At the Water's Edge (AWE): Coastal Resilience in St. Vincent and the Grenadines and Grenada
Project Framework

DRAFT – Do not distribute. Contact Dr. Vera Agostini (AWE Science Lead - vagostini@tnc.org) with questions.

This document aims to capture the approach we are taking in the *At the Water's Edge (AWE): Coastal Resilience in St. Vincent and the Grenadines and Grenada* project. While we initially define the context for the entire project, **the focus of most of the document is on one project component: understanding and visualizing vulnerability to climate change (objective 1).** For more context and details on the project please see project proposal and Y1 annual report. The project started in July 2011 (phase I), and is now in its second phase (July 2012-June 2013).

This document is intended to provide opportunity for review and refinement of ideas, both within and outside of the project team. It is not meant for wider circulation. We are using it to facilitate calls with key staff and other partners to solicit input that will help refine this framework.

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1. Introduction

1.1 Background

Grenada, St. Vincent & the Grenadines (GSVG), and the larger Caribbean community are severely threatened by the impacts of climate change. These impacts include sea level rise (SLR), coastal erosion, increases in storm intensity and frequency, riverine and coastal flooding, coral bleaching, and habitat loss (Simpson et al. 2010). As countries develop adaptation strategies to cope with these changes there is need to better understand the complex relationships between people and nature (Moss et al. 2001). ***The goal of this project is to demonstrate that governments and communities of small island states can enhance their resilience to climate change by protecting, restoring and effectively managing their marine and coastal ecosystems and strengthening local capacity for adaptation (EBA).*** The focus for phase I of the AWE project has been on understanding and describing the socioeconomic and ecosystem vulnerability to sea level rise and storm surge impacts and laying the groundwork for Ecosystem Based Adaptation at select sites. ***Local government agencies and stakeholders were key partners in this process.*** We have conducted a wide range of workshop and informal meetings with a variety of partners (table x) to leverage expert knowledge and remain relevant to local context and needs. Activities during Phase II will be focused on refining vulnerability assessments and developing Decision Support Tools to help government and communities visualize and interact with information and make sound decisions.

Identifying risk and vulnerabilities is an important part of developing priorities for adaptation. Sea level rise and storm surge are among the most pressing and important impacts island communities face (refs). They are also the impacts on which the Conservancy's coastal ecosystem-based adaptation (EBA) work has focused more widely in other geographies. As a result we have access to a number of experiences and tools to leverage (see costalresilience.org).

1.2 Project objectives

The AWE project has six objectives (see proposals for full descriptions):

1. Help communities assess their social, ecological, and economic vulnerability from sea level rise and storms with user-friendly decision support tools;
2. Build local capacity and leadership that will empower governments and communities to address climate change impacts beyond the life of the project;
3. Work with vulnerable communities and key stakeholders to design and implement a suite of innovative community-based conservation projects that demonstrate EBA solutions to climate change;
4. Begin to demonstrate the cost effectiveness of EBA and the economic impacts these island nations could suffer by not investing in natural solutions;
5. Identify key indicators of success and integrate monitoring and evaluation frameworks into each of the EBA projects; and
6. Share lessons learned from the Grenadine Bank with local, regional, and global decision makers.

As we work to understand and represent socio-economic and ecological vulnerability in the context of GSVG (objective 1) we are gathering, modeling, analyzing, and visualizing information representing exposure, sensitivity, and adaptive capacity to climate change. By helping to build capacity and a new generation of local leaders (objective 2), we are contributing to strengthening social adaptive capacity of local communities. As we engage with local communities to test and implement nature-based solutions to climate change (objective 3), we are helping to increase adaptive capacity of both social as well as natural systems. Demonstrating the cost effectiveness of EBA will help increase support for EBA and green infrastructure projects (objective 4). Our activities focused on designing measures of effectiveness (objective 5) will help assess whether we are indeed increasing adaptive capacity or reducing sensitivity and vulnerability of social and natural systems.

1.3 Scale

The vulnerability analysis during phase I of this project has prioritized nation-wide data collection and analysis efforts to generate a country wide view of vulnerability; we have leveraged important opportunities presented by activities under objective 2 and 3 to assess needs and requirements for site based analyses. These analyses will then take place during phase II of this project, when our main focus will shift to site level vulnerability.

1.4 Intended 'clients'

The main project target audiences we have identified based on the outcomes from in country visits, needs for activities across the project, and conversations with partners on the ground are (1)local government planners and (2) communities. There are other important 'clients' regionally and globally for whom this work will be relevant, but we realize outputs and communication will likely need to be revised for those specific audiences.

2. Ecological and Socio-Economic vulnerability

The aim of this project is to help strengthen resilience of coastal communities in GSVG and decrease their vulnerability to and risk posed by sea level rise and storm surge. Many definitions of vulnerability have evolved from a variety of contexts such as economic development, sustainability, disaster mitigation, and relief arenas (Moss e al. 2001, Cutter et al. 2009). We are using the framework in Figure 1 to describe vulnerability, which uses the most recent definition of vulnerability from the International Panel on Climate Change (IPCC, 2007). This framework helps guide and weave together project activities across objectives and prioritize action on the ground. As the IPCC explains, assessing the impacts of climate change, the vulnerability of natural and human environments, and the potential for response through adaptation allows for prioritization of actions and tradeoffs to be considered between adaptation and mitigation (refs).

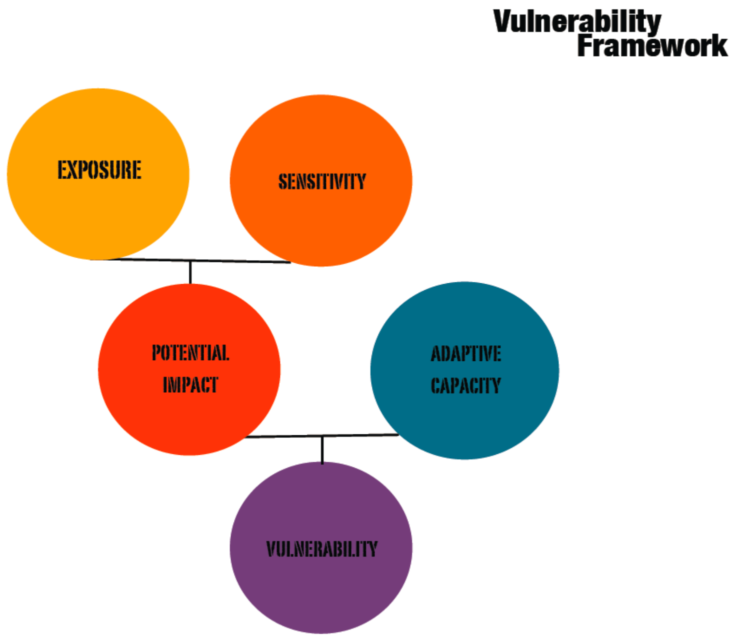


Figure 1 Adapted from Marshall 2009.

We consider **V = *f* (E + S) – A**

Where:

V = V*ulnerability* of a system;

E = *Exposure*, or the amount of a system impacted by *x* scenario;

S = *Sensitivity*, defined by characteristics of a system that influence its likelihood to experience harm. These characteristics can exacerbate or diminish the effect of climate exposure.

A = *Adaptive Capacity*, describing the ability of a system to anticipate, respond to, cope with, and recover from climate impacts

*NOTE: the team is in the process of working out the details of this mathematical representation so above should be considered work in progress.

2.1 Definitions

Resilience: the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change" (IPCC, 2007)

Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. It is a function of the character, magnitude, and rate of climate change, and variation to which a system is exposed, the sensitivity, and the adaptive capacity of that system (IPCC 2007).

Exposure is the degree to which a system (i.e. a region, resource, or community) experiences climate change and variation. It is a result of the magnitude, frequency, duration, and/or spatial extent of a weather event or pattern (Marshall et al. 2010).

Sensitivity refers to the characteristics of a system that influence its likelihood to experience harm. These characteristics can exacerbate or diminish the effect of climate exposure.

Impact is the cumulative experience of a system to climate exposure and is based on both sensitivity and total exposure of the system (**E + S)**.

Adaptive Capacity describes the ability of a system to anticipate, respond to, cope with, and recover from climate impacts (short and long term). For communities, it can be influenced by economic status, human resources, and environmental capacity (Moss et at. 2001). For natural systems it is defined by both natural as well as human context (for example the ability of a mangrove to migrate is driven by characteristics specific of a particular species as well as the surrounding built environment).
In year one we focused on asset based aspects of adaptive capacity, including human and civic resources, economic resources, and community health.

2.2 Mapping vulnerability

Although the utility of vulnerability analyses to identify priority activities for future development and hazard mitigation has been well documented (IPCC 2007; Moss et al. 2001; Cutter et al. 2009; Wongbusarakum, S. and C. Loper 2011) and there are several examples of mapping specific aspects of vulnerability (Granger 2003; O'Brien et al 2004; Shepard et al. 2011; and others), approaches to spatially and comprehensively describe vulnerability are limited. For example, adaptive capacity has usually not been explicitly and spatially described (Marshall et al. 2010; Wongbusarakum, S. and C. Loper 2011) except for a limited number of efforts (World Risk Index; Cinner? refs). In addition, the concept of adaptive capacity is commonly developed for social systems (refs) but not traditionally described for natural systems.

Our approach aims to advance the evolving fields of climate vulnerability assessments and vulnerability mapping by developing a model that allows for the incorporation of these three aspects of vulnerability in a spatially explicit fashion for both natural and human systems. A spatiality explicit model can allow communities, decision makers, foreign aid organizations, and others to prioritize actions and focus energies and resources where they are needed most. For example, it could help decision makers select development projects where there is the highest potential for success and the greatest potential for improving benefits for both humans and nature. It could also help natural resource managers select conservation projects that have the highest chance of success given climate change context.

Spatial information and analysis guides our work under objective 1; as such information and tools we adopt need to be able to effectively deliver a 'spatial view'. Spatially describing sensitivity and exposure is something we (TNC) have been doing at other sites (e.g. Long Island, see Shepard et all 2011 and coastalresilience.org). As outlined above adaptive capacity has usually not been explicitly and spatially described. We consider adaptive capacity as an important player in the vulnerability game, as it will help empower communities to support good preparedness practices, help prioritize and strengthen investments in nature, and help reduce impacts from climate change. We also note that local and regional disaster management agencies are moving from a response focused agenda to an adaptation/prevention focused agenda (refs), so the ability to define and map adaptive capacity will be important and relevant in this context. Adaptive capacity is herein described within the context of both short term (e.g. flooding from storms) as well as long term impacts (e.g. sea level rise). The idea being that although a storm is an isolated event, there are a number of actions a community can take over time to help prepare for and be more resilient to even short term events.

Nature: during Phase I we have focused on mapping the location of four habitats: mangroves, coral reefs, seagrass, and beaches, with a particular emphasis on mangroves. Phase II will likely see an increased focus on coral reefs, and some resources devoted to seagrass and beaches. These habitats are most heavily impacted by coastal hazards and present the greatest potential to provide protection from flooding and wave action (refs). Mangroves act as a buffer from storms and flooding, absorbing impacts from waves, and help guard against coastal erosion, in addition to providing critical fish habitat. Coral reefs also provide valuable ecosystem services by buffering the shoreline from waves thus decreasing potential for land based erosion and flooding. Seagrass beds help to trap sand in coastal bays, working with reefs to attenuate waves. Beach dunes act as barriers to storms and help anchor coastal ecosystems.

Our ability to map vulnerability of these four habitats has been limited due to the variability in data available in GSVG for each of these four habitats; we have reliable information on mangroves and have worked with a mangrove expert to augment that information (Dr. Gregg Moore, University of New Hampshire). Building on this work we have spatially described mangrove vulnerability for GSVG. Data on the other habitats is limited to extent and is not geographically comprehensive. Our Phase I activities have focused on validating the information that exists for these habitats, identifying gaps, and outlining additional habitat characteristics that will need to be collected during Phase II. We will continue to build information on mangroves, coral reefs, seagrass and beaches during Phase II and most likely at specific sites rather than at a national scale (see discussion below on scale of the project). A table illustrating the features that could be used to represent vulnerability of these four habitats and associated indices is included in Appendix B.

People: Our focus for human systems has been to spatially capture proxies that can represent the sensitivity of communities. We map three aspects of community structure:

1. livelihood (fishing and tourism);
2. critical infrastructure and facilities (transportation, utilities and emergency response); and
3. social systems (people and access).

And use all or a combination of these to represent socio-economic exposure, sensitivity and adaptive capacity. A table of these three aspects and the features we mapped to represent them is included in Appendix A. These choices are guided by a wide range of climate vulnerability literature (Cutter et al., 2003; Deressa et al., 2008; Granger, 2003; Marshall, et al., 2009; O'Brien, K., et al, 2004; Wongbusarakum and Loper, 2011) our experiences in other regions (e.g See Shepard et al., in review; Ferdana et al., 2010) and in-country feedback (see report from first in country workshop). Our initial focus for livelihood has been on fisheries and tourism and the impacts of coastal hazards have on the infrastructure supporting these industries; these were the two major sectors highlighted by partners at our first in country workshop. We plan to expand this category in future phases of this work.

We have worked with local partners to establish the context specific aspects of community sensitivity and adaptive capacity for the Grenadine Bank. As our analysis develops in Year two and we transition to site focused work (see section on scale and intended audiences below) we will likely adjust some of what we outline below based on feedback from colleagues and partners from specific sites and expand our definitions to include additional parameters.

Exposure: To calculate exposure we map characteristics of communities and natural systems and the extent of flooding under different sea level rise and storm surge scenarios (see hazard mapping section below for methods). Tables that describe variables used to represent exposure of human and natural systems are included in Appendix A and B.

Sensitivity: To compute and map sensitivity we have defined proxies that can be mapped and can be used to capture the characteristics that make a system more susceptible to harm given a scenario. Tables that describe variables used to represent sensitivity of human and natural systems are included in Appendix A and B.

Adaptive Capacity: One clear result from research on socio-economic vulnerability and adaptive capacity is that some dimensions of adaptive capacity are generic, while others are specific to particular climate change impacts (IPCC, 2007). Here we have focused on representing adaptive capacity within the context of hazards brought on by sea level rise and increased storm frequency. We will further explore and map adaptive capacity during Phase II. Phase I has focused on designing potential indicators to represent asset based aspects of adaptive capacity and identifying needs for new data collection to take place in Year Two.

For natural systems, what "adaptive capacity" means has yet to be clearly defined within this context (coastal hazards). During phase I we have worked with Dr. Gregg Moore (University of New Hampshire) to represent mangrove adaptive capacity (see Appendix B for parameters used). We have begun to design indices to represent adaptive capacity of coral reefs and beaches (Appendix B).

2.3 Mapping hazards

The hazards this project will focus on are flooding from both SLR and storm surge impacts. Hazards from wave and wind action (both related to storm surge) are relevant but were not addressed during Phase I, except indirectly as incorporated into our flooding predictions. The extent to which we will be able to address these during Phase II activities remains to be determined.

Inundation/flooding:

In order to assess potential inundation and flooding for both SLR and storm surge, digital elevation models (DEM) are often used to estimate the behavior of water flow across a modeled topographic surface. Many types of elevation data sets have been used in previous studies to quantify the potential inundation from SLR (Gesch, 2009) and storm surge. Outside of data rich geographies, it is often difficult to obtain elevation data that is precise enough to accurately model potential flood areas for both storm surge and SLR. Fortunately, we were able to obtain high-resolution LiDAR (airborne Light Detection And Ranging) data for the majority of Grenada and orthophoto-derived elevation for all of St. Vincent and the Grenadines. The elevation data we used to generate maps of areas inundated provides planners with an estimation of potential flood zones for both SLR and storm surge and can be used to predict impact on both ecological and socioeconomic features.

Sea Level Rise

For SLR flood estimations, we used a method described in Poulter and Halpin (2008) referred to as the "bathtub fill" method that simply fills low-lying elevation points, generating a map of areas inundated based on user-defined SLR increments. We mapped two SLR scenarios: 1 meter and 2 meters. Though near-term SLR estimates are around the order of .25 meters, the elevation data that we are expecting to acquire is not accurate enough to support low interval SLR mapping. Following the best available SLR mapping science (Gesch 2009), our elevation data is able to support whole meter interval mapping. Furthermore, these scenarios are consistent with several recent studies (Nicholls 2011) that anticipate 1 to 2 meters of SLR by the end of this century. We anticipate that these scenarios will effectively highlight the most susceptible places to SLR impacts throughout our study area, while still employing the best available spatial analysis and data standards.

Storm surge mapping

For storm surge, we used the model MIKE 21, a program that generates storm surge maps based on variables of topography, bathymetry, wind speed, storm size, and storm movement in two dimensions.

It was developed by DHI Water.Environment.Health (see attached supplemental material). In order to represent storm surge mapping, we contracted with Smith Warner International Ltd. who conducted a series of storm surge simulations with and without specified SLR scenarios. Seven storm surge scenarios were investigated, displayed by using the Maximum Envelope of Water (MEOW). Specifically, these included:

1. A simulation of Hurricane Ivan as a Category 5 hurricane∗
2. A Category 4 hurricane, specifically Hurricane Lenny
3. A Category 4 hurricane, Hurricane Lenny, with a 1 meter Sea Level Rise scenario included in the simulation.
4. A Category 4 hurricane, Hurricane Lenny, with a 2 meter Sea Level Rise scenario included in the simulation.
5. A 100-year storm event (1% annual chance of occurrence) ∗∗
6. A 100-year storm event (1% annual chance of occurrence) with a 1 meter Sea Level Rise scenario built in.
7. A 100-year storm event (1% annual chance of occurrence) with a 2 meter Sea Level Rise scenario built in.

∗ In actuality, when Hurricane Ivan went past Grenada, it was a Cat 3 storm and edged up to Cat 4. For this scenario however, Ivan will be run as a Cat 5 storm and the storm surge evaluated. This provides a "worst case scenario" illustration of the potential impacts of a major storm.

∗ ∗ The 100-year events were developed through a query of the National Hurricane Center database using Smith Warner International's in-house model HurWave to select all of the tropical storms and hurricanes that have passed within a user-specified radius of the Grenadine Bank.

3. An integrated view of vulnerability – getting closer to EBA solutions

3.1 Nature's services: how nature mediates socio-economic vulnerability

One of the main tenets of the At the Water's Edge (AWE) project is that nature can provide solutions that can attenuate the impacts of coastal hazards and help communities become more resilient. In light of this, an explicit role for nature within the socio-economic vulnerability framework is important. This will help point to the role that nature has in mediating vulnerability of socio-economic systems and highlight how nature can help reduce vulnerability. We view natural systems as playing a role in every component of our socio-economic vulnerability framework, with a range of ecosystem services acting to mediate the vulnerability of a place. The type of services (as defined in the Millenium Ecosystem Assessemnt, 2006) and their links to our specific vulnerability components (Exposure, Sensitivity, Adaptive Capacity) are outlined below* (also see figure 2).

Regulating services: The regulation obtained from ecosystem processes. In the context of coastal hazards from flooding this means protection and soil retention (shoreline stability). A coral reef or a mangrove for example can reduce *Exposure* by mitigating the impacts of flooding on a community.

Seagrass can reduce exposure by helping a beach be more stable and thus persist and provide a buffer between a community and the ocean (ref).

Provisioning services: The products obtained from ecosystems including food and freshwater. Coral reefs, seagrass and mangroves are important sources of food and livelihood. Healthy mangroves for example provide purified water (regulating service), and also provide nursery habitat for numerous species to grow and then serve as food for local communities. The *Adaptive capacity* of a community can be high if the natural systems they depend upon for food or water are able to continue providing those goods after the impact of a coastal hazard (be it short term or long term, i.e. a storm or sea level rise) and be the basis for a variety of livelihoods. By the same token the *Sensitivity* of a community to short term coastal hazards can be high if their sources of food and water are highly exposed and/or limited and their livelihood base eroded.

Cultural services (recreation, spiritual and historic): The non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience. The *Adaptive Capacity* of a community for example can be higher if they have access to sites that have spiritual, recreational and cultural value to that community as this will enrich their well-being (providing the fabric for good social relations, social cohesion, mutual respect and ability to help others) and overall health. In addition preserving access to multiple sites that are of importance to the tourism industry (e.g. beaches, dive sites etc.) will increase livelihood based adaptive capacity characteristics.

*All of the above services are supported by important processes (for example, soil and sand formation are key for coastal protection services) represented by “supporting services”.

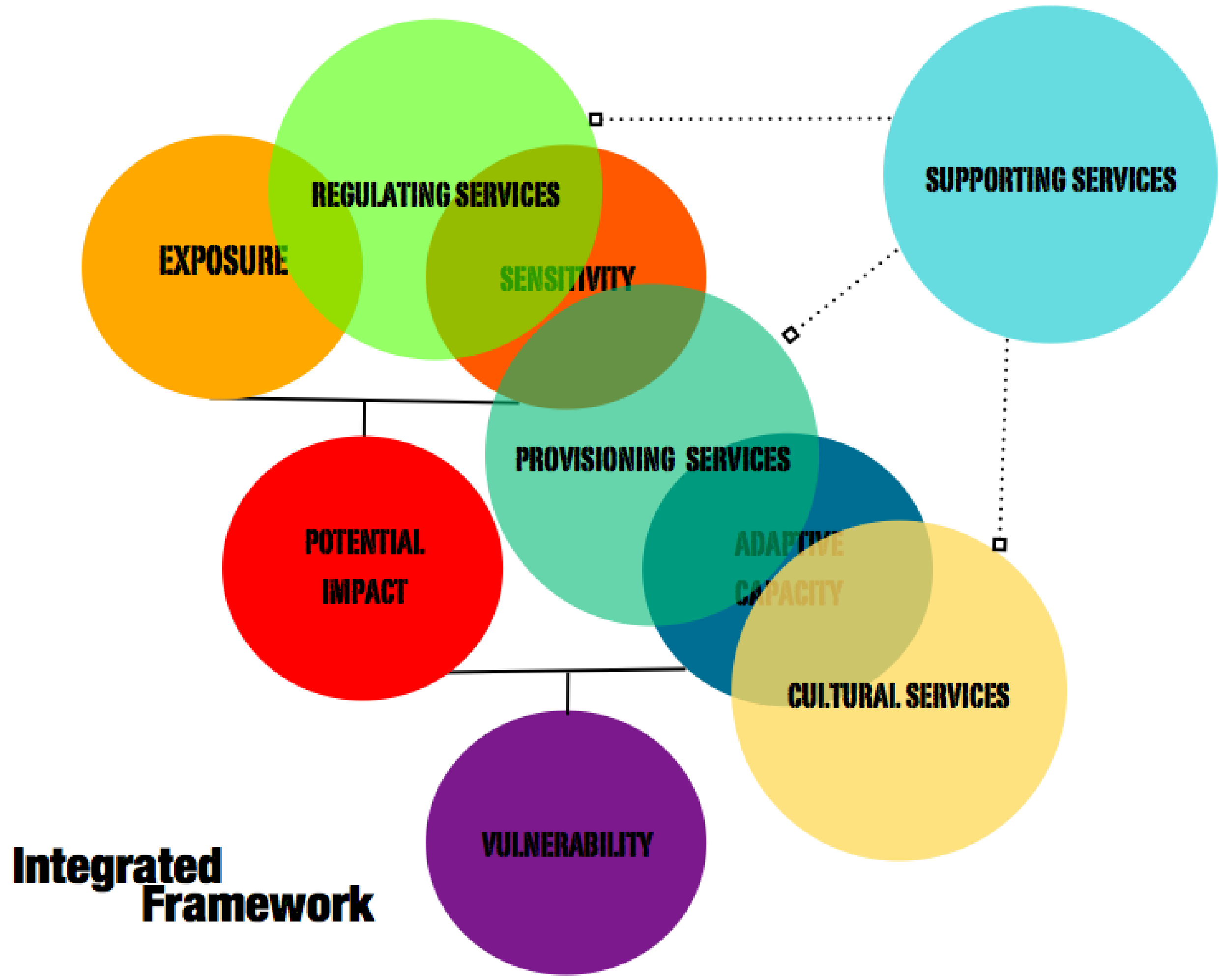


Figure 2. Integrated framework

As explained in section 2 the four relevant habitats for the project region are: mangroves, coral reefs, seagrass and beaches. The specific services each habitat provides in a coastal hazard context is outlined in tables 1a, b, c and d. Tables are based on Barbier et al., 2011. **Please note that these tables are a work in progress, so they should be viewed as an example of the process we are using to help connect the dots between services and habitats.**

3.2 Mapping integrated vulnerability

Mapping integrated vulnerability will: a) help us communicate the important role that nature can play in mediating vulnerability (and risk) in specific places; b) help us assess, for specific places, the need and potential for EBA strategies; c) help make decisions about allocation of resources and strategies towards specific EBA actions (which could include gray/green solutions). The integrated vulnerability of a place is a function of its socio-economic and ecological vulnerability and the potential of existing nature to provide specific services related to coastal hazards (figure 3). It does not attempt to capture gray/green infrastructure that may be in place.

In order to map integrated vulnerability we will need to integrate our current SE vulnerability indices (Appendix A) with indices representing the potential that existing nature holds to provide specific services related to coastal hazards (table 1). While our SE indices are well in development, the development of our "potential to provide services" indices is in a very early stage (tables below are a DRAFT). We fully realize that the science of demonstrating and quantifying specific benefits nature may provide within the context of coastal hazards is young, and we are thus operating within these limitations. Our hope is that this effort will help us harness that work and apply it to conservation action on the ground.


Table 1a: Coral reefs (based on Barbier et al., 2011)

Ecosystem service	Ecosystem process and Function	Role in mediating vulnerability
Coastal Protection	Wave dissipation and formation	Reduces *exposure* to wave force
	Sediment formation and retention	Supports other habitats (e.g. seagrass) which in turn reduce exposure
Maintenance of Fisheries	Provision of suitable reproductive habitat and nursery grounds	Leads to multiple sources of food and livelihood which reduce both sensitivity and adaptive capacity
	Provision of sheltered living space	Leads to multiple sources of food and livelihood which reduce sensitivity and increase adaptive capacity
Tourism, ed., maintenance & res.	Provision of unique and aesthetic reefscapes	Leads to multiple sources of livelihood and overall feeling of well-being (e.g. spiritual connectedness) increasing adaptive capacity
	Provision of suitable habitat for diverse fauna and flora	Leads to multiple sources of livelihood and overall feeling of well-being (e.g. spiritual connectedness) increasing adaptive capacity

 Table 1b: Mangroves (based on Barbier et al., 2011)

Ecosystem service	**Ecosystem process and Function**	**Role in mediating vulnerability**
Coastal protection	Attenuation and/or dissipation of wave and wind energy	Reduce exposure to wind and wave force
Erosion Control	Sediment stabilization and soil retention in root structure	Reduce exposure by providing soil control (stabilization and retention)
Maintenance of Fisheries	Provision of suitable reproductive habitat and nursery grounds	Leads to multiple sources of food and livelihood which reduce sensitivity and increase adaptive capacity
	Provision of sheltered living space	Leads to multiple sources of food and livelihood which reduce sensitivity and increase adaptive capacity
Tourism, ed., maintenance & res.	Provision of unique and aesthetic reefscapes	Leads to multiple sources of livelihood and overall feeling of well-being (e.g. spiritual connectedness) increasing adaptive capacity
	Provision of suitable habitat for diverse fauna and flora	Leads to multiple sources of livelihood and overall feeling of well-being (e.g. spiritual connectedness) increasing adaptive capacity

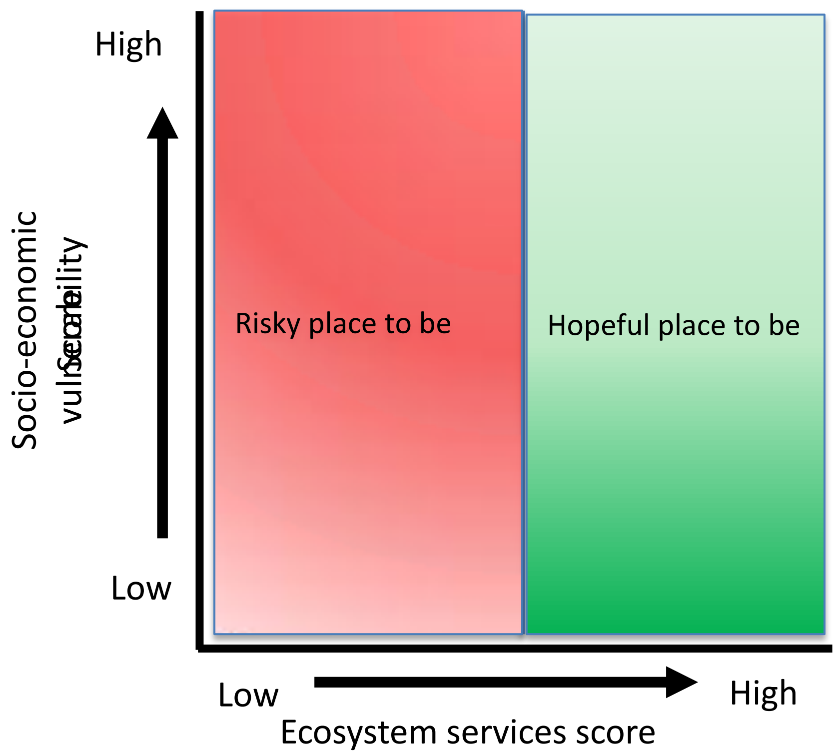
 Table 1c: Seagrass (based on Barbier et al., 2011)

Ecosystem service	**Ecosystem process and Function**	**Role in mediating vulnerability**
Coastal protection	Attenuation and/or dissipation of wave and wind energy	Reduce exposure to wind and wave force
Erosion Control	Sediment stabilization and soil retention in root structure	By providing soil control (stabilization and retention), mangroves reduce exposure
Maintenance of Fisheries	Provision of suitable reproductive habitat and nursery grounds	Leads to multiple sources of food and livelihood which reduce sensitivity and increase adaptive capacity
	Provision of sheltered living space	Leads to multiple sources of food and livelihood which reduce sensitivity and increase adaptive capacity
Tourism, ed., maintenance & res.	Provision of unique and aesthetic reefscapes	Leads to multiple sources of livelihood and overall feeling of well-being (e.g. spiritual connectedness) increasing adaptive capacity
	Provision of suitable habitat for diverse fauna and flora	Leads to multiple sources of livelihood and overall feeling of well-being (e.g. spiritual connectedness) increasing adaptive capacity

Table 1d: Beaches and Dunes (based on Barbier et al., 2011)

Ecosystem service	**Ecosystem process and Function**	**Role in mediating vulnerability**
Coastal protection	Attenuation and/or dissipation waves and reduction in flooding and spray from sea	Reduce exposure to wave force
Erosion Control	Sediment stabilization and soil retention in root structure of beach vegetation	Beaches are the last buffer zone between the ocean and communities; a healthy beach reduces exposure
Tourism, ed., maintenance & res.	Provision of unique and aesthetic reefscapes	Leads to multiple sources of livelihood and overall feeling of well-being (e.g. spiritual connectedness) increasing adaptive capacity
	Provision of suitable habitat for diverse fauna and flora	Leads to multiple sources of livelihood and overall feeling of well-being (e.g. spiritual connectedness) increasing adaptive capacity

Figure 3: Integrated vulnerability



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APPENDIX A

Socio-economic indices

Exposure Index Description and Rational of Variables

Variable	Measure of variable per enumeration district	Reason	Influence on Sensitivity
Length of Road	Total length of road per ED inundated by *x* scenario.	Adaptation plans may look to target areas that have the greatest total area at risk to inundation.	More length = more exposed
Percent of total Length of Road	Percent of total length of road per ED inundated by *x* scenario.	ED with fewer roads offer populations limited options for evacuation in emergencies. EDs with higher percentages of inundation of total road area are more exposed than EDs with greater road options.	Higher % = more exposed
Building Area Inundated	Total area of building footprints per ED inundated by *x* scenario.	Adaptation plans may look to target areas have the greatest total area at risk to inundation. Area of footprints are an indicator of the total amount of building area at risk to inundation during a given scenario.	More area = more exposed
Percent of Total Area Inundated	Percent of total area of building footprint per ED inundated by *x* scenario.	Areas with higher percentages of total building foot prints inundated have a higher relative exposure.	Higher % = more exposed
Number of Buildings Inundated	Total number of buildings per ED inundated by *x* scenario.	Adaptation plans may look to target areas have the greatest total number of buildings at risk to inundation. Building points are an indicator of the total amount of building area at risk to inundation during a given scenario.	Higher # = more exposed
Percent of Total Number of Buildings Inundated	Percent of total number of buildings per ED inundated by *x* scenario.	Areas with higher percentages of total building points inundated have a higher relative exposure.	Higher % = more exposed
Number of fishing facilities inundated	Total number of fishing facilities per ED inundated by *x* scenario.	The more critical livelihood facilities that are lost to x scenarios is and indcator of how exposed the industry is.	Higher # = more exposed
Number of tourism facilities inundated	Total number of tourism facilities per ED inundated by *x* scenario.	The more critical livelihood facilities that are lost to x scenarios is and indcator of how exposed the industry is.	Higher % = more exposed
TOTAL Exposure Index	Sum of all scaled variables, scaled	Exposure is a function of the total amount of features inundated given *x* scenario	Higher score = more exposed

updated: December 2012

Livelihood Sensitivity Index Description and Rational of Variables

Variable	Measure of variable per enumeration district	Reason	Affect on Sensitivity
ED income from non natural resource related industries	Percentage of total workforce in ED who reported non-natural resource related industries as their primary industry of work	The higher the percent of total income derived from non natural resources vulnerable to climate change the less sensitive	Higher percentage = less sensitive
ED income generated by fisheries	Percentage of total workforce in ED who reported fisheries as their primary industry of work	The higher the percent of total income derived from natural resources vulnerable to climate change the more sensitive	Higher percentage = more sensitive
ED income generated by tourism	Percent of total workforce in ED who reported hotels and restaurants as their primary industry of work	The higher the percent of total income derived from natural resources vulnerable to climate change the more sensitive	Higher percentage = more sensitive
Critical fisheries facilities	Total number of critical fisheries facilities (landing sites, fish markets, ship-building, emergency gear storage, general gear storage) in ED.	Multiple fisheries facilities reduces an ED sensitivity (although it increases exposure)	Higher number = less sensitive
Critical tourism facilities	Total number of critical tourism facilities (hotels, marina, dive-shops) in ED.	Multiple tourism facilities reduces an ED sensitivity (although it increases exposure)	Higher number = less sensitive
Types of fishing facilities	Number of types of fishing facilities in ED.	The fewer types of fishing facilities the more sensitive to storm events	Fewer types = more sensitive
Types of tourism facilities	Number of types of tourism facilities in ED.	The fewer types of fishing facilities the more sensitive to storm events	Fewer types = more sensitive
TOTAL Livelihood Sensitivity Index	Sum of all scaled variables, scaled.	Livelihoods are an important aspect of community structure. Natural resource based livelihoods can experience greater detrimental effects from climate change than non-natural resource based industries.	
Note: Adapted from Wongbusarakum and Loper 2011			

Social Sensitivity Index Description and Rational of Variables

Variable	Measure of variable per enumeration district	Reason	Affect on Sensitivity
Population	Total number of people in ED.	More people likely require extra considerations related to disaster preparations and evacuations.	More people = more sensitive
Population Density	Population density per square mile in ED.	Higher density of people may need special planning for evacuations and transportation.	Higher density = more sensitive
Housing Units	Total number of housing units in ED.	More housing units provide greater exposure opportunity and increases a communities total sensitivity.	More units = more sensitive
Housing Unit Density	Density of housing units per square mile from in ED.	Many housing units within a small area likely require additional evacuation support and shelter assistance.	Higher density = more sensitive
Age Under 5	Percentage of population under 5 in ED.	Children under 5 are dependent upon others in emergency situations and may require special assistance	Higher % = more sensitive
Age Over 65	Percentage of population over 65 in ED.	Adults over 65 may be dependent upon others in emergency situations and may also require mobility assistance	Higher % = more sensitive
Households without Internet	Percentage of housing units without Internet in ED.	Internet access can provide valuable pre and during emergency information. Households without access to this information may not receive the most up-to-date information pertaining to evacuation routes, storm trajectory, and emergency shelter locations.	Higher % = more sensitive
Households without Radio	Percentage of housing units without radio in ED.	Radio communication is one of the most common avenues for disseminating storm and emergency related information. Without access to this information households may be less prepared for emergencies.	Higher % = more sensitive
Households without Vehicle	Percentage of housing units without vehicle in ED.	Occupied housing units without access to vehicles may indicate mobility limitations during an evacuation.	Higher % = more sensitive
TOTAL Social Sensitivity Index	Sum of all scaled variables, scaled.	A suite of variables contribute to a communities overall sensitivity. An aggregate view of some of these variables can give a sense of a communities overall sensitivity.	Higher score = more sensitive
Note: Adapted from Shepard et. al, 2011			

Critical Infrastructure Facilities Sensitivity Index Description and Rational of Variables

Variable	Measure of variable per enumeration district	Reason	Influence on Sensitivity
Transportation Terminals	Total number of transportation terminals (airports, bus, ferry, and port terminals) in ED.	Greater access to transportation terminals decreases a populations' sensitivity because they are vital both for transit within the community and as important connection points to the surrounding communities.	Fewer terminals = more sensitive
Critical Facilities	Total number of critical facilities (water treatment, cell tower, electricity plants, sewage stations facilities) in ED.	Greater access to critical facilities decreases a populations' sensitivity because they provide crucial services to communities and are important resources.	Fewer facilities = more sensitive
Emergency Response Facilities	Total number of emergency response facilities (fire, police, medical, hurricane shelters) in ED.	Greater access to emergency response facilities and services decreases a populations' sensitivity because they provide crucial services to communities and are important resources before, during, and after natural disasters.	Fewer facilities = more sensitive
Community Facilities	Total number of community facilities (schools and religious centers) in ED.	Greater access to community facilities decreases a populations' sensitivity because they provide social and logistical support to communities and are useful for information dissemination and supply distribution.	Fewer facilities = more sensitive
Road Density	Road density in ED (road length per square mile).	Higher road density decreases a populations' sensitivity because it indicates the number of route options during an evacuation and low road density likely means fewer evacuation routes.	Lower density = more sensitive
TOTAL Critical Infrastructure and Facilities Index	Sum of all scaled variables, scaled	Extensive infrastructure decreases an enumeration districts' sensitivity as communities with access to critical facilities and infrastructure are more likely to be prepared for events and more likely to receive services provided by the infrastructure.	Higher score = more sensitive
Note: Adapted from Shepard et. al, 2011			

Adaptive Capacity Index Description and Rational of Variables

Variable	Measure of variable per enumeration district	Reason	Affect on Sensitivity
Highest Level of Education Attained (Human & Civic Resources)	Percentage population in ED with high school degree or equivalent.	Education is a measure of human capitol. The greater human capitol that a community possesses the more able it is to adapt to changing circumstances. Education level also indicates levels of competence. Lower education constrains the ability to understand warning information and access to recovery information.	Higher % = more adaptive
Access to Social Networks (Human & Civic Resources)	Percentage of population in ED with some religious affiliation.	Social networks, such as religious communities, promote social relationships, close social bonds that facilitate cooperative action, and linkages via which ideas and resources are accessed. Access to these types of capital increases a communities overall adaptive capacity.	Higher % = more adaptive
Available workforce (Human & Civic Resources)	Percentage of population in ED in the workforce (i.e. age 15 or older)	Population in the workforce is an indicator of human resources available for adaptation after meeting other pressing needs.	Higher % = more adaptive
Diversity of Industries (Economic)	Standard deviation of distributed workforce across industries within an ED.	Reduced livelihood options can constrain a populations' potential for rapid economic recovery after a disaster. It is also an indicator of the ability of the labor force to adapt to new industries in response to fluctuations in market needs. Communities with a workforce that is more evenly distributed across industries will be more adaptable as industry patterns shift.	Lower STDV = more adaptive
Households with Insurance (Economic)	Percentage of households with dwelling insurance	Access of population to resources to help recover after a disaster.	Higher % = more adaptive
Health Insurance (Health)	Percentage of population with health insurance.	Access of population to basic services to buffer against health issues related climate change or disasters.	Higher % = more adaptive
Education enrolment (Health)	Percentage of population enrolled part or full time.	The Human Development Index (HDI), uses education enrolment as an indicator for assessing the human condition at the country level. More recently, the American Human Development Index (AHDI) measures the well-being among states in the US. (from cutter 2009)	Higher % = more adaptive
TOTAL Community Adaptive Capacity Index	Sum of all scaled variables, scaled.	Human and civic resources are a critical component of the coping and adaptive capacity of communities. This category includes literacy, level of education, access to retraining programs, and other factors that determine how flexible individuals may be in adapting to new employment opportunities or shifts in living patterns brought about by climate variability or change.	Higher score = more adaptive

Note: Adapted from Moss et al 2001 and Shepard et. al, 2011

APPENDIX B

Mangrove indices:

Exposure Index Description and Rational of Variables

Variable	Measure of variable per enumeration district	Reason	Influence on Exposure
Sea Level Rise	% of mangrove equal to or less than SLR scenario	Mangroves need to vertically keep pace with SLR to survive	lower= less exposed

Adaptive Capacity Index Description and Rational of Variables

Variable	Measure of variable per enumeration district	Reason	Influence on Adaptive Capacity
Elevations and land-use above mangroves (room to migrate)	Migration index; amount of non-developed, low-slope and low-elevation adjacent land available for migration relative to existing mangrove size	Impervious surfaces and structures limit potential for natural reforestation, migration, infiltration of storm water runoff. The degree of landscape alteration affects ability for natural establishment or migration of mangroves	higher= more adaptive

Sensitivity Index Description and Rational of Variables

Variable	Measure of variable per enumeration district	Reason	Influence on Sensitivity
Topography within and adjacent to mangroves	Elevation of Mangrove	Relative topography (steepness) influences sensitivity to flood/storm impacts, and landward migration. Slope and elevation infers topographic opportunity for, or barrier to, landward migration as well as likelihood of direct coastal hazard impacts	higher= less sensitive

Forest Structure (% cover, density)	Mangrove patch index: size and shape	Forest size, dimensions, percent cover and density have the potential to influence sensitivity by buffering wind, wave and surge impacts if sufficiently large, dense, etc. Larger, wider stands of mangrove with dense stem density are more likely to have lower sensitivity b/c they are less prone to damage and have more reproductive capacity	Larger size and more regular shape= less sensitive
Species Diversity and Richness	Species richness	Low diversity implies greater sensitivity to coastal hazards, but may be dependent on which species and the intensity of the hazards themselves. Differing tolerances of species to flood, salinity, anoxia and coastal energy	Higher richness=less sensitive
Mangrove watershed land use and development	Percent of mangrove contributing watershed developed or agricultural land use combined with size of watershed basin (as a proxy for the amount of drainage to the mangrove)	Ratio of previous: impervious infers range of sensitivity to flooding, natural buffers and associated factors. More altered the landscape results in more potential erosion, storm flow, and damage not buffered by natural coastal vegetation. Watersheds can contribute significant volumes of water, sediments, and pollutants to mangroves, thus increase intensity and duration of exposure to coastal hazards. Larger watersheds, particularly when highly populated, are expected to increase sensitivity of mangrove to impacts of coastal hazards	Higher= more sensitive
Coastal Openness: Exposure and Fetch	position on coast (open vs. protected)	Influences wind, wave and storm force energy of coastal habitats. Various degrees of exposure and fetch combine to influence sensitivity to coastal hazards	More protected= less sensitive

nutrient Excess (Eutrophication)	Watershed index (see above)	Excess nutrients can increase sensitivity to coastal hazards by promoting algal blooms, decreasing water quality, and impacting associated organisms, all of which impact mangrove health	Higher= more sensitive
Legacy Pollutants and Chemicals	Watershed index (see above)	Pollutants can have a cryptic cytological and genetic impact affecting plant health, reproductive ability and success, or other factors that may amplify sensitivity to impacts associated with coastal hazards	Higher= more sensitive

<u>Indices by habitat</u> **(this is a DRAFT, not comprehensive, a work in progress but indicative of the approach)**

Indicator	Habitat	Characteristic
Exposure	Mangroves and beaches	Amount of habitat flooded
	Coral reefs and seagrass	TBD
Sensitivity	Mangroves	Extent
		Species
		Thickness of stand
		Slope
		Proximity of other relevant habitat
		Adjacent land use type
		Exposure to waves
	Coral Reefs	Extent
		Slope
		Direction of prevailing swell
		Topography
		Reef topography
		Reef type
	Beaches	Shape and size
		Condition
		Height
		Direction of prevailing swell
		Average height of prevailing swell
	Seagrass	TBD
		TBD
Adaptive Capacity	Mangroves	Age
		Species
		Slope
		Ability to vertically accrete
		Ability to migrate landward
		Ability to re-seed
		Shape and size
	Coral Reefs	Reef type
		Condition
		Reef topography
		TBD
	Beaches	Ability to vertically accrete
		Connectivity
		Ability to migrate landward
	Seagrass	TBD
		TBD