to the Conservation Needs in the GCTP area

The assessment conducted on the ecosystems understudied present a case for establishment of a Marine Protected Area in the Greater Cape Three Points as a precautionary approach to reduce pressures on ecosystem services and enhance their continued supply for human well-being (reference to conceptual framework – Figure 1). IUCN's listed criteria for selecting an area to be included in an MPA or in determining boundaries for an MPA (Kelleher & Kenchington, 1992) include:

1. Naturalness – refers to the extent to which the area has been protected from, or has not been subject to human-induced change.
2. Biogeographic importance – refers to areas which contain unique or unusual geological features.
3. Ecological importance – refers to areas which contributes to maintenance of essential ecological processes or life-support systems; encompasses a complete ecosystem; contains a variety of ecosystems; contains ecosystem for rare or endangered species; contains nursery or juvenile areas; contains feeding; contains breeding or rest areas; contains rare or unique ecosystem for any species; and preserves genetic diversity.
4. Economic importance – refers to the area's existing or potential contribution to economic value by providing protection for recreation, subsistence use by traditional inhabitants, appreciation by tourists, for nursery area or source of supply for economically important species.
5. Social importance – refers to the existing or potential value of the area has to the local, national or international communities because of its heritage,

historical, cultural, traditional aesthetic, educational or recreational qualities.

6. Scientific – refers to the value of the area for research and monitoring.
7. International or National – refers to the area's potential to be listed on the World or a significance national Heritage List or declared as a Biosphere Reserve or included on a list of areas of international or national importance or an area which is the subject of an international or national conservation agreement.
8. Practicality/feasibility – refers to the degree of insulation of the area from external destructive influences, social and political acceptability, degree of community support, accessibility for education and tourism, recreation compatibility with existing uses particularly by locals, ease of management and compatibility with existing management regimes.

Referring to the listed criteria above, this study regards the ecosystems assessed in the GCTP area as eligible for gaining MPA status. The area possesses unique geographical features which enhance its biogeographic importance. The Princess Town area has a distinctive layout, consisting of the sea, estuary and lagoon situated in one location, which depicts an important aesthetic value. The Cape Three Points area also contains unique geographical features of rocky beaches interspersed with sandy beaches. The presence of rounded boulders of various sizes in the bay provides a key aesthetic value. These important geographical features are also important for providing ecosystem for a wide range of biodiversity. The area hosts a suite of critical coastal ecosystems that are relevant for sustaining fishery livelihoods as well as tourism, not only in the local communities, but in Ghana at large, emphasizing its ecological and economic importance. Contribution of the coastal ecosystems to the local economy has been outlined in Tble 14 and Figures 32 and 34). There is also a high potential of developing ecotourism which can also promote scientific research in the area, given the unique geographical features and biodiversity richness.

The Princess Town area was identified as critical for providing nursery site and habitat for economically, socially and ecologically important fish species which are key to the inshore multi-species artisanal fishery practiced in the area. Juveniles of *Pseudotolithus senegalensis*, a commercially important species in Ghana’s fishery, listed as endangered on the IUCN Red List of threatened species were encountered in the study. As threatened species, the IUCN recommends resource and ecosystem protection as one of the conservation actions to be taken to mitigate their decreasing population trend (Nunoo & Nascimento, 2015). *Sardinella maderensis*, another important fish species to the artisanal fishery in Ghana by virtue of its numerous quantities harvested, were encountered in the fish samples obtained in the area, suggesting that they rely on ecosystems in Princess Town for their survival. These species are listed as vulnerable on the IUCN Red List of threatened species and are considered fully exploited in Ghana, signifying the need for conservation measures to be put in place to revive these stocks (Tous et al., 2015). A forest reserve area designated for the conservation of birds by BirdLife International (BirdLife International, 2019) exists adjacent to Cape Three Points, demonstrating the conservation value of the place.

The ecosystems assessed were not highly impacted by intensive anthropogenic activities as it is in certain urban areas. This could be attributed to their location in rural communities as indicated by Nortey et al. (2016) in their assessment of mangrove ecosystems in rural and urban communities. Instituting formal conservation measures as a precautionary approach (Hoyt, 2009; Agardy et al., 2011) to secure the ecosystems will prevent them from moving to the high risk zone. The participatory mapping and assessment exercise revealed that community members are aware of services provided by the ecosystem and are knowledgeable about the system's functioning to a large extent. They also expressed affirmation towards the concept of ecosystem conserving to sustain their livelihoods.

Complete Protection or Multiple Use Conservation: Selecting a Suitable Approach for Managing Ecosystems in the GCTP Area

MPAs are established to protect critical ecosystems of commercial species or species of recreational or other value (Agardy et al., 2011; Kelleher & Kenchington, 1992; Marine Conservation Instsitute, 2019). They range from no-entry areas, which are implemented to protect all marine resources in a complete restricted access regime, to widespread, multiple-use protected areas that implement regulatory mechanisms that enable limited take for certain species in a multi-species fisheries management (IUCN-WCPA, 2008). In as much as establishing **no-take** MPAs contribute significantly towards recovery and protection of marine ecosystems and serve as benchmarks for assessing the success of management regimes, they also prevent traditional users of the resources from access, jeopardizing the survival or well-being of local communities (IUCN-WCPA, 2008; Kelleher, 1999; Kelleher & Kenchington, 1992). Ideally, conservation needs should be balanced with the needs of local people who depend on the ecosystem for their livelihoods (Kelleher, 1999).

Establishing **multiple-use** MPAs helps to achieve this by limiting resource extraction and allowing recreational and other economic activities according to the objectives of the MPA (IUCN-WCPA, 2008). Multiple-use MPAs contribute to economic activity which usually gains the support of communities (Kelleher, 1999). Ecosystems in the GCTP area are suitable for designation as multiple-use MPA with the view that placing a single type of restriction across the ecosystems in the area will not fully meet the conservation needs of all the ecosystems. It was observed from the study that the different ecosystems understudied have different values, different levels of risk to different pressures and different conservation needs. To enhance sustainable livelihoods of people in the area, a multiple-use MPA with different management schedules in different dedicated zones will be ideal to ensure protection of critical ecosystems and develop economic activities in the area. Since livelihoods of coastal communities in the area are tied to the ecosystems, adopting a multi-use MPA that allows for human use and activities with different levels of restriction in order to balance conservation efforts with economic gains and also develop opportunities for the development of ecotourism is imperative.

Zoning involves dividing the coastal / marine area under management into different units in which uses are regulated to accomplish explicit goals. Zoning allows for sustainable exploitation of natural resources, while giving regard to the parameters required for long-term conservation (Habtemariam & Fang, 2016; Kelleher, 1999; Malta Environmental Planning Authority, 2005).

Referring to the MPA case studies reviewed in Chapter 2, it can be observed that zoning plans developed for the Negombo lagoon provided the platform for allocating various parts of the fishery management area for various activities to address the different needs of the area (Salm et al., 2000). Also, in the Gladden Spit and Silk Cayes Marine Reserve case, 378 acres was dedicated as a no-take zone, with the rest designated as general use zone in order to merge conservation needs of the area with development needs (Belize Fisheries Department, 2012).

Habtemariam & Fang (2016), recount that there is no "best" method for developing a zoning scheme for an area since the suitability of a zoning method depends on its ability to satisfy the features of the area to be designated. This study based its zoning method on the ecological, socio-economic, cultural, level of management and risk factors assessed for the ecosystems in the study area. These were used to develop a suitability criteria for attributing each ecosystem a particular conservation status according to two (2) dedicated zones proposed for conserving coastal ecosystems in the GCTP area. These were "General Use Zone (GUZ)" and "Sanctuary zone (SZ)".

General Use Zones refer to areas which provide opportunities for wise use (Great Barrier Reef Marine Park Authority, 2018). Wise use of coastal areas involve the implementation of ecosystem approaches within the context of sustainable development to maintain the ecological character of the areas being used (Ramsar Convention Secretariat, 2010). Thus, within the GUZ, activities such as sustainable commercial fishing, aquaculture, and tourism are permissible provided they are not detrimental to the healthy functioning of the ecosystem (Parks and Wildlife Service, 2017). To enhance wise use, activities such as commercial fishing must be effectively managed within the GUZ. This can be achieved via seasonal closures, restrictions on fishing vessel size, restrictions on the length, mesh size and number of nets used, and ban on destructive fishing activities such as dynamite fishing (Great Barrier Reef Marine Park Authority, 2018).

Sanctuary Zones refers to areas with high spiritual or aesthetic value which is preserved for low-impact activities such as swimming, snorkeling, subsistence fishing and diving. (Habtemariam & Fang, 2016). Sanctuary zone allows for the protection of a wide range of marine plants and animals in the area, and as well, enhances the protection of important habitats such as mangroves and rocky shores. It also provides safe places for threatened species and protect nursery areas for some fish species. Furthermore, SZs provide sites for scientists to monitor relatively undisturbed marine environments for research purposes (Parks and Wildlife Service, 2017). High impact activity such as commercial fishing is prohibited in the SZ.

Ecosystem Suitability for Awarding Conservation Status

In Princess Town, the Nyan estuary was suitable for designation as a GUZ. It scored highest for the combination of criteria set for selecting an ecosystem as a GUZ – Ecological, Socio-economic & Recreational value, and Level of risk to pressures. The estuary scored highest in species diversity, portraying its importance for the supply of biodiversity that support fisheries. Coupled with its provisioning of nursery services, supporting internationally threatened species and supporting decomposition and nutrient supply, it was ranked the highest for the ecological category. The estuary is also an important ecosystem for socio-economic gains, providing a source of livelihood to the people. The level of risk of the estuary to pressures in the area was scored high, indicating the need to effectively manage anthropogenic activities in the area. The estuary also scored high for tourism value and place for community recreation. The Nyan estuary and its surrounding mangrove forest is thus proposed as a General Use Zone to allow for the regulation of activities permitted in the estuary to prevent destruction of the ecosystem and enhance wise use of the estuary. Following the example of general use zones in the Great Barrier Reef Marine Park (Great Barrier Reef Marine Park Authority, 2018), permissible and prohibited activities in the zone should be spelt out in a co-management regime.

The Enhuli lagoon was suitable for designation as a SZ since it ranked highest for the combination of criteria set for that category – Ecological, Cultural & Management. Recognizing the spiritual value of the lagoon to the community and the fact that there already exist traditional rules governing the use of the lagoon (serving as a moderate level of protection), the Enhuli lagoon scored highest for Cultural and Management categories. This was complemented by the high score assigned to it for the ecological category. The lagoon together with the mangrove forest bordering it is thus proposed as a Sanctuary zone in the GCTP area.

According to the suitability criteria employed by the study, cumulatively, the rocky bay was most suitable for designation as a GUZ since it scored highest for that category. However, the study proposes the rocky bay and its surrounding mangrove forests in Cape Three Points to be designated as a Sanctuary Zone instead. This is because the bay is a unique case of a habitat—critical for the provision of nursery for fish and the provision of vital flora and fauna for the food web of fish species in the area—which is being exposed to high pressures of waste disposal, coastal deforestation and open defaecation by the community. Though the area has no direct economic value to the community in terms of fishing or tourism, however, protecting it from the anthropogenic pressures exerted on it is vital for maintaining the health of the ecosystem to support fishing activities in near areas. Similar to the Chumbe Island Coral Park case, where the pristine, uninhabited Chumbe Island off Zanzibar was protected to develop tourism in the area (CHICOP, 2017), the rocky bay which has high ecological value and significant levels of risk to pressures, is being proposed as a Sanctuary Zone to enhance conservation of the habitat and protect nursery areas. This could be beneficial for developing recreational activities in the area as well. This proposal is an indication that selection of a place for protection may not be restricted to the direct, economic values obtained from the place, but may be based on conserving the ecological integrity of the ecosystem by protecting it from the threats it is exposed to, to enhance the overall ecological value of the ecosystem or to generate future socio-economic or cultural benefits (National Geographic Education Staff, 2011).

The sandy beach at Cape Three Points scored low for each of the criteria set by this study for special zone designation and thus was excluded from the special zones category. That is not to say there was no value placed on it. It was valued by the community as critical for the provisioning of cultural services. However, for the suitability criteria developed for this study, the sandy beach was not assigned a special zone.

Recognizing that ecosystems are interconnected and activities outside an MPA can impact on it, it is important to protect the area as part of a broader national plan on coastal ecosystems (Agardy et al., 2011). Such an integrated plan may institute the establishment of networks of several MPAs to enhance provision of important spatial links needed to maintain ecosystem processes and connectivity. This will enhance ecosystem resilience by spreading risk in the case of localized disasters, climate change, failures in management or other hazards, and thus help to ensure the long-term sustainability of populations. (IUCN-WCPA, 2008). There exists a forest reserve in the GCTP area, designated as an International Bird Area (IBA) in 2001 for the conservation of bird populations (BirdLife International, 2019). The proposed MPA should take into consideration, the existing management provisions of this reserve, and harmonize coastal ecosystem conservation in the area to include such provisions. Lessons from the IBA management can guide the effective implementation of conservation efforts in the area.

Establishing a network of MPAs in the GCTP area, where several individual MPAs of small-to-moderate sizes are designed and operated jointly with different protection levels, will provide crucial spatial links needed to conserve coastal ecosystems in the area (IIUCN-WCPA, 2008). The study proposes the establishment of MPAs at Princess Town and Cape Three Points in an MPA network, to facilitate effective conservation of ecosystems in the GCTP area. This presents a practical way to reduce place-based socio-economic impacts without compromising conservation and fisheries benefits, rather than creating one single large MPA which may be challenged by economic, social and political constraints in its implementation (Agardy et al., 2011; IUCN-WCPA, 2008).

Policy Considerations for Ghana's MPA Implementation

Marine Protected Areas are seldom a quick-fix for marine conservation and management, but instead a tool that requires careful, well-balanced, institutional design, with the broadest possible stakeholder participation (Dalton, 2005). Policies and related proposals for the creation of MPAs often raise significant conflicts, especially where they introduce 'no take', 'closed' areas (Grip & Blomqvist, 2020). This is a result of the lack of scientific studies to inform policies needed for MPA site identification, size determination, designating zones, monitoring and development of institutional structures. Imposition of MPA directives and inadequate or no participation of local stakeholders (communities) in the design and implementation of MPAs also contribute to the conflicts associated with MPA policies. Thus, more concern should be given to the communication that occurs prior to the implementation of MPAs (Chuenpagdee et al., 2013). Chuenpagdee et al. (2013) emphasized on the relevance of the step zero analysis in the design of MPAs, which enhances investigation of the conditions, drivers, and processes prior to the inception of MPAs in a social, cultural, and political context. The step zero analysis induces deliberations on important policy aspects related to the design and implementation of MPAs and fosters community stakeholder participation. These are issues that require strategic approaches in addressing Ghana's MPA process. The integrated assessment conducted by this study enhances the step zero analysis for MPA design and implementation in the Greater Cape Three Points Area.

Policy on Ghana's MPAs should strengthen mechanisms for conducting adequate step zero analysis which will highlight avenues for engaging stakeholders and capturing communities' perceptions in the conception and implementation of MPAs. From the Belize MPA case (Chapter 2), the GSSCMR demonstrates how involvement of the local communities, non-governmental organizations and government agencies in a co-management venture enhanced effective management of the reserve. Currently, the issue of co-management in the management of marine resources is being critically considered in Ghana (MOFAD, 2017). This requires coordination within a comprehensive framework for engaging coastal communities in mapping, assessing and prioritizing ecosystem services values towards the establishment of Marine Protected Areas in Ghana. Technical capacity development of implementing government agencies or MPA managers in conducting comprehensive ecosystem assessments should also be addressed in the national MPA policy. To gain support from the numerous interest groups in an MPA, it is essential to build the capacity of the various groups to be able to manage the protected area, exhibit professionalism in carrying out their roles and mainstream communication in the process (Hamú et al., 2004).

Sites identified for MPA status designation should be integrated into an overall plan for marine area management that provides protection of marine ecosystem as a whole, because the success of MPAs depends on management of the surrounding coastal ecosystems due to their ecological interconnectedness. Optimal sizes of MPAs should be determined for each location depending on the conservation needs, state of habitats, level of resource use and the characteristics including the quality and spatial heterogeneity of the biological communities concerned.

Furthermore, as a policy mechanism, zoning should be mandatory in the design of MPAs. Based on the factors identified in the ecosystem assessment, a zoning mechanism allows for multiple uses and the need for periodic scientific assessments, which will help to refine the design and implementation of MPAs. Zoning plans developed for the Negombo lagoon in the Sri Lanka case (Chapter 2) demonstrates how different parts of a protected area can be allocated for various activities to address the different needs of the area. Also, in the Belize case (Chapter 2), GSSCMR has designated 378 acres as a no-take zone, with the rest designated as general use zone in order to merge conservation needs of the area with development needs.

Finally, there is the need to deepen the national dialogue on MPAs that will lead to the creation of policies on MPAs that integrates government and local institutional needs with a diversity of stakeholders with interests in the management of coastal and marine areas. A strategy to liaise with academic and research institutions to conduct research that feeds into MPA designation and implementation is necessary (Kelleher, 1999). From the Tanzania case (Chapter 2), CHICOP was developed out of research conducted by volunteers to establish the conservation value of the island, likewise the GSSCMR (Chapter 2), which was spearheaded by the research carried out by a community-based organization. The role of research in establishing a robust MPA can thus not be overlooked.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

This study was conducted as the first attempt to operationalize the establishment of Marine Protected Areas in Ghana based on the Ecosystem-Based Approach. The objective for proposing the design of a network of Marine Protected Areas (MPAs) in the Greater Cape Three Points (GCTP) area by this study, was focused on protecting critical coastal ecosystems in the area for the purpose of conserving biodiversity as part of National efforts to rebuilding Ghana's fish stocks, whilst allowing for the development of sustainable economic activities of the people. Both monetary and non-monetary values of coastal ecosystems as perceived by inhabitants of the Princess Town and Cape Three Points communities were assessed. These values, together with the ecological status of the ecosystems; the levels of risk of each ecosystem to pressures in the area; and existing management measures in place to conserve the ecosystems, were used to develop an appropriate conservation plan for Princess Town and Cape Three Points within the GCTP area. A set of indicators selected for each assessment type (ecological, economic and socio-cultural assessments) were used to determine each of the ecosystems' suitability to be designated for a particular type of protection. An ecosystem was designated General Use Zone status if its cumulative score for ecological value, socio-economic value and recreational value was high, and its level of risk to pressures was medium – to – high. On the other hand, an ecosystem was designated Sanctuary Zone if its cumulative score for ecological value and cultural / spiritual value was high and there existed a management measure in place for protecting it. Field surveys for the assessments were conducted within a period from August, 2017 to November, 2018. As an outcome of the assessment, the study proposes a network of multiple-use MPAs in the GCTP area, and presents a zoning map with dedicated zones for different levels of restriction within each MPA, as a demonstration of the potential for achieving conservation goals in the area.

Conclusions

Establishing and managing areas for conservation purposes in Ghana may pose a challenging task, given the copious dimensions to be considered and covered to achieve sustainable results. Managers or implementing institutions may tend to be weary of the processes and hastily develop protected areas which may not withstand the challenges associated with MPAs. Nevertheless, establishing and sustaining a resilient MPA is achievable when the processes involved are articulated properly. The “ecosystem / habitat suitability” method applied in this study allows for addressing specific conservation needs of ecosystems revealed via an integrated assessment for designing appropriate conservation measures.

Applying this method in the GCTP area as a pilot study, the following conclusions were drawn:

- Both the Nyan estuary and the Enhuli lagoon at Princess Town were in generally good conditions for sustaining aquatic life. Temperature, salinity, pH, nitrate and phosphate levels recorded between December, 2017 and December, 2018 were within recommended limits for aquatic life as stated in literature.

- The two coastal water bodies provide habitat and nursery for economically, socially and ecologically important fish species in the local and national fishery at large.
- The rocky bay at Cape Three Points hosts a variety of rocky shore fauna with *Nerita senegalensis* (the black nerite) occurring highest in the samples investigated, indicating an ecosystem dominated by grazers who control algal dominance.
- Mangroves stored relatively high amounts of carbon, an average total carbon of 3,653.77±367.95 MgC/ha, with a carbon dioxide equivalent of 13,409.35±1,350.39 $MgCO_2e$/ha. Average leaf litter fall of mangroves sampled between March and December, 2018, was estimated at an average of 1.41 ± 0.3 kg/ha/yr for Princess Town and 1.15 ± 0.09 kg/ha/yr for Cape Three Points.
- Ecosystem services of high priority to the two communities understudied in the GCTP according to their perceptions were: Provisioning service – fish and shellfish which support the local multi-species artisanal fishery; Regulating and Maintenance services – nursery / ecosystem provisioning for fish, climate regulation to reduce surface water acidity and decomposition & fixing of nutrients to maintain productive systems; and Cultural services – areas of spiritual importance, areas for landing, sorting and processing fish to support commercial fisheries and areas for generating tourism activities.
- The economic values of the prioritized ecosystem services were estimated as: Princess Town – US$5.65 /kg/ind./ha/yr. (Provisioning services); US$693,713.7 /site/yr (Regulating and Maintenance services); and

US$544.37 /site/yr (Cultural services) and Cape Three Points – US$26.93 /kg/ind./ha/yr (Provisioning services); US$393,175.24 /site/yr (Regulating and Maintenance services); and US$1650.90 /site/yr (Cultural services).

- Major anthropogenic pressures which threatened ecosystems in the Princess Town area were plastic pollution, fertilizer input, overfishing and coastal deforestation. Ecosystems in the Cape Three Points area were mainly threatened by open defaecation, marine debris, waste disposal and dynamite fishing.
- At Princess Town, the Enhuli lagoon and mangrove forests were at low-to-medium risk to a combination of all the selected pressures, whilst the Nyan estuary was at medium risk to a combination of all the selected pressures.
- At Cape Three Points, the mangroves were at low-to-medium risk to a combination of all the selected pressures assessed in the area, whilst the rocky bay and the sandy beach were at medium risk to a combination of the same pressures.
- Cumulatively, both Princess Town and Cape Three Points were at medium risk to the set of pressures assessed for coastal ecosystems in each area.
- Conservation of coastal ecosystems in the GCTP area was proposed to comprise of a network of individual multiple-use MPAs established to enhance conservation of key species and development of sustainable economic activities.
- Within the multiple-use MPA proposed to be established at Princess Town, the Nyan estuary with its surrounding mangroves was suitable to be designated as a General Use Zone, while the Enhuli lagoon with its surrounding mangroves was suitable to be designated as a Sanctuary Zone.

- Within the multiple-use MPA proposed to be established at Cape Three Points, the rocky bay was suitable to be designated as a Sanctuary Zone.

Recommendations

To achieve effective conservation of coastal ecosystems which are considered critical for fisheries in the GCTP area, the study recommends the following:

1. A follow-up project should be developed to further engage relevant stakeholders for validation of the plan proposed in this study and design a final plan to be implemented for conserving ecosystems in the GCTP area.
2. The District Assembly Government should assist in providing legal backing for the provisions developed concerning accessibility and use of the various zones in view of the anthropogenic pressures assessed.
3. MPA managers should replicate the integrated assessment approach used for this pilot study in other coastal areas of Ghana to enhance the establishment of a network of MPAs in different levels across the country to assist in sustainable small-scale fishery development and rebuilding Ghana's fish stocks.
4. A nationally adopted document regarding criteria for designating and implementing MPAs at different levels should be developed.
5. Complete bans or temporal or spatial restrictions should be imposed on those anthropogenic activities which pose high risks on each ecosystem individually.

The study recommends areas for further studies to fill the gaps encountered in conducting this study as:

a. Economic assessment of multi-species fishery in a similar study should estimate the prices per unit of individual species of importance in the area to help gain a better understanding of the economic value of the activity.

b. Stock assessment should be conducted on important fish species in the Nyan estuary and Enhuli lagoon to verify their overexploitation status as perceived by the communities during the field survey.

c. Further research should be conducted on the impact of various anthropogenic pressures on ecosystems for a more precise assessment.

d. Further studies in this area should investigate the user-conflicts that exist within the area to enhance zoning plans.

e. The net productivity of the mangrove system should be investigated to understand the contribution of mangrove litter to fish productivity in the ecosystem.

f. Harmonized methods for non-use ecosystem services valuation (for example, provision of landing site) should be further developed to be able to capture their monetary values in such an assessment.

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APPENDICES

Appendix A – Interview guide for key informants in the Greater Cape Three Points Area

Interview guide for key informants

Examination of the present conditions and recent trends
What is the contribution of fishing to the community?
What other sources of livelihoods are there for fishermen in the community?
Comparing historical fishing to current fishing in the community, has there been significant changes?
What are the significances of the estuary, lagoon, beaches and mangroves to fishing in the community?
Existing management measures
Is Conservation of these ecosystems and biodiversity an issue of concern to people in your community? If yes, what steps have been taken to protect these ecosystems?
Are there any legal provisions for natural resource (fisheries) management in the area?
Are there customary laws / regulations / norms for protecting or managing the resources in the area?
What are the punishments meted out for non-compliance?
How effective are these provisions?
. Are there special protected areas in the vicinity (please indicate on the map)?
. Are there dedicated custodians of the ecosystems (lagoon, estuary, mangroves, and beaches) in charge of the estuary and lagoon in the community?

. What roles do they play in protecting the ecosystems?
Understanding current vulnerability to multiple stresses
. What have been the major threats to fishing in the community related to anthropogenic sources?
. Please rate the threats from "High threat" [3] to threat "Not Applicable (N/A) [0] and indicate the degree to which exposure to each threat has caused ecosystem change.
Recreation and Tourism
. How many tour guides are in the community?
. What are their roles?
. What are the tourist attractions in the area? Please show on the map.
. Is there a tourist fee charged for accessing the tourist attractions? If yes, how much is it (please give a range)?
. Is the area used for any recreational activity such as sailing, canoeing, swimming, surfing, leisure fishing?
. Are there special bathing areas in the lagoon / estuary? (Please indicate on the map.)
. What are the main activities carried out to protect the interest of tourism in the community?

Appendix B – Questionnaire for obtaining data for economic valuation of ES

Questionnaire for community members involved in fisheries

Name of Interviewer:
Number of respondent:
Date:
Location / Name of village:
Product harvested:
VALUATION OF PRODUCTION
Description of the harvesters
1. Do you have a diversity of income from different sources? Please specify
Quantity and value of product
2. Is the product seasonal? If yes, give details about its seasonality
3. What are the products used for? E.g livestock feed, eating, selling, etc
4. What is the local unit used to quantify the product, e.g. Tins, buckets, baskets, etc
5. How many times do you harvest in a week?
6. What is the total quantity you harvest in a week?
7. What percentage of the product you harvest is for your own use? 100% dependent 80% dependent 50% dependent 20% dependent
8. What percentage of the product you harvest is sold?

100% dependent 80% dependent 50% dependent 20% dependent
9. Where do you usually sell the product?
10. How much is a unit of the product sold for?
Fixed costs
11. Please state your fixed costs and indicate how much you commit to them (eg. Land, boat, fishing gears)
12. How long do you expect each of your tools / equipment to last? Eqpt 1 ………………………..(……yrs) Eqpt 2……………………….. (……yrs) Eqpt 3……………………….. (……yrs) Eqpt 4……………………….. (……yrs) Eqpt 5……………………….. (……yrs)
Operational costs
13. What are your operational costs and how much are they? (eg. Fuel, wages, food, marketing)
Maintenance costs
14. How often do you maintain your tools / equipment?
15. How much do you spend on maintenance in a year?
Non-marketed goods
16. If you were not able to harvest this product, what effect will it have on your livelihood?

17. If you could no longer harvest the product and had to replace it, what product would you need to buy and what would it cost for an equivalent amount?
18. What reasons do you ascribe to these changes? (Threats to the provisioning of the service)
Rules for the product
19. Are there rules on accessing, processing or selling the product, which affect how much is harvested? Please explain
20. Are there restrictions on harvesting this product in regard to the quantity that can be harvested?
VALUATION OF SPIRITUAL SERVICE
21. How much are you willing to pay per month for the protection of the sacred sites in the community?
VALUATION OF AESTHETICS SERVICE
22. Where is you most beautiful place in the community you like to sit and relax?
23. How much are you willing to pay for the management of the place to look appealing to spend time there?

Appendix C: Physicochemical Parameters Recorded for Coastal Water Bodies in the Study Area

Appendix C1: Physicochemical parameters of the Nyan estuary (Nov.17 – Nov. 18)

	TEMPERATURE (°C)			PH			DO			SALINITY(ppt)			NITRATE			PHOSPHATE		
Month	S	MW*	Av *	S	MW	Av	S	MW	Av	S	MW	Av	Surface	MW	Av	S	MW	Av
Nov' 17	28.99	27.75	28.37	7.35	7.48	7.41	1.36	1.29	1.32	0.60	11.22	5.91	3.71	3.60	3.65	1.53	1.59	1.56
Dec' 17	28.28	28.26	28.27	8.47	8.43	8.45	5.97	5.88	5.93	13.5	14.17	13.83	1.29	1.54	1.42	0.59	0.76	0.68
Jan' 18	27.23	27.56	27.39	8.16	8.07	8.11	5.76	5.20	5.48	0.47	1.53	1.00	1.54	1.07	1.30	0.20	0.14	0.17
Feb' 18	30.13	29.67	29.90	8.42	8.49	8.46	3.26	3.42	3.34	26.4	27.00	26.70	1.39	1.44	1.42	1.36	1.85	1.61
Mar' 18	29.16	28.93	29.05	8.35	8.50	8.43	2.97	3.02	3.00	28.73	28.73	28.73	1.29	1.49	1.39	0.15	0.14	0.15
Apr' 18	31.32	31.12	31.22	8.12	8.16	8.14	2.28	1.93	2.10	35.13	35.27	35.20	0.91	0.87	0.89	0.068	0.09	0.08
May' 18	30.68	25.38	28.03	7.50	7.53	7.52	5.32	5.05	5.18	30.89	31.65	31.27	1.35	0.99	1.17	0.05	0.06	0.05
Jun' 18	28.88	28.68	28.78	7.27	7.22	7.25	1.15	1.11	1.13	4.05	4.35	4.20	0.61	0.33	0.47	0.12	0.19	0.15
Jul' 18	27.33	27.18	27.26	7.51	7.42	7.46	1.15	1.11	1.13	3.2	4.25	3.72	0.09	0.15	0.12	0.08	0.08	0.08
Aug' 18	28.70	28.13	28.42	8.22	8.17	8.19	0.75	0.73	0.74	19.15	28.82	23.99	0.62	0.58	0.60	0.39	0.61	0.50
Sept' 18	27.30	26.97	27.13	8.07	7.96	8.02	0.51	0.52	0.52	10.07	30.25	20.16	1.25	1.23	1.24	0.174	0.22	0.19
Oct'18				7.10	7.09	7.10				2.13	1.20		0.00	0.00	0.00	0.24	0.17	0.20
Nov' 18	27.56	27.50	27.53	7.46	7.41	7.44	0.48	0.40	0.44	3.14	3.25	3.19	0.11	0.22	0.16	0.15	0.11	0.13
Total			28.45			7.84			2.72			16.49			1.1			0.4
Standard deviation			1.2			0.5			2.0			12.6			0.9			0.5
Standard Error			0.3			0.1			0.6			3.6						

*S = Surface; MW = Mid Water; Av = Average

Appendix C2: Physicochemical parameters of the Enhuli lagoon (Nov.17 – Nov. 18)

	TEMPERATURE °C)			PH			DO			SALINITY(ppt)			NITRATE			PHOSPHATE		
Month	S	MW*	Av*	S	MW	Av	S	MW	Av	S	MW	Av	Surface	MW	Av	S	MW	Av
Nov' 17	30.74	30.86	30.80	7.71	7.72	7.72				21.65	21.34	21.50	1.97	1.71	1.84	0.59	0.77	0.68
Dec' 17	31.01	30.84	30.93	8.41	8.46	8.43	5.58	5.38	5.48	27.47	27.53	27.50	1.49	1.54	1.51	0.32	0.45	0.38
Jan' 18	23.75	28.61	26.18	8.08	8.26	8.17	5.63	5.31	5.47	23.20	24.07	23.63	2.15	2.25	2.20	0.11	0.10	0.10
Feb' 18	31.84	31.80	31.82	8.47	8.50	8.49	3.34	3.13	3.24	30.60	30.47	30.53	1.22	1.23	1.22	0.90	0.99	0.94
Mar' 18	31.87	31.76	31.82	8.57	8.33	8.45	2.83	2.71	2.77	30.33	30.27	30.30	1.39	1.29	1.34	0.41	0.19	0.30
Apr' 18	30.62	30.52	30.57	8.38	8.36	8.37	1.44	0.91	1.17	37.13	37.53	37.33	1.85	1.60	1.73	0.22	0.09	0.15
May' 18	32.31	32.36	32.33	7.98	7.97	7.98	5.42	5.19	5.30	36.94	36.87	36.91	1.38	1.01	1.20	0.07	0.08	0.08
Jun' 18	31.68	31.62	31.65	7.66	7.66	7.66	1.48	1.46	1.47	28.29	28.33	28.31	1.53	1.41	1.47	0.20	0.06	0.13
Jul' 18	30.37	30.05	30.21	7.20	7.20	7.20	1.00	0.94	0.97	24.97	25.43	25.20	0.57	0.40	0.49	0.08	0.03	0.06
Aug' 18	29.31	29.32	29.31	7.66	7.67	7.67	0.68	0.50	0.59	23.49	23.50	23.49	0.84	1.01	0.93	0.04	0.01	0.03
Sept' 18	31.16	30.85	31.00	7.79	7.77	7.78	0.60	0.46	0.53	23.78	23.77	23.78	0.83	0.83	0.83	0.06	0.09	0.07
Oct'18				7.61	7.63	7.62				24.00	22.20	23.10	0.77	0.86	0.82	0.08	0.06	0.07
Nov' 18	32.38	32.29	32.34	7.39	7.39	7.39	0.48	0.41	0.44	22.01	22.03	22.02	0.90	0.84	0.87	0.10	0.12	0.11
			30.75			7.92			2.49			27.20			1.26			0.24
Standard deviation			1.7			0.43			2.08			5.30			0.48			0.28
Standard Error			0.5			0.1			0.6			1.4704			0.134			0.08

*S = Surface; MW = Mid Water; Av = Average

Appendix D: Species Composition of Fish Sampled

Appendix D1: Species composition of estuary samples

No. of species (S)	Scientific name	Common name	Family - 13	Status on IUCN Red List of Threatened species	No. sampled	No. of individuals of species / total no. of individuals (pi)	ln(pi)	Shannon-Weiner index (H) = {pi*ln(pi)}
1	*Acanthurus monroviae*	Monrovia doctorfish	Acanthuridae	Least concern	7	0.009589041	-4.64713	-0.044561563
2	*Albula vulpes*	Bone fish	Albulidae	Near threatened	1	0.001369863	-6.59304	-0.009031568
3	*Brachydeuterus auritus*	Bigeye grunt	Haemulidae	Near threatened	1	0.001369863	-6.59304	-0.009031568
4	*Caranx hippos*	Crevalle jack	Carangidae	Least concern	35	0.047945205	-3.0377	-0.145642982
5	*Chloroscombus chrysurus*	Atlantic bumper	Carangidae	Least concern	26	0.035616438	-3.33495	-0.11877897
6	*Citharichthys stampflii*	Smooth flounder	Paralichthyidae	Least concern	1	0.001369863	-6.59304	-0.009031568
7	*Epinephelus aeneus*	White grouper	Serranidae	Near threatened	1	0.001369863	-6.59304	-0.009031568
8	*Ethmalosa fimbriata*	Bonga shad	Clupeidae	Least concern	3	0.004109589	-5.49443	-0.022579859
9	*Eucinistomus melanopterus*	Flagfin mojarra, Butterfish	Gerreidae	Least concern	328	0.449315068	-0.80003	-0.35946595
10	*Galeoides decadactylus*	Thread fin	Polynemidae	Near threatened	7	0.009589041	-4.64713	-0.044561563

No. of species (S)	Scientific name	Common name	Family - 13	Status on IUCN Red List of Threatened species	No. sampled	No. of individuals of species / total no. of individuals (pi)	ln(pi)	Shannon-Weiner index (H) = {pi*ln(pi)}
11	*Hemichromis fasciatus*	Banded jewelfish / 5-spot cichlid	Cichlidae	Least concern	19	0.026027397	-3.64861	-0.094963706
12	*Lisa dumerilli*	Grooved mullet	Mugilidae	Data deficient	61	0.083561644	-2.48217	-0.207414261
13	*Lisa falcipinius*	Sicklefin mullet	Mugilidae	Data deficient	38	0.052054795	-2.95546	-0.153845778
14	*Lisa grandisquamis*	Largescaled mullet	Mugilidae	Data deficient	78	0.106849315	-2.23634	-0.238950939
15	*Lutjanus dentatus*	African brown snapper	Lutjanidae	Data deficient	1	0.001369863	-6.59304	-0.009031568
16	*Lutjanus endecacanthus*	Guinea snapper	Lutjanidae	Data deficient	6	0.008219178	-4.80129	-0.039462617
17	*Lutjanus goreensis*	Gorean snapper/Grouper	Lutjanidae	Data deficient	15	0.020547945	-3.88499	-0.079828651
18	*Mugil bananiensis*	Banana mullet	Mugilidae	Least concern	25	0.034246575	-3.37417	-0.115553723
19	*Mugil curema*	White mullet	Mugilidae	Least concern	18	0.024657534	-3.70267	-0.091298781
20	*Pomadasys perotaei*	Parrot grunt	Haemulidae	Data deficient	3	0.004109589	-5.49443	-0.022579859
21	*Pseudotolithus senegalensis*	Cassava croaker	Sciaenidae	Endangered	5	0.006849315	-4.98361	-0.034134292

No. of species (S)	Scientific name	Common name	Family - 13	Status on IUCN Red List of Threatened species	No. sampled	No. of individuals of species / total no. of individuals (pi)	ln(pi)	Shannon-Weiner index (H) = {pi*ln(pi)}
22	*Pseudotolithus typus*	Longneck croaker	Sciaenidae	Least concern	1	0.001369863	-6.59304	-0.009031568
23	*Sarotheredon malenotheron*	Black chinned tilapia	Cichlidae	Not evaluated	17	0.023287671	-3.75983	-0.087557713
24	*Sarotherodon galilaeus*	Mango tilapia / Galilaea tilapia	Cichlidae	Least concern	4	0.005479452	-5.20675	-0.028530138
25	*Tilapia guineensis*	Guinean tilapia	Cichlidae	Least concern	2	0.002739726	-5.8999	-0.016164102
26	*Tilapia zillii*	Redbelly tilapia	Cichlidae	Least concern	3	0.004109589	-5.49443	-0.022579859
27	*Trachinotus ovatus*	Silver fish	Carangidae	Least concern	24	0.032876712	-3.41499	-0.112273667
					730			**-2.134918377**

No. of species (S) - 27

Shannon-Weiner index (H) = {pi*ln(pi)} - 2.1; Max possible value of H (Hmax) = LN(27) - 3.3

Evenness [E] = (H / Hmax) - 0.65

Appendix D2: Species composition of lagoon samples

No. of species (S)	Scientific name	Common name	Family - 11	Status on IUCN Red List of Threatened species	No. sampled	No. of individuals of species / total no. of individuals (pi)	ln(pi)	Shannon-Weiner index (H) = {pi*ln(pi)}
1	*Albula vulpes*	Bone fish	Albulidae	Near threatened	7	0.006306306	-5.06621	-0.03195
2	*Caranx hippos*	Crevalle jack	Carrangidae	Least concern	4	0.003603604	-5.62582	-0.02027
3	*Caranx senegallus*	Senegal jack	Carangidae	Least concern	3	0.002702703	-5.9135	-0.01598
4	*Chloroscombus chrysurus*	Atlantic bumper	Carangidae	Least concern	1	0.000900901	-7.01212	-0.00632
5	*Ethmalosa fimbriata*	Bonga shad	Clupeidae	Least concern	154	0.138738739	-1.97516	-0.27403
6	*Eucinostomus melanopterus*	Flagfin mojarra/ Butterfish	Gerreidae	Least concern	16	0.014414414	-4.23953	-0.06111
7	*Galeoides decadactylus*	Thread fin	Polynemidae	Near threatened	3	0.002702703	-5.9135	-0.01598
8	*Hemicaranx bicolour*	Bicolour jack	Carangidae	Least concern	3	0.002702703	-5.9135	-0.01598
9	*Hemichromis fasciatus*	Banded jewelfish / 5-spot cichlid	Cichlidae	Least concern	35	0.031531532	-3.45677	-0.109
10	*Lisa falcipinius*	Sicklefin mullet	Mugilidae	Data deficient	5	0.004504505	-5.40268	-0.02434

No. of species (S)	Scientific name	Common name	Family - 11	Status on IUCN Red List of Threatened species	No. sampled	No. of individuals of species / total no. of individuals (pi)	ln(pi)	Shannon-Weiner index (H) = {pi*ln(pi)}
11	*Lisa grandisquamis*	Largescaled mullet	Mugillidae	Data deficient	6	0.005405405	-5.22036	-0.02822
12	*Lutjanus dentatus*	African brown snapper	Lutjanidae	Data deficient	1	0.000900901	-7.01212	-0.00632
13	*Lutjanus goreensis*	Gorean snapper/Grouper	Lutjanidae	Data deficient	2	0.001801802	-6.31897	-0.01139
14	*Monodactylus sebae*	Afrcican moony	Monodactylidae	Least concern	1	0.000900901	-7.01212	-0.00632
15	*Mugil bananensis*	Banana mullet	Mugilidae	Least concern	3	0.002702703	-5.9135	-0.01598
16	*Pomadasys perotaei*	Parrot grunt	Haemulidae	Data deficient	1	0.000900901	-7.01212	-0.00632
17	*Sardinella aurita*	Round sadinella	Clupeidae	Least concern	23	0.020720721	-3.87662	-0.08033
18	*Sardinella maderensis*	Flat / Common sardines	Clupeidae	Vulnerable	552	0.497297297	-0.69857	-0.3474
19	*Sarotheredon malenotheron*	Black chinned tilapia	Cichlidae	Not evaluated	121	0.109009009	-2.21632	-0.2416
20	*Tilapia guineensis*	Guinean tilapia	Cichlidae	Least concern	76	0.068468468	-2.68138	-0.18359

No. of species (S)	Scientific name	Common name	Family - 11	Status on IUCN Red List of Threatened species	No. sampled	No. of individuals of species / total no. of individuals (pi)	ln(pi)	Shannon-Weiner index (H) = {pi*ln(pi)}
21	*Tilapia zillii*	Redbelly tilapia	Cichlidae	Least concern	92	0.082882883	-2.49033	-0.20641
21					**1109**			**-1.70882**

No. of species (S) - 21

Shannon-Weiner index (H) = {pi*ln(pi)} - 1.7; Max possible value of H (Hmax) = LN(21) - 3.0

Evenness [E] = (H / Hmax) - 0.56

Appendix D3: Species composition of rocky bay samples

No. of species (S)	Scientific name	Common name	Family - 11	Status on IUCN Red List of Threatened species	No. sampled	No. of individuals of species / total no. of individuals (pi)	ln(pi)	Shannon-Weiner index (H) = {pi*ln(pi)}
1	*Littorina angulifera*	Mangrove periwinkle	Littorinidae	Not evaluated	542	0.144764957	-1.93264	-0.279779102
2	*Littorina striata*		Littorinidae	Not evaluated	2	0.000534188	-7.53476	-0.00402498
3	*Tectarius granosus*	Beaded prickly winkle	Littorinidae	Not evaluated	177	0.047275641	-3.05176	-0.144273915
4	*Thais haemastoma*	Red-mouthed rock shell	Muricidae	Not evaluated	2	0.000534188	-7.53476	-0.00402498
5	*Perna perna*	Brown mussel	Mytilidae	Not evaluated	88	0.023504274	-3.75057	-0.088154494
6	*Nerita senegalensis*	Black nerite	Neritidae	Not evaluated	2072	0.553418803	-0.59164	-0.32742483
7	*Thais callifera*	Murex snail	Muricidae	Not evaluated	9	0.002403846	-6.03069	-0.01449684
8	*Siphonaria pectinata*	Stripped false limpet	Siphonariidae	Not evaluated	664	0.177350427	-1.72963	-0.30675021
9	*Pagurus bernhardus*	Common marine hermit crab	Paguridae	Not evaluated	48	0.012820513	-4.35671	-0.055855241
10	*Actinia equina*	Beadlet anemone	Actiniidae	Not evaluated	55	0.014690171	-4.22058	-0.062000992
11	*Grapsus grapsus*	Black rock crab	Grapsidae	Not evaluated	10	0.00267094	-5.92532	-0.015826188

No. of species (S)	Scientific name	Common name	Family - 11	Status on IUCN Red List of Threatened species	No. sampled	No. of individuals of species / total no. of individuals (pi)	ln(pi)	Shannon-Weiner index (H) = {pi*ln(pi)}
12	*Littorina cingulifera*		Littorinidae	Not evaluated	2	0.000534188	-7.53476	-0.00402498
13	*Planaxis lineatus*	Dwarf planaxis	Planaxidae	Not evaluated	11	0.002938034	-5.83001	-0.017128782
14	*Semifusus morio*	Giant hairy melongena	Melongenidae	Not evaluated	3	0.000801282	-7.1293	-0.005712578
15	*Diadema antillarum*	Black sea urchin	Diadematidae	Not evaluated	7	0.001869658	-6.282	-0.011745192
15					**3692**			**-1.341223305**

No. of species (S) - 15
Shannon-Weiner index (H) = {pi*ln(pi)} - 1.3; Max possible value of H (Hmax) = LN(15) - 2.7
Evenness [E] = (H / Hmax)

Appendix E: Mangrove trees composition and Biomass, Carbon stocks and Carbon dioxide equivalent Estimation

Appendix E1: Mangrove Tree Parameters for estuary

No.	Species per 1,000m2 plot	Circumsference (C) (cm)	DBH = (C/π) (cm)	AG biomass (Wtop = 0.251pD2.46)	AG Carbon Stock (Wtop * 0.46)	BG biomass (Wbot = 0.199p0.899D2.2 2)	BG Carbon Stock (Wbot * 0.39)
1	*Rhizophora mangle*	46.50	14.80	157.60	72.50	66.69	26.01
2	*Rhizophora mangle*	50.80	16.17	195.91	90.12	81.16	31.65
3	*Rhizophora mangle*	44.40	14.13	140.67	64.71	60.19	23.47
4	*Rhizophora mangle*	33.50	10.66	70.35	32.36	32.20	12.56
5	*Rhizophora mangle*	16.90	5.38	13.07	6.01	7.05	2.75
6	*Rhizophora mangle*	20.00	6.37	19.78	9.10	10.25	4.00
7	*Rhizophora mangle*	21.30	6.78	23.09	10.62	11.78	4.60
8	*Rhizophora mangle*	25.40	8.08	35.61	16.38	17.42	6.79
9	*Rhizophora mangle*	13.40	4.26	7.38	3.40	4.21	1.64
10	*Rhizophora mangle*	21.95	6.99	24.86	11.44	12.60	4.91
11	*Rhizophora mangle*	21.70	6.91	24.17	11.12	12.28	4.79
12	*Rhizophora mangle*	22.40	7.13	26.14	12.02	13.18	5.14
13	*Rhizophora mangle*	23.50	7.48	29.41	13.53	14.66	5.72
14	*Rhizophora mangle*	36.50	11.62	86.87	39.96	38.96	15.19
15	*Rhizophora mangle*	26.50	8.43	39.52	18.18	19.14	7.46
16	*Rhizophora mangle*	32.90	10.47	67.29	30.95	30.94	12.07
17	*Rhizophora mangle*	40.00	12.73	108.82	50.06	47.74	18.62

No.	Species per 1,000m2 plot	Circumsference (C) (cm)	DBH = (C/π) (cm)	AG biomass (Wtop = 0.251pD2.46)	AG Carbon Stock (Wtop * 0.46)	BG biomass (Wbot = 0.199p0.899D2.2 2)	BG Carbon Stock (Wbot * 0.39)
18	*Rhizophora mangle*	32.30	10.28	64.31	29.58	29.70	11.58
19	*Rhizophora mangle*	35.30	11.23	80.01	36.81	36.17	14.11
20	*Rhizophora mangle*	38.70	12.32	100.32	46.15	44.36	17.30
21	*Rhizophora mangle*	45.50	14.48	149.39	68.72	63.55	24.78
22	*Rhizophora mangle*	49.50	15.75	183.80	84.55	76.62	29.88
23	*Rhizophora mangle*	24.05	7.65	31.13	14.32	15.43	6.02
24	*Rhizophora mangle*	28.60	9.10	47.67	21.93	22.67	8.84
25	*Rhizophora mangle*	28.50	9.07	47.27	21.74	22.49	8.77
26	*Rhizophora mangle*	29.50	9.39	51.45	23.67	24.28	9.47
27	*Rhizophora mangle*	28.30	9.01	46.45	21.37	22.14	8.64
28	*Rhizophora mangle*	21.20	6.75	22.83	10.50	11.66	4.55
29	*Rhizophora mangle*	26.50	8.43	39.52	18.18	19.14	7.46
30	*Rhizophora mangle*	20.90	6.65	22.04	10.14	11.30	4.41
1	*Laguncularia racemosa*	20.10	6.40	14.47	6.66	10.36	4.04
2	*Laguncularia racemosa*	15.60	4.96	7.76	3.57	5.90	2.30
3	*Laguncularia racemosa*	20.50	6.52	15.19	6.99	10.82	4.22
4	*Laguncularia racemosa*	17.85	5.68	10.81	4.97	7.96	3.10
5	*Laguncularia racemosa*	10.10	3.21	2.66	1.22	2.25	0.88
6	*Laguncularia racemosa*	8.00	2.55	1.50	0.69	1.34	0.52
7	*Laguncularia racemosa*	12.40	3.95	4.41	2.03	3.55	1.38
8	*Laguncularia racemosa*	10.00	3.18	2.60	1.20	2.20	0.86

No.	Species per 1,000m2 plot	Circumsference (C) (cm)	DBH = (C/π) (cm)	AG biomass (Wtop = 0.251pD2.46)	AG Carbon Stock (Wtop * 0.46)	BG biomass (Wbot = 0.199p0.899D2.2 2)	BG Carbon Stock (Wbot * 0.39)
9	*Laguncularia racemosa*	8.40	2.67	1.69	0.78	1.49	0.58
10	*Laguncularia racemosa*	23.90	7.61	22.16	10.19	15.22	5.93
11	*Laguncularia racemosa*	14.00	4.46	5.95	2.73	4.64	1.81
			8.29	2045.91	941.12	945.69	368.82
	Average carbon stock /plot (kgC/m2)			2.045905778	0.941116658	0.945692516	0.368820081
	Average carbon stock / ha (MgC/ha)			20.45905778	9.411166581	9.45692516	3.688200812

Appendix E2: Mangrove Tree Parameters for lagoon

No.	Species per 1,000m2 plot	Circumsference (C) (cm)	DBH = (C/π) (cm)	AG biomass (Wtop = 0.251pD2.46)	AG Carbon Stock (Wtop * 0.46)	BG biomass (Wbot = 0.199p0.899D2.22)	BG Carbon Stock (Wbot * 0.39)
1	*Rhizophora mangle*	6	1.91	1.02	0.47	0.655305749	0.26
2	*Rhizophora mangle*	67	21.34	387.66	178.32	138.9422297	54.19
3	*Rhizophora mangle*	11.05	3.52	4.60	2.12	2.542216067	0.99
4	*Rhizophora mangle*	8.05	2.56	2.11	0.97	1.258389415	0.49
5	*Rhizophora mangle*	64	20.38	346.34	159.32	125.5069409	48.95
6	*Rhizophora mangle*	39	12.42	102.41	47.11	41.79377782	16.30
7	*Rhizophora mangle*	63.25	20.14	336.44	154.76	122.26512	47.68
8	*Rhizophora mangle*	154	49.04	3003.35	1381.54	881.5444231	343.80
9	*Rhizophora mangle*	4	1.27	0.38	0.17	0.266392125	0.10
10	*Rhizophora mangle*	29.5	9.39	51.53	23.70	22.48811624	8.77
11	*Rhizophora mangle*	56	17.83	249.37	114.71	93.30944838	36.39
12	*Rhizophora mangle*	64	20.38	346.34	159.32	125.5069409	48.95
13	*Rhizophora mangle*	50.25	16.00	191.03	87.87	73.36184901	28.61
14	*Rhizophora mangle*	68	21.66	402.05	184.94	143.5879477	56.00
15	*Rhizophora mangle*	37.75	12.02	94.52	43.48	38.87799363	15.16
16	*Rhizophora mangle*	60	19.11	295.50	135.93	108.7536841	42.41
17	*Rhizophora mangle*	50	15.92	188.70	86.80	72.55404193	28.30
18	*Rhizophora mangle*	47.5	15.13	166.33	76.51	64.74526539	25.25
19	*Rhizophora mangle*	91	28.98	823.28	378.71	274.1701016	106.93
20	*Rhizophora mangle*	54	17.20	228.03	104.89	86.07209004	33.57

No.	Species per 1,000m2 plot	Circumsference (C) (cm)	DBH = (C/π) (cm)	AG biomass (Wtop = 0.251pD2.46)	AG Carbon Stock (Wtop * 0.46)	BG biomass (Wbot = 0.199p0.899D2.22)	BG Carbon Stock (Wbot * 0.39)
21	*Rhizophora mangle*	66	21.02	373.58	171.85	134.380341	52.41
22	*Rhizophora mangle*	59	18.79	283.53	130.42	104.7706571	40.86
23	*Rhizophora mangle*	58	18.47	271.86	125.05	100.8691469	39.34
24	*Rhizophora mangle*	88	28.03	758.11	348.73	254.5070014	99.26
25	*Rhizophora mangle*	65	20.70	359.81	165.51	129.9020048	50.66
26	*Rhizophora mangle*	53	16.88	217.78	100.18	82.57348847	32.20
27	*Rhizophora mangle*	36	11.46	84.10	38.69	34.98966253	13.65
28	*Rhizophora mangle*	70	22.29	431.76	198.61	153.1319634	59.72
29	*Rhizophora mangle*	65	20.70	359.81	165.51	129.9020048	50.66
30	*Rhizophora mangle*	26	8.28	37.77	17.37	16.98983005	6.63
31	*Rhizophora mangle*	75.5	24.04	520.06	239.23	181.1300198	70.64
32	*Rhizophora mangle*	55.5	17.68	243.93	112.21	91.46998852	35.67
33	*Rhizophora mangle*	68	21.66	402.05	184.94	143.5879477	56.00
34	*Rhizophora mangle*	40	12.74	108.99	50.13	44.21008835	17.24
35	*Rhizophora mangle*	61	19.43	307.76	141.57	112.8185298	44.00
36	*Rhizophora mangle*	39.5	12.58	105.67	48.61	42.99260438	16.77
37	*Rhizophora mangle*	44	14.01	137.78	63.38	54.62772869	21.30
38	*Rhizophora mangle*	39	12.42	102.40	47.10	41.79092304	16.30
39	*Rhizophora mangle*	32	10.19	62.95	28.96	26.93898038	10.51
40	*Rhizophora mangle*	7.85	2.50	1.98	0.91	1.190032549	0.46
41	*Rhizophora mangle*	8.11	2.58	2.15	0.99	1.279306182	0.50
42	*Rhizophora mangle*	35	11.15	78.47	36.10	32.86845274	12.82

No.	Species per 1,000m2 plot	Circumsference (C) (cm)	DBH = (C/π) (cm)	AG biomass (Wtop = 0.251pD2.46)	AG Carbon Stock (Wtop * 0.46)	BG biomass (Wbot = 0.199p0.899D2.22)	BG Carbon Stock (Wbot * 0.39)
43	*Rhizophora mangle*	6.95	2.21	1.47	0.68	0.908143478	0.35
44	*Rhizophora mangle*	4.04	1.29	0.39	0.18	0.272342132	0.11
45	*Rhizophora mangle*	4.11	1.31	0.40	0.19	0.282928728	0.11
46	*Rhizophora mangle*	36	11.46	84.10	38.69	34.98966253	13.65
47	*Rhizophora mangle*	28	8.92	45.32	20.85	20.02806682	7.81
48	*Rhizophora mangle*	32	10.19	62.95	28.96	26.93898038	10.51
49	*Rhizophora mangle*	3.05	0.97	0.19	0.09	0.145912953	0.06
50	*Rhizophora mangle*	4.03	1.28	0.38	0.18	0.270847857	0.11
51	*Rhizophora mangle*	47	14.97	162.06	74.55	63.24197827	24.66
52	*Rhizophora mangle*	3.05	0.97	0.19	0.09	0.145912953	0.06
53	*Rhizophora mangle*	38	12.10	96.07	44.19	39.45188755	15.39
54	*Rhizophora mangle*	47	14.97	162.06	74.55	63.24197827	24.66
55	*Rhizophora mangle*	29	9.24	49.41	22.73	21.65069078	8.44
56	*Rhizophora mangle*	26.67	8.49	40.21	18.50	17.97708603	7.01
57	*Rhizophora mangle*	32.5	10.35	65.39	30.08	27.88234287	10.87
58	*Rhizophora mangle*	36	11.46	84.10	38.69	34.98966253	13.65
59	*Rhizophora mangle*	39	12.42	102.41	47.11	41.79377782	16.30
60	*Rhizophora mangle*	59	18.79	283.53	130.42	104.7706571	40.86
61	*Rhizophora mangle*	66	21.02	373.58	171.85	134.380341	52.41
62	*Rhizophora mangle*	36	11.46	84.10	38.69	34.98966253	13.65
63	*Rhizophora mangle*	45.75	14.57	151.66	69.76	59.56846931	23.23
64	*Rhizophora mangle*	46	14.65	153.71	70.70	60.29351295	23.51

No.	Species per 1,000m2 plot	Circumsference (C) (cm)	DBH = (C/π) (cm)	AG biomass (Wtop = 0.251pD2.46)	AG Carbon Stock (Wtop * 0.46)	BG biomass (Wbot = 0.199p0.899D2.22)	BG Carbon Stock (Wbot * 0.39)
	sum			14476.98	6659.41	5123.337821	1998.10
	Average carbon stock /plot (kgC/m2)			14.48	6.66	5.123337821	1.99810175
	Average carbon stock / ha (MgC/ha)			144.77	66.59	51.23337821	19.9810175

Appendix E3: Mangrove Tree Parameters for Rocky bay

No.	Species / 1,000m2 plot	Circumsference (C) (cm)	DBH = (C/π) (cm)	AG biomass (Wtop = 0.251pD2.46)	AG Carbon Stock (Wtop * 0.46)	BG biomass (Wbot = 0.199p0.899D2.22)	BG Carbon Stock (Wbot * 0.39)
1	*Rhizophora mangle*	57.5	18.30	265.7097601	122.23	106.8486835	41.67
2	*Rhizophora mangle*	24.1	7.67	31.28862902	14.39	15.50188086	6.05
3	*Rhizophora mangle*	27.4	8.72	42.90332921	19.74	20.6116524	8.04
4	*Rhizophora mangle*	27.6	8.78	43.6778197	20.09	20.94713938	8.17
5	*Rhizophora mangle*	10.6	3.37	4.14836573	1.91	2.503142541	0.98
6	*Rhizophora mangle*	13.8	4.39	7.938293682	3.65	4.496122466	1.75
7	*Rhizophora mangle*	37.1	11.81	90.42414833	41.60	40.3939794	15.75
8	*Rhizophora mangle*	10.3	3.28	3.865486689	1.78	2.34857914	0.92
9	*Rhizophora mangle*	53	16.87	217.4419072	100.02	89.16593969	34.77
10	*Rhizophora mangle*	104	33.10	1141.633289	525.15	398.2177127	155.30
11	*Rhizophora mangle*	17	5.41	13.25955521	6.10	7.143370332	2.79
12	*Rhizophora mangle*	177	56.33	4223.172729	1942.66	1296.603566	505.68
13	*Rhizophora mangle*	83	26.42	655.4758819	301.52	241.3570146	94.13
14	*Rhizophora mangle*	78	24.82	562.5709883	258.78	210.2599604	82.00
15	*Rhizophora mangle*	53	16.87	217.4419072	100.02	89.16593969	34.77
16	*Rhizophora mangle*	48	15.28	170.4033205	78.39	71.55864482	27.91
17	*Rhizophora mangle*	67.5	21.48	394.1957072	181.33	152.5319899	59.49
18	*Rhizophora mangle*	109	34.69	1281.426775	589.46	441.9706049	172.37
19	*Rhizophora mangle*	80	25.46	598.7230488	275.41	222.4161564	86.74

No.	Species / 1,000m2 plot	Circumsference (C) (cm)	DBH = (C/π) (cm)	AG biomass (Wtop = 0.251pD2.46)	AG Carbon Stock (Wtop * 0.46)	BG biomass (Wbot = 0.199p0.899D2.22)	BG Carbon Stock (Wbot * 0.39)
20	*Rhizophora mangle*	85	27.05	695.0165825	319.71	254.458273	99.24
21	*Rhizophora mangle*	37	11.78	89.82574969	41.32	40.15266614	15.66
22	*Rhizophora mangle*	32	10.18	62.84830306	28.91	29.08971807	11.34
23	*Rhizophora mangle*	23	7.32	27.89170646	12.83	13.97469558	5.45
24	*Rhizophora mangle*	23.3	7.42	28.79520502	13.25	14.38257691	5.61
25	*Rhizophora mangle*	26	8.27	37.7102182	17.35	18.34625361	7.16
26	*Rhizophora mangle*	17	5.41	13.25955521	6.10	7.143370332	2.79
27	*Rhizophora mangle*	26	8.27	37.7102182	17.35	18.34625361	7.16
28	*Rhizophora mangle*	21	6.68	22.29893258	10.26	11.41913992	4.45
29	*Rhizophora mangle*	25	7.96	34.24183503	15.75	16.81641357	6.56
30	*Rhizophora mangle*	33	10.50	67.79051004	31.18	31.1463749	12.15
31	*Rhizophora mangle*	23	7.32	27.89170646	12.83	13.97469558	5.45
32	*Rhizophora mangle*	17.5	5.57	14.23961375	6.55	7.618176466	2.97
33	*Rhizophora mangle*	30	9.55	53.62198612	24.67	25.20668567	9.83
34	*Rhizophora mangle*	34	10.82	72.95629072	33.56	33.28049339	12.98
35	*Rhizophora mangle*	33	10.50	67.79051004	31.18	31.1463749	12.15
36	*Rhizophora mangle*	15	4.77	9.745611769	4.48	5.410397271	2.11
37	*Rhizophora mangle*	21	6.68	22.29893258	10.26	11.41913992	4.45
38	*Rhizophora mangle*	20	6.37	19.77690825	9.10	10.2469154	4.00
39	*Rhizophora mangle*	25	7.96	34.24183503	15.75	16.81641357	6.56
40	*Rhizophora mangle*	18	5.73	15.26142096	7.02	8.109825725	3.16

No.	Species / 1,000m2 plot	Circumsference (C) (cm)	DBH = (C/π) (cm)	AG biomass (Wtop = 0.251pD2.46)	AG Carbon Stock (Wtop * 0.46)	BG biomass (Wbot = 0.199p0.899D2.22)	BG Carbon Stock (Wbot * 0.39)
41	*Rhizophora mangle*	17	5.41	13.25955521	6.10	7.143370332	2.79
42	*Rhizophora mangle*	37	11.78	89.82574969	41.32	40.15266614	15.66
43	*Rhizophora mangle*	18	5.73	15.26142096	7.02	8.109825725	3.16
44	*Rhizophora mangle*	24	7.64	30.97021811	14.25	15.35944478	5.99
45	*Rhizophora mangle*	18	5.73	15.26142096	7.02	8.109825725	3.16
46	*Rhizophora mangle*	15.5	4.93	10.56429662	4.86	5.818927286	2.27
47	*Rhizophora mangle*	22	7.00	25.00255574	11.50	12.66149278	4.94
48	*Rhizophora mangle*	30	9.55	53.62198612	24.67	25.20668567	9.83
49	*Rhizophora mangle*	15.5	4.93	10.56429662	4.86	5.818927286	2.27
50	*Rhizophora mangle*	104	33.10	1141.633289	525.15	398.2177127	155.30
51	*Rhizophora mangle*	69	21.96	416.0958387	191.40	160.1590713	62.46
52	*Rhizophora mangle*	5.3	1.69	0.75395122	0.35	0.537277917	0.21
53	*Rhizophora mangle*	59	18.78	283.0874119	130.22	113.1352722	44.12
54	*Rhizophora mangle*	80	25.46	598.7230488	275.41	222.4161564	86.74
55	*Rhizophora mangle*	4	1.27	0.377304676	0.17	0.287660175	0.11
56	*Rhizophora mangle*	20	6.37	19.77690825	9.10	10.2469154	4.00
57	*Rhizophora mangle*	40	12.73	108.8158573	50.06	47.7397061	18.62
1	*Laguncularia racemosa*	20.8	6.62	15.74467032	7.24	8.35052793	3.26
2	*Laguncularia racemosa*	19	6.05	12.60177223	5.80	6.830402925	2.66

No.	Species / 1,000m2 plot	Circumsference (C) (cm)	DBH = (C/π) (cm)	AG biomass (Wtop = 0.251pD2.46)	AG Carbon Stock (Wtop * 0.46)	BG biomass (Wbot = 0.199p0.899D2.22)	BG Carbon Stock (Wbot * 0.39)
3	*Laguncularia racemosa*	17	5.41	9.585220633	4.41	5.33592768	2.08
4	*Laguncularia racemosa*	90	28.64	578.2748978	266.01	215.7901914	84.16
5	*Laguncularia racemosa*	17.5	5.57	10.29369668	4.74	5.690596566	2.22
6	*Laguncularia racemosa*	16	5.09	8.257202296	3.80	4.66401234	1.82
7	*Laguncularia racemosa*	14	4.46	5.945285778	2.73	3.467508773	1.35
8	*Laguncularia racemosa*	18.1	5.76	11.18373999	5.14	6.132813608	2.39
9	*Laguncularia racemosa*	10.8	3.44	3.139931732	1.44	1.949009996	0.76
10	*Laguncularia racemosa*	18.2	5.79	11.33635355	5.21	6.20828736	2.42
11	*Laguncularia racemosa*	13	4.14	4.954483815	2.28	2.941491322	1.15
12	*Laguncularia racemosa*	15	4.77	7.045020556	3.24	4.041438035	1.58
13	*Laguncularia racemosa*	14.6	4.65	6.591826873	3.03	3.806069104	1.48
14	*Laguncularia*	10.4	3.31	2.861539743	1.32	1.792368664	0.70

No.	Species / 1,000m2 plot	Circumsference (C) (cm)	DBH = (C/π) (cm)	AG biomass (Wtop = 0.251pD2.46)	AG Carbon Stock (Wtop * 0.46)	BG biomass (Wbot = 0.199p0.899D2.22)	BG Carbon Stock (Wbot * 0.39)
	racemosa						
15	*Laguncularia racemosa*	11.5	3.66	3.66449771	1.69	2.24059073	0.87
16	*Laguncularia racemosa*	13.5	4.30	5.436493058	2.50	3.19855848	1.25
17	*Laguncularia racemosa*	21	6.68	16.1197103	7.42	8.529825834	3.33
18	*Laguncularia racemosa*	11.2	3.56	3.433792938	1.58	2.112892199	0.82
19	*Laguncularia racemosa*	14.5	4.61	6.48131386	2.98	3.748437675	1.46
				14977.46113	6889.63	5430.498821	2117.89
Average carbon stock /plot (kgC/m2)				14.97746113	6.889632122	5.430498821	2.11789454
Average carbon stock / ha (MgC/ha)				149.7746113	68.89632122	54.30498821	21.1789454

Appendix E4: Mangrove leaf-litter biomass and carbon stocks for estuary

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
March							
T1P1	28.42	0.02842	15.82	12.43	0.02233	0.0100485	0.100485
T1P2	34.82	0.03482	16.66	11.76	0.024578824	0.011060471	0.110604706
T1P3	10.03	0.01003	5.04	4.14	0.008238929	0.003707518	0.037075179
T1P4	21.92	0.02192	10.09	7.75	0.016836472	0.007576412	0.075764123
T1P5	13.65	0.01365	7.5	5.83	0.0106106	0.00477477	0.0477477
T2P1	14.76	0.01476	7.63	5.92	0.011452058	0.005153426	0.05153426
T2P2	21.7	0.0217	11.68	7.91	0.014695805	0.006613112	0.066131122
T2P3	16.48	0.01648	8.74	6.99	0.013180229	0.005931103	0.05931103
T2P4	10.84	0.01084	5.42	4.37	0.00874	0.003933	0.03933
T2P5	30.36	0.03036	15.56	12.68	0.024740668	0.011133301	0.111333008
					0.155403584	0.069931613	**0.699316126**
April							
T1P1	8.65	0.00865	4.11	3	0.006313869	0.002841241	0.028412409
T1P2	22.24	0.02224	12.83	9.6	0.016640998	0.007488449	0.074884489
T1P3	15.03	0.01503	8.73	7.2	0.012395876	0.005578144	0.055781443
T1P4	10.85	0.01085	5.96	7	0.012743289	0.00573448	0.057344799
T1P5	23.52	0.02352	13.15	9.8	0.017528213	0.007887696	0.078876958
T2P1	12.16	0.01216	6.98	5.4	0.00940745	0.004233352	0.042333524
T2P2	21.1	0.0211	10.5	4.2	0.00844	0.003798	0.03798
T2P3	8.16	0.00816	4.17	3.4	0.006653237	0.002993957	0.029939568

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
T2P4	17.79	0.01779	9.26	4.4	0.008453132	0.003803909	0.038039093
T2P5	17.63	0.01763	8.59	6.4	0.013135274	0.005910873	0.059108731
T1P5					0.111711337	0.050270102	**0.502701015**
May							
T1P1	40.48	0.04048	21.31	8.39	0.015937457	0.007171855	0.071718555
T1P2	34.45	0.03445	17.25	7.42	0.014818493	0.006668322	0.066683217
T1P3	12.7	0.0127	6.94	3.2	0.005855908	0.002635159	0.026351585
T1P4	19.5	0.0195	9.09	3.5	0.007508251	0.003378713	0.033787129
T1P5	11.84	0.01184	7.03	4.68	0.007882105	0.003546947	0.035469474
T2P1	16.99	0.01699	7.59	3.37	0.00754365	0.003394642	0.033946423
T2P2	7.5	0.0075	3.46	1.47	0.003186416	0.001433887	0.014338873
T2P3	24.77	0.02477	13.44	5.95	0.010965885	0.004934648	0.049346484
T2P4	32.27	0.03227	17.7	9.03	0.016463169	0.007408426	0.074084263
T2P5	10.3	0.0103	5.4	2.68	0.005111852	0.002300333	0.023003333
					0.095273186	0.042872934	**0.428729336**
June							
T1P1	23.51	0.02351	12.71	10.27	0.018996672	0.008548502	0.085485024
T1P2	20.18	0.02018	12.91	8.28	0.012942711	0.00582422	0.0582422
T1P3	16.49	0.01649	7.2	5.9	0.013512639	0.006080688	0.060806875
T1P4	17.27	0.01727	10.3	7.93	0.013296223	0.0059833	0.059833005
T1P5	42.42	0.04242	13.58	10.66	0.033298763	0.014984443	0.149844433
T2P1	13.77	0.01377	10.43	8.25	0.010891898	0.004901354	0.049013543

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
T2P2	25.69	0.02569	10.28	7.62	0.019042588	0.008569164	0.085691644
T2P3	10.94	0.01094	10.94	9.1	0.0091	0.004095	0.04095
T2P4	23.77	0.02377	9.29	7.37	0.018857363	0.008485813	0.084858132
T2P5	23.5	0.0235	9.32	6.99	0.017625	0.00793125	0.0793125
					0.167563857	0.075403736	**0.754037355**
July							
T1P1	42.2	0.0422	11.02	5.12	0.019606534	0.00882294	0.088229401
T1P2	17.62	0.01762	10.08	6.93	0.01211375	0.005451188	0.054511875
T1P3	11.57	0.01157	11.57	6.39	0.00639	0.0028755	0.028755
T1P4	33.87	0.03387	10	5.38	0.01822206	0.008199927	0.08199927
T1P5	26.61	0.02661	10.07	4.84	0.012789712	0.00575537	0.057553704
T2P1	25.74	0.02574	12.43	7.5	0.015530973	0.006988938	0.069889381
T2P2	18.57	0.01857	10	5.4	0.0100278	0.00451251	0.0451251
T2P3	16.36	0.01636	11.35	5.68	0.008187207	0.003684243	0.036842432
T2P4	37.64	0.03764	10.32	6.19	0.022576705	0.010159517	0.101595174
T2P5	48.49	0.04849	13	7.74	0.0288702	0.01299159	0.1299159
					0.154314942	0.069441724	**0.694417237**
August							
T1P1	37.8	0.0378	11.8	9	0.028830508	0.012973729	0.129737288
T1P2	33.2	0.0332	9	6.8	0.025084444	0.011288	0.11288
T1P3	16.2	0.0162	9.2	7.2	0.012678261	0.005705217	0.057052174
T1P4	51.6	0.0516	10.8	8.8	0.042044444	0.01892	0.1892
T1P5	32.4	0.0324	10.2	8.4	0.026682353	0.012007059	0.120070588

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
T2P1	14.8	0.0148	10.2	8	0.011607843	0.005223529	0.052235294
T2P2	17	0.017	9	6.6	0.012466667	0.00561	0.0561
T2P3	24.6	0.0246	10	8.4	0.020664	0.0092988	0.092988
T2P4	35.2	0.0352	8.8	6.8	0.0272	0.01224	0.1224
T2P5	28.2	0.0282	11	8.4	0.021534545	0.009690545	0.096905455
					0.228793066	0.10295688	**1.029568799**
September							
T1P1	38.48	0.03848	10.48	7.15	0.026253053	0.011813874	0.11813874
T1P2	33.14	0.03314	10.27	7.88	0.02542777	0.011442497	0.114424966
T1P3	34.57	0.03457	11.05	8.21	0.025685041	0.011558268	0.115582683
T1P4	31.15	0.03115	8.77	6.64	0.023584493	0.010613022	0.106130217
T1P5	6.71	0.00671	6.71	4.93	0.00493	0.0022185	0.022185
T2P1	30.25	0.03025	10.93	7.11	0.019677722	0.008854975	0.088549748
T2P2	27.8	0.0278	12.36	8.74	0.019657929	0.008846068	0.08846068
T2P3	18.77	0.01877	10.66	8.84	0.015565366	0.007004415	0.070044146
T2P4	19.13	0.01913	10.6	6.84	0.012344264	0.005554919	0.055549189
T2P5	66.91	0.06691	11.29	6.55	0.038818468	0.01746831	0.174683105
					0.211944105	0.095374847	**0.953748474**
October							
T1P1	33.87	0.03387	14.43	9.48	0.022251393	0.010013127	0.100131268
T1P2	42.6	0.0426	13.55	9.51	0.029898598	0.013454369	0.13454369
T1P3	9.47	0.00947	9.47	7.37	0.00737	0.0033165	0.033165
T1P4	14.52	0.01452	14.52	11.3	0.0113	0.005085	0.05085

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
T1P5	17.69	0.01769	13.5	10.4	0.013627852	0.006132533	0.061325333
T2P1	20.34	0.02034	15.01	11.21	0.015190633	0.006835785	0.068357848
T2P2	16.73	0.01673	11.02	8.88	0.013481162	0.006066523	0.060665227
T2P3	11.8	0.0118	11.8	8.86	0.00886	0.003987	0.03987
T2P4	38.53	0.03853	14.24	10.2	0.027598736	0.012419431	0.124194312
T2P5	31.43	0.03143	13.92	10.58	0.023888606	0.010749873	0.107498728
					0.173466979	0.078060141	**0.780601407**
November							
T1P1	45.37	0.04537	25.49	15.91	0.028318427	0.012743292	0.127432921
T1P2	68.22	0.06822	32.52	13.9	0.029159225	0.013121651	0.131216513
T1P3	29.45	0.02945	16.17	11.18	0.020361843	0.009162829	0.091628293
T1P4	16.58	0.01658	10.6	7.81	0.012216019	0.005497208	0.054972085
T1P5	42.57	0.04257	18.51	12.98	0.029851896	0.013433353	0.134333533
T2P1	24.8	0.0248	12.96	8	0.015308642	0.006888889	0.068888889
T2P2	25.92	0.02592	12.42	9.62	0.020076522	0.009034435	0.090344348
T2P3	27.53	0.02753	14.24	11.16	0.021575478	0.009708965	0.097089649
T2P4	33.54	0.03354	14.56	10.37	0.023888036	0.010749616	0.107496161
T2P5	52.53	0.05253	16.77	12.18	0.038152379	0.017168571	0.171685707
					0.238908466	0.10750881	**1.075088098**
December							
T1P1	21.67	0.02167	21.67	16.86	0.01686	0.007587	0.07587
T1P2	21.87	0.02187	15.3	12.1	0.017295882	0.007783147	0.077831471
T1P3	15.67	0.01567	15.67	12.69	0.01269	0.0057105	0.057105

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
T1P4	12.5	0.0125	12.5	10.02	0.01002	0.004509	0.04509
T1P5	21.09	0.02109	21.09	15.35	0.01535	0.0069075	0.069075
T2P1	9.9	0.0099	9.9	8.2	0.0082	0.00369	0.0369
T2P2	10.36	0.01036	10.36	8.52	0.00852	0.003834	0.03834
T2P3	25.45	0.02545	9.22	7.33	0.020233026	0.009104862	0.091048617
T2P4	34.66	0.03466	16.94	13.12	0.026844109	0.012079849	0.120798489
T2P5	28.94	0.02894	15.32	12.63	0.023858499	0.010736324	0.107363244
					0.159871516	0.071942182	**0.719421821**

Appendix E5: Mangrove leaf-litter biomass and carbon stocks for lagoon

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
March							
T1P1	31.28	0.03128	15.64	13.05	0.0261	0.011745	0.11745
T1P2	39.83	0.03983	19.92	16.88	0.033751526	0.015188187	0.151881867
T1P3	26.5	0.0265	13.25	11.44	0.02288	0.010296	0.10296
T1P4	22.72	0.02272	11.36	9.2	0.0184	0.00828	0.0828
T1P5	41.37	0.04137	20.69	17.59	0.035171498	0.015827174	0.158271742
T2P1	48.7	0.0487	24.35	20.18	0.04036	0.018162	0.18162
T2P2	39.46	0.03946	19.73	16.16	0.03232	0.014544	0.14544
T2P3	30.75	0.03075	15.38	13.28	0.026551365	0.011948114	0.119481144
T2P4	36.43	0.03643	18.22	15.09	0.030171718	0.013577273	0.135772731
T2P5	28.76	0.02876	14.38	11.63	0.02326	0.010467	0.10467
	34.58				0.288966108	0.130034748	**1.300347485**
April							
T1P1	28.35	0.02835	14.18	10.44	0.020872638	0.009392687	0.093926869
T1P2	32.87	0.03287	16.44	11.95	0.023892731	0.010751729	0.10751729
T1P3	8.89	0.00889	4.4	3.69	0.007455477	0.003354965	0.033549648
T1P4	20.6	0.0206	10.3	7.23	0.01446	0.006507	0.06507
T1P5	27.08	0.02708	13.54	9.62	0.01924	0.008658	0.08658
T2P1	37.47	0.03747	18.74	13.41	0.026812844	0.01206578	0.120657799
T2P2	21.03	0.02103	10.52	7.68	0.0153527	0.006908715	0.069087148
T2P3	13.6	0.0136	6.8	4.8	0.0096	0.00432	0.0432

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
T2P4	21.74	0.02174	10.87	7.77	0.01554	0.006993	0.06993
T2P5	32.46	0.03246	16.23	12.29	0.02458	0.011061	0.11061
					0.17780639	0.080012875	**0.800128754**
May							
T1P1	17.52	0.01752	8.76	6.24	0.01248	0.005616	0.05616
T1P2	60.76	0.06076	15.17	9.75	0.039051417	0.017573138	0.175731378
T1P3	11.95	0.01195	5.96	4.44	0.008902349	0.004006057	0.04006057
T1P4	21.17	0.02117	10.59	7.94	0.015872502	0.007142626	0.071426261
T1P5	20.81	0.02081	10.41	7.25	0.014493036	0.006521866	0.06521866
T2P1	21.27	0.02127	10.01	7.65	0.016255295	0.007314883	0.073148826
T2P2	17.48	0.01748	8.1	6.15	0.013271852	0.005972333	0.059723333
T2P3	5.78	0.00578	2.89	1.7	0.0034	0.00153	0.0153
T2P4	12.02	0.01202	6.02	4.47	0.00892515	0.004016317	0.040163173
T2P5	31.22	0.03122	11.15	7.23	0.020244	0.0091098	0.091098
					0.1528956	0.06880302	**0.688030201**
June							
T1P1	7.62	0.00762	7.62	5.89	0.00589	0.0026505	0.026505
T1P2	7.25	0.00725	7.25	5.6	0.0056	0.00252	0.0252
T1P3	4.77	0.00477	4.77	3.5	0.0035	0.001575	0.01575
T1P4	9.29	0.00929	9.29	6.36	0.00636	0.002862	0.02862
T1P5	2.99	0.00299	2.99	2.11	0.00211	0.0009495	0.009495
T2P1	12.12	0.01212	12.12	9.44	0.00944	0.004248	0.04248
T2P2	23	0.023	23	17.37	0.01737	0.0078165	0.078165

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
T2P3	11.96	0.01196	11.96	9.2	0.0092	0.00414	0.0414
T2P4	17.43	0.01743	17.43	11.86	0.01186	0.005337	0.05337
T2P5	14	0.014	14	9.85	0.00985	0.0044325	0.044325
					0.08118	0.036531	**0.36531**
July							
T1P1	26.83	0.02683	10	5.78	0.01550774	0.006978483	0.06978483
T1P2	14.92	0.01492	10.19	7.3	0.010688518	0.004809833	0.048098332
T1P3	9.55	0.00955	9.55	6.4	0.0064	0.00288	0.0288
T1P4	6.34	0.00634	6.34	4.74	0.00474	0.002133	0.02133
T1P5	10.91	0.01091	10.91	7.5	0.0075	0.003375	0.03375
T2P1	23.61	0.02361	10.2	6.74	0.015601118	0.007020503	0.070205029
T2P2	54.25	0.05425	11.98	8.51	0.038536519	0.017341434	0.173414336
T2P3	27.49	0.02749	10.97	6.9	0.017290884	0.007780898	0.077808979
T2P4	31.22	0.03122	11.73	7.42	0.019748713	0.008886921	0.088869207
T2P5	20.34	0.02034	10.56	6.4	0.012327273	0.005547273	0.055472727
					0.148340765	0.066753344	**0.667533441**
August							
T1P1	8	0.008	8	6.4	0.0064	0.00288	0.0288
T1P2	1	0.001	1	0.8	0.0008	0.00036	0.0036
T1P3	6.6	0.0066	6.6	5.6	0.0056	0.00252	0.0252
T1P4	14.2	0.0142	9.4	7	0.010574468	0.004758511	0.047585106
T1P5	6	0.006	6	4.6	0.0046	0.00207	0.0207
T2P1	8.8	0.0088	8.8	6.4	0.0064	0.00288	0.0288

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
T2P2	44	0.044	10	8.2	0.03608	0.016236	0.16236
T2P3	17.2	0.0172	11.6	8.6	0.012751724	0.005738276	0.057382759
T2P4	23.2	0.0232	8.8	6.8	0.017927273	0.008067273	0.080672727
T2P5	31	0.031	10.4	8.6	0.025634615	0.011535577	0.115355769
					0.12676808	0.057045636	**0.570456362**
September							
T1P1	1.83	0.00183	1.83	1.4	0.0014	0.00063	0.0063
T1P2	11.34	0.01134	11.34	7.84	0.00784	0.003528	0.03528
T1P3	7.73	0.00773	7.73	5.87	0.00587	0.0026415	0.026415
T1P4	11.47	0.01147	11.47	8.23	0.00823	0.0037035	0.037035
T1P5	5.14	0.00514	5.14	3.62	0.00362	0.001629	0.01629
T2P1	12.12	0.01212	10.83	7.79	0.008717895	0.003923053	0.039230526
T2P2	46.19	0.04619	12.15	8.94	0.033986716	0.015294022	0.152940222
T2P3	21.83	0.02183	13.45	8.16	0.013244074	0.005959833	0.059598335
T2P4	16.9	0.0169	10.19	6.67	0.01106212	0.004977954	0.049779539
T2P5	13.91	0.01391	13.91	7.46	0.00746	0.003357	0.03357
					0.101430805	0.045643862	**0.456438622**
October							
T1P1	8.57	0.00857	8.57	6.2	0.0062	0.00279	0.0279
T1P2	6.27	0.00627	6.27	4.32	0.00432	0.001944	0.01944
T1P3	1.16	0.00116	1.16	0.9	0.0009	0.000405	0.00405
T1P4	31.67	0.03167	10.78	7.49	0.022004481	0.009902016	0.099020162
T1P5	2.79	0.00279	2.79	2.22	0.00222	0.000999	0.00999

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
T2P1	21.05	0.02105	13.44	10.46	0.016382664	0.007372199	0.073721987
T2P2	46.14	0.04614	14.75	11	0.034409492	0.015484271	0.154842712
T2P3	20.97	0.02097	12.37	8.91	0.015104503	0.006797026	0.067970263
T2P4	6.29	0.00629	6.29	4.78	0.00478	0.002151	0.02151
T2P5	29.63	0.02963	14.48	10.75	0.02199741	0.009898835	0.098988346
					0.128318549	0.057743347	**0.57743347**
November							
T1P1	12.68	0.01268	12.68	6.53	0.00653	0.0029385	0.029385
T1P2	3.4	0.0034	3.4	2	0.002	0.0009	0.009
T1P3	6.35	0.00635	6.35	3.26	0.00326	0.001467	0.01467
T1P4	42.53	0.04253	19	11.28	0.025249389	0.011362225	0.113622253
T1P5	16.89	0.01689	16.89	10.68	0.01068	0.004806	0.04806
T2P1	43.97	0.04397	12.86	8.48	0.028994215	0.013047397	0.130473966
T2P2	58.43	0.05843	16.23	10.06	0.03621724	0.016297758	0.162977579
T2P3	32.76	0.03276	12.04	7.07	0.019236977	0.00865664	0.086566395
T2P4	37.76	0.03776	19.15	11.58	0.022833462	0.010275058	0.10275058
T2P5	61.44	0.06144	15.12	9.91	0.040269206	0.018121143	0.181211429
					0.195270489	0.08787172	**0.878717201**
December							
T1P1	10.22	0.01022	8.48	7.28	0.008773774	0.003948198	0.039481981
T1P2	37.14	0.03714	17.1	14.6	0.031710175	0.014269579	0.142695789
T1P3	6.07	0.00607	5.12	4.53	0.005370527	0.002416737	0.024167373
T1P4	34.45	0.03445	11.59	9.68	0.028772735	0.012947731	0.129477308

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
T1P5	12.94	0.01294	10.53	8.9	0.010936942	0.004921624	0.049216239
T2P1	2.3	0.0023	2.3	1.93	0.00193	0.0008685	0.008685
T2P2	52.3	0.0523	39.94	33.42	0.043762293	0.019693032	0.19693032
T2P3	21.32	0.02132	16.62	13.76	0.017651215	0.007943047	0.079430469
T2P4	9.53	0.00953	9.53	8.24	0.00824	0.003708	0.03708
T2P5	37.91	0.03791	25.86	21.98	0.032222034	0.014499915	0.144999153
					0.189369696	0.085216363	**0.852163634**

Appendix E6: Mangrove leaf-litter biomass and carbon stocks for lagoon

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
March							
T1P1	58.46	0.05846	58.46	40	0.04	0.018	0.18
T1P2	67.43	0.06743	67.43	39	0.039	0.01755	0.1755
T1P3	40.82	0.04082	40.82	30	0.03	0.0135	0.135
T1P4	71.58	0.07158	71.58	52	0.052	0.0234	0.234
T1P5	58.68	0.05868	58.68	45	0.045	0.02025	0.2025
T2P1	56.7	0.0567	56.7	40	0.04	0.018	0.18
T2P2	44.51	0.04451	44.51	29	0.029	0.01305	0.1305
T2P3	58.19	0.05819	58.19	44	0.044	0.0198	0.198
T2P4	40.98	0.04098	40.98	27	0.027	0.01215	0.1215
T2P5	19.24	0.01924	19.24	13	0.013	0.00585	0.0585
					0.359	0.16155	**1.6155**
April							
T1P1	75.9	0.0759	75.9	49	0.049	0.02205	0.2205
T1P2	74.65	0.07465	74.65	46	0.046	0.0207	0.207
T1P3	31.6	0.0316	31.6	21	0.021	0.00945	0.0945
T1P4	47.03	0.04703	47.03	31	0.031	0.01395	0.1395
T1P5	40.36	0.04036	40.36	30	0.03	0.0135	0.135
T2P1	67.16	0.06716	67.16	38	0.038	0.0171	0.171
T2P2	41.32	0.04132	41.32	29	0.029	0.01305	0.1305
T2P3	52.21	0.05221	52.21	31	0.031	0.01395	0.1395

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
T2P4	49.98	0.04998	49.98	32	0.032	0.0144	0.144
T2P5	70.08	0.07008	70.08	41	0.041	0.01845	0.1845
					0.348	0.1566	**1.566**
May							
T1P1	62	0.062	62	29	0.029	0.01305	0.1305
T1P2	56	0.056	56	29	0.029	0.01305	0.1305
T1P3	5	0.005	5	3	0.003	0.00135	0.0135
T1P4	19	0.019	19	10	0.01	0.0045	0.045
T1P5	14	0.014	14	9	0.009	0.00405	0.0405
T2P1	51	0.051	51	23	0.023	0.01035	0.1035
T2P2	59	0.059	59	23	0.023	0.01035	0.1035
T2P3	47	0.047	47	22	0.022	0.0099	0.099
T2P4	51	0.051	51	26	0.026	0.0117	0.117
T2P5	33	0.033	33	17	0.017	0.00765	0.0765
					0.191	0.08595	**0.8595**
June							
T1P1	14.19	0.01419	7.6	5.64	0.0105305	0.004738713	0.047387132
T1P2	42.07	0.04207	12.27	8.72	0.0298982	0.013454171	0.134541711
T1P3	45.48	0.04548	17.53	11.22	0.0291093	0.013099174	0.13099174
T1P4	17.98	0.01798	9.81	7.18	0.0131597	0.005921853	0.059218532
T1P5	26.5	0.0265	14.14	10.98	0.0205778	0.009260007	0.092600071
T2P1	24.31	0.02431	9.77	6.52	0.0162233	0.007300465	0.073004647
T2P2	12.43	0.01243	5.8	4.57	0.0097940	0.004407292	0.044072922

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
T2P3	18.58	0.01858	10.18	8.12	0.0148202	0.006669088	0.066690884
T2P4	39.88	0.03988	14.88	9.94	0.0266403	0.011988121	0.11988121
T2P5	1.38	0.00138	1.38	1.15	0.0011500	0.0005175	0.085376539
					0.17	0.077356385	**0.853765388**
July							
T1P1	29.06	0.02906	13.24	9.48	0.0208073	0.00936329	0.0936329
T1P2	36.24	0.03624	10.84	5.95	0.0198919	0.008951347	0.089513469
T1P3	36.94	0.03694	15.05	8.23	0.0202004	0.009090185	0.090901854
T1P4	25.38	0.02538	15	9.63	0.0162940	0.007332282	0.07332282
T1P5	46.85	0.04685	15.01	8.52	0.0265931	0.011966882	0.119668821
T2P1	44.3	0.0443	10.3	7.82	0.0336336	0.015135117	0.151351165
T2P2	9.38	0.00938	5.43	4	0.0069098	0.003109392	0.031093923
T2P3	9.38	0.00938	9.38	6.57	0.0065700	0.0029565	0.029565
T2P4	10.59	0.01059	9.34	5.92	0.0067123	0.003020531	0.03020531
T2P5	4.36	0.00436	4.36	3	0.0030000	0.00135	0.0135
					0.16	0.072275526	**0.722755262**
August							
T1P1	36.2	0.0362	10	7.2	0.0260640	0.0117288	0.117288
T1P2	48.8	0.0488	10.6	7.2	0.0331472	0.014916226	0.149162264
T1P3	43.4	0.0434	10	7.4	0.0321160	0.0144522	0.144522
T1P4	31	0.031	10	7.4	0.0229400	0.010323	0.10323
T1P5	23	0.023	10.8	7.8	0.0166111	0.007475	0.07475
T2P1	52.2	0.0522	8.6	5.8	0.0352047	0.015842093	0.15842093

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
T2P2	9.4	0.0094	9.4	6	0.0060000	0.0027	0.027
T2P3	19.6	0.0196	8.2	6.6	0.0157756	0.007099024	0.070990244
T2P4	8.2	0.0082	8.2	6.2	0.0062000	0.00279	0.0279
T2P5	6	0.006	6	4.8	0.0048000	0.00216	0.0216
					0.20	0.089486344	**0.894863438**
September							
T1P1	39.37	0.03937	11.5	7.56	0.02588150	0.011646673	0.11646673
T1P2	100.82	0.10082	9.43	4.33	0.04629381	0.020832213	0.208322131
T1P3	31.53	0.03153	10.83	8.02	0.02334909	0.010507089	0.105070886
T1P4	14.65	0.01465	9.05	6.58	0.01065160	0.004793221	0.04793221
T1P5	13.6	0.0136	8.16	5.6	0.00933333	0.0042	0.042
T2P1	46.34	0.04634	9.27	5.06	0.02529454	0.011382544	0.113825437
T2P2	38.88	0.03888	7.65	5.75	0.02922353	0.013150588	0.131505882
T2P3	9.03	0.00903	9.03	7.26	0.00726000	0.003267	0.03267
T2P4	15.65	0.01565	8.01	6.2	0.01211361	0.005451124	0.054511236
T2P5	6.06	0.00606	6.06	4.35	0.00435000	0.0019575	0.019575
					0.19	0.087187951	**0.871879514**
October							
T1P1	46.51	0.04651	14.66	9.54	0.030266	0.013619879	0.136198793
T1P2	46.9	0.0469	10.88	5.71	0.024614	0.011076245	0.110762454
T1P3	31.5	0.0315	11.52	7.76	0.021219	0.009548438	0.095484375
T1P4	19.08	0.01908	19.08	11.3	0.011300	0.005085	0.05085
T1P5	22.01	0.02201	12.04	8.2	0.014990	0.00674559	0.067455897

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
T2P1	60.64	0.06064	10.88	7.14	0.039795	0.01790775	0.1790775
T2P2	34.93	0.03493	9.37	5.72	0.021323	0.009595498	0.095954984
T2P3	54.09	0.05409	11.62	8.38	0.039008	0.017553648	0.17553648
T2P4	22.85	0.02285	10.12	6.8	0.015354	0.00690919	0.069091897
T2P5	17.94	0.01794	10	6.59	0.011822	0.005320107	0.05320107
					0.23	0.103361345	**1.03361345**
November							
T1P1	54.38	0.05438	13.69	9.29	0.03690	0.01660596	0.166059598
T1P2	63.47	0.06347	19.44	11.38	0.03715	0.016719644	0.167196435
T1P3	58.04	0.05804	14.18	10.76	0.04404	0.019818736	0.198187362
T1P4	30.17	0.03017	10.43	8.36	0.02418	0.010882027	0.108820268
T1P5	33.48	0.03348	14.74	11.17	0.02537	0.011417043	0.114170434
T2P1	78.1	0.0781	13.79	10.23	0.05794	0.026072034	0.260720341
T2P2	87.45	0.08745	17.17	15.52	0.07905	0.03557081	0.355708096
T2P3	20.33	0.02033	20.33	15.27	0.01527	0.0068715	0.068715
T2P4	7.61	0.00761	7.61	5.41	0.00541	0.0024345	0.024345
T2P5	33.85	0.03385	19.37	14.32	0.02502	0.011261198	0.112611977
					0.35	0.157653451	**1.576534512**
December							
T1P1	46.2	0.0462	18.3	11.72	0.029588	0.013314689	0.133146885
T1P2	92.3	0.0923	22.58	14.08	0.057555	0.025899593	0.258995926
T1P3	23.87	0.02387	16.34	11.24	0.016420	0.00738889	0.073888898
T1P4	15.53	0.01553	15.53	11.31	0.011310	0.0050895	0.050895

Plots	Total weight (g)	Total weight (TW) (kg)	Wet sub-sample (WS)	Dry sub-sample (DS)	Biomass (B) = (DS/WS)*TW (kg)	Carbon stock(C') = B*0.45	C/ha (MgC/ha)
T1P5	31.99	0.03199	11.21	7.9	0.022544	0.010144911	0.101449108
T2P1	41.49	0.04149	10.13	6.66	0.027278	0.012274978	0.122749783
T2P2	71.7	0.0717	23.93	15.1	0.045243	0.020359444	0.203594442
T2P3	62.6	0.0626	9.47	6.64	0.043893	0.019751721	0.197517212
T2P4	30.28	0.03028	30.28	20.42	0.020420	0.009189	0.09189
T2P5	55.94	0.05594	21.36	13.29	0.034805	0.015662414	0.156624143
					0.31	0.13907514	**1.390751398**

Appendix E7: Mangrove soil biomass and carbon stocks for estuary

	Sample volume- Wet Soil(cm3)	Oven-dry sample(g)	Dbd (g/cm3)	Dry mass before combustion (g)	Dry mass after combustion (g)	LOI(mg)	%LOI	%Corg	%Corg - whole no.	Soil carbon density	Total carbon – (Sample 1+Sample 2) / 2
Samples from 15 cm depth											
T1P1	20	31.36	1.57	31.36	29.41	0.06	6.22	5	5	117.60	317.115
T1P2	20	14.39	0.72	14.39	12.63	0.12	12.23	8	8	86.34	322.50125
T1P3	20	9.79	0.49	9.79	7.33	0.25	25.13	13	13	95.45	269.78875
T1P4	20	13.67	0.68	13.67	12.29	0.10	10.10	7	7	71.77	243.53875
T1P5	20	23.71	1.19	23.71	22.95	0.03	3.21	4	4	71.13	284.19
T2P1	20	25.26	1.26	25.26	24.23	0.04	4.08	5	5	94.73	399.2625
T2P2	20	7.63	0.38	7.63	5.81	0.24	23.85	13	13	74.39	320.565
T2P3	20	29.44	1.47	29.44	28.82	0.02	2.11	4	4	88.32	255.3
T2P4	20	10.04	0.50	10.04	8.26	0.18	17.73	10	10	75.30	191.075
T2P5	20	9.76	0.49	9.76	7.94	0.19	18.65	11	11	80.52	303.69625
Av SC / plot (1000m2)											**290.70325**
Total SC / ha (MgC/ha)											**2907.03**
Samples from 85 cm depth											
TIP1	20	30.39	1.52	30.39	29.49	0.03	2.96	4	4	516.63	
T1P2	20	26.29	1.31	26.29	25.25	0.04	3.96	5	5	558.66	
T1P3	20	20.9	1.05	20.9	19.69	0.06	5.79	5	5	444.13	
T1P4	20	24.43	1.22	24.43	23.52	0.04	3.72	4	4	415.31	

	Sample volume- Wet Soil(cm3)	Oven-dry sample(g)	Dbd (g/cm3)	Dry mass before combustion (g)	Dry mass after combustion (g)	LOI(mg)	%LOI	%Corg	%Corg - whole no.	Soil carbon density	Total carbon – (Sample 1+Sample 2) / 2
T1P5	20	23.4	1.17	23.4	22.15	0.05	5.34	5	5	497.25	
T2P1	20	27.6	1.38	27.6	25.53	0.08	7.50	6	6	703.80	
T2P2	20	26.67	1.33	26.67	25.44	0.05	4.61	5	5	566.74	
T2P3	20	12.42	0.62	12.42	10.81	0.13	12.96	8	8	422.28	
T2P4	20	7.22	0.36	7.22	5.91	0.18	18.14	10	10	306.85	
T2P5	20	17.71	0.89	17.71	16.03	0.09	9.49	7	7	526.87	

Appendix E8: Mangrove soil biomass and carbon stocks for lagoon

	Sample volume-Wet Soil(cm3)	Oven-dry sample(g)	Dbd (g/cm3)	Dry mass before combustion (g)	Dry mass after combustion (g)	LOI(mg)	%LOI	%Corg	%Corg - whole no.	Soil carbon density	Total carbon – (Sample 1+Sample 2) / 2
Samples from 15 cm depth											
T1P1	20	14.63	0.73	14.63	8.25	0.44	43.61	21	21	230.42	451.05
T1P2	20	4.97	0.25	4.97	2.72	0.45	45.27	22	22	82.01	351.89
T1P3	20	12.42	0.62	12.42	9.71	0.22	21.82	12	12	111.78	361.15
T1P4	20	10.02	0.50	10.02	7.9	0.21	21.16	12	12	90.18	306.30
T1P5	20	11.79	0.59	11.79	6.83	0.42	42.07	20	20	176.85	503.12
T2P1	20	8.03	0.40	8.03	5.65	0.30	29.64	15	15	90.34	495.88
T2P2	20	6.25	0.31	6.25	3.58	0.43	42.72	21	21	98.44	328.13
T2P3	20	9.67	0.48	9.67	6.83	0.29	29.37	15	15	108.79	402.79
T2P4	20	5.86	0.29	5.86	3.88	0.34	33.79	17	17	74.72	320.79
T2P5	20	10.19	0.51	10.19	7.32	0.28	28.16	15	15	114.64	469.95
Av SC / plot (1000m2)											**399.10**
Total SC / ha (MgC/ha)											**3991.03**
Samples from 85cm depth											
TIP1	20	17.56	0.88	17.56	14.89	0.15	15.21	9	9	671.67	
T1P2	20	13.3	0.67	13.3	10.79	0.19	18.87	11	11	621.78	
T1P3	20	8.45	0.42	8.45	5.52	0.35	34.67	17	17	610.51	
T1P4	20	8.78	0.44	8.78	6.48	0.26	26.20	14	14	522.41	
T1P5	20	13.01	0.65	13.01	9.32	0.28	28.36	15	15	829.39	
T2P1	20	15.15	0.76	15.15	11.17	0.26	26.27	14	14	901.43	
T2P2	20	6.25	0.31	6.25	3.5	0.44	44.00	21	21	557.81	

	Sample volume-Wet Soil(cm3)	Oven-dry sample(g)	Dbd (g/cm3)	Dry mass before combustion (g)	Dry mass after combustion (g)	LOI(mg)	%LOI	%Corg	%Corg - whole no.	Soil carbon density	Total carbon – (Sample 1+Sample 2) / 2
T2P3	20	10.93	0.55	10.93	7.84	0.28	28.27	15	15	696.79	
T2P4	20	7.02	0.35	7.02	4.34	0.38	38.18	19	19	566.87	
T2P5	20	13.87	0.69	13.87	10.3	0.26	25.74	14	14	825.27	

Appendix E9:Mangrove soil biomass and carbon stocks for rocky bay

	Sample volume-Wet Soil(cm3)	Oven-dry sample(g)	Dbd (g/cm3)	Dry mass before combustion (g)	Dry mass after combustion (g)	LOI(mg)	%LOI	%Corg	%Corg - whole no.	Soil carbon density	Total carbon – (Sample 1+Sample 2) / 2
Samples from 15 cm depth											
T1P1	20	26.38	1.319	26.38	22.79	0.14	13.61	9	9	178.07	380.69
T1P2	20	12.65	0.6325	12.65	10.28	0.19	18.74	11	11	104.36	284.74
T1P3	20	19.74	0.987	19.74	17.35	0.12	12.11	8	8	118.44	554.43
T1P4	20	15.92	0.796	15.92	14.1	0.11	11.43	8	8	95.52	325.18
T1P5	20	19	0.95	19	17.12	0.10	9.89	7	7	99.75	282.78
T2P1	20	32.09	1.6045	32.09	29.25	0.09	8.85	7	7	168.47	478.85
T2P2	20	34.07	1.7035	34.07	31.92	0.06	6.31	6	6	153.32	432.70
T2P3	20	23.81	1.1905	23.81	22.26	0.07	6.51	6	6	107.15	318.65
T2P4	20	16.91	0.8455	16.91	14.44	0.15	14.61	9	9	114.14	322.14
T2P5	20	23.17	1.1585	23.17	20.84	0.10	10.06	7	7	121.64	491.71
Av SC / plot (1000m2)											**387.19**

	Sample volume- Wet Soil(cm3)	Oven-dry sample(g)	Dbd (g/cm3)	Dry mass before combustion (g)	Dry mass after combustion (g)	LOI(mg)	%LOI	%Corg	%Corg - whole no.	Soil carbon density	Total carbon – (Sample 1+Sample 2) / 2
Total SC / ha (MgC/ha)											**3871.86**
Samples from 85cm depth											
TIP1	20	15.25	0.7625	15.25	12.99	0.15	14.82	9.04	9	583.31	
T1P2	20	12.16	0.608	12.16	10.28	0.15	15.46	9.31	9	465.12	
T1P3	20	29.13	1.4565	29.13	25.54	0.12	12.32	8.00	8	990.42	
T1P4	20	26.11	1.3055	26.11	24.84	0.05	4.86	4.91	5	554.84	
T1P5	20	21.92	1.096	21.92	20.64	0.06	5.84	5.31	5	465.80	
T2P1	20	30.95	1.5475	30.95	28.61	0.08	7.56	6.03	6	789.23	
T2P2	20	33.51	1.6755	33.51	31.92	0.05	4.74	4.86	5	712.09	
T2P3	20	20.79	1.0395	20.79	19.1	0.08	8.13	6.26	6	530.15	
T2P4	20	20.79	1.0395	20.79	19.1	0.08	8.13	6.26	6	530.15	
T2P5	20	22.53	1.1265	22.53	19.17	0.15	14.91	9.08	9	861.77	

Appendix E10: Summary of Carbon Stocks and Carbon sequestered

Mangrove system	Aboveground & Belowgroud Carbon stocks (MgC/ha)	Soil Carbon stocks (MgC/ha)	Leaflitter Carbon stocks (MgC/ha)	TOTAL CARBON	Carbon sequestered in aboveground & belowground pool (Mg/CO_2e)	Carbon Sequestered in soil pool (Mg/CO2e)	Carbon sequestered in leaflitter pool (Mg/CO_2e)	Total Carbon Sequesrered Per Hectare ($Mg/CO_2e/ha$)
Estuary	13.04	2907.03	0.76	**2920.83**	47.8568	10668.8	2.7892	**10719.446**
Lagoon	85.65	3991.03	0.72	**4077.4**	314.3355	14647.08	2.6424	**14964.058**
Rockybay	90.07	3871.86	1.16	**3963.09**	330.5569	14209.726	4.2572	**14544.54**
				3653.773333				13409.348

Appendix F: Value of Fisheries in the Study Area

Appendix F1: Characteristics of respondents and pricing components in Princess Town

No.	Gender	Age (yrs)	Level of education	Products harvested	Purpose for harvesting	Number of trips per week	No. of trips per month	Price per kg (GHC)	Equipment cost (@10yrs life expectancy)	Maintenance cost /yr	Value of spiritual service (GHS)	Value of aesthetic service (GHS)
1	Male	47	SHS	Fish	Subsistence	1					100 (2)	100 (2)
2	Male	42	Basic	Fish	Commercial	6	24	5.6	530	20	500 (10)	300
3	Male	42	Basic	Fish	Commercial	7	28	2.8	540	30		
4	Male	28	JHS	Fish	Commercial	6	24	1.0	950	50		
5	Male	37	JHS	Fish	Commercial	3	12	2.8	1000	100	5 each	700 collectively
6	Male	20	Basic	Fish	Commercial	6	24	1.9	170	20	3 each	200 collectively
7	Male	43	Basic	Fish	Commercial	1	4	0.7			500 collectively	300 collectively
8	Male	16	Basic	Fish	Commercial	3	12	2.2	356	120	250 collectively	250 collectively
9	Male	18	SHS	Fish	Commercial	4	16	0.9				600
10	Male	36	Basic	Fish	Commercial	3	12	0.4	1450	150	2 each	1 each
11	Male	42	JHS	Fish	Commercial	6	24	0.7			400 collectively	250 collectively
12	Male	48	No education	Fish	Commercial	3	12	2.2	130	70		

No.	Gender	Age (yrs)	Level of education	Products harvested	Purpose for harvesting	Number of trips per week	No. of trips per month	Price per kg (GHC)	Equipment cost (@10yrs life expectancy)	Maintenance cost /yr	Value of spiritual service (GHS)	Value of aesthetic service (GHS)
13	Male	32	Primary	Fish	Subsistence							
14	Male	40	JHS	Fish	Subsistence							
15	Male	30	SHS	Fish	Subsistence						500 collectively	200 collectively
16	Male	40	SHS	Fish	Commercial	5	20	3.3	107.6			
17	Male	46	No education	Fish	Commercial	5	20	11.1			400 collectively	20 each
								2.7	581.5111	70		
									58.15111	840		
1	Female	67	No education	Shellfish	Subsistence	6						
2	Female	30	No education	Shellfish	Subsistence							
3	Female	30	No education	Shellfish	Subsistence							1000 collectively
4	Male	29	JHS	Shellfish	Commercial	5	20	1.6				
5	Female	60	No education	Shellfish	Commercial	2	8	1.33	10		200 collectively	200 collectively
6	Female	26	No education	Shellfish	Subsistence						700 collectively	800 collectively
7	Female	28	No education	Shellfish	Commercial	7	28	1	10			500 collectively

No.	Gender	Age (yrs)	Level of education	Products harvested	Purpose for harvesting	Number of trips per week	No. of trips per month	Price per kg (GHC)	Equipment cost (@10yrs life expectancy)	Maintenance cost /yr	Value of spiritual service (GHS)	Value of aesthetic service (GHS)
8	Female	42	No education	Shellfish	Commercial	1	4	0.8	10			
9	Male	43	Basic	shellfish	Commercial	6	24	2			15000 collectively	800 collectively
10	Female	43	No education	Shellfish	Commercial	1	4	0.8			250 collectively	250 collectively
11	Male	16	Basic	Shellfish	Commercial	1	4	3				
12	Female	50	No education	Shellfish	Commercial	2	8	0.67				
13	Female	50	No education	Shellfish	Commercial	2	8	2				
14	Male	33	No education	Shellfish	Subsistence	1						
15	Female	19	JHS	Shellfish	Commercial	2	8	0.93				
16	Female	16	JHS	Shellfish	Subsistence							
17	Female	60	No education	Shellfish	Subsistence							300 collectively
18	Female	24	jhs	Shellfish	Commercial	3	12	0.8	5		500 collectively	
19	Female	50	No education	Shellfish	Commercial	6	24	0.8	12			300 collectively
20	Female	50	No	Shellfish	Commercial	6	24	2				250

No.	Gender	Age (yrs)	Level of education	Products harvested	Purpose for harvesting	Number of trips per week	No. of trips per month	Price per kg (GHC)	Equipment cost (@10yrs life expectancy)	Maintenance cost /yr	Value of spiritual service (GHS)	Value of aesthetic service (GHS)
			education									collectively
21	Female	27	jhs	Shellfish	Commercial	2	8	2	5		600 collectively	500 collectively
22	Male	48	No education	Shellfish	Commercial	6	24	2			500 collectively	700 collectively
23	Female	28	jhs	Shellfish	Commercial	6	24	1			800 collectively	500 collectively
24	Female	35	No education	Shellfish	Commercial	3	12	2.4	5			1000
25	Female	50	No education	Shellfish	Commercial	5	**20**	**0.8**	5		1000 collectively	600 collectively
26	Female	23	Jhs	Shellfish	Commercial	4	**16**	**0.8**	5		700 collectively	1000 collectively
27	Female	45	No education	Shellfish	Commercial	7	**28**	**1.2**	5		700 collectively	250 collectively
28	Female	65	No education	Shellfish	Subsistence							
29	Female	15	JHS	Shellfish	Subsistence						400 collectively	200 collectively
30	Female	28	JHS	Shellfish	Subsistence						500 collectively	300 collectively
31	Female	30	jhs	Shellfish	Commercial	2	**8**	**0.8**	5			

No.	Gender	Age (yrs)	Level of education	Products harvested	Purpose for harvesting	Number of trips per week	No. of trips per month	Price per kg (GHC)	Equipment cost (@10yrs life expectancy)	Maintenance cost /yr	Value of spiritual service (GHS)	Value of aesthetic service (GHS)
32	Male	15	No education	Shellfish	Subsistence						900 collectively	700 collectively
33	Male	39	JHS	Shellfish	Commercial	6	**24**	**0.2**	10		1000 collectively	1500 collectively
34	Female	14	jhs	Shellfish	Commercial	2	**8**	**1**			1000 collectively	500 collectively
35	Female	45	No education	Shellfish	Commercial	2	**8**	**0.5**	10		500 collectively	500 collectively
36	Female	20	JHS	Shellfish	Subsistence			**1.33**			500 collectively	500 collectively
37	Female	22	Jhs	Shellfish	Commercial	3	**12**	**1**	10			
38	Female	20	JHS	Shellfish	Commercial	3	**12**	**1.26**	10			
								1.260	**7.8**			

Appendix F2: Characteristics of respondents and pricing components in Cape Three Points

No.	Gender	Age (yrs)	Level of Education	Products harvested	Purpose	Number of trips per week	No. of trips per month	Price per kg (GHC)	Value of spiritual service (GHS)	Value of aesthetic service (GHS)
1	Male	40	Basic	Fish	Commercial	7	28	0.055556		
2	Male	38	JHS	Fish	Commercial	4	16	1.666667		300 collectively
3	Male	48	No education	Fish	Commercial	4	16	3.333333		10 each
4	Male	52	No education	Fish	Subsistence					300 collectively
5	Male	42	JHS	Fish	Commercial	3	12	1.666667		5 each
6	Male	44	JHS	Fish	Commercial	7	28	5.555556		50 each
7	Male	39	No education	Fish	Subsistence					10 each
8	Male	55	SHS	Fish	Commercial	7	28	3.703704		10 each
9	Male	24	JHS	Fish	Commercial	4	16	1.666667		
10	Male	22	SHS	Fish	Subsistence					
11	Male	25	SHS	Fish	Subsistence					2 each
12	Male	40	No education	Fish	Subsistence					10 each
13	Male	35	No education	Fish	Commercial	6	24	0.555556		100 collectively
14	Male	80	No education	Fish	Commercial	3	12	1.111111		800 collectively
15	Male	35	JHS	Fish	Commercial	5	20	1.555556		
16	Male	45	No education	Fish	Subsistence					700 collectively

No.	Gender	Age (yrs)	Level of Education	Products harvested	Purpose	Number of trips per week	No. of trips per month	Price per kg (GHC)	Value of spiritual service (GHS)	Value of aesthetic service (GHS)
17	Male	19	JHS	Fish	Subsistence					900 collectively
18	Male	33	No education	Fish	Commercial	5	20	1.111111		600 collectively
19	Male	57	Basic	Fish	Commercial	3	12	3.333333		800 collectively
20	Male	28	Basic	Fish	Subsistence					
21	Male	40	No education	Fish	Commercial	7	28	3.703704		
22	Male	18	JHS	Fish	subsistence	7	28	16.66667		
23	Male	25	SHS	fish	Commercial	5	20	16.66667		
1	Female	15	JHS	Shellfish	Subsistence	2		-		500 collectively
2	Female	30	No education	Shellfish	Commercial	7		-		
3	Female	19	SHS	Shellfish	Commercial	7		-		1000 collective
4	Female	45	JHS	Shellfish	Commercial	7		-		
5	Female	65	No education	Shellfish	Commercial	7		-		
6	Female	23	JHS	Shellfish	Commercial	2		-		800 collectively
7	Female	20	JHS	Shellfish	Commercial	7		-		300 collectively
8	Female	26	JHS	Shellfish	Commercial	2		-		200 collectively

No.	Gender	Age (yrs)	Level of Education	Products harvested	Purpose	Number of trips per week	No. of trips per month	Price per kg (GHC)	Value of spiritual service (GHS)	Value of aesthetic service (GHS)
9	Female	30	No education	Shellfish	Commercial	2		-		300 collectively
10	Female	21	No education	Shellfish	Commercial	2		-		200 collectively
11	Female	17	JHS	Shellfish	Commercial	3		-		500 collectively
12	Female	40	No education	Shellfish	subsistence	6		-		300 collectively
13	Female	18	JHS	Shellfish	Commercial	6		-		200 collectively
14	Female	24	No education	Shellfish	Commercial	7		-		
15	Female	30	No education	Shellfish	Commercial	7		-		
16	Female	31	No education	Shellfish	Commercial	7		-		
17	Female	43	No education	Shellfish	Commercial	6		-		
18	Female	30	No education	Shellfish	subsistence	3		-		
19	Female	20	JHS	Shellfish	subsistence	3		-		
20	Female	32	No education	Shellfish	subsistence	3		-		
21	Female	31	No education	Shellfish	subsistence	2		-		
22	Female	62	No education	Shellfish	subsistence	2		-		

Appendix F3: Estimation of economic value of fishing and NPV

	No. of trips / month	Quantity per one trip/kg	Monthly gross output (kg)	Annual gross output (kg)	Unit price /kg (GHC)	Monthly Income = Output * Price (GHC)	Yearly Income (OV) (GHC)	Yearly Cost (OC) (GHC)	Monthly cost	Unit cost(GHC) = Monthly cost/ Monthly output	Economic value = Annual gross * (Unit price - Unit cost) ($USD)	OV-OC	(1+r)^t	NPV = (OV-OC) / (1+r)^t
Estuary - finfish	28	1.4	39.2	470.4	2.74 ($USD 0.5)	107.41	1288.90 ($USD 232.0)	898.15 ($USD 161.67)	74.85	1.91 ($USD 0.34)	68.83	390.75	8.59	45.46 ($USD 8.18)
Lagoon - finfish	28	2.1	59.6	716	2.74 ($USD 0.5)	163.41	1960.96 ($USD 352.97)	898.15 ($USD 161.67)	74.85	1.25 ($USD 0.23)	189.02	1062.81	8.59	123.66 ($USD 22.26)
Shellfish	28		198.8	2,386.2	1.26 ($USD 0.23)	250.60	3007.17 ($USD 541.29)	8 ($USD 1.44)	0.67	0.003 ($USD 0.001)	547.38	2999.17	1.27	2361.55 ($USD 425.08)
Off Rocky bay - finfish	28		152.8	1,833.6	4.16 ($USD 0.7)	635.16	7621.89 ($USD 1371.94)	898.15 ($USD 161.67)	74.85	0.490 ($USD 0.088)	473.79	6723.74	8.59	782.31 ($USD 140.82)

r = 0.27

t = 9yr (finfish), 1yr (shellfish)

Appendix G: Prioritization of Ecosystem Services

Appendix G1 – List of ES Identified That Support Fisheries in the Study Area, Classified According to CICESS(Haines-Young & Potschin, 2018)

ES Class	**ES Description**	**Typology of Data for mapping**	***Mangrove (PT & CTP)***[1]	***Lagoon (PT)***	***Estuary (PT)***	***Rocky bay (CTP)***	***Sandy beach (CTP)***
Provisioning							
Wild animals and their outputs	Food: finfish, shellfish	Status of fish population (Species composition)	Shellfish (Periwinkles, Oysters and Bloody cockerels)	Finfish (Flagfin majorra, Mullets and Crevalle jack); Shellfish (Periwinkles, Oysters and Bloody cockerels)	Finfish (Common sardine, Bonga shad and Tilapias); Shellfish (Periwinkles, Oysters and Bloody cockerels)	Shellfish (Crabs)	N/A[2]
Regulating and Maintenance							
Bio-remediation	Biological filtration by microorganisms, algae, plants and animals (eg. Oysters,	Indicators of water quality (nitrate and phosphate concentrations, oxygen	Presence oysters, clams and mussels	Presence oysters, clams and mussels	Presence of algae, oysters, clams and mussels	Presence of algae	N/A

[1] PT – Princess Town; CTP – Cape Three Points

[2] N/A – Not Applicable

ES Class	**ES Description**	**Typology of Data for mapping**	***Mangrove (PT & CTP)***[1]	***Lagoon (PT)***	***Estuary (PT)***	***Rocky bay (CTP)***	***Sandy beach (CTP)***
	clams and mussels)	conditions).					
Maintain Maintaining nursery populations and ecosystems	Relevant spawning areas for anadromous migratory species and nursery ecosystem for fisheries and invertebrates	Presence of coastal waters; Biodiversity value (Species diversity or abundance, endemics or red list species and spawning location)	Presence of juvenile fish. Presence of endangered species.	Presence of juvenile fish. Presence of endangered species.	Presence of juvenile fish. Presence of endangered species.	Presence of juvenile fish. Presence of endangered species.	Turtle nesting grounds.
Global climate regulation by reduction of greenhouse gas concentrations	Global climate regulation by greenhouse gas/carbon sequestration by ecosystems	Presence of mangrove forests (Carbon stocks)	Presence of mangrove trees	Presence of mangrove trees	Presence of mangrove trees	Presence of mangrove trees	N/A
Decomposition and fixing processes	Decomposition of biological materials and	Presence of mangrove forests (leaf	Litterfall from mangrove trees.	Litterfall from mangrove trees.	Litterfall from mangrove	Litterfall from mangrove	N/A

ES Class	**ES Description**	**Typology of Data for mapping**	***Mangrove (PT & CTP)***[1]	***Lagoon (PT)***	***Estuary (PT)***	***Rocky bay (CTP)***	***Sandy beach (CTP)***
	their incorporation in soils	litter fall).	Presence of mangrove crabs	Presence of mangrove crabs	trees. Presence of mangrove crabs	trees. Presence of mangrove crabs	
Cultural							
Physical use of plants and animal	Watching plants and animals where they live; using nature to destress	Viewpoints. Presence of protected areas	Presence of monkeys	Presence of monkeys	Presence of birds	N/A	N/A
Physical use of land/seascapes	Using landscapes / seascapes for various activities	N/A	N/A	N/A	N/A	N/A	Landing beach
Educational	Natural and cultural heritage which are subject matter of education	Location of eco-museums, and environmental interpretative Centres	N/A	*Tourism office in Fort* Fredericksburg	*Tourism office in Fort* Fredericksburg	Tourism office in the community	N/A

ES Class	**ES Description**	**Typology of Data for mapping**	***Mangrove (PT & CTP)***[1]	***Lagoon (PT)***	***Estuary (PT)***	***Rocky bay (CTP)***	***Sandy beach (CTP)***
Heritage, cultural	Things in nature that help people identify with the history or culture of where they live or come from	Number of visitors for tourism purposes	N/A	Artisanal fishery.	Artisanal fishery.	Artisanal fishery.	N/A
Aesthetic	Artistic representations of nature	Contrasting landscapes (lakes close to mountains)	N/A	Closed lagoon with a hilly view	Estuary, connecting the Nyan river to the Sea	Round boulders laid out in a bay	N/A

N/A = Not Applied; PT = Princess Town; C3P = Cape Three Points

Appendix: G2: Prioritization of ecosystem services - Princess Town community

Participant	Gender	Age	Level of education	F	BR	D&F	N	H	CS	T	A	S	H	E	LS
P1	Male	47	SHS	1	-	5	-	3	-	4	-	3	-	-	-
P2	Male	42	Basic	1	2	5	4	3	-	-	-	-	-	-	-
P3	Male	42	Basic	3	4	-	-	-	-	5	2	1	-	-	-
P4	Male	28	JHS	1	-	-	2	3	4	-	5	-	-	-	-
P5	Male	37	JHS	1	-	3	4	-	-	-	-	2	5	-	-
P6	Male	20	Basic	1	-	3	4	-	5	2	-	-	-	-	-
P7	Male	43	Basic	1	-	-	4	-	-	-	2	3	-	-	-
P8	Male	16	Basic	1	-	2	3	-	4	-	-	-	-	5	-
P9	Male	18	SHS	1	-	-	2	-	3	4	-	-	-	5	-
P10	Male	36	Basic	1	-	5	-	-	4	-	-	2	3	-	-
P11	Male	42	JHS	1	-	-	2	-	-	-	5	3	4	-	-
P12	Male	48	No education	1	-	-	2	-	-	-	4	3	5	-	-
P13	Male	32	Primary	1	-	-	3	5	-	-	-	-	4	2	-
P14	Male	40	JHS	1	-	-	2	-	5	-	-	3	4	-	-
P15	Male	30	SHS	1	-	2	-	5	-	3	-	-	-	4	-
P16	Male	40	SHS	1	2	-	3	-	-	5	-	4	-	-	-
P17	Male	46	No education	1	-	-	2	3	-	5	-	-	-	4	-
P18	Male	29	JHS	-	-	-	1	-	4	5	2	3	-	-	-
P19	Female	67	No education	-	-	-	1	-	4	5	2	3	-	-	-
P20	Female	30	No education	1	3	5	2	4	-	-	-	-	-	-	-
P21	Female	30	No education	1	-	-	2	4	-	3	-	5	-	-	-

Participant	Gender	Age	Level of education	F	BR	D&F	N	H	CS	T	A	S	H	E	LS
P22	Male	29	JHS	1	-	-	2	4	-	3	-	-	-	5	-
P23	Female	60	No education	1	2	-	3	-	-	5	-	4	-	-	-
P24	Female	26	No education	2	-	5	-	-	1	-	3		4	-	-
P25	Female	28	No education	2	-	1	-	-	-	-	3	5	4	-	-
P26	Female	42	No education	1	5	-	4	-	-	2	3		-	-	-
P27	Male	43	Basic	1	-	-	2	-	-	-	3	5	-	4	-
P28	Female	43	No education	1	-	-	2	-	4	-	3	5	-	-	-
P29	Male	16	Basic	1	-	-	2	3	4	-	-		-	5	-
P30	Female	50	No education	1	-	-	-	-	4	-	5	3	2	-	-
P31	Female	50	No education	1	-	2	3	-	-	4	-	5	-	-	-
P32	Male	33	No education	5	-	3	1	2	-	-	-	-	-	4	-
P33	Female	19	JHS	1	2	3	4	5	-	-	-	-	-	-	-
P34	Female	16	JHS	1	-		2	-	4	-	-	3	-	5	-
P35	Female	60	No education	1	-	5	4	-	-	2	-	-	-	3	-
P36	Female	24	jhs	-	1	5	2	-	-	-	-	3	-	4	-
P37	Female	50	No education	4	5	-	-	-	-	3	-	2	1	-	-
P38	Female	50	No education	4	5	-	-	-	-	-	3	-	2	1	-
P39	Female	27	jhs	-	-	-	1	-	2	-	5	-	4	3	-
P40	Male	48	No education	5	1	2	3	-	4	-	-	-	-	-	-
P41	Female	28	jhs	1	-	-	-	-	-	5	2	-	3	4	-
P42	Female	35	No education	1	-	2	-	3	-	-	-	4	-	5	-
P43	Female	50	No education	-	-	3	2	-	4	5	1	-	-	-	-

Participant	Gender	Age	Level of education	F	BR	D&F	N	H	CS	T	A	S	H	E	LS
P44	Female	23	Jhs	-	-	3	2	-	4	5	1	-	-	-	-
P45	Female	45	No education	4	-	5	-	-	-	3	2	-	1	-	-
P46	Female	65	No education	-	-	-	1	2	-	-	3	4	-	5	-
P47	Female	15	JHS	1	-	-	2	3	4	-	-	-	-	-	-
P48	Female	28	JHS	1	4	-	2	-	-	5	3	-	-	-	-
P49	Female	30	jhs	1	-	-	-	-	-	3	5	4	2	-	-
P50	Male	15	No education	1	-	2	-	-	-	-	5	3	-	4	-
P51	Male	39	JHS	1	-	2	-	3	4	-	-	-	-	5	-
P52	Female	14	jhs	-	1	2	-	3	4	-	-	-	-	5	-
P53	Female	45	No education	1	-	2	-	-	3	-	-	5	-	4	-
P54	Female	22	Jhs	1	-	2	-	-	3	-	-	5	-	4	-
P55	Female	20	JHS	-	1	-	-	-	-	2	-	3	5	4	-

SUMMARY					
ES	**RANK**				
	1	**2**	**3**	**4**	**5**
F - Food	38	2	1	3	2
BR - Bio-remediation	4	4	1	2	3
D&F - Decomposition & Fixing	1	10	6	-	8
N - Nursery	5	18	6	7	-
H - Habitat	-	2	9	3	3
CS - Carbon sequestration	1	1	3	15	2
T - Tourism	-	4	6	3	10
A - Aesthetics	2	6	8	1	6
S - Spiritual	1	3	12	5	7
H - Heritage	2	3	2	6	3
E - Education	1	1	2	10	9
LS - Landing site	-	-	-	-	-

Appendix G3: Prioritization of ecosystem services - Cape Three Points community

Participant	Gender	Age	Level of education	F	BR	D&F	N	H	CS	T	A	S	H	E	LS
P1	Female	15	JHS	1	-	2	-	-	3	-	-	5	-	4	-
P2	Female	30	No education	1	2	3	-	4	5	-	-	-	-	-	-
P3	Male	40	Basic	-	-	4	2	1	-	3	5	-	-	-	5
P4	Male	38	JHS	1	-	-	2	-	3	5	-	-	4	-	-
P5	Male	48	No education	-	-	-	2	-	-	4	3	1	-	-	-
P6	Male	42	JHS	1	-	-	-	-	3	2	-	5	-	4	-
P7	Male	44	JHS	1	-	-	2	-	3	-	-	4	-	5	-
P8	Male	55	SHS	-	1	2	3	-	-	-	4	-	5	-	-
P9	Male	24	JHS	1	2		3	4	-	-	-	5	-	-	-
P10	Male	35	No education	1	2	5	3	-	-	-	-	4	-	-	-
P11	Male	80	No education	1	-	-	-	-	4	-	5	-	2	3	-
P12	Male	35	JHS	1	3	2	-	-	-	3		-	-	-	5
P13	Male	33	No education	1	-	3	-	2	-	-	4	-	-	-	5
P14	Female	19	SHS	1	-		2		3	-	4	-	5	-	
P15	Female	45	JHS	1	-	3			3	-		-	2	4	5
P16	Female	65	No education	1	-	3	2	4	-	-	4	-	5	-	-
P17	Female	23	JHS	1	4	-	-	-	-	2	-	5	-	-	3
P18	Female	20	JHS	1	-	3	2	-	4	-	5	-	-	-	-
P19	Female	26	JHS	1	3		4	-	2	-	-	5	-	-	-
P20	Male	57	Basic	1		3	-	-	-	5	-	2	-	-	4
P21	Male	40	No education	1	5	-	2	-	4		-	-	3	-	-
P22	Male	18	JHS	3	-	-	1	-	-	5	4	-	2	-	-

Participant	Gender	Age	Level of education	F	BR	D&F	N	H	CS	T	A	S	H	E	LS
P23	Male	25	SHS	-	4	3	2	-	-	5	-	-	-	-	1
P24	Male	22	SHS	-	4	3	2	-	-	5	-	-	-	-	1
P25	Female	30	No education	1	-	3	2	-	-	-	-	-	4	-	5
P26	Female	21	No education	3	-	-	2	-	-	-	4	-	1	5	-
P27	Male	25	SHS	1	-	-	-	5	-	-	2	-	-	4	3
P28	Female	17	JHS	1	-	-	2	-	3	-	4	-	-	-	5
P29	Female	40	No education	1	-	-	2	-	-	4	-	-	3	-	5
P30	Female	18	jhs	2	4	-	1	-	3	-	-	5	-	-	-
P31	Female	24	No education	1	-	-	3	-	2	-	5	-	-	-	4
P32	Female	30	No education	1	-	5	-	3	-	-	4	-	-	-	2
P33	Female	31	No education	1	-	-	2	-	4	-	5	-	-	3	-
P34	Female	43	No education	1	5	-	2		-	-	-	4	-	-	3
P35	Female	30	No education	2	-	-	1	3	-	4	-	-	-	-	5
P36	Male	40	No education	1	-	5	-	2	-	-	-	-	4	-	3
P37	Male	19	JHS	1	-	3	-	-	4	-	5	-	2	-	-
P38	Male	28	Basic	-	-	3	4	5	-	2		-	-	-	1
P39	Female	20	JHS	1	-	-	3		-	2	4	-	-	5	-
P40	Male	45	No education	1	-	3	-	4	-	-	-	2	-	-	5
P41	Female	32	No education	1	-	-	-	5	-	4	-		3	-	2
P42	Female	31	No education	1	5	-	-	3	-	4	-	-	-	2	-
P43	Male	39	No education	1	-	-	2	-	3	-	4	-	-	-	5
P44	Female	62	No education	1	-	3	2	-	4	-		5	-	-	-
P45	Male	52	No education	-	-	-	2	-	-	5	4	-	3	1	-

SUMMARY ES	**RANK**				
	1	**2**	**3**	**4**	**5**
F - Food	34	3	2	-	-
BR - Bio-remediation	1	3	2	4	3
D&F - Decomposition & Fixing	-	3	13	1	3
N - Nursery	3	19	5	2	-
H - Habitat	1	2	3	4	3
CS - Carbon sequestration	-	2	9	6	1
T - Tourism	-	4	2	5	6
A - Aesthetics	-	1	1	11	6
S - Spiritual	1	2	-	3	7
H - Heritage	1	4	4	3	3
E - Education	1	1	2	4	3
LS - Landing site	3	2	4	2	10

Appendix H: Prioritization of Pressures

Appendix H1: Princess Town prioritization of pressures

Serial No.	Gender	Age	Level of education	O	R	Cdev	FL	PP	M	DF	S	CD	BA
P1	Male	47	SHS	x			x	x				x	
P2	Male	42	Basic		x						x	x	x
P3	Male	42	Basic	x			x	x	x			x	
P4	Male	28	JHS	x	x	x	x						
P5	Male	37	JHS	x				x		x		x	
P6	Male	20	Basic			x	x	x		x			
P7	Male	43	Basic	x			x	x				x	
P8	Male	16	Basic				x		x		x		x
P9	Male	18	SHS	x				x	x		x		
P10	Male	36	Basic	x			x	x		x			
P11	Male	42	JHS	x			x	x				x	
P12	Male	48	No education	x		x	x		x				
P13	Male	32	Primary	x			x	x				x	
P14	Male	40	JHS	x			x					x	x
P15	Male	30	SHS	x			x	x				x	
P16	Male	40	SHS				x	x				x	x
P17	Male	46	No education	x	x			x				x	
P18	Male	29	JHS				x	x	x	x			
P19	Female	67	No education	x				x		x			x
P20	Female	30	No education	x	x	x	x						
P21	Female	30	No education	x					x	x		x	
P22	Male	29	JHS	x				x			x	x	

Serial No.	Gender	Age	Level of education	O	R	Cdev	FL	PP	M	DF	S	CD	BA
P23	Female	60	No education	x			x	x				x	
P24	Female	26	No education				x	x		x	x		
P25	Female	28	No education			x	x	x					x
P26	Female	42	No education	x		x	x	x					
P27	Male	43	Basic	x			x		x	x			
P28	Female	43	No education	x			x	x				x	
P29	Male	16	Basic	x	x		x					x	
P30	Female	50	No education	x			x	x		x			
P31	Female	50	No education	x				x				x	x
P32	Male	33	No education	x		x		x	x				
P33	Female	19	JHS				x		x		x	x	
P34	Female	16	JHS			x		x		x		x	
P35	Female	60	No education	x			x	x					x
P36	Female	24	jhs	x			x	x				x	
P37	Female	50	No education	x				x		x	x		
P38	Female	50	No education	x	x	x						x	
P39	Female	27	jhs							x	x	x	x
P40	Male	48	No education	x			x	x				x	
P41	Female	28	jhs	x			x	x	x				
P42	Female	35	No education	x	x			x			x		
P43	Female	50	No education	x			x				x		x
P44	Female	23	Jhs			x		x	x			x	
P45	Female	45	No education	x				x	x	x			
P46	Female	65	No education	x							x	x	x

Serial No.	Gender	Age	Level of education	O	R	Cdev	FL	PP	M	DF	S	CD	BA
P47	Female	15	JHS	x			x			x	x		
P48	Female	28	JHS	x	x	x						x	
P49	Female	30	jhs	x	x		x			x			
P50	Male	15	No education	x			x	x	x				
P51	Male	39	JHS	x				x			x	x	
P52	Female	14	jhs	x		x	x		x				
P53	Female	45	No education	x			x			x	x		
P54	Female	22	Jhs	x	x		x		x				
P55	Female	20	JHS	x	x	x		x					

Summary		
Pressure	No. of people	Percentage
O - Overexploitation	44	80
R - Rainfall/storms	5	9
Cdev - Coastal development	7	13
FL - Fertilizer input	35	64
PP - Plastic pollution	35	64
M - Mining	15	27
DF - Dynamite fishing	16	29
S - Sewage	14	25
CD- Coastal deforestation	27	49
BA - Brown algae	11	20

Appendix H2: Cape Three Points prioritization of pressures

Serial No.	Gender	Age	Level of education	CD	OD	Cdev	MD	SW	BA	DF
P1	Female	15	JHS		x			x	x	x
P2	Female	30	No education		x	x			x	x
P3	Male	40	Basic	x	x		x			x
P4	Male	38	JHS	x		x	x	x		
P5	Male	48	No education		x		x	x		x
P6	Male	42	JHS	x	x				x	x
P7	Male	44	JHS		x		x	x		x
P8	Male	55	SHS	x			x	x		x
P9	Male	24	JHS		x	x	x			x
P10	Male	35	No education		x	x	x	x		
P11	Male	80	No education		x		x	x		x
P12	Male	35	JHS	x	x	x				x
P13	Male	33	No education		x		x	x		x
P14	Female	19	SHS	x	x		x			x
P15	Female	45	JHS			x	x	x	x	
P16	Female	65	No education	x	x		x			x
P17	Female	23	JHS		x		x	x		x
P18	Female	20	JHS		x			x	x	x
P19	Female	26	JHS		x		x	x	x	
P20	Male	57	Basic	x	x		x	x		
P21	Male	40	No education	x	x				x	x
P22	Male	18	JHS			x	x	x		x
P23	Male	25	SHS		x		x	x		x

Serial No.	Gender	Age	Level of education	CD	OD	Cdev	MD	SW	BA	DF
P24	Male	22	SHS		x		x	x	x	
P25	Female	30	No education	x	x		x			x
P26	Female	21	No education		x	x	x	x		
P27	Male	25	SHS		x		x	x		x
P28	Female	17	JHS		x		x	x		x
P29	Female	40	No education				x	x	x	x
P30	Female	18	jhs	x	x		x			x
P31	Female	24	No education	x	x	x				x
P32	Female	30	No education		x		x		x	x
P33	Female	31	No education							
P34	Female	43	No education		x					x
P35	Female	30	No education		x	x	x			
P36	Male	40	No education		x			x		x
P37	Male	19	JHS	x	x		x			x
P38	Male	28	Basic	x	x	x	x			
P39	Female	20	JHS		x		x	x	x	
P40	Male	45	No education		x	x			x	x
P41	Female	32	No education	x	x		x	x		
P42	Female	31	No education	x	x		x		x	
P43	Male	39	No education		x		x		x	x
P44	Female	62	No education	x	x	x				x
P45	Male	52	No education		x		x	x		x

Summary

Pressure	No. of people	Percentage (%)
CD- Coastal deforestation	17	38
OD - Open defaecation	39	87
Cdev - Coastal development	13	29
MD - Marine debris	33	73
SW - Solid waste disposal	24	53
BA - Brown algae	14	31
DF - Dynamite fishing	32	71

Appendix I: Value of Tourism in Princess Town

Year	No.of visitors	Amount (US$) = No. of visitors * 30.6
2008	81	2478.6
2009	102	3121.2
2010	191	5844.6
2011	132	4039.2
2012	136	4161.6
2013	106	3243.6
2014	6	183.6
2015	6	183.6
2016	5	153
2017	5	153
2018	3	91.8
2019	7	214.2
Average		**1989**