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VULNERABILITY ANALYSIS TO CLIMATE CHANGE IN THE CARIBBEAN

BELIZE, GUATEMALA AND HONDURAS

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Reviewed by:

Juan Carlos Villagrán & Zulma de Mendoza (Regional Staff members).

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Prepared by:

Climate Change and Watersheds Program, Tropical Agricultural Research and Higher Education Center.

- Lenin Corrales
- Pablo Imbach
- Claudia Bouroncle
- Juan Carlos Zamora
- Daniel Ballestero

Mesoamerican Reef Program, The Nature Conservancy

- Fernando Secaira
- Hernando Cabral
- Ignacio March
- James Rieger

FOREWORD: THE USAID REGIONAL PROGRAM FOR AQUATIC RESOURCES MANAGEMENT AND ECONOMIC ALTERNATIVES AND ADAPTATION TO CLIMATE CHANGE

The objective of the USAID Region Program for Water Resources Management and Economic Alternatives is to reinforce the management of resources on the Central American coast, reduce threats relating to unsustainable fishing and coastal development practices, support biodiversity conservation and improve lifestyles of towns in the region. Climate change will have a serious effect on coral reefs, sea beds, beaches and coastal wetlands, all ecosystems that sustain fisheries and tourism, the main means of living for the population; and it will likewise severely affect the infrastructure of the countries' communities, cities and the businesses. The implementation of methods for adapting to climate change is therefore a key element of the Regional Program, in order to maintain functionality of the ecosystems that sustain fishing and tourism and to improve the communities' adaptive capacity.

The Program has 4 trans-boundary focus sites: the Gulf of Honduras, the Gulf of Fonseca, the Mosquitia of Honduras and Nicaragua and the area between Punta Cahuita in Costa Rica and Bocas del Toro in Panama. In 2011 the Regional Program developed the bases for implementing adaptation methods in the Gulf of Honduras, as follows:

1. As a first step the development of a Climate Change Vulnerability Analysis and a Climate Change Adaptation Plan was coordinated, to be prepared by the different agencies of the Governments of Belize, Nicaragua and Honduras responsible for managing fishing and protected areas and for establishing and managing government agendas on climate change. The purpose for this coordinated effort was to include the government entities in this process, and to assure the subsequent implementation of the adaptation methods recommended. The different agencies involved were the Belizean Department of Fisheries, the Coastal Zone Management Authority and the Ministry of the Environment Office of Climate Change; the Guatemalan UNIPESCA, CONAP and Ministry of the Environment and Natural Resources offices for climate change and coastal management; and the Honduran DIGEPESCA, Forestry Conservation Institute Protected Areas Office and Department of the Environment and Natural Resources office for Climate Change. Personnel of these institutions were present at the national consultations described here.
2. A Vulnerability to Climate Change analysis was prepared for the Belizean, Guatemalan and Honduran Caribbean (USAID, 2012b), determining potential impacts to the area and estimating the adaptive capacity of the coastal communities in order to identify the most relevant areas and the most vulnerable municipalities.
3. National discussions were held with key stakeholders with the results of the vulnerability analysis and jointly identifying the adaptation strategies required. These conferences were held from August 22 to the 28, 2011 in the cities of Belize, La Ceiba and Guatemala (USAID, 2012c).

4. A series of Proposed Climate Change Adaptation Strategies were developed for the Belizean, Guatemalan and Honduran Caribbean region, with strategic recommendations and specific actions given for each country.

Contemplated for the next phase:

1. Conversion of the proposed Climate Change Adaptation Strategies into two national plans for adaptation of the marine coast, one for Honduras and the other for Guatemala, and incorporation of the recommendations in the National Plan to be developed by Belize.
2. Development of climate change adaptation methods to be used in the management of protected areas in the Gulf of Honduras and Bay Islands.
3. Support for the adaptation methods selected during the implementation of the Regional Program from 2012 to 2015.

Table of Contents

ACRONYMS

CATIE	Centro Agronómico Tropical de Investigación y Enseñanza
CC	Climate Change
CMIP3	Coupled Model Intercomparison Project phase 3
CONAP	Consejo Nacional de Areas Protegidas (Guatemala)
CRISP	Coral Reef Initiative for the South Pacific
CRW	Coral Reef Watch (NOAA)
DHW	Degree Heat Week
DIGEPESCA	Dirección General de Pesca (Honduras)
GEI	Green House Gases
ICF	Instituto de Conservación Forestal de Honduras (Honduras)
IPCC	Intergovernmental Panel of Experts on Climate Change
MARN	Ministerio de Ambiente y Recursos Naturales (Guatemala)
masl	Meters above sea level
NOAA	National Oceanographic Atmospheric Administration (USA)
SERNA	Secretaría de Recursos Naturales
SSH	Sea surface height
SST	Sea surface temperature
TNC	The Nature Conservancy
UNIPESCA	Unidad de Pesca (Guatemala)
USAID	United States Agency for International Development
WCRP	World climate Research Program

1 Introduction

The Caribbean communities of Belize, Guatemala and Honduras depend strongly on fishing and tourism for their livelihoods. These activities in turn are based on the use of goods and services from different types of coastal and marine habitats including reefs, sea grasses, lagoons and mangroves, among others. In addition housing, urban, transportation and recreational infrastructure has also been built along the coast and on the coastal plains, making them vulnerable to storms, hurricanes and floods. However, coral reefs, mangroves and coastal lagoons reduce their effects, providing a key service to reduce vulnerability.

Coastal and marine habitats are seriously disturbed by human activities through overfishing, contamination, sedimentation and tourism activities; and weather variability and climate change will substantially worsen these conditions. Given the strong dependence of coastal communities and national economies on these ecosystems, adaptation actions must be implemented to:

1. Improve the resilience of coastal ecosystems to climate change and extreme weather events, so that they can continue to provide the goods and services that assist the long-term sustenance of the communities and biodiversity.
2. Build the capacity of human coastal communities to adapt to the changes and extreme events that will inevitably occur.
3. Finally, improve adaptive capacity and reduce the sensitivity of coastal infrastructure – ports, fuel discharge areas, roads and airports – all of key importance to the three national economies.

1.1 Manifestations of climate change and their effect on the marine coast environment.

The ocean performs key functions that are critical for the climate through its close link with the atmosphere by storing heat, carrying it to all different regions of the planet, evaporating masses of water, freezing and thawing polar regions, and storing and exchanging gases such as carbon dioxide (CO_2) (Herr and Galland 2009). Increased concentrations of greenhouse gases without precedent in human history (IPCC 2007), is creating negative changes to the oceans, threatening the services be provided by oceans to ecosystems and human populations (Herr and Galland 2009). **Figure 1** shows the physical and chemical changes that the increase in greenhouse gases produce in the coastal and ocean environment.

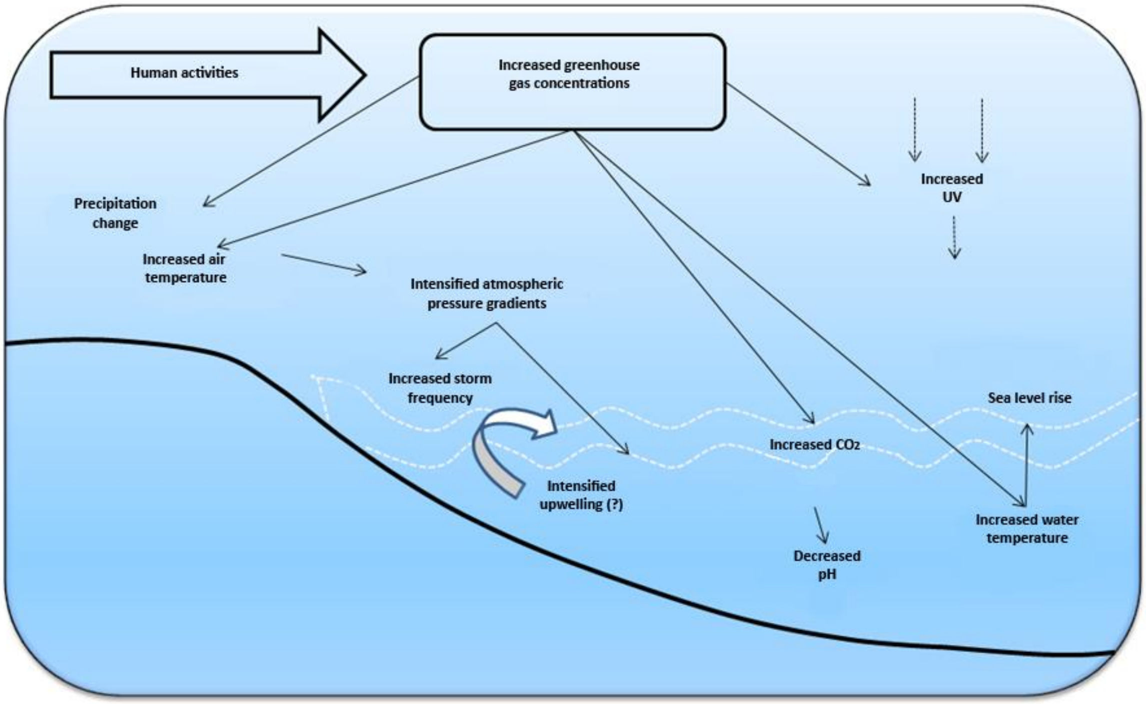

Figure 1. Important abiotic changes associated with climate change (modified Harley 2006)

These changes are interrelated and create synergies that increase the strength of their effects and subsequent impacts on ecosystems and people. For example, higher air temperatures and direct sunlight increase sea surface and sea column temperature which in turn change rainfall patterns, increase hurricanes´ strength, expand water volumes and raise sea level. These effects finally increase the strength of the marine currents, tides, waves, rainfall and winds that affect the coast, producing coastal erosion, flooding, salt water intrusion, the destruction of vegetation and human infrastructure as well as important changes to the ecosystems (USAID et al. 2009). **Table 1** shows the effects of climate change and their potential impacts on marine systems and habitats.

Table 1. Possible effects of climate change on the marine coast environment (prepared by the authors based on CRRH 1996; Harley 2006; IPCC 2007; Kokot 2004; Nicholls et al, 2007; Orr et al. 2009; UICN 2003; USAID et al. 2009)

Effects of climate change	Impacts
Increased CO_2 in the atmos-phere	Ocean acidification
Ocean acidification	Decrease in the growth of coral and invertebrates that require calcium carbonate to develop.
Increase in the air temperature	Ocean warming: temperature of the surface water and water column. Changes in wind currents. Changes in rainfall patterns, Local weather anomalies.
Ocean warming	Thermal expansion of the sea, raising the sea level. Increased thermal stratification.

Effects of climate change	Impacts
	Changes in marine currents. Reduction and changes in upwelling. Thermal stress on ecosystems and species.
Rise in sea level	Permanent flooding of coastal zones and loss of coastal ecosystems and infrastructure. Changes in estuarine salinization levels and tidal residence times. Changes in flooding levels and patters. Coastal erosion and loss of beaches. Saltwater intrusion in the coastal aquifers.
Rainfall changes	Increase in torrential rainfalls, causing flooding and changes in estuarine saline levels. Longer dry periods that change estuarine saline levels.
Changes in ocean currents	Changes in larval dispersion patterns. Increased beach erosion. Changes in rainfall and wind patterns. Changes in marine surgence.
Increase in storms´ intensity	Destructive winds and flooding of the ecosystems and infrastructure. Coastal flooding and erosion. Flooding in coastal zones, plains and riverbeds, and impact on vulnerable mountain areas.

Ocean acidification is an ongoing phenomenon. Records for the Northern Pacific dating back to 1990 (UNESCO 2009) show a correlation with the increase in atmospheric carbon dioxide (Figure 2).

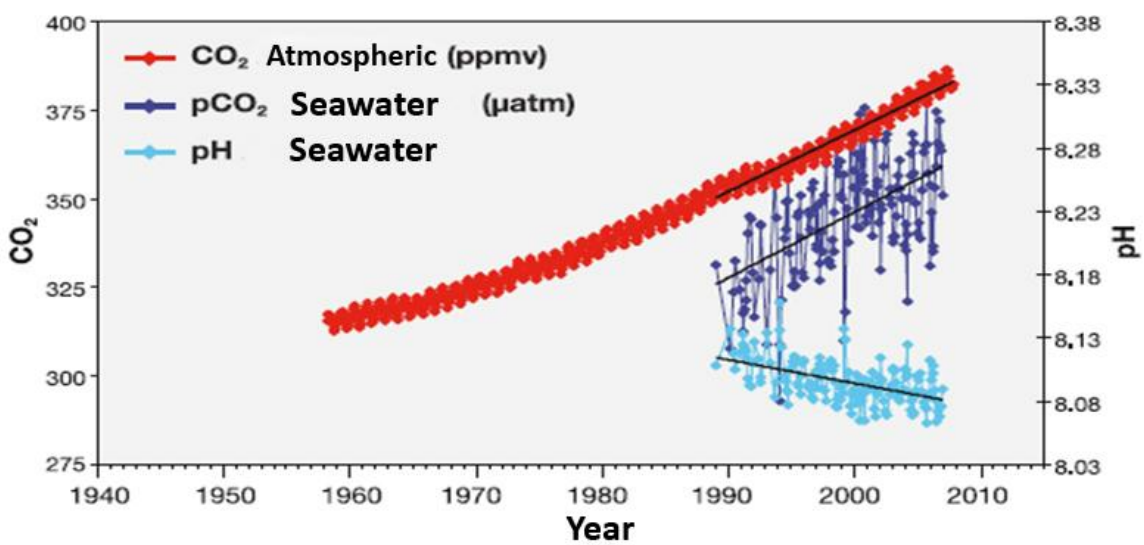

Figure 2. Ocean acidification and its correlation to atmospheric CO_2 in the Pacific (UNESCO 2009)

1.2 Defining the vulnerability of natural systems and human communities to climate change

Current and future effects of climate change are constantly more complex, creating more pressure on ecosystems and affecting the lifestyles of the people who depend on natural resources under constantly changing conditions. For this reason coastal communities need to anticipate and prepare for change, and institutions must promote and facilitate planning and preparation for the future (Marshall *et al*. 2009). The time for this preparation is now; consequently the vulnerability assessment considered the currently adaptive capacity to face today´s and future impacts of climate change effects.

Climate change is a global process over which local communities have little influence. However communities can face climate change through the adoption of key measures designed to reduce their vulnerability, decrease the impacts and allow more time for a better adaptation (Marshall *et al*. 2009).

Marshall *et al*. (2009) declared that vulnerability assessments should cover both the individual as well as community scale, as interactions between the different scales are important. In this sense the community is formed of individuals; however individual responses are frequently determined by community standards, making it impossible to understand vulnerability on individual alone.

People will also have to face direct impacts of climate change such as changes in drinking water availability, coastal erosion, salt water infiltrations, flooding of residential and agricultural lands and underground water sources (CRISP 2011).

People will also have to face impacts of climate change in the ecosystems. Fishing and recreational activities will be impacted (Marshall *et al*. 2009) by degradation of fish habitats as coral reefs and mangroves, loss of beaches and snorkeling and diving areas. The coastal protection provided by barrier reefs and mangroves will be undermined. The effects of climate change will have significant effects on the social and cultural life of many societies (CRISP 2011).

The concept of vulnerability was defined by the Intergovernmental Panel on Climate Change[1] (IPCC 2001) Group of Experts as: "*The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes.*"

Vulnerability is formed of three components: exposure, sensitivity and adaptive capacity.

1. Exposure refers to the presence of an effect of climate change that can have negative repercussions. It is measured by the extent of the anomaly in climate or biophysical aspect; for example, how many degrees the average temperature will change or how many centimeters of sea level rise, and the area that will be affected.

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[1] UNEP (United Nations Environmental Program) and the WMO (World Meteorological Organization) formed in 1988 the Intergovernmental Panel on Climate Change and the United Nations Framework Convention on Climate Change (UNFCCC).

2. Sensitivity refers to the presence of an object that is susceptible or sensitive to climate risks. For example, if agriculture exists today or in the future in areas that will be subject to increase temperature and/or flooding as a result of sea level rise.
3. Adaptive capacity refers to the capacity of a system to change to better confront adverse impacts or recover from them. It assesses human communities and individuals, companies and national economies capacities. For example, it assesses farmers have the capacity to change crops, increase irrigation (to cope with increase temperature) or move to another area (if flooding is the threat).

In a social context, the terms exposure, sensitivity and adaptive capacity are defined as follows:

1. **Exposure** is defined as the degree to which a community is in contact with weather phenomena or specific climate impacts. This specifically includes residential areas and resources that are exposed to different impacts and weather phenomena. For example, houses located close to the high tide line have higher exposure to sea level rise. Coastal plantations have higher exposure to infiltrations of salt water and flooding. Shallow reefs that are fully exposed to sunlight in areas with little wind have higher exposure to rise in surface water temperatures (CRISP 2011).
2. **Sensitivity** is the degree to which a community is negatively affected by climate changes. For example, families or communities may be highly sensitive if commercial coastal or subsistence plantations are "exposed" to changes in temperature, rainfall and floods derived from climate change. If exposed reefs form the principal fishing area that is the source of food and income for a community, then that community is highly sensitive to coral bleaching resulting from raise of ocean temperature (CRISP, 2011; Marshall *et al*., 2009).
3. **Adaptive capacity** is the potential of a community to adapt, to ameliorate or to recuperate from the impacts of climate change; it is determined by knowledge and organizational, productive, social and institutional resources. For example a well-informed community with good organizations, cultural traditions and community participation may be capable of developing good plans and making decisions that help all members of the community. A household with sufficient income from diversified sources is better able to adapt to climate change, in comparison with those that depend on one activity and/or are below poverty level. Adaptive capacity is the component of vulnerability that is most susceptible to the influence of social systems, and consequently is an evident focus for adaptation (CRISP 2011; Marshall et al. 2009).

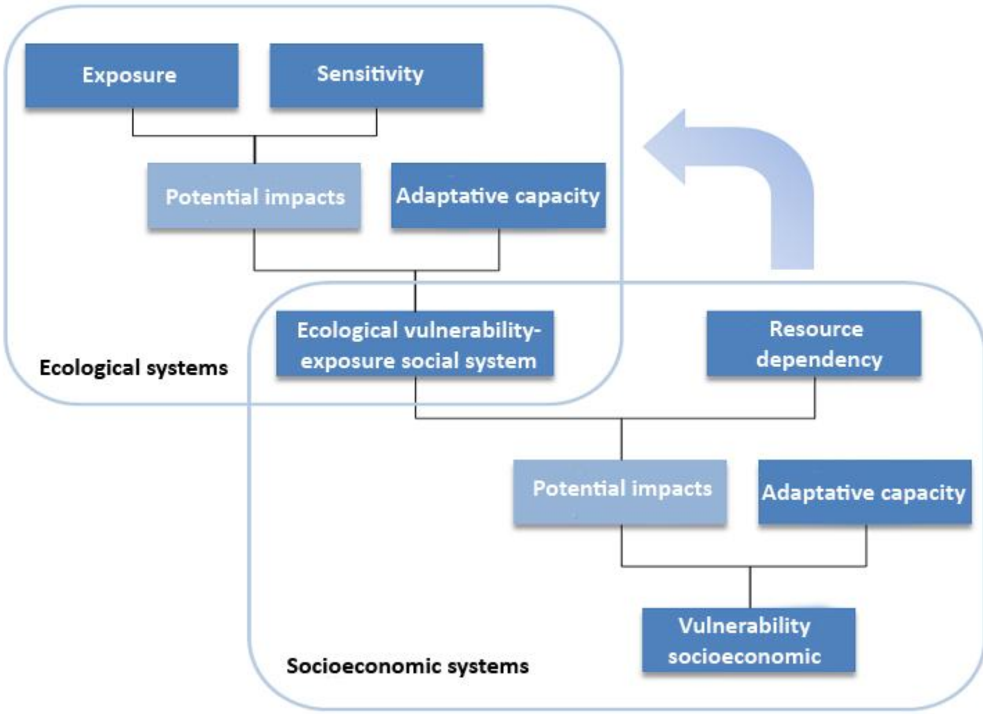


Figure 3. Co-dependence between ecological and social systems. The different elements cannot be evaluated without referring to the others (Hobday et al. In revision: taken from Marshall et al. 2009)

2 Objectives

2.1 General Objective

To determine the level of climate change vulnerability of natural and social systems in the coastal zone of the Belizean, Guatemalan and Honduran Caribbean; and to identify areas where is a priority to implement adaptation actions.

2.2 Specific Objectives

1. To present the scientific bases for trends of climate change, so that they are available to decision makers as the basis of their adaptation policies and practices.
2. To identify the impacts of climate change that are predicted for marine-coastal habitats that are the basis of coastal communities´ livelihoods and that reduce the risk of extreme weather events.
3. To identify the projected impacts of climate change on the livelihoods of coastal communities that depend n the natural systems.
4. To identify the areas where coastal ecosystem restoration or conservation is priority, in order to continue or improve the provision of goods and services to those communities.

3 Methodology

This vulnerability analysis was carried out based on the methodological framework proposed by Schröter et al. (2005), and modified by the consultants:

3.1 Define the study area

Exposure and sensitivity to climate change were analyzed using the boundaries of the watersheds of the Mesoamerican Reef and the exclusive economic zones of Belize, Guatemala and Honduras (**Figure 4-A**). Watersheds were originally included considering that changes in storms, hurricanes and rains derived from climate change determine the volume of water and sediments affecting the availability of fresh water, estuarine salinity, flooding and sedimentation in the marine zone. However, only changes in terrestrial vegetation were considered in this analysis.

The coastal municipalities of Belize, Guatemala and Honduras **(Figure 4-B)** were used to analyze the adaptive capacity of human communities, as these were the most appropriate administrative unit with statistical information on social and economic aspects for the three countries.

3.2 Define the period of the analysis

The degree of exposure of natural and social systems to climate change depends on the level of change in physical and climate variables. Therefore we use climate change projections to determine the targets´ exposure.

Two temporal horizons were used for sea surface temperature, from 2030-2039 and from 2090-2099; a temporal horizon of 2070-2099 was used to determine change in rainfall patterns and air temperature, due to the high level of uncertainty for the period 2030-2039. Historical information available up to 2010 was used to determine past sea level rise. It was not projected in the future, but it considered areas that are below 8 meters above sea level as potentially affected by sea level rise and storms surges and hurricanes waves and floods.

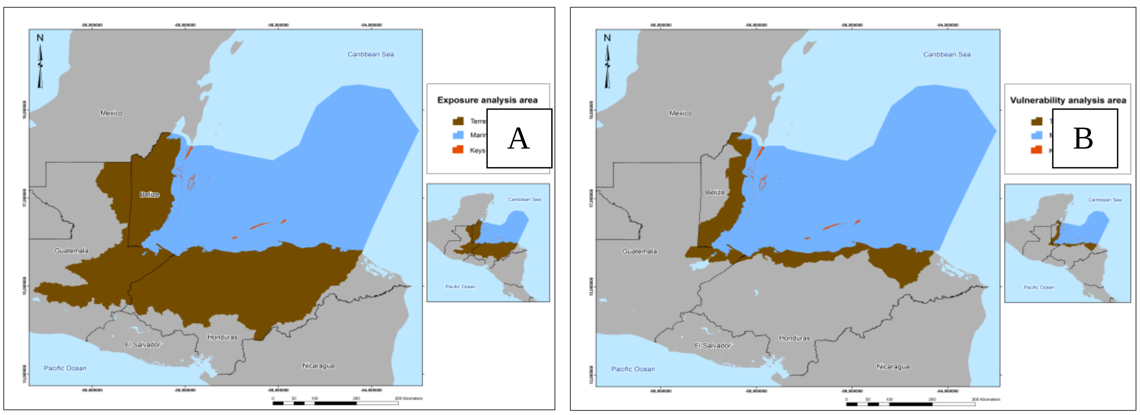


Figure 4. Study area. Map A shows the study area used in the exposure and sensitivity analysis. Map B shows the study area for the adaptive capacity analysis in the coastal marine zone, and consequently vulnerability to CC.

The analysis included historical records of physical and climate variables:

- Air temperature: 1900-2010
- Hurricanes and tropical storms: 1898 – 2010
- Sea level: 1951-2010
- Sea surface water thermal stress: 2006-2010

Future vulnerability depends on the evolution of social systems such as human capacity, population growth, change and growth of economic activities, infrastructure. These aspects were not projected in the future; only current adaptive capacity and sensitivity were estimated considering that the plan seeks to reduce current vulnerability; and that governments, private sector and individuals can and must take action now. Future exposure helps us to plan for a less sensitive development and for societies with greater adaptive capacity.

3.3 Focal issues or targets

Climate change affects differently every element of the social and natural systems. Banking may not be as affected as fisheries, and manatees less than corals. Similarly most adaptation measures can only be targeted to specific elements. Therefore the analysis chooses the most relevant elements of the social and natural system as focal issues.

The focal issues of this analysis are elements of the natural systems (ecosystems, habitats, species, and key sites for species) that are considered important due to their contribution of goods and services, and that could be affected by climate change. Social focal issues are key elements of the social system that are critical for human communities and the economy and that are likely to be affected by climate change given the location or their dependence on natural resources sensitive to climate change.

Natural system elements

1. Coral reefs and corals
2. Fish spawning aggregation sites.
3. Sea grasses.
4. Important fishing sites.
5. Marine turtle nesting sites.
6. Beaches.
7. Mangroves and other coastal wetlands.
8. Coastal and migratory birds.

Social system objects

1. Human populations: housing and service buildings (schools, hospitals, shopping centers, etc.)
2. Artisanal and industrial fishing
3. Tourism: hotels, restaurants, tourism attractions and accesses
4. Coastal infrastructure: ports, marinas, piers, roads, industrial installations and airports
5. Commercial and subsistence agriculture

3.4 Hypothesis of climate change on target natural systems

Analysis develops hypothesis of the potential impact that climate change effects will have on focal issues. They are based on literature review and adapted from Cambers et al. 2007. In this analysis we did not evaluate the likelihood and certainty of the hypothesis.

Table 2. Hypothesis of impact on natural systems

Target	CC effect	Hypothesis of potential impact on targets
Coral reefs and reefs	Increase of sea surface temperature	Sea temperature increase cause bleaching (zooxantelas algae (which live in symbiosis with corals, leave the coral) and may cause coral mortality if algae does not return. The longer the heating periods the lesser possi-

Target	CC effect	Hypothesis of potential impact on targets
		bilities of recovery. Also, corals affected by other pressures (contamination and overfishing) are less resistant becoming more susceptible to bleaching and less apt to recover.
	Increase of CO_2 in seawater	Sea absorbs CO2 from air, therefore an increase of atmospheric CO_2 increases CO_2 concentration in the water, which in turn reduces the quantity of ions needed for the formation of calcium carbonate, therefore reducing growth for bony fishes, corals and other invertebrates.
	Increase in the intensity of rains	Increased precipitation will increase sediment discharge, reducing available light at the mouth of rivers and causing a reduced growth and increased mortality as well as complete destruction by sedimentation.
	Increase in the intensity of storms and hurricanes	Increase in the frequency and intensity of storms will augment the destruction of coral reefs without allowing their recovery. In general, reefs can recover in 10-15 years from natural phenomena; the increased frequency of storms will allow less capacity for growth, so reefs will deteriorate. It will also increase the intensity of rains (see previous impact) which will increase in run off and sedimentation.
	Sea-level rise	Growth of healthy corals can be maintained despite the pace of sea level rise unless changes occur so rapidly that the available light is reduced, hampering coral growth. As sea levels rise, this reduces the capacity of reef crests to dissipate waves and tides, reducing the function of protecting the coast against extreme climactic events. Sea level rise will affect the coast, which may generate more sediments and debris that will affect corals.
Coastal wetlands: mangroves, lagoons, savannas	Sea-level rise	Possible loss of mangrove area due to erosion at the edges or loss of sandbars and lagoons that offer protection. Increase in mangrove surface by relocation and natural migration to the interior where topography, soils and human use allows it. As sea levels rise, the salinity of coastal lagoons will increase, altering the species composition (red mangrove is more tolerant to salinity than other mangrove species). Increase in salinity reduces the survival of seedlings, growth and the photosynthetic capacity of less tolerant species (button, black and white mangroves).
	Increase in air temperature	Mangrove productivity, growth, litter production, and the expansion of certain species are expected to increase in combination with high levels of atmospheric CO_2 and the increase in temperature. If the water temperature reaches over 35°C, it can cause thermal stress to *Rhizophora mangle*. If the temperature goes over 38°C, it can reduce the invertebrate diversity that live in the roots of the mangroves and possibly prevent the establishment of seedlings.
	Increase in ocean CO_2	Increase in mangrove productivity. Stomatal conductance is reduced.
	Increase in the intensity of rains	Increased precipitation reduces salinity, exposes sulfates and increases nutrient availability.
	Increase in drought	The decrease in rainfall and the increase in evaporation are expected to

Target	CC effect	Hypothesis of potential impact on targets
	periods	cause a reduction in mangrove areas, especially in inland zones with hypersaline areas that will also suffer a decline in growth rates.
	Increase in the intensity of storms and hurricanes	Mangrove coverage will be severely affected by the increase in the intensity of hurricanes. Mangrove mortality rates caused by category 4 hurricanes in the Caribbean are between 68 and 99% in the affected areas.
Beaches, coastal dunes, low islands and keys	Sea-level rise	This will accelerate erosion of beaches and cays, eventually altering the coastal topography, eliminating dunes and barriers between the sea and interior lagoons or bays. It will also eliminate cays and small islands.
	Increase in the intensity of storms and hurricanes	It will exacerbate beach erosion and wash out sand barriers, cays and islands.
Sea turtles and nesting sites	Sea-level rise	Loss of habitats for nesting sea turtles and birds due to an increase in erosion and the altered topography of beaches caused by sea-level rise and more frequent and intense storms. Increased tidal height will also flood the eggs from below. If the sand is saturated by the waves of the storms and the subsoil is flooded and does not drain properly, the embryos will drown.
	Increase in the intensity of storms and hurricanes	Further erosion and destruction of beaches and nests.
	Increase in water temperature	Could alter migratory routes of turtles (studies indicate that migratory routes are heavily influenced by sea surface temperature and chlorophyll concentration).
	Increase in air temperature	The sex is determined by the temperature in the middle third of incubation period. Higher temperatures favor females and lower temperatures favor males within a thermal tolerance range of 25 to 35 ° C. Hypothesis have been stated that populations could self-regulate if there are more individuals from one sex. Temperature could affect the severity of infections and could increase the outbreak of diseases of marine turtles.
Marine and coastal birds	Increase in air temperature	Approximately 60% of the studies performed on reproduction show that at long term, the egg laying dates are changing according to the patterns of global warming.
	Changes in wind patterns	Change in the migration patterns of birds due to changes in the geographical displacement of winds and an increase in the frequency and intensity of storms.
	Increase in the intensity of storms and hurricanes	The increased frequency of storms in the Caribbean may be the cause for the reduction of some migratory birds. Mortality caused by winds, rains and floods has been documented for aquatic birds such as the Brown Pelican (*Pelecanus occidentalis*), and the Clapper Rail (*Rallus longirostris*). Hurricanes cause habitat loss for migratory birds like beaches, coastal wetlands, islands, keys and forests.
	Sea-level rise	Loss of habitats such as beaches, islands, keys and coastal wetlands.
Sea grasses	Sea-level rise	Studies have not defined how it will affect. Changes in light availability, wave energy, type of substrate and herbivores will influence marine prairies depending on the species.

Target	CC effect	Hypothesis of potential impact on targets
	Increase in the intensity of rains and longer periods of drought	More intense rains and storms will increase sediment transport that can bury marine prairies and reduce light availability. Longer periods of drought will reduce the supply of fresh water so salinity will increase, which can be a stress factor for sea grass.
	Increase in water temperature	Grasses could be affected by a change of 1.5˚ C, reducing their metabolism. Temperatures of 35˚ C or higher could inhibit root sprout of some species.
	Increase in ocean CO_2	Increase in CO_2 will increase sea grass productivity. Together with a slight rise in temperature, these chemical changes will augment biomass and detritus.
	Increase in the intensity of storms and hurricanes	The increase in storms and tidal waves and the subsequent change in river flow and sediment transport could destroy sea grasses. Their capacity for recovery could diminish with storm frequency. Marine prairies grow in low energy environments and an increase in water turbulence could cause their displacement or disappearance.
Coastal and pelagic fishes	Increase in water temperature	The rise in water temperature has caused coral bleaching and mortality and a proliferation of algae, which has significantly reduced fish density and coral reef biomass. Data from the Sabana-Camagüey Archipelago, Cuba. Migration of diverse species to colder waters could cause mass extinctions due to low dispersion capacity or lack of habitat. Changes in temperatures will impact the distribution and abundance of fish.
	Increase in ocean CO_2	There is convincing evidence that suggests that acidification affects the calcification process, through which corals, mollusks and other invertebrates build their skeletons, shells and plates from calcium carbonate.
	Increase in the intensity of storms and hurricanes	Increase in storm intensity will degrade critical habitat for fish like reefs, mangroves and sea grasses, which in turn will reduce the fish populations that use them.

3.5 Hypothesis of climate change impacts on social system targets

Tourism, fishing industry, infrastructure and communities will be affected directly by climate change effects. Most are known impacts as floods and destructive winds from hurricanes, but others are still uncertain, particularly in the severity of the impact, like increase salinity in aquifers or less disposable freshwater for human consumption. In this table we combined climate change effects given the synergic action.

Table 3. Hypothetical impact on social systems

Target	CC effects	Hypothesis of potential impact on targets
Tourism attractions	Sea-level rise Increase in storm and hurricane intensity Increase in surface wa-	Sea level rise and temperatures will seriously affect coral reefs, fish stocks and beaches, essential tourist attractions Access trails to tourist attractions and docks will be affected.

Target	CC effects	Hypothesis of potential impact on targets
	ter temperature	
Tourism infrastructure: hotels, restaurants, development	Sea-level rise Increase in storm and hurricane intensity	The rise in sea-level will be exacerbated by more frequent and intense tropical storms that will damage coastal infrastructure, stopping tourist activities and increasing construction and maintenance costs.
Coastal cities, towns and communities	Sea-level rise Increase storm and hurricane intensity	The rise in sea level will be exacerbated by more frequent and intense tropical storms that will damage coastal infrastructure, stopping tourist activities and increasing construction and maintenance costs. More frequent and intense tropical storms and the intensification of rains will increase the occurrence, severity and coverage of flooding in the coastal plains, affecting towns and communities.
Communication and transport infrastructure: docks, marinas, roads, fuel unloading	Sea-level rise Increase in storm and hurricane intensity	The rise in sea level will be exacerbated by more frequent and intense tropical storms that will damage coastal infrastructure, stopping tourist activities and increasing construction and maintenance costs. More frequent and intense tropical storms and the intensification of rains will increase the occurrence, severity and coverage of flooding in the coastal plains, affecting communication lines, industrial installations and ports.
Rivers, lagoons and coastal aquifers (freshwater)	Sea-level rise Increase in storm and hurricane intensity Changes in precipitation patterns	The rise in air temperature will increase evapotranspiration and reduce annual average rainfall decreasing the quantity of freshwater and increasing salinity. Sea level rise, reduced rainfall, and increased freshwater extraction will increase saline intrusion. Freshwater extraction from aquifers for human consumption will increase.

3.6 Methodology for measuring potential impact and vulnerability

Potential impacts and vulnerability were analyzed using the four most critical climate change effects that can be mapped for the study area. Then, we selected those targets with mapped information and which are sensitive to those effects with a good degree of certainty. The effects used to measure potential impact were:

- Rise in sea surface temperature
- Increase in storm intensity
- Rise in sea level
- Changes in rainfall patterns and air temperature

Exposure and sensitivity indicators were defined for each effect of climate change. Indicators were scored using the methodology proposed by Preston *et al*. (2008), according to which indicators were given a score from 1 to 5, where 1 represents the lowest exposure or sensitivity, and 5 the greatest. The indicators were estimated for three temporal scenarios: current, 2030-2039 and 2090-99.

The adaptive capacity of human communities was then estimated using 8 indicators, evaluated on the same scale with the lowest adaptive capacity 5, and the greatest 1. In this analysis, which considered only current conditions; the conditions measures by the indicators were not projected in the future. Then, the three types of indicators (exposure, sensitivity and adaptive capacity) were added to estimate the net vulnerability from each effect in the current scenario (**Figure 5**).

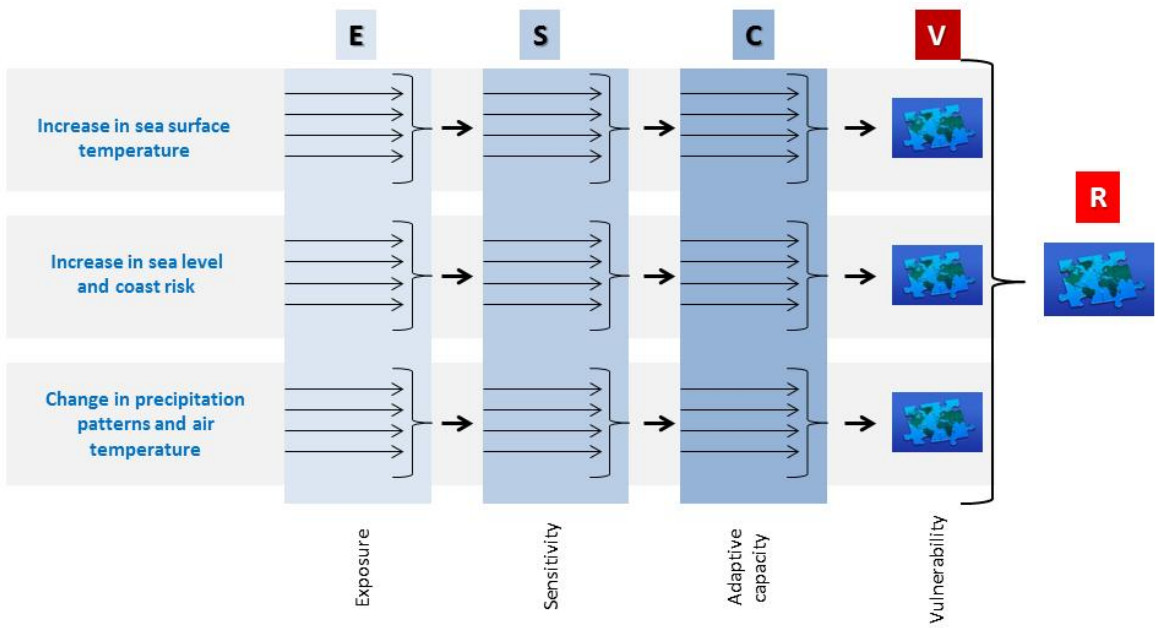


Figure 5. Conceptual approach to assess potential impact and vulnerability for each of the three effects of climate change and to integrate the vulnerability of the study area.

Following is a description of the methodology used to measure the potential impact of each climatic effect, the indicators used and sources of information.

3.6.1 Rise in sea surface temperature

The effects of rising sea surface temperature are various, including a rise in sea level as a result of the water's expansion as it heats. An important consequence of the rise in sea surface temperature (SST) is its effect on strengthening extreme weather events (Herr and Galland, 2009). Although it is not clear if these storms will be affected in the future by climate change, their intensity is expected to increase as SST rises (IPCC 2007), representing a possible risk to people as well as marine-coastal ecosystems in a region known to be prone to these annual events (**Figure 6**).

Changes in SST have important biological implications for the living conditions of many living organisms (plankton, sea weeds, crustaceans, fish and mammals). The target selected (coral reefs, sea grasses, spawning aggregation sites and important fishing sites) will suffer an increasing impact as sea temperatures rise.

Scientists discovered in 1980s that corals begin to stress with an increase of just 1° C over the highest average temperature of the hottest summer month (Glynn and D'Croz 1990), referred to as the “bleaching threshold”. Stress caused by water over normal temperatures could begin the bleaching process eight weeks after the initiation of the variation, and general bleaching and death can occur if corals remain under those conditions for 12 weeks (NOAA Coral Reef Watch 2011).

Eventhough SST and thermal stress impacts corals, the analysis also assess impact on fishing areas, spawning aggregations and seagrasses. The impact on those targets is not well known and hypothesis have been developed (see table 2). In **table 4** presentes exposure and sensitivity indicators and the sources of information used.

Table 4. Exposure and sensitivity indicators used to evaluate the impact of rising SST

Indicators	Date Source
Exposure indicators	
Degree Heating Weeks (DHW) period 2006-2010	Sea surface temperatures anomalies (NOAA 2011)
Degree Heating Weeks (DHW) 2030-2039 under scenarios A2 y B1	Models generated by CATIE, 2011, for 2030-2039 under scenarios A2 y B1
Degree Heating Weeks (DHW) 2090-2099, under scenarios A2 y B1	Models generated by CATIE, 2011, for 2090-2099, under scenarios A2 y B1
Sensitivity indicators	
Coral reefs exposed to temperature anomalies	Coral reef coverage (WRI 2011) and DHW 2006-2010 and models of DHW 2030-2039, 2090-2099
Fishing importance sites exposed to temperature anomalies	Fishing importance sites (WWF 2007) and DHW 2006-2010 and models of DHW 2030-2039, 2090-2099
Sea grasses exposed to temperature anomalies	Sea grass coverage (TNC 2008) and DHW 2006-10 and models of DHW 2030-2039, 2090-2099
Reproduction aggregation sites exposed to temperature anomalies	Coverage of reproduction aggregation sites of TNC (2008) and DHW 2006-2010 and models of DHW 2030-2039, 2090-2099

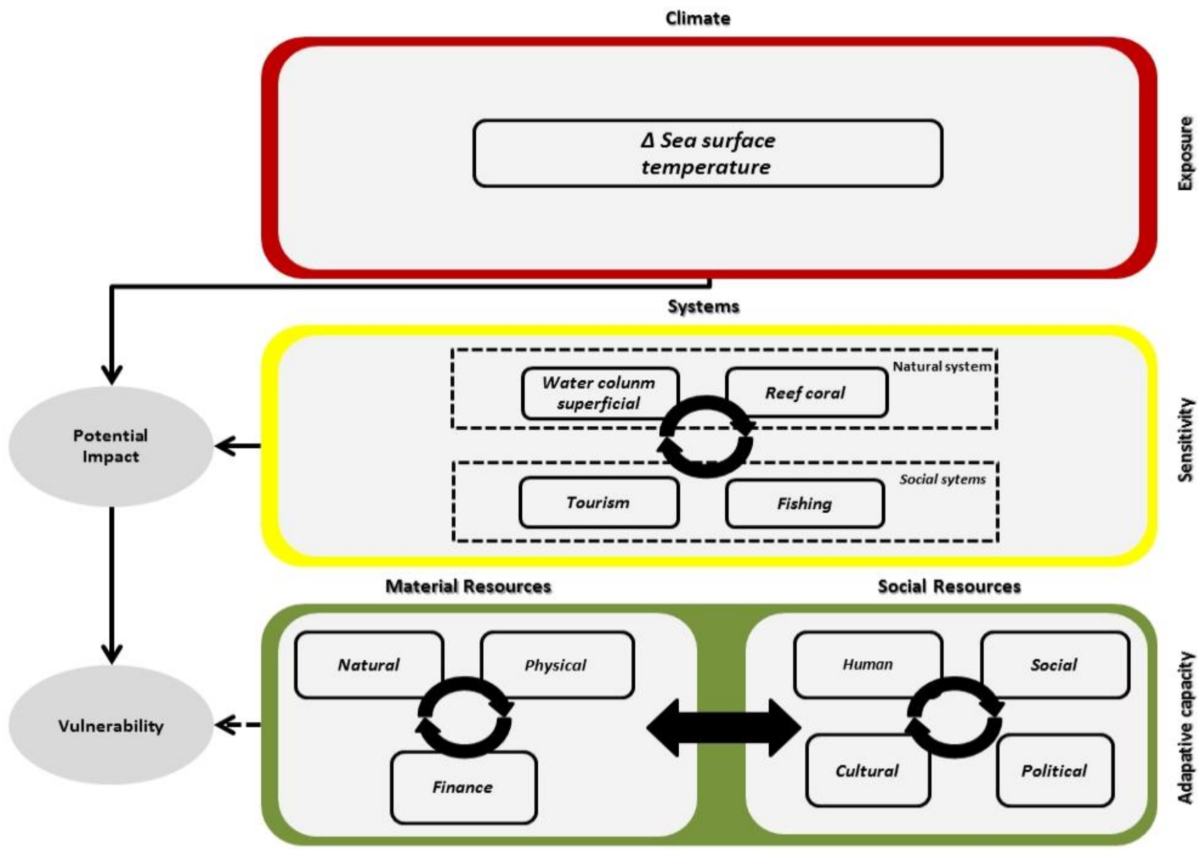


Figure 6. Causal model used to measure the potential impact of the rise in sea surface temperature

The methodology used to analyze changes in sea surface temperature (SST) was developed by the "Coral Reef Watch" (CRW, http://coralreefwatch.noaa.gov/), part of the National Oceanic and Atmospheric Administration (NOAA), and consists of:

1. Nocturnal data selected from the Coast Watch database, to eliminate the effect of direct sunlight and to reduce variations in SST caused by solar warming.
2. Monthly mean SST calculations.
3. Levels of thermal stress evaluated by comparing the maximum monthly average from the base climatology (MMM, 2001 – 2005) with the monthly temperature for the study period (SST, 2006 – 2011). Table 5 shows the thermal stress evaluated according to the different states that may or may not produce sufficient stress to cause coral bleaching.

The base climatology data used in the analysis were taken from the "NOAA Coast Watch" (http://coastwatch.noaa.gov/) database which contains global Sea Surface Temperature data at a spatial resolution of 5 km^2. Thermal stress was evaluated using scenarios of future SST increases based on Donner (2009). The database presents simulations for two emission scenarios (B1 and A2), one for each scenario; and evaluates temporal thresholds such as those mentioned above (for 2030-2039 and for 2090-2099), for a total of four simulations of future climate.

Data are reported as SST anomalies, which are the difference between current and future temperatures. The first step was to add these to the base climatology (2001-2005), and then find "*hotspots*" where there is a rise in Sea Surface Temperature, using the same methodology as the baseline data.

Table 5. Thermal stress indicator for marine areas subject to a rise in sea surface temperature (NOAA Coral Reef Watch 2011)

State	Interpretation	Definition
Without stress (1)	No thermal stress	"Hotspot" (1) equals 0
Attention (2)	Low thermal stress	"Hotspot" (1) above zero but below the SST threshold for bleaching
Warning (3)	Accumulating thermal stress	Over the SST threshold for bleaching; DHW(2) above 0
Warning level 1 (4)	Bleaching is expected	Over the SST threshold for bleaching; DHW(2) 4 or above
Warning level 2 (5)	Generalized bleaching and some mortality is expected	Over the SST threshold for bleaching; DHW(2) 8 above

Notes: (1) "Hotspot": areas where SST data exceed the average temperature observed in the hottest month of the year. (2) DHWs show the amount of stress from heat accumulated in a certain area over the last 12 weeks (3 months). In other words, "Hotspot" values are added when the temperature exceeds the bleaching threshold.

3.6.2 Increase in hurricane intensity

The question analyzed here is: What areas are historically more affected by hurricanes? What areas have more frequent hurricanes, and which have been struck by stronger hurricanes?

All the analysis targets are sensitive to hurricanes, especially human populations, reefs and beaches. Hurricane Center has mapped hurricane trajectories for the last 150 years with their intensity marked on the trajectory in the study area, and then overlapped on the targets location.

Table 6. Hurricane exposure and sensitivity indicators

Indicators	Source of Data
Exposure indicators	
Areas affected by hurricane intensity	Historical data for tropical cyclones (NOAA, 2011)
Areas affected by increased frequency of hurricanes	Historical data for tropical cyclones (NOAA, 2011)
Sensitivity indicators for natural systems	
Agriculture exposed to more frequent hurricanes	Coral reef coverage (WRI, 2011) and areas affected by increased frequency of hurricanes
Agriculture exposed to higher intensity hurricanes	Coral reef coverage (WRI, 2011) and areas affected by hurricane intensity
Infrastructure exposed to more frequent hurricanes	Coral reef coverage (WRI, 2011) and areas affected by increased frequency of hurricanes
Urban and inhabitated areas exposed to higher intensity hurricanes	Coral reef coverage (WRI, 2011) and areas affected by hurricane intensity
Urban and inhabitated areas exposed to	Coral reef coverage (WRI, 2011) and areas affected by increased fre-

Indicators	Source of Data
more frequent hurricanes	quency of hurricanes

Table 7. Hurricanes are classified in 5 categories according to wind speed

Category	1	2	3	4	5
Wind speed (km/h)	119–153	154–177	178–209	210–249	≥250
Tide height (m)	1.2–1.5	1.8–2.4	2.7–3.7	4.0–5.5	≥5,5
Pressure at the center of the hurricane (hPa)	980	965–979	945–964	920–944	<920

Source: NOAA. 2011. The Saffir-Simpson Hurricane Wind Scale. See http://www.nhc.noaa.gov/sshws.shtml

3.6.3 Rise in sea level and risks to the coast

This analysis was based on estimated relative (sea to land) and absolute changes of sea level (SL). Relative measurements are based on tide gauges installed on the land surface which are affected by changes in their surface position, thereby affecting their measurements. Absolute changes are measured using high precision satellite instruments that were installed in the 1990s.

Ocean volume increases over very large geological time scales (10^9 years), while morphological changes to ocean watersheds and tectonic plates that occur on temporal sales of 10^7 – 10^8 years, could result in changes in sea level of hundreds of meters. Sea level has changed over temporal scales of hundreds of thousands of years as the result of climate changes caused by the cyclical exchanges of water between sheets of ice and the ocean. In addition changes in the elevation of the earth's crust (isostatic ice) continue to occur, and estimates of changes in global sea level should be corrected or a consideration made for this effect.

Global ocean volume changes due to climate change also occur on temporal scales measured in decades as a result of thermal dilation and exchanges of water between the ocean and other reservoirs, including the atmosphere. Global changes in sea level have been noted on this scale, due to changes in ocean currents and atmospheric pressure. Sea level can be modified at the local and regional levels by tectonic, subsidence and sedimentation processes. Regional processes may predominate in the current scenarios of rising global sea level (~ 3 mm/year), with regional variations ranging from -1 mm/year to 10 mm/year.

Sea level has been measured globally by NASA and the European Space Agency since 1992 with a precision of 5 mm at 10-day intervals, using altimeters aboard geophysical observation satellites in polar orbits. The altimeters measure the distance between the satellite and the surface using radar pulses, with sea surface height (SSH) calculated considering the precise position of the satellite with respect to an ellipsoid surface of reference (a model of the form of the earth's surface). Global average sea height is altimetrically calculated, averaging SSH measurements of all the oceans on the plant. Unlike the oceanographic measuring stations that measure relative sea level, the altimeter allows the registry of absolute variations in global sea level, precise to tenths of mm/year. These variations in global sea level include: a) expansion or contraction due to variations in water density (determined by changes in temperature and salinity); b) Exchange of water with continents, the atmosphere and polar caps: c) low frequency variations in ocean circulation.

In the conceptual model for coastal vulnerability to sea level rises (**Figure 7**), exposure (in red) is driven by the interaction between the weather system and coastal topography. Sensitivity (in yellow) is a function of the ecosystems, productive activities and infrastructure present on the coast. The combination of exposure and sensitivity creates the potential for an adverse effect. Adaptive capacity (in green) is based on material and social capital used to address potential impacts and vulnerability. The critical processes and interaction are represented by arrows.

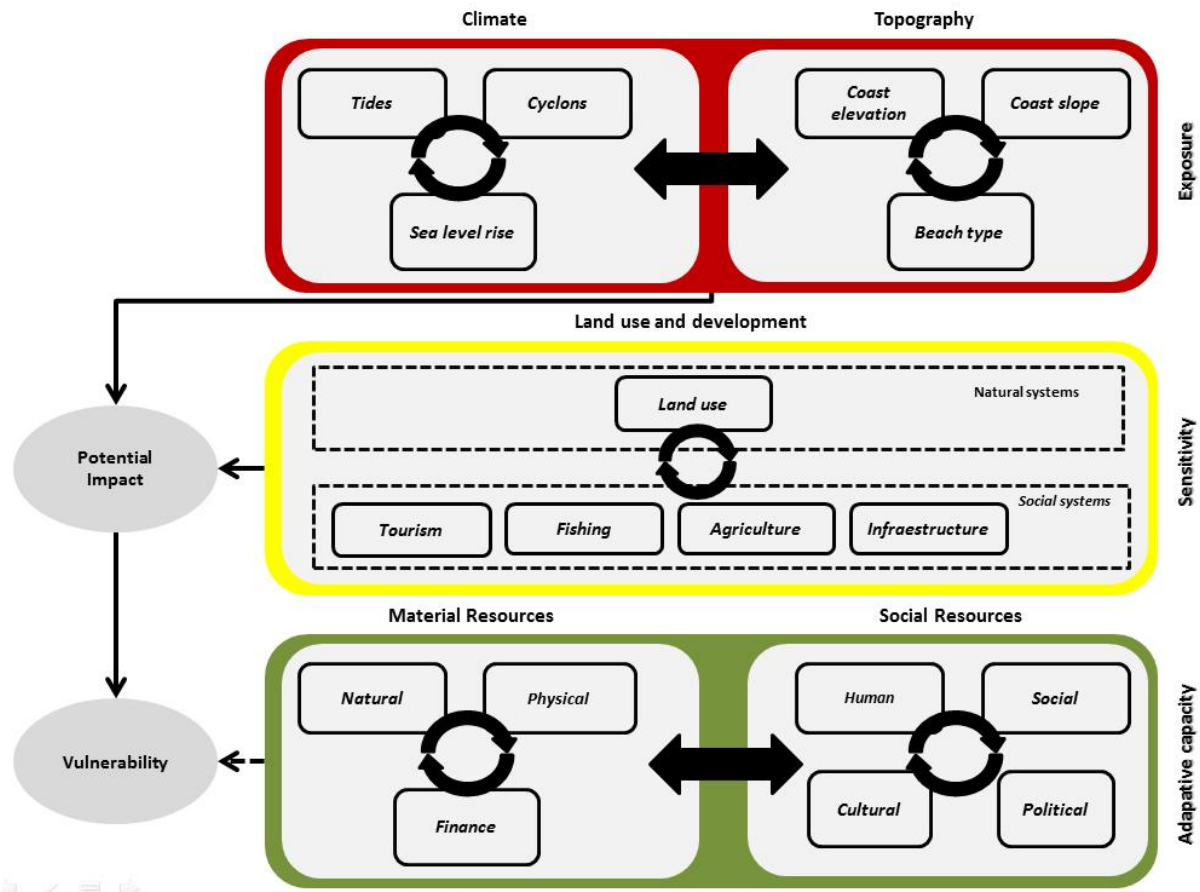


Figure 7. Conceptual model for coastal vulnerability to sea level rise

Table 8. Indicators and sources of data used to evaluate exposure and sensitivity to sea level rise.

Indicators	Sources of data
Exposure indicators	
Areas exposed to sea-level rise	Digital elevation models of 90 m, with thresholds of 1, 2, 4, 8 and 16 m above sea level
Km of coast exposed to sea-level rise	Data series of marine graphical of countries and Data series for remote sensors Topex/Poseidon, Jason I and Jason II
Sensitivity indicators	
Urban areas exposed to sea-level rise	Digital elevation models of 90 m
Wetlands areas exposed to sea-level rise	Digital elevation models of 90 m
Natural vegetation areas exposed to sea-level rise	Vegetation maps 20xx
Fishing areas in coastal lagoons exposed to sea-level rise	WWF (2007)
Areas with agricultural capacity exposed to sea-level rise	Ability to use agricultural land
Area and/or extension of infrastructure exposed to sea-level rise	Coverage of roads and highways
	Urbanized areas and towns
Population exposed to sea-level rise	Population growth projected for 2015, National Census
	Population density, National Census

Each indicator was evaluated on an exponential scale of risk to sea level rises and qualified according to the scale given in Table 9

Table 9. Assessment of the indicator for sea level rise on the coast

Elevation	Rating	
< 1 m	Very high	Areas highly vulnerable to tidal flooding and erosion, extreme rainfall and storms of all categories with the current sea level Areas covered with sea level rise expected by 2090
1 to 2 m	High	Areas subject to flooding by storms subject to the current sea level. Areas highly vulnerable to tidal flooding and erosion, extreme rainfall and storms of all categories with sea level rises expected by 2090
2 - 4 m	Medium	Areas exposed to extreme events (3, 4, 5) with actual conditions Areas exposed to flooding by storms and waves with the sea-level rise expected by 2090
4 - 8 m	Low	Areas exposed to Category 5 extreme events with current conditions Areas flooded by extreme events in sea-level rise
8 - 16 m	Very low	Areas not currently exposed and less exposed to sea-level rise

The data used to analyze sea level rise referred to the relative rise (from tide gauges) and absolute rise in sea level (from remote sensors) in the Ports of Cortés and Castilla in Honduras and Santo Tomás in Guatemala. The following table lists the number of years of collecting data of each type.

Table 10. Years of data compiled per port and remote sensing station to calculate relative and absolute rise in sea level

Port	Years of data Relative increase	Years of data Absolute increase	Total years
Cortés	20	18	38
Castilla	13	18	31
Santo Tomás	16	18	34

3.6.4 Changes in rainfall patterns and air temperature

The following databases and climate change scenarios and models used to analyze projected temperature and rainfall anomalies were used to analyze exposure:

Baseline climate data: Changes in air temperature and rainfall were evaluated using the WorldClim (Hijmans *et al*. 2005) climatological database, which provided a set of global weather data at a spatial resolution of 1 km^2 for the period of 1960-1990.

Future climate data: The climate change scenarios used come from the World Climate Research Program (WCRP), from group CMIP3 (*Coupled Model Intercomparison Project phase 3*), used in the IPCC AR4 report. These scenarios have been scaled down (to a resolution of 2.5 minutes, approximately 5 km) by The Nature Conservancy (TNC) – California in three groups of radiative forcing (IPCC-SRES), B1 and A2 with 48, 52 and 36 scenarios respectively for the period 2070-2100, for a total of 136 future climate simulations (Table 11).

Table 11. Simulations used for General Atmospheric-Ocean Circulation Models (GAOCM)

GAOCM	20th Cent	Low emissions (B1)	High emissions (A2)
BCC-CM1	1	1	0
BCCR-BCM2.0	1	1	1
CCSM3	8	8	4
CGCM3.1(T47)	5	5	5
CGCM3.1(T63)	1	1	0
CNRM-CM3	1	1	1
CSIRO-Mk3.0	1	1	1
ECHAM5/MPI-OM	4	3	3
ECHO-G	3	3	3
FGOALS-g1.0	3	3	0
GFDL-CM2.0	1	1	1
GFDL-CM2.1	1	1	1
GISS-AOM	2	2	0
GISS-EH	3	0	0
GISS-ER	5	1	1
INM-CM3.0	1	1	1

GAOCM	20th Cent	Low emissions (B1)	High emissions (A2)
IPSL-CM4	1	1	1
MIROC3.2(hires)	1	1	0
MIROC3.2(medres)	3	3	3
MRI-CGCM2.3.2	5	5	5
PCM	4	3	4
UKMO-HadCM3	2	1	1
UKMO-HadGEM1	1	1	0
Total	58	48	36

Calculating exposure to changes in rainfall and air temperature: Exposure to rainfall is measured according to the number of simulations that predict a drop of over 50% in rainfall based on the IPCC methodology on probability of change, which evaluates the amount from simulations that exceed the established threshold (decrease in rainfall over 50%). When <33% of the total simulations for emissions scenarios (B1, A1B or A2) surpass the threshold then exposure is Very Low, from 33 to 50% is Low, from 50 to 66% Medium, from 66 to 90% High and from 90 to 100% Very High.

Exposure to changes in temperature is measured according to the amount of simulations that predict a temperature rise in excess of 3° C. The same methodology was used as that used to evaluate exposure to changes in rainfall.

Changes in vegetation type according to the Holdridge life zones system: a simulation of the Holdridge life zones system was developed to evaluate the probabilities of change in vegetation type as a product of climate change. The Holdridge system which is based on values of latitudinal region, altitudinal floor and ground moisture, was used to construct the methodology proposed by Zamora-Pereira (2011), based on the following steps:

- **Definition of altitudinal floors:** Using World Clim (Hijmans *et al* 2005) as the base climate data, monthly average and then annual biotemperatures were calculated to define the altitudinal floors and finally an average was obtained for the twelve months. This is the mean annual biotemperature, which was used to generate a layer of information that defines the altitudinal floors, with the ranges separated between 0-1.5, 1.5-3, 3-6, 6-12, 12-17, 17-24, 24-30 degrees.
- **Definition of ground moisture:** The second variable calculated was monthly precipitation. When added these values gave the total annual precipitation, or absolute annual precipitation. This layer of information was useful in obtaining moisture provinces. Annual precipitation data were reclassified in the following ranges: 62.5-125, 125-250, 250-500, 500-1000, 1000-2000, 2000-4000, 4000-8000, > 8000 mm.
- **Definition of latitudinal region:** The third and last variable is biotemperature at sea level. This was obtained by combining the average biotemperatures for a site and at its elevation, thereby defining the latitudinal region of the life zone according to geometric progression that indicates that temperature decreases as elevation above sea level increases.

- **Construction of base life zone maps:** Finally the current life zones distribution map was constructed by overlapping layers of the above information using a geographic analysis program (ArcGIS 9.3). This constitutes the map of reference for later analysis of changes in the distribution of life zones.
- **Future life zones:** The same methodology was used to determine scenarios of future life zone distribution, with a total of 136 future distribution maps constructed. Climate variable values are reported as climate anomalies for each month; that is, the difference between current climatological data (1961-1990) and future simulated data (2070-2100).
- **Calculating exposure uncertainty:** Uncertainty of future climate results refers to the different possibilities for different data in the proposed future timeframe. An analysis was run comparing change between life zones using current distribution as the base and comparing it with each of the 136 simulations; the IPCC (2005) uncertainty methodology was then applied to reclassify the area according to the number of simulations that indicated changes in forest type. Exposure was determined to be Very Low when <33% of the total emissions scenario simulations (B1, A1B or A2) indicated change in forest type; from 33 to 50% Low, from 50 to 66% Medium, from 66 to 90% High and from 90 to 100% Very High.

The research question was: What areas are vulnerable to changes in air temperature and rainfall patterns?

Table 12. Indicators to evaluate vulnerability to changes in rainfall and air temperature in coastal lands

Exposure indicators	Data
Area exposed to Δ in precipitation from 2030-2039	Models generated by CATIE based in scenario A1
Area exposed to Δ temperature from 2039-2039	Models generated by CATIE based in scenario B2
Area exposed to Δ precipitation from 2090-2099	Models generated by CATIE based in scenario A1
Area exposed to Δ temperature from 2090-2099	Models generated by CATIE based in scenario B2
Sensitivity indicators	**Data**
Area of natural vegetation exposed to Δ in precipitation and air temperature	Land use maps and vegetation types.
Areas for fishing in coastal lagoons exposed to Δ in precipitation and air temperature	Maps of sites of importance for fishing of WWF (2008)
Area of agricultural use exposed to Δ in precipitation and air temperature	Land use maps and vegetation types.
Population exposed to Δ in precipitation and air temperature	Land use maps and vegetation types and national statistics institute.

Note: Δ= Change

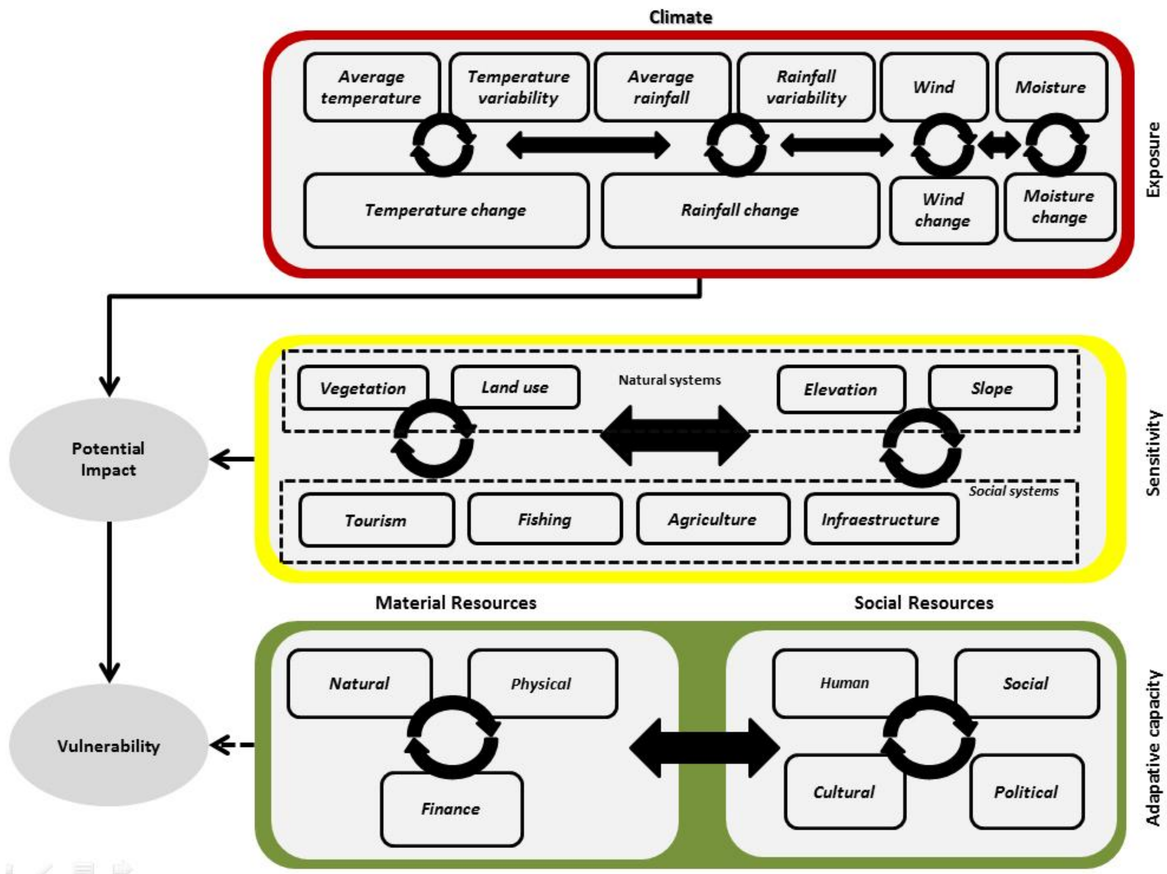


Figure 8. Conceptual model for assessing vulnerability to changes in rainfall and air temperature

3.7 Estimating the adaptive capacity of human communities

Adaptive capacity can be estimated at the individual, community, sector and regional scale. Although an estimation of the adaptive capacity of a community may derive from the adaptive capacity of the individuals that form the community, an assessment of community characteristics may offer information that better reflects the capacity to respond to climate change (Marshall *et al*. 2009).

Different factors must be considered and evaluated using a variety of methods, including the analysis of census information, key informant surveys from businesses, industry, government, research organizations, NGOs, indigenous groups and the public in general (Marshall *et al*. 2009).

Each site may have certain unique characteristics that make some indicators better than others for evaluating vulnerability. A list of possible social indicators for each factor that contributes to vulnerability may be extensive, especially when those indicators for adaptive capacity depend on specific local situations, as these could cover a wide range of social conditions (CRISP 2011). Thirteen indicators were chosen for this project shown in

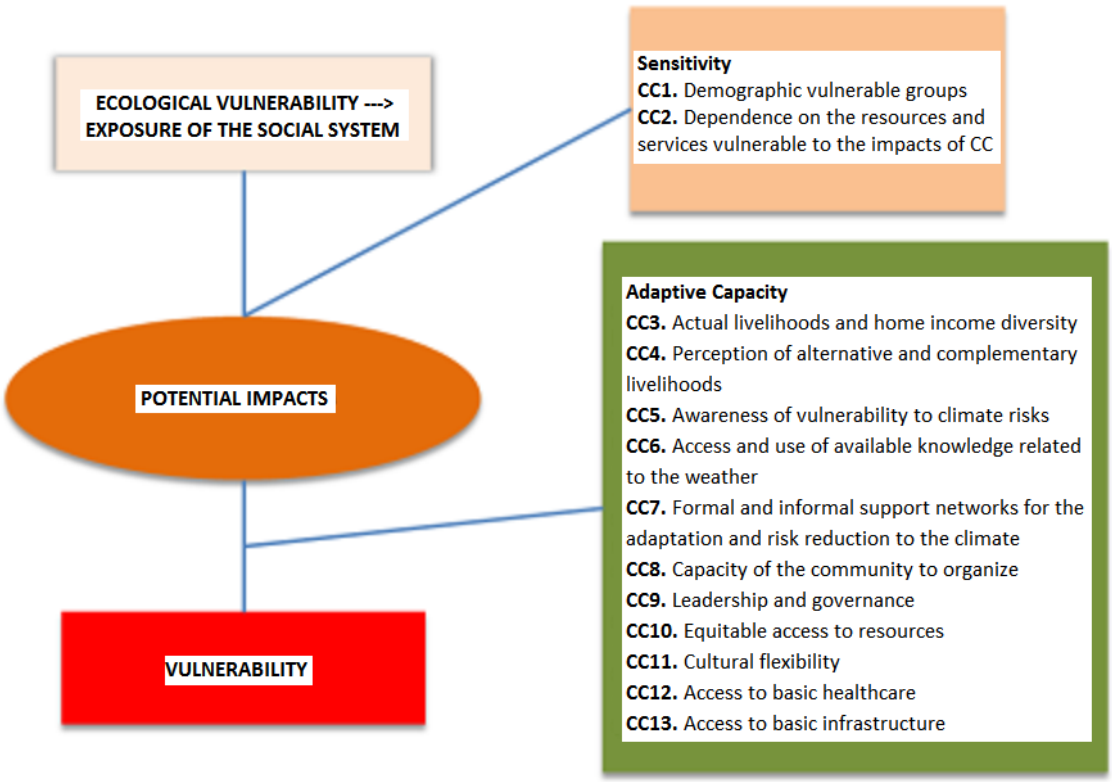


Figure 9. However municipal level data available in the three countries allowed the evaluation of only 6 indicators (**Table 13**).

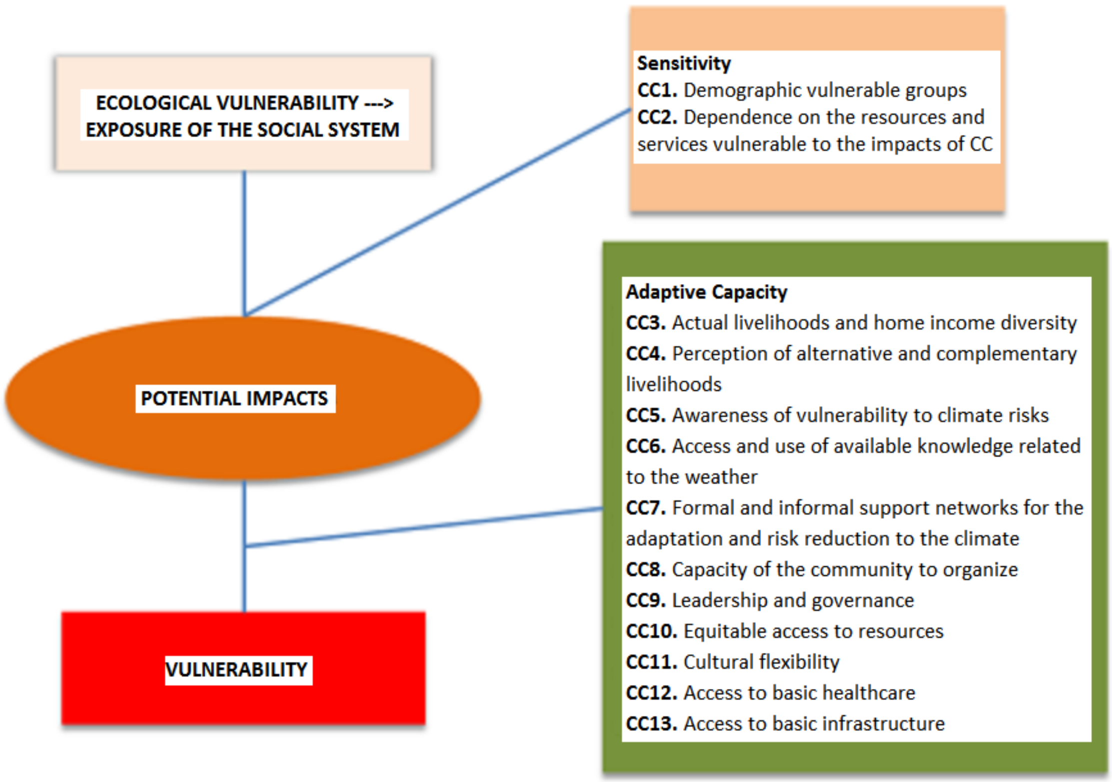


Figure 9. Conceptual framework to analyze human communities adapative capacity

Table 13. Criteria to analyze adaptive capacity at the regional and local level, possible data collection methods and examples of utility (adapted from Wongbusarakum and Loper 2011)

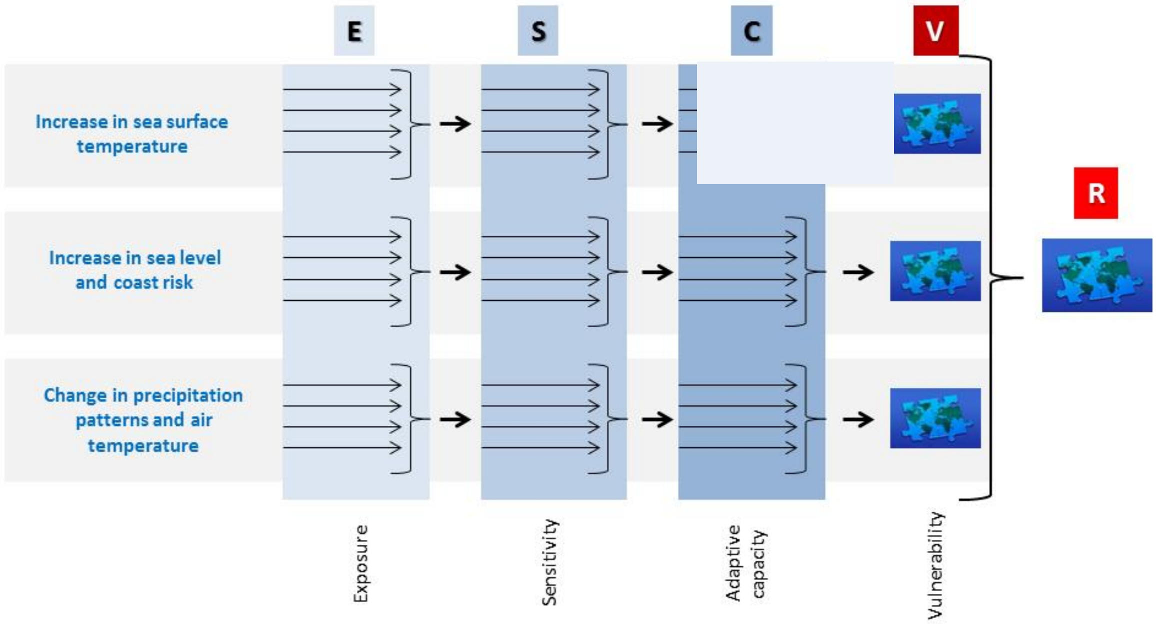
Criteria	Indicator	Use of information
CC1.Demographic vulnerable groups	% of the population in poverty and extreme poverty	Identify groups with higher risks associated to CC and require most support.
CC2. Dependence on the resources and services vulnerable to the impacts of CC	% of the population whose principal livelihoods (more than 50% of their income) depend on de natural resources: tourism, fishing and agriculture	Predict impacts of CC in livelihoods, the economy and food security, points out the livelihoods that are highly sensitive to particular climate threats.
CC3. Actual livelihoods and home income diversity	Number of local productive activities.	Identify the economic sensitivity of the communities to CC and other external threats. Identify necessary options for livelihood diversification.
CC4. Perception of alternative and complementary livelihoods	Quantity of existing skills in key activities (fishing, agriculture and tourism)	Identify possibilities necessary resources for livelihoods adaptation to CC and other external threats
CC6. Access and use of available knowledge related to the weather	% analphabetism.	Capacity of communities to understand the impacts of CC and the need to educate, identify actual and potential uses of information on CC
CC7. Formal and informal support networks for the adaptation and risk reduction to the climate	Number and type of existing networks.	Adjust extension and education programs to face CC, fill gaps in information networks.
CC8. Capacity of the community to organize	Number and type of community organizations.	Identify potential networks that can transfer information related to CC and give support, collaborate with existing networks that can support adaptation and planning.
CC9. Leadership and governance	Number of coordination platforms with impacts on resources or territories	Assessing whether a community is able to restructure itself after suffering an impact, determine the level of confi-

Criteria	Indicator	Use of information
	to CC.	dence within a community, identify areas that should be strengthened for adaptation work, understand the level of stakeholder participation in management and decision-making.
CC12. Access to basic healthcare	Life expectancy at birth	Identify vulnerable segments of the population that could be less capable of adapting to CC
CC13. Access to basic infrastructure	Calories per capita	Identify access to basic infrastructure, as greater adaptation is expected with greater access
CC13. Access to basic infrastructure.	Kilometers of roads (in relation to the surface with 99% of population)	Identify the access to basic infrastructure because more access is expected to be more adaptive.
	% population with access to drinking water	

Indicators were applied per municipality and data was classified in 5 categories (1 major and 5 minor capacities). These were then added to give the adaptive capacity for each municipality.

3.8 Integrating vulnerability data

Vulnerability was estimated at the municipality level considering impact (exposure and sensitivity) in relation to the adaptive capacity of human communities. Adaptive capacity reduces impact, and therefore reduces vulnerability. Vulnerability was not calculated for rising sea temperatures, as this effect impacts only marine and not terrestrial targets. Following is a description of how the different indicators for exposure, sensitivity and adaptive capacity were added to determine vulnerability.



Exposure to changes in rainfall and temperature: maps showing potential changes in rainfall or temperature (two maps) under two emissions scenarios (A2 and B1) were reclassified in five categories according to the probability of change (with 5 the highest probability).

Exposure to sea level rise: maps showing areas exposed to the rise in sea level. A digital elevation model was reclassified (90 m spatial resolution) in five categories (Very high: 0-1 meter above sea level; High: 1-2 masl; Medium: 2-4 masl; Low: 4-8 masl; and Very low: 8-16 masl).

Mapping sensitivity of targets: the analysis considered natural vegetation (mangroves), fishing sites (coastal lagoons), areas with potential for agricultural and population use. The maps are binary and indicate target´s presence (1 for the areas where the element is present, 0 for sites where the element is absent). A summarized map was then constructed by adding and reclassifying them using a logarithmic code instead of a binary code to differentiate each of the elements in the map (Coastal lagoon: 10, Mangrove, 100, capacity for agricultural use: 1000). A logical order of elements present in the same space was respected where areas overlapped, with priority given to natural elements (coastal lagoons and mangroves), and finally potential elements (capacity for soil use).

In the case of temperature and rainfall changes, the potential vegetation map developed by CATIE using Holdridge life zones (Zamora-Pereira, JC; Molina, LG; Imbach, P. Pending publication) was added to areas with natural vegetation cover (code 10000). The map projects future potential changes in vegetation according to changes in rainfall and temperature according to different scenarios.

Calculating sensitivity for each effect. A sensitivity map was constructed by multiplying the exposure map of one effect (categories 1 to 5) with the targets (presence) sensitivity map, resulting in a map with values between 1 (very low) and 5 (very high). There was no need to reclassify the map.

Adaptive capacity: determined as previously explained for all coastal municipalities, classified in five categories. Important to note that categories are ranked inversely: category 1 is very high capacity and 5 is very low.

Vulnerability to each impact: This was obtained by **multiplying** the final sensitivity map (with categories from 1 to 5) by the adaptive capacity map (1 to 5). Vulnerability results vary from very low (1) to very high (25). The results were reclassified in five classes in order to obtain the relative vulnerability of the study area. For example one pixel with sensitivity 4 (high) in a municipality with a capacity 2 (high), results in a pixel with vulnerability 8 (low). The final area maps cover only the coastal-marine municipalities.

Vulnerability	Class	Result from multiplying capacity by sensitivity
Very high	5	21-25
High	4	16-20
Medium	3	11-15
Low	2	6-10
Very low	1	1-5

Integrated vulnerability: The reclassified score (1 to 5) for vulnerability to changes in rainfall and temperature and vulnerability to sea level rise were added, and the results reclassified in 5 categories.

4 Potential Impact of Climate Change

4.1 Rise in sea surface temperature

4.1.1 Exposure

Figure 10 shows the level of exposure to thermal stress in the study area from 2006 to 2010. High and medium values of thermal stress were observed in the zone near Punta Manabique, indicating that coral bleaching can be expected in that area. Bleaching occurred in different points of Belize and Honduras during this period, but was not a generalized event. Various areas are also undergoing thermal stress, demonstrating the need for a monitoring system in the zone to identify bleaching and the capacity coral reefs to recover.

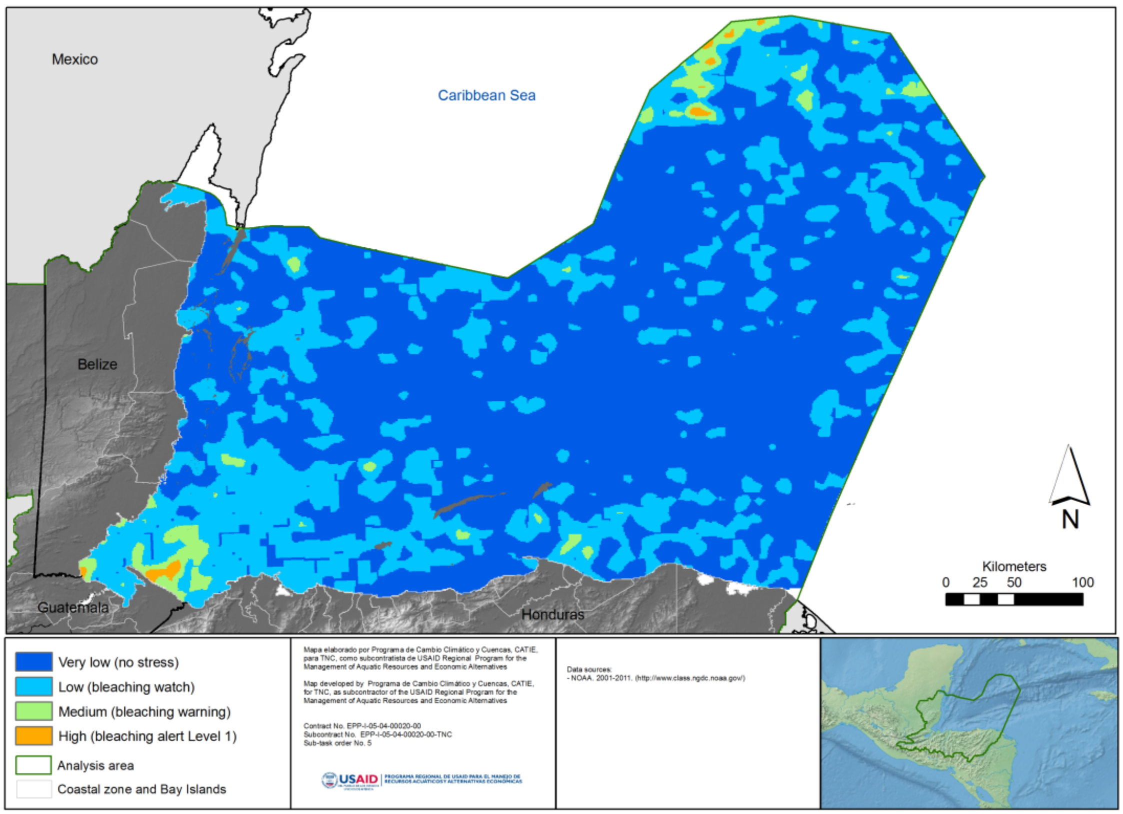


Figure 10. Thermal stress level 2006-2010

Thermal stress was very marked from 1998 to 2007, as can be seen by the following map. A generalized bleaching throughout the world occurred in 1998, seriously affecting the reefs in the study area.

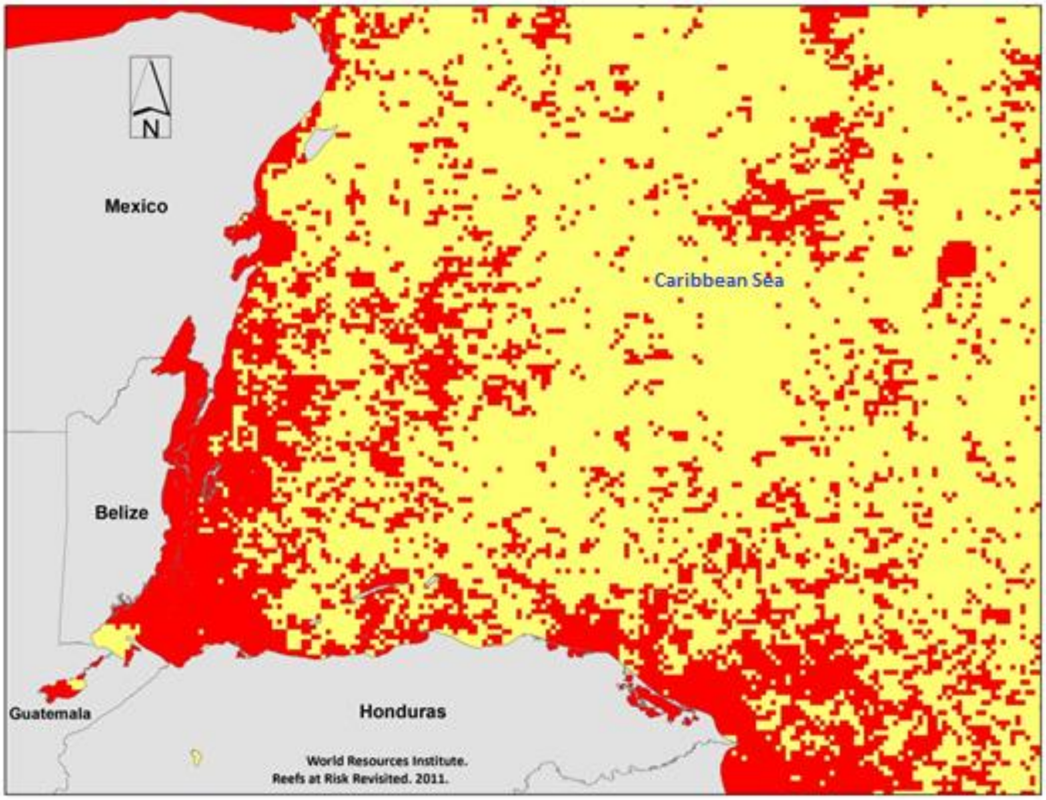


Figure 11. Thermal stress levels 1998-2007

An assessment of the future exposure to thermal stress of the study area shows that both emissions scenarios (B1 and A2) for the period 2030-2039 show a continued warming towards the Punta Manabique zone and towards the exterior of the Gulf of Honduras (**Figure 12**). However the results for the same emissions scenarios for the period 2090-2099 show that the entire study area, theBelizean, Guatemalan and Honduras Caribbean marine territory will be under thermal stress (**Figure 13**).

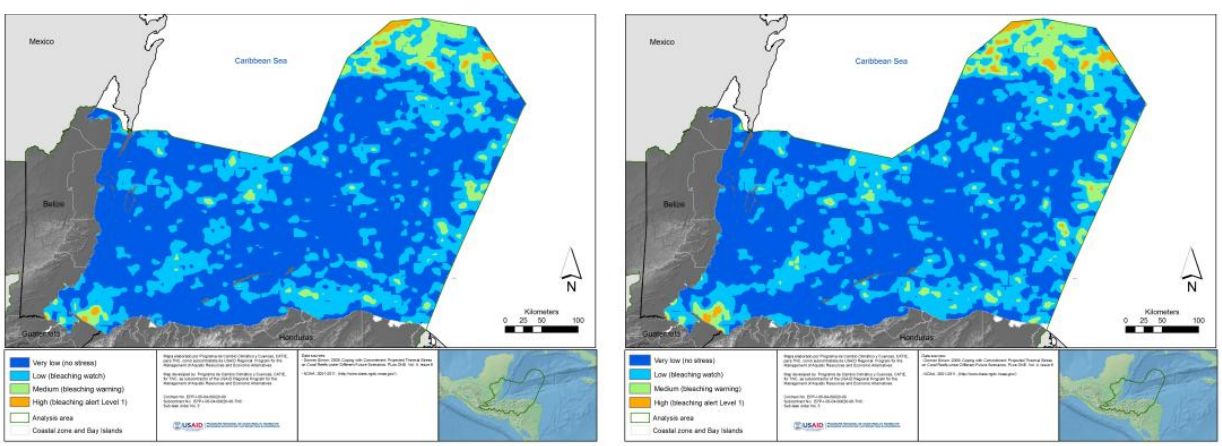


Figure 12. Thermal stress levels for 2030-2039 under emissions scenarios B1 (left) and A2 (right)

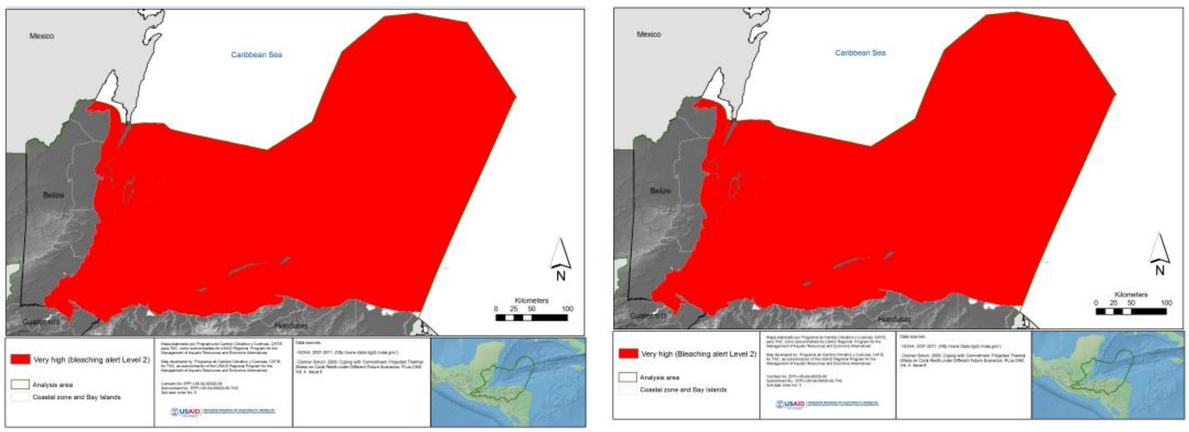


Figure 13. Thermal stress levels for 2090-2099 under emissions scenarios B1 (left) and A2 (right)

4.1.2 Sensitivity

Layers showing current and future thermal stress were laid over coral reefs, sea grasses, grouper and snapper spawning aggregation sites and important fishing sites. As previously noted few zones have been exposed to thermal stress in recent years. The period 2030-2039 shows increased exposure and impacts in the Gulf of Honduras, while the 2090-2099 period shows all the objects mentioned as exposed and suffering a general thermal stress, with a high impact predicted. This represents a severe threat to the coral reefs, which could suffer a general bleaching in the entire study area.

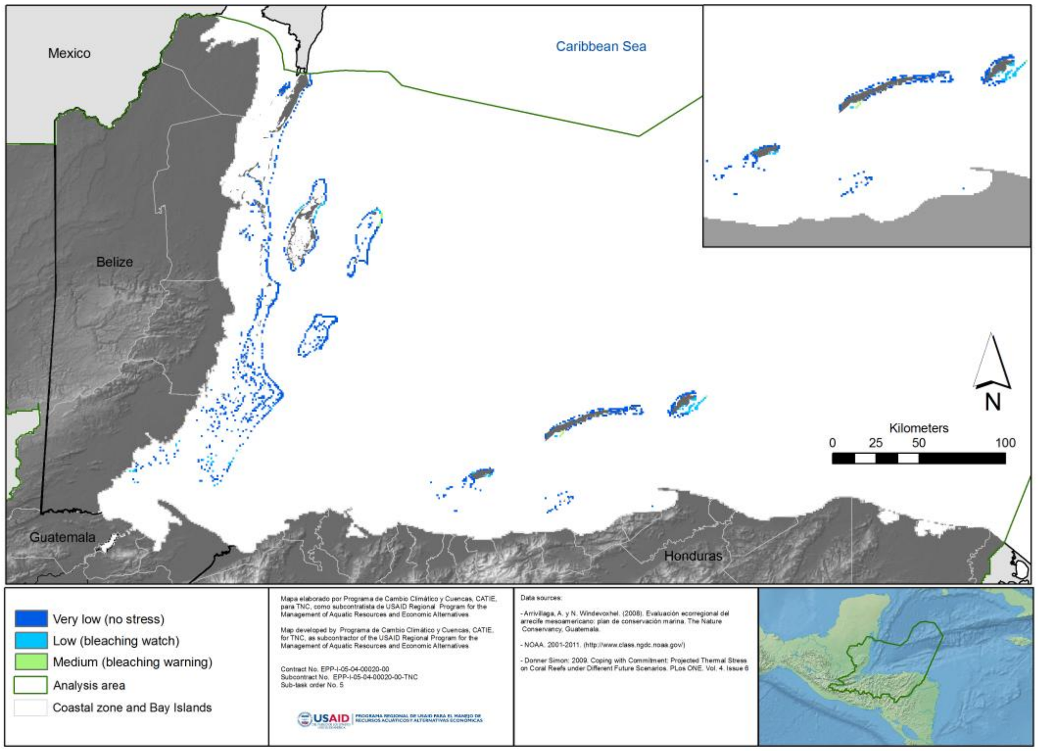


Figure 14. Reef sensitivity to sea surface warming during the period 2030-2039 under emissions scenario B1

4.2 Frequency and intensity of hurricanes in the Caribbean

According to history the Caribbean of Belize, Guatemala and Honduras are historically affected by hurricanes. This region is highly vulnerable due to the presence of human communities, sensitive ecosystems and low adaptive capacity. Although hurricanes affect the entire region, their effects differ; they are more frequent in some areas, while others are impacted by major hurricanes more often that other areas. Figure 16 shows how high and medium strength hurricanes converge in northern Belize and La Mosquitia of Honduras. This, together with soil quality, may explain why the predominant vegetation in these regions is pine savannahs, formed by centuries of hurricanes.

Figure 15. The recovery of mangrove forests from hurricane damage can take years. The interruption of hydrological flows caused by humans makes this process even more difficult (F.Secaira.)

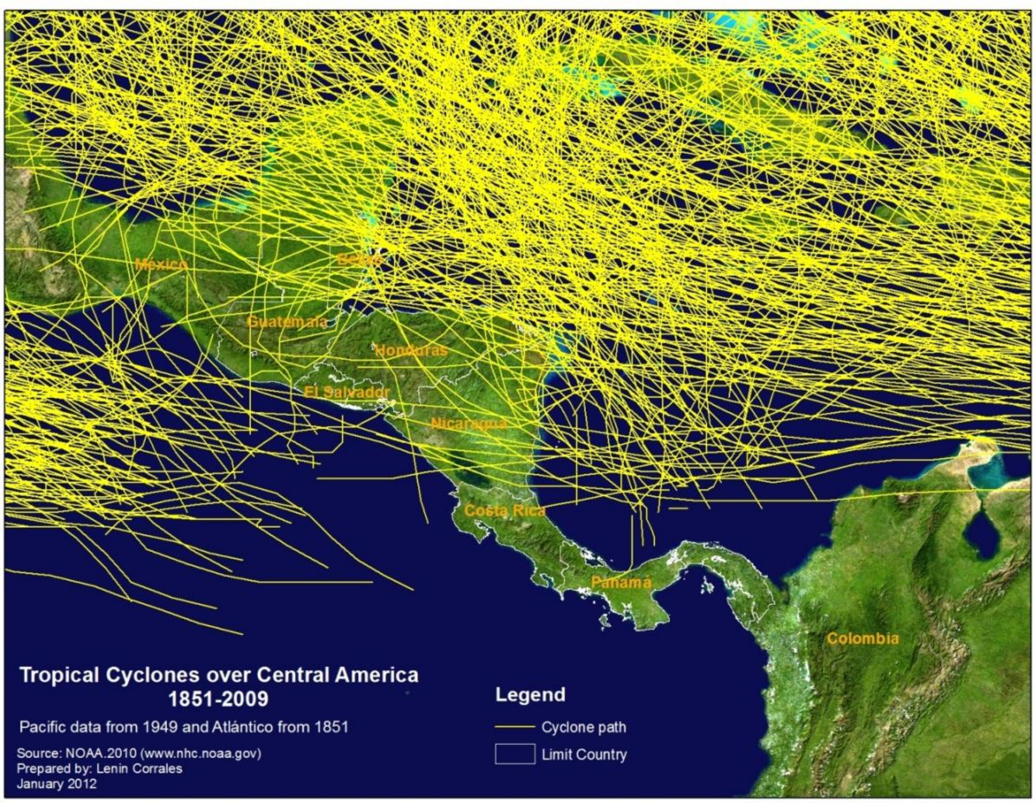


Figure 16. Hurricane trajectories over Central America

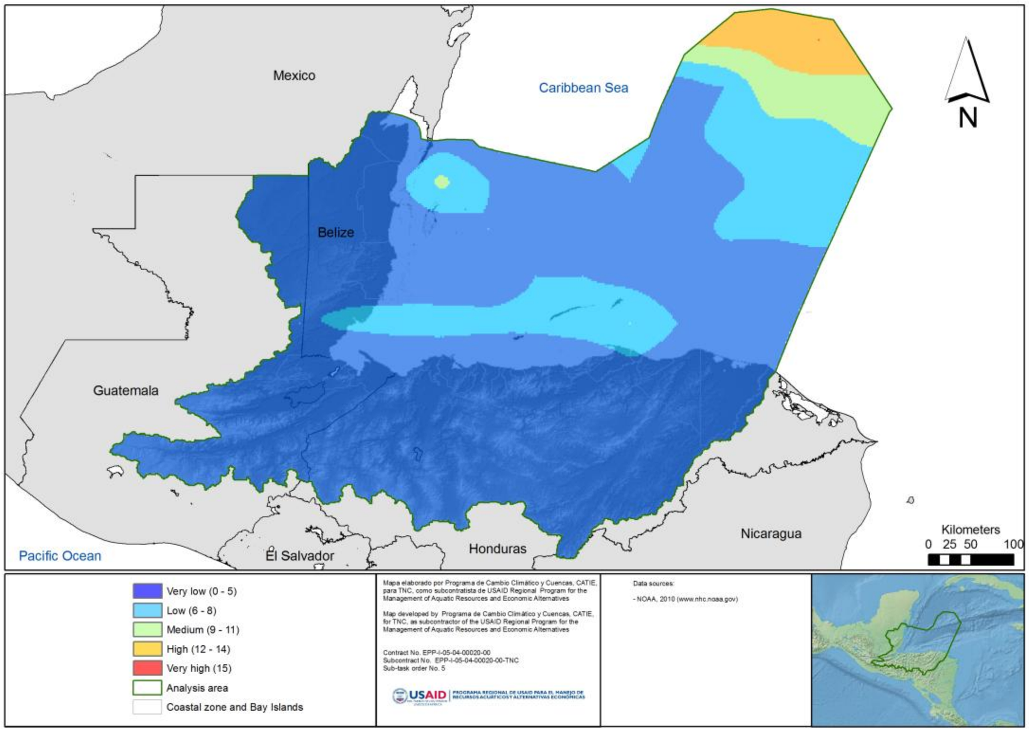


Figure 17. Hurricane frequency 1851-2009

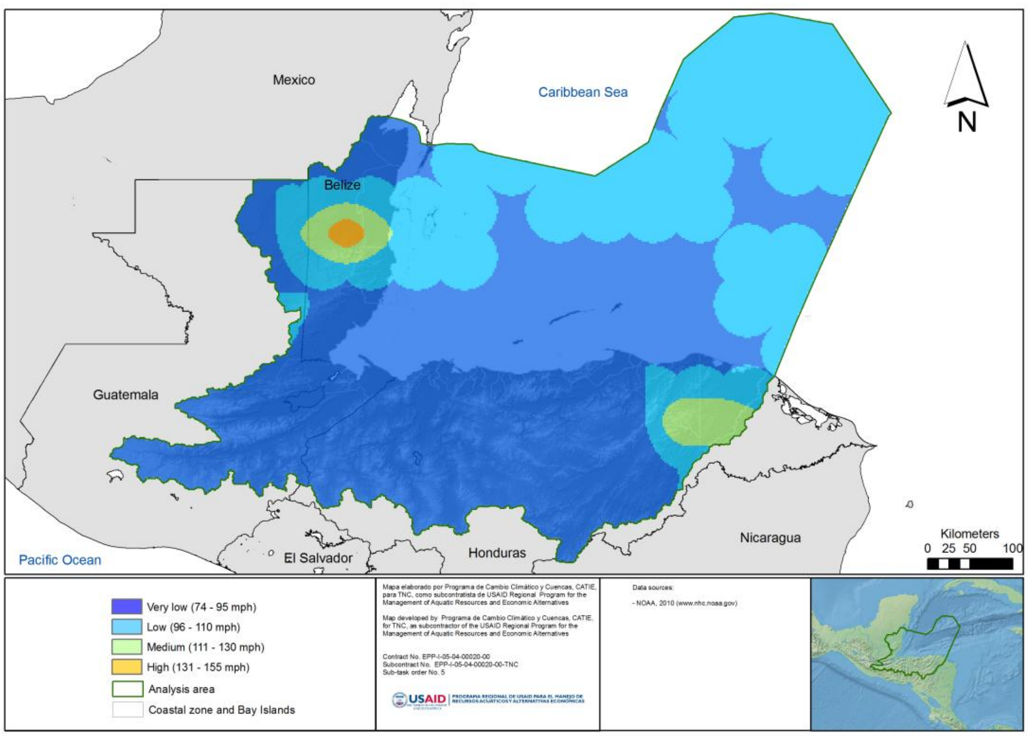


Figure 18. Hurricane intensity 1851-2009

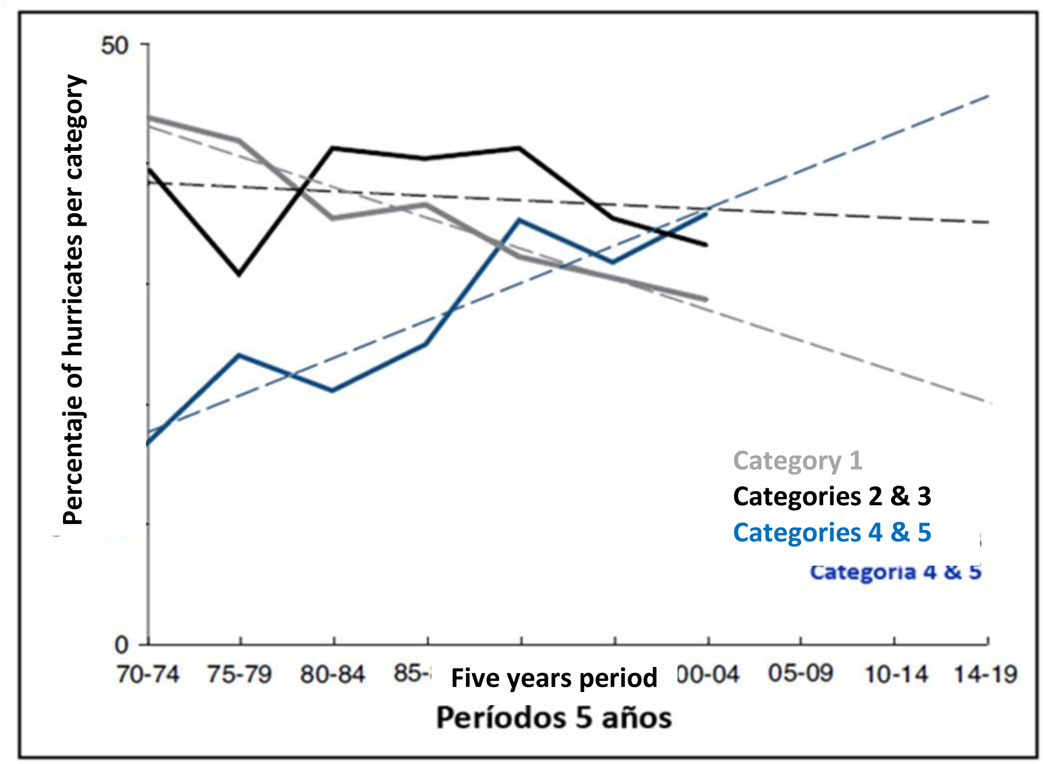


Figure 19. Hurricane frequency by category from 1970 to 2004. Source Wilkinson, C., and Souter, D. (2008)

Hurricanes strength has increased over the last 150 years of recorded history. Accoordiing to records events categories 4 and 5 are more often now, and events categories 1 and 2 are less frequent (see figure 19). Hurricane strength will continue to increase as sea surface temperature will increase according to climate change projections.

4.3 Rise in sea level

One of the greatest consequences of climate change is the rise in sea level, which intensifies stress in many areas and in particular areas with human activities (Feenstra et al. 1998). Change in sea level is produced by global, regional and local factors such as changes in sea surface temperature, salinity, winds, ocean currents, contributions from El Niño and La Niña phenomena (IPCC *2007a*), glacial isostatic adjustment and subsidence, either natural or caused by humans. Consequently the relative rise of sea level is a consequence of climate change as well as many other factors that vary from place to place (Nicholls 2010).

According to the IPPC (2007a) the global sea level rose at an average rate of 1.8 [1.3 a 2.3] mm per year from 1961 to 2003. Other authors (Domingues et al. 2007) have estimated a rise of

1.5 ± 0.4 mm yr^{-1} during the same period, similar to the range managed by the IPPC for that period. Sea level rise in Southern Florida Keys is estimated at 30 cm over the past 110 years, for an average of almost 3 mm per year.

If GHG are stabilized by 2100 at levels of scenario A1B (720 ppm), thermal expansion itself would cause an additional rise in sea level of 0.3 to 0.8 m in 2100 over that of 1980–1999 (IPCC 2007a). Other factors such as changes in currents and ice thawing may also aggravate this impact. According to predictions for the Caribbean Sea level will rise from 0.18-0.59 m by 2099 (Cambers et al. 2007). Results obtained by other authors such as Rahmstorf (2007) with the application of future IPPC climate change scenarios (2010) hold that sea level could increase between 0.5 to 1.4 m over the 1990 level (IPCC 2007a).

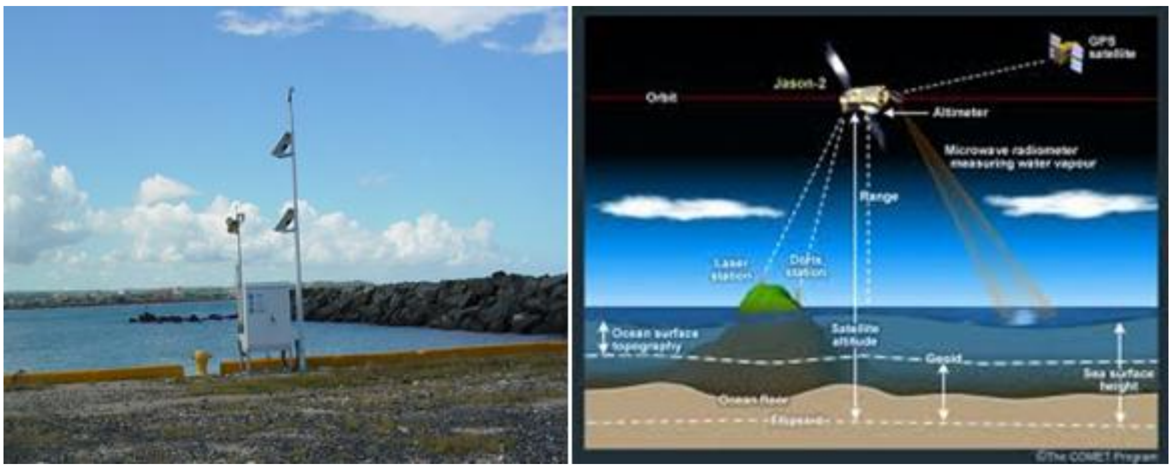


Figure 20. Methods for measuring sea level: tide gauge (relative) and satellite (absolute)

Records from tide gauges in 3 ports in the study area were analyzed, as well as satellite measurements taken since measurement began in 1992 (Figures 21, 22, 23).

It is a proven fact that sea level has increased in absolute terms at three different points in the study area, and in relative terms in two points. Sea level in Puerto Cortés rose 9.2 mm per year from 1945-1975 (Figure 22), and in Puerto Castilla 3.1 mm per year from 1954-1970 (Figure 21), both relative to land. This is a total rise of almost 30 mm, similar to data from the keys of southern Florida. Results measured by tide gauges in the Port of Santo Tomás in Guatemala (Figure 23) show a reverse trend from 1962 to 1982, although not the absolute measurements taken by satellite.

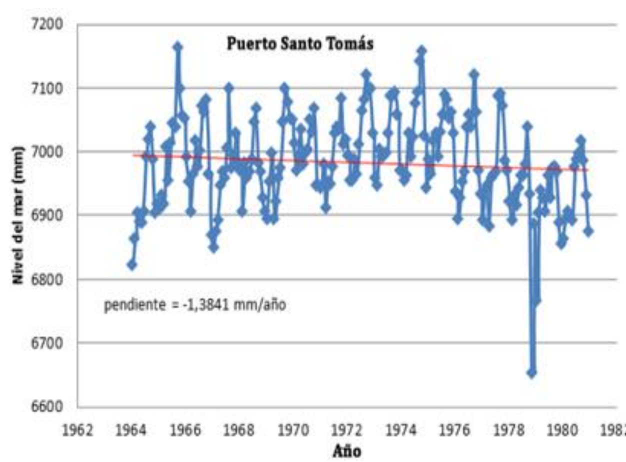


Figure 21. Relative change in sea level in Santo Tomás

Figure 24 shows the results in absolute terms for analysis stations placed in front of the ports for the period 1992-2010. All cases show a clear rising trend. Data indicate an increase of 8 cm in Puerto Castilla, 3.4 cm in Puerto Cortés and 3.5 cm in Puerto Santo Tomás.

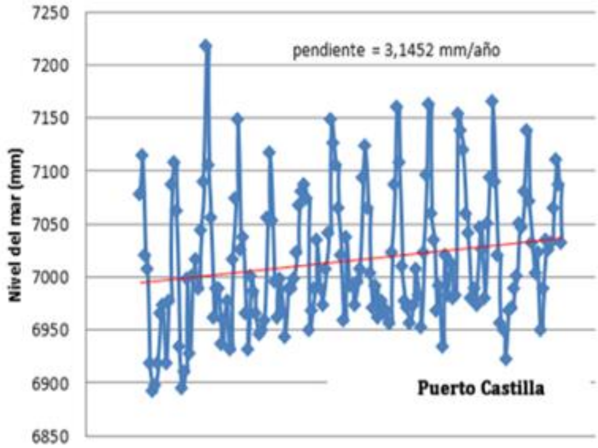


Figure 22. Relative change in sea level in Puerto Castilla

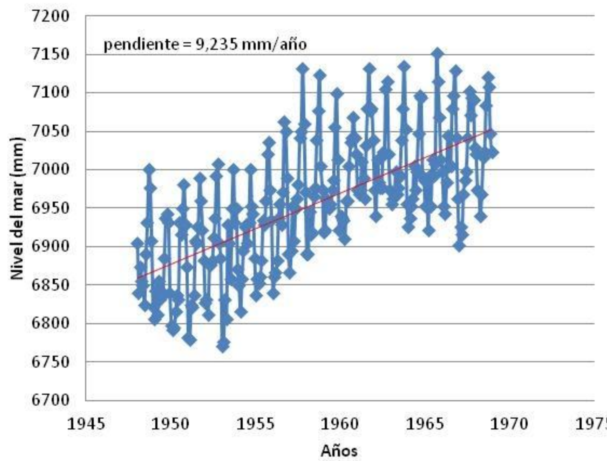


Figure 23. Relative change in sea level in Puerto Cortés

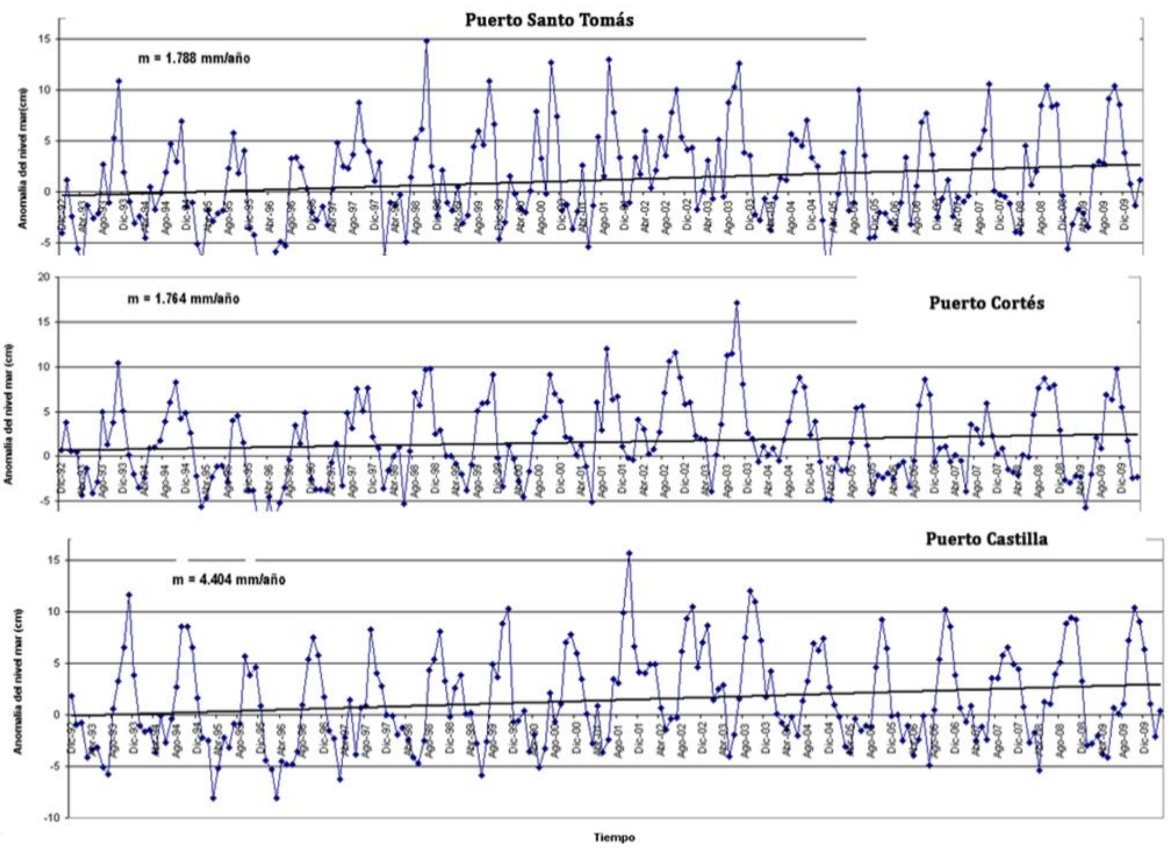


Figure 24. Absolute rise in sea level in the Ports of Santo Tomás (Guatemala), Puerto Cortés and Puerto Castilla (Honduras) for periods of time between 1992 and 2009

4.3.1 Exposure

Exposure to coastal hazards is defined by proximity to the coast and the topography. Most of the territory evaluated is at a sufficiently high altitude to avoid exposure to sea level rise. The only aggravating factor is that the population and infrastructure are concentrated within the first kilometers of the coast.

Areas with greater exposure are the Districts of Corozal and Belize City in Belize, and the municipalities of Trujillo and Brus Laguna in Honduras. The municipality of Livingston in Guatemala and the Honduran Municipalities of Arizona, Esparta, La Masica, La Ceiba, Jutiapa and Utila include areas with significant exposure (**Figure 25**).

Table 14. Assessment of exposure to the rise in sea level

Elevation above sea level	Grading	Justification
< 1 meter	Very high	Areas highly exposed to flooding and erosion due to tides, extreme rains, and storms of all categories with the actual sea level. Areas covered with the foreseen sea level rise for 2090.
1 to 2 meters	High	Areas exposed to flooding by storms at the current sea level. Areas highly exposed to flooding and erosion due to tides, extreme rains, and storms of all categories with the foreseen sea level rise for 2090.
2 - 4 meters	Medium	Areas exposed to extreme events (3, 4, 5) under current conditions. Areas exposed to flooding by storms and tides with the sea level rise predicted for 2090.
4 - 8 meters	Low	Areas exposed to extreme category 5 events under current conditions Areas exposed to flooding by extreme events with the current sea level.
8 - 16 meters	Very low	Areas not currently exposed and not exposed with sea level rise.

Areas at 1, 2, 4, 8 and 16 meters above sea level were determined using the digital elevation model at 90 m following the scoring table, giving as a result the exposures stated in the map in Figure 25.

4.3.2 Sensitivity

Regional sensitivity to impacts is in function of their development patterns, such as their use for fishing, agriculture, infrastructure and population, and their current altitude above sea level. One variable not considered in this study was distance from the coast and flooding zones. The population of coastal municipalities and districts in 2010 was 237,500 in Belize, 166,200 in Guatemala and 733,600 in Honduras, for a total of 1,137,300 inhabitants.

More developed areas and those with a greater population are more sensitive, such as Belize City, Puerto Barrios, Puerto Cortés, La Ceiba, and Trujillo (Figure 27). In comparison, the Municipality of Brus Laguna, with a significant exposure, is considered to have a relatively low sensitivity given its lack of development and low population density.

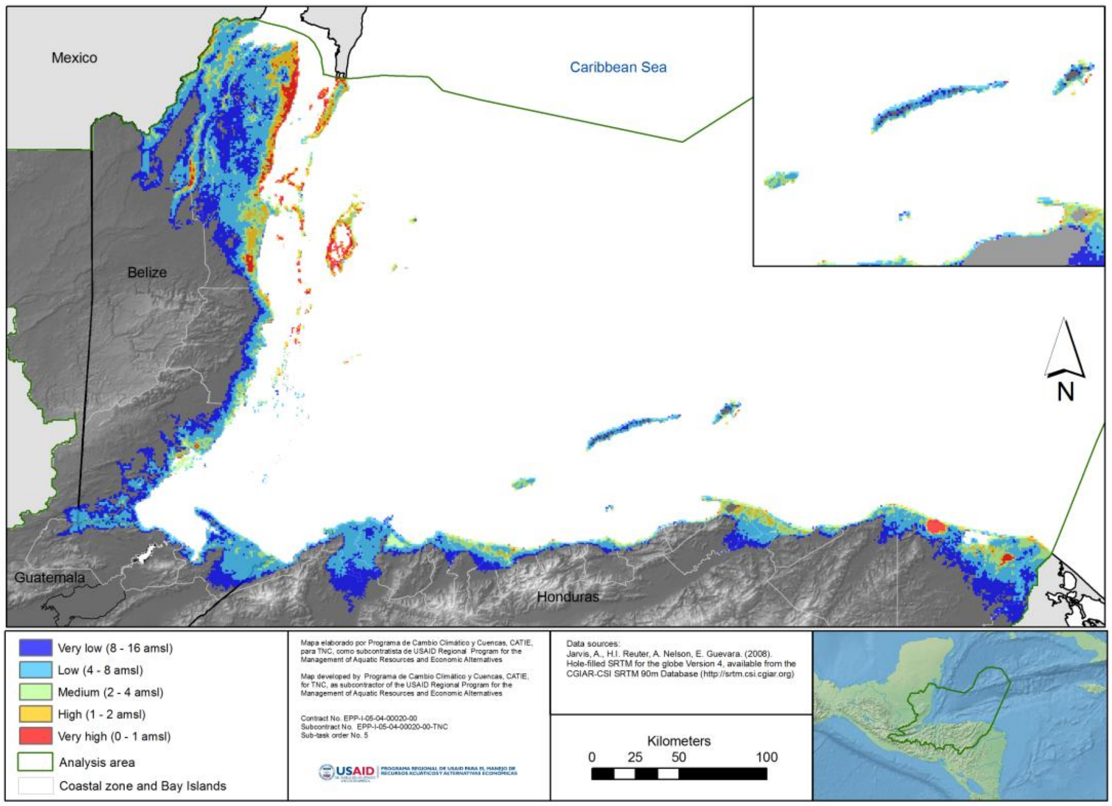


Figure 25. Coastal zone exposure to sea level rise

Figure 26. The impact of sea level rise deriving from the magnitude of increase and presence of sensitive ecosystems and infrastructure costs. The clear intrusion of sea level can be seen in La

Ceiba, Honduras (left) and Livingston, Guatemala (right) in local infrastructure which was originally built far from the shore (Photos L.Corrales and Black Caribbean National).

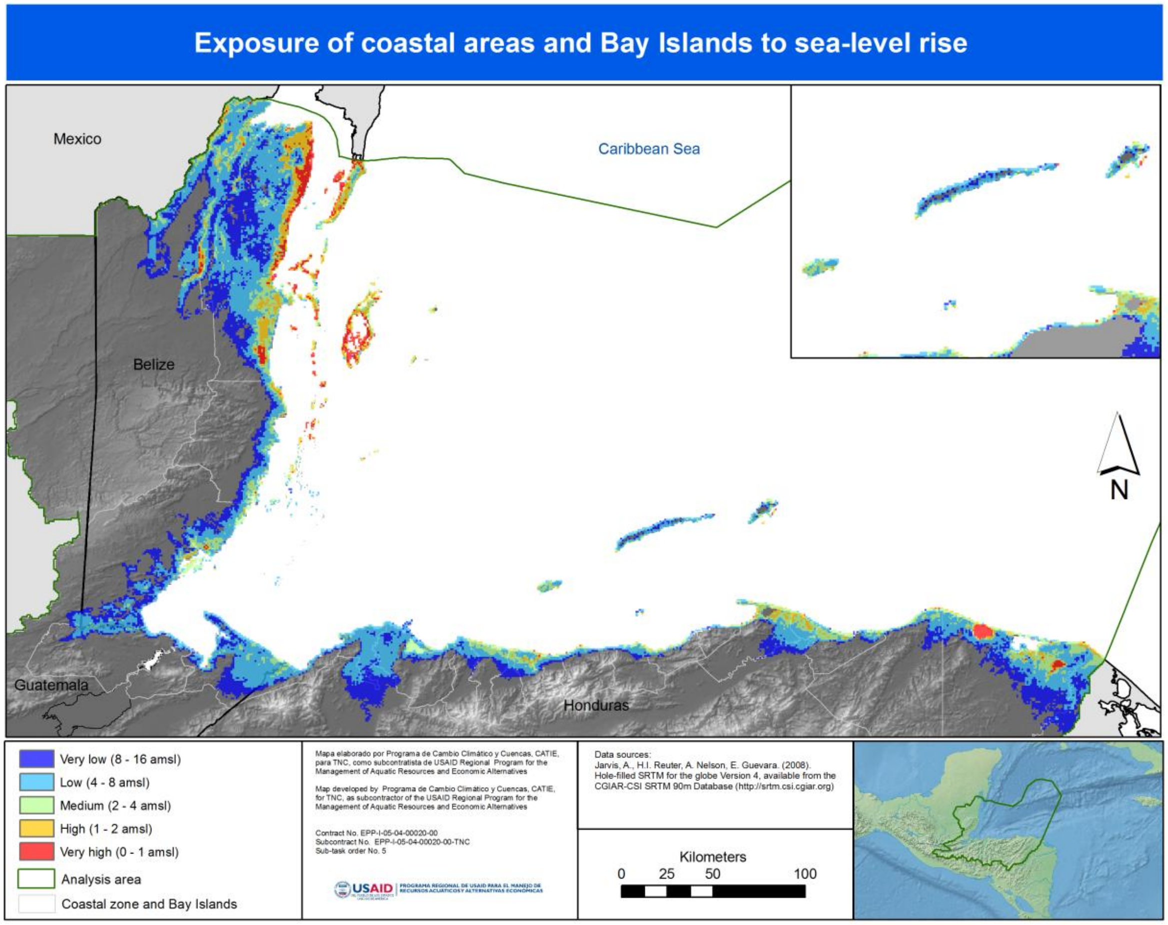


Figure 28. Coastal zone sensitivity to sea level rise.

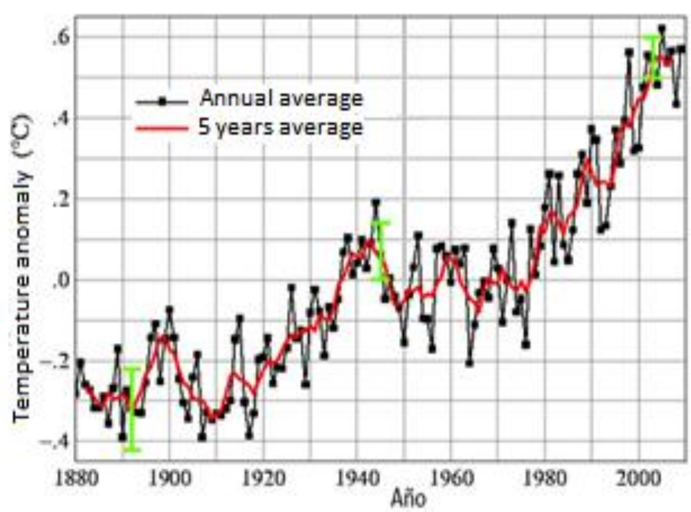


Figure 27. Increase in global temperature from 1880 to 2010

4.4 Changes in air temperature and rainfall patterns

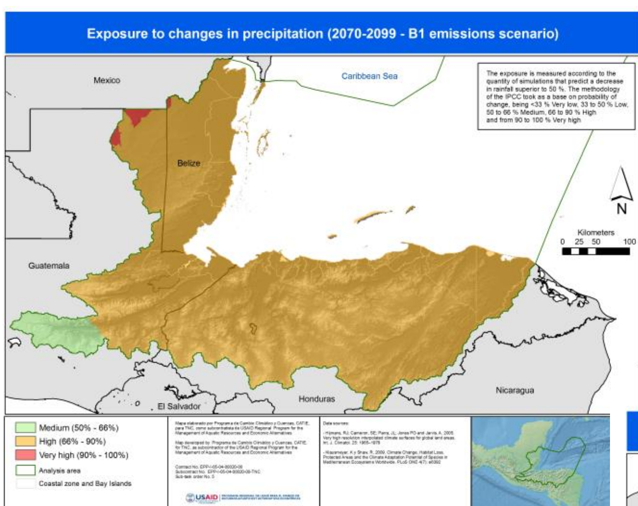
An analysis of a set of climate change indices taken in 2005 for Central America and for the period 1961-2003 show that the region is undergoing a general warming trend, with a greater occurrence of days with maximum extreme temperatures and a rise in the minimum temperature, while low temperature events have decreased.

Annual rainfall indices indicate no significant increase, although rains have been observed to be more intense. That is, rainfall patterns have changed, resulting in more intense rains during a shorter period of time (Aguilar et al. 2005).

4.4.1 Exposure

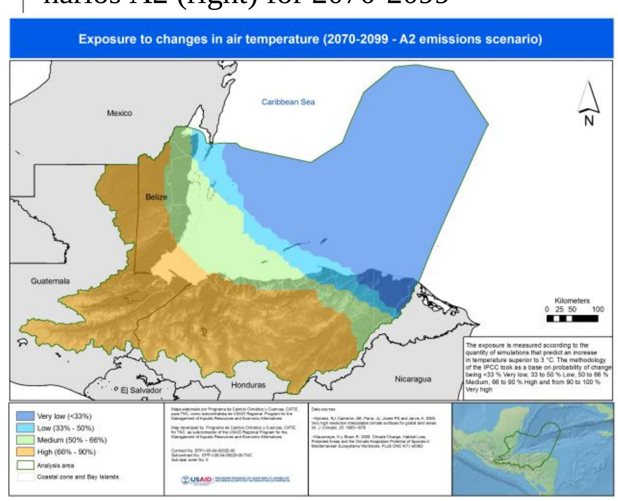
The mean annual global temperature has risen close to one degree (0.6°C) since 1888 (**Figure 28**). In Central America the average annual temperature has risen approximately 1^{o} C since 1900; the number of hot days and nights increased 2.5% and 1.7% respectively per decade, while cold nights and days decreased -2.2% and -2.4% respectively. Extreme temperature have risen 0.2^{o} C to 0.3^{o} C per decade. (Aguilar et al. 2005).

The analysis considered changes in air temperature according to emissions scenarios B1 and A2 for the period 2070-2099. Exposure was measured according to the certainty that an increase of over 3°C will ocurr, according to the different scenarios modeled. The IPCC methodology specifies the following categories:



Classification	% of scenarios that predict a 3 ^{0}C
Very low	<33% of
Low	33 to 50%
Medium	50 to 66%
High	66 to 90%
Very high	90 to 100%

Figure 29. Exposure of study area to changes in air temperature according to emissions scenarios A2 (right) for 2070-2099



If future scenarios correspond to B1 type emissions, then the probably of a 3° C change in air temperature for the region would be very low. However, changes under emissions scenario type A2 would exceed 3°C with a high probability of occurrence mainly in the districts of southern Belize, Guatemala, and the western municipalities of

Honduras. Values for the rest of the region show a medium probability, which could possible result in important impacts on coastal habitats such as lagoons and mangroves due to the increase in surface temperature. The increased beach temperature would also affect turtle nesting sites as sex ratio is determined by temperature during incubation.

Exposure to changes in precipitation

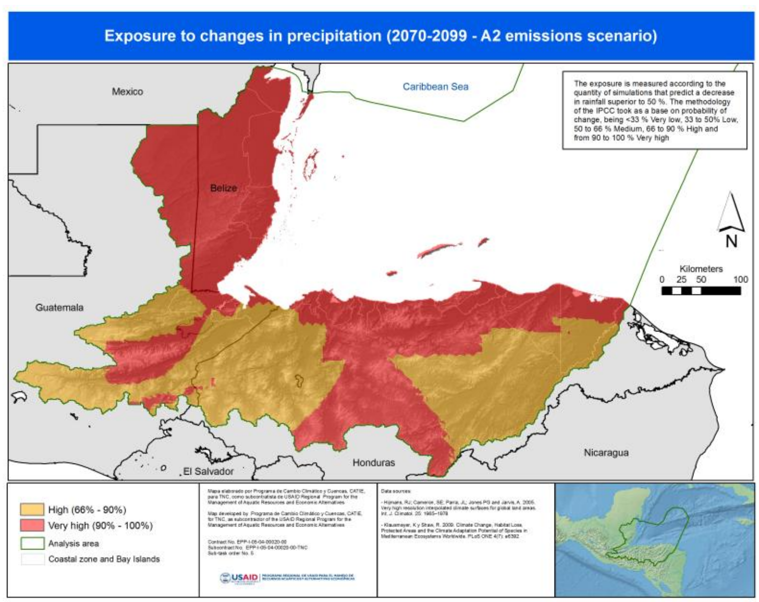
Figure 30 shows study area exposure to changes in rainfall according to emissions scenarios B1 and A2 for the period 2070-2099. Exposure is measured according to the probability of change based on the number of simulations that predict a decrease in rainfall. The IPCC methodology for probability of change was used:

Classification	% of scenarios that predict a 3 ^{0}C
Very low	<33% of
Low	33 to 50%
Medium	50 to 66%
High	66 to 90%
Very high	90 to 100%

Figure 30. Study area exposure to changes in rainfall for the period 2070-2099, according to emissions scenarios B1 (above) and A2 (below)

4.4.2 Sensitivity

Agriculture is the most important sector that is sensitive to increased temperature and reduced rainfall. Projections using scenario A2 shows that most agricultural areas will be highly affected.



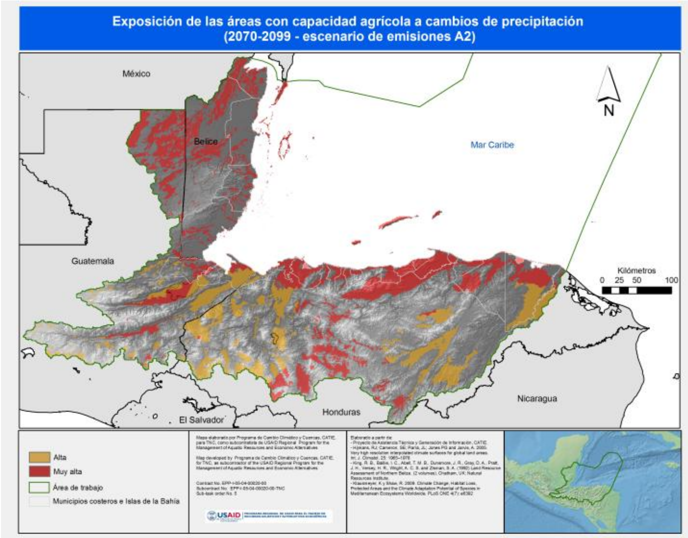
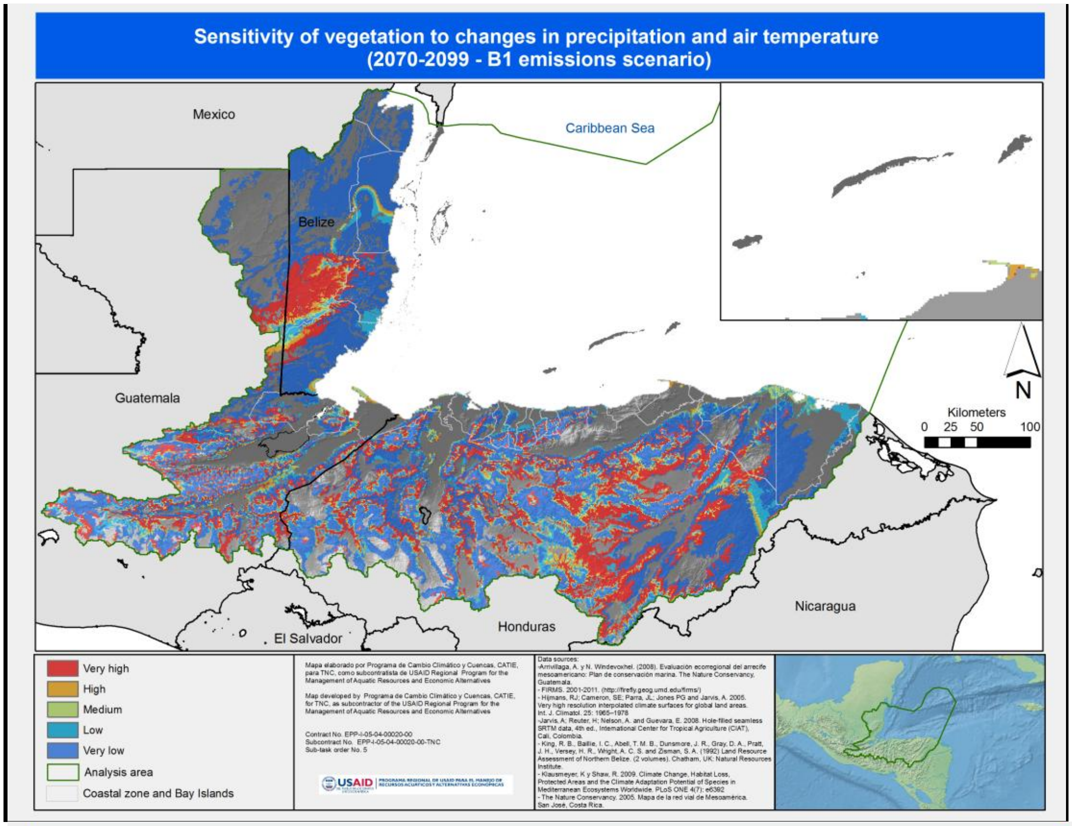


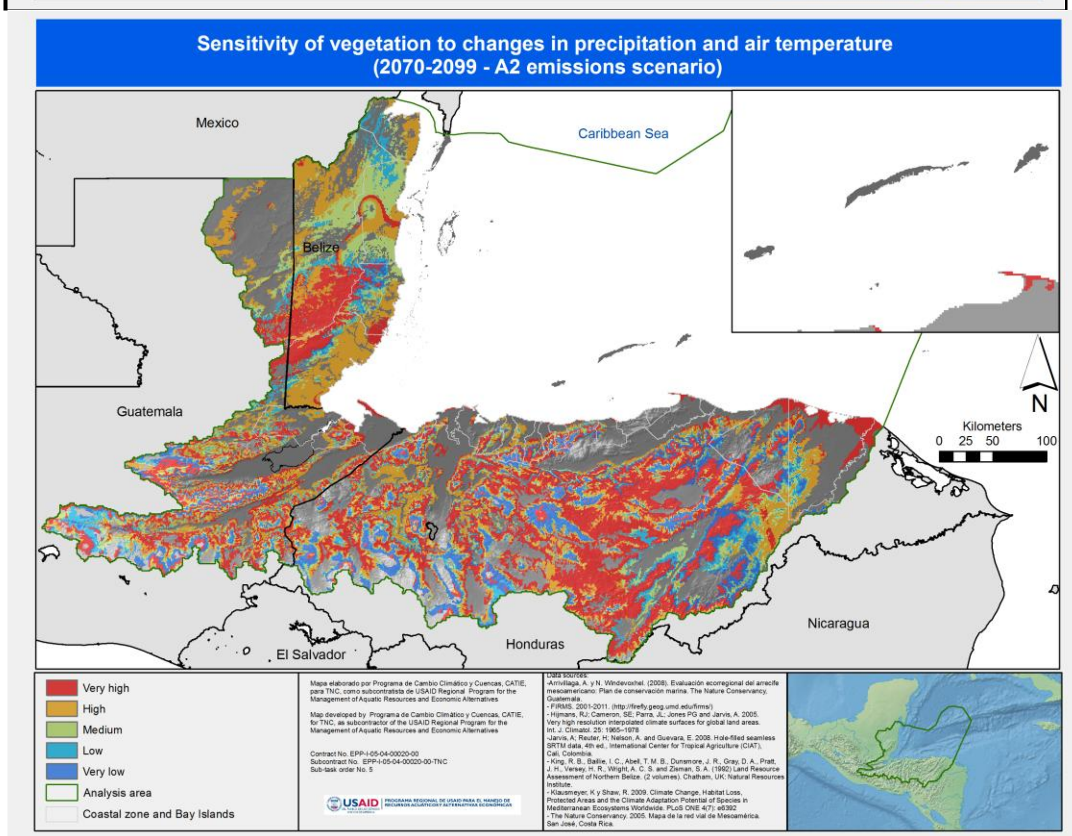
Figure 30a: agricultural lands affected by changes in precipitation.

Natural vegetation´s sensitivity to changes in temperature and rainfall was assessed by quantifying probability of changes in Holdridge life zones. Holdridge combined temperature, humidity, altitude and latitude to define life zone, therefore predicting changes in tempereatura and humidity will predict changes in life zones as well. Each life zone is composed by an particular combination of species, so a shift from one life zone to another caused by changes in temperature and humidity will change the species composition.

Figure 31 Maps (figure 31) show the results obtained using emissions scenarios B1 and A2 for the period 2090-2099. According to the results most current life zones in most will change, with the greatest changes occurring in higher elevations (above 2,000 masl).

Figure 31 (next page). Changes in life zones reflect vegetation sensitivity to changes in rainfall and temperature for the period 2070-2099, according to B1 (above) and A2 (lower) emissions scenarios


Sensitivity of vegetation to changes in precipitation and air temperature
(2070-2099 - B1 emissions scenario)
Mexico
Caribbean Sea
Belize
Guatemala
Honduras
El Salvador
Nicaragua
N
Kilometers
0 25 50 100
Very high
High
Medium
Low
Very low
Analysis area
Coastal zone and Bay Islands


Sensitivity of vegetation to changes in precipitation and air temperature
(2070-2099 - A2 emissions scenario)
Mexico
Caribbean Sea
Belize
Guatemala
Honduras
El Salvador
Nicaragua
N
Kilometers
0 25 50 100
Very high
High
Medium
Low
Very low
Analysis area
Coastal zone and Bay Islands

5 Vulnerability to Climate Change

5.1 Results of the adaptive capacity analysis

The adaptive capacity of the coastal municipalities and districts in the study region show values ranging from medium to low, while the Municipalities of Livingston in Guatemala and Balfate, Jutiapa and Limón in Honduras show the greatest capacity to confront their exposure and sensitivity to coastal hazards. However this capacity is lower in the District of Belize with an important population, as well as in the Municipality of Puerto Cortes, La Ceiba, Trujillo and the Bay Islands in Honduras, suggesting that coastal zone management may be a singular challenge (**Figure 32**).

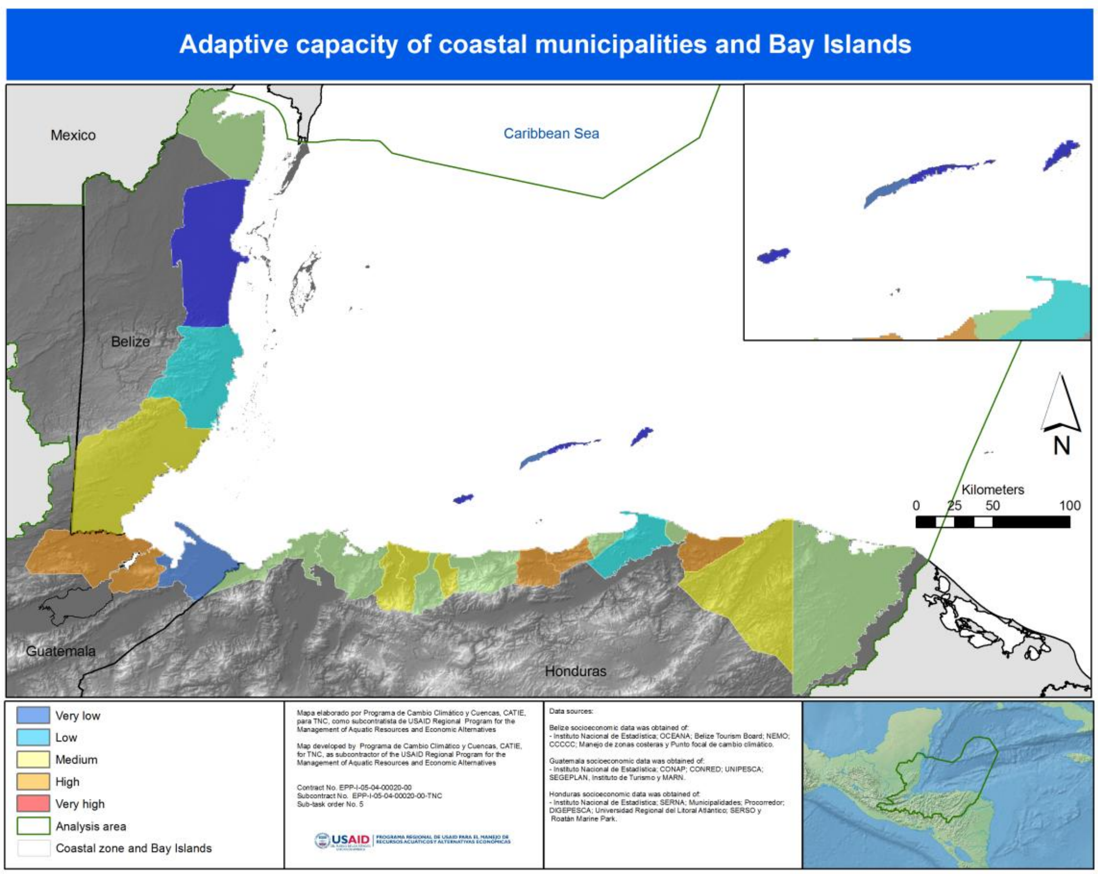


Figure 32. Adaptive capacity of the coastal municipalities and the Bay Islands

5.2 Vulnerability to a potential rise in sea level

Combining the different indicators shows that the regional vulnerability to a rise in sea level is concentrated in the northern districts of Belize and the municipalities of central Honduras, the areas with the greatest population density (**Figure 33**). This high vulnerability is in function of multiple challenges such as topography, infrastructure development and low adaptive capacity expressed by its social indicators. We could therefore conclude that all the coastal municipalities and districts need to develop adaptation strategies at the level of local government, in association with other government offices that are responsible for social development.

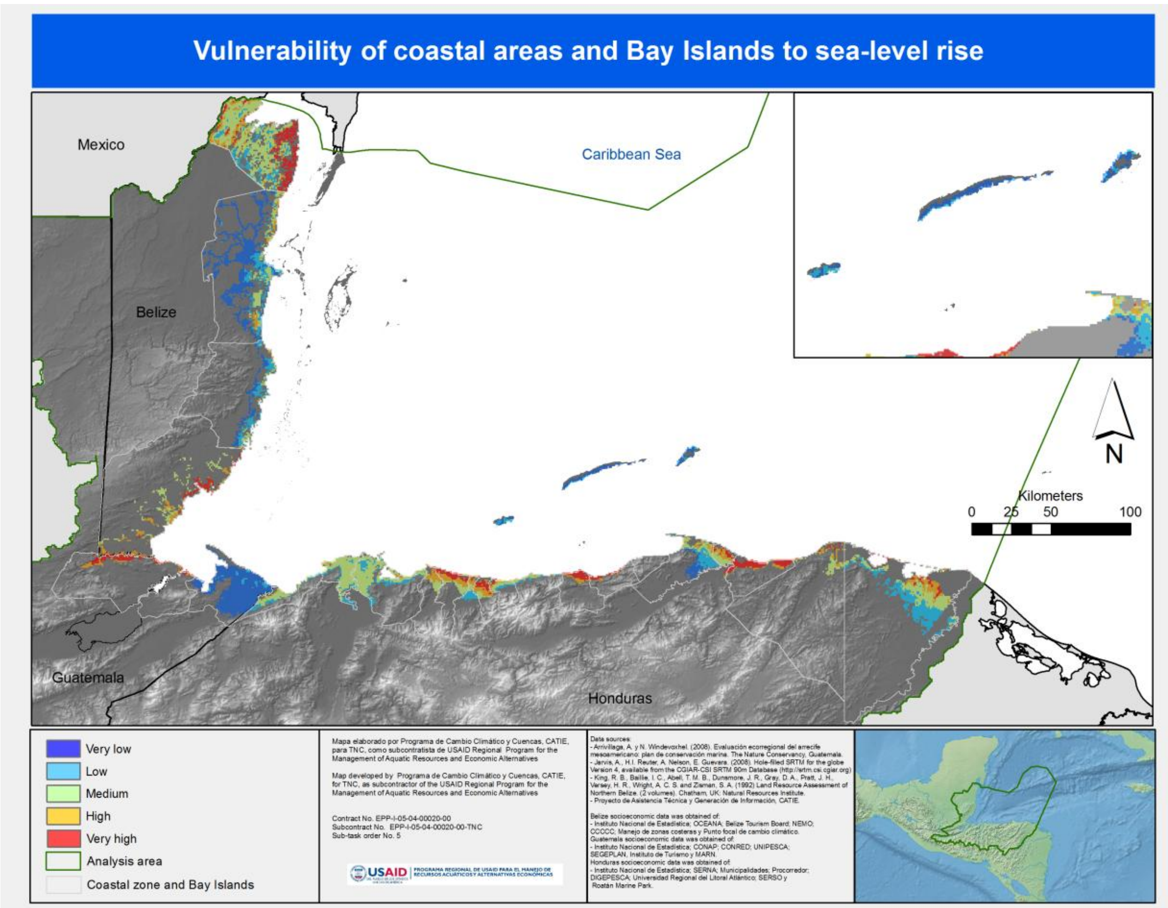


Figure 33. Coastal zone and Bay Islands vulnerability to a rise in sea level

5.3 Vulnerability to a potential rise in temperature and drop in rainfall

Regional vulnerability is obtained by combining the probable changes in vegetation shows that coastal habitats (coastal lagoons, mangroves, sea turtle nesting sites), coastal lagoon fishing areas, agricultural areas and areas with a population density that could suffer some kind of impact from future changes in temperature and rainfall, together with the adaptive capacity at the municipal level.

Figure 34 shows that coastal municipalities of Honduras have the greatest vulnerability to changes in temperature and rainfall, given the sensitivity of their large agricultural areas.

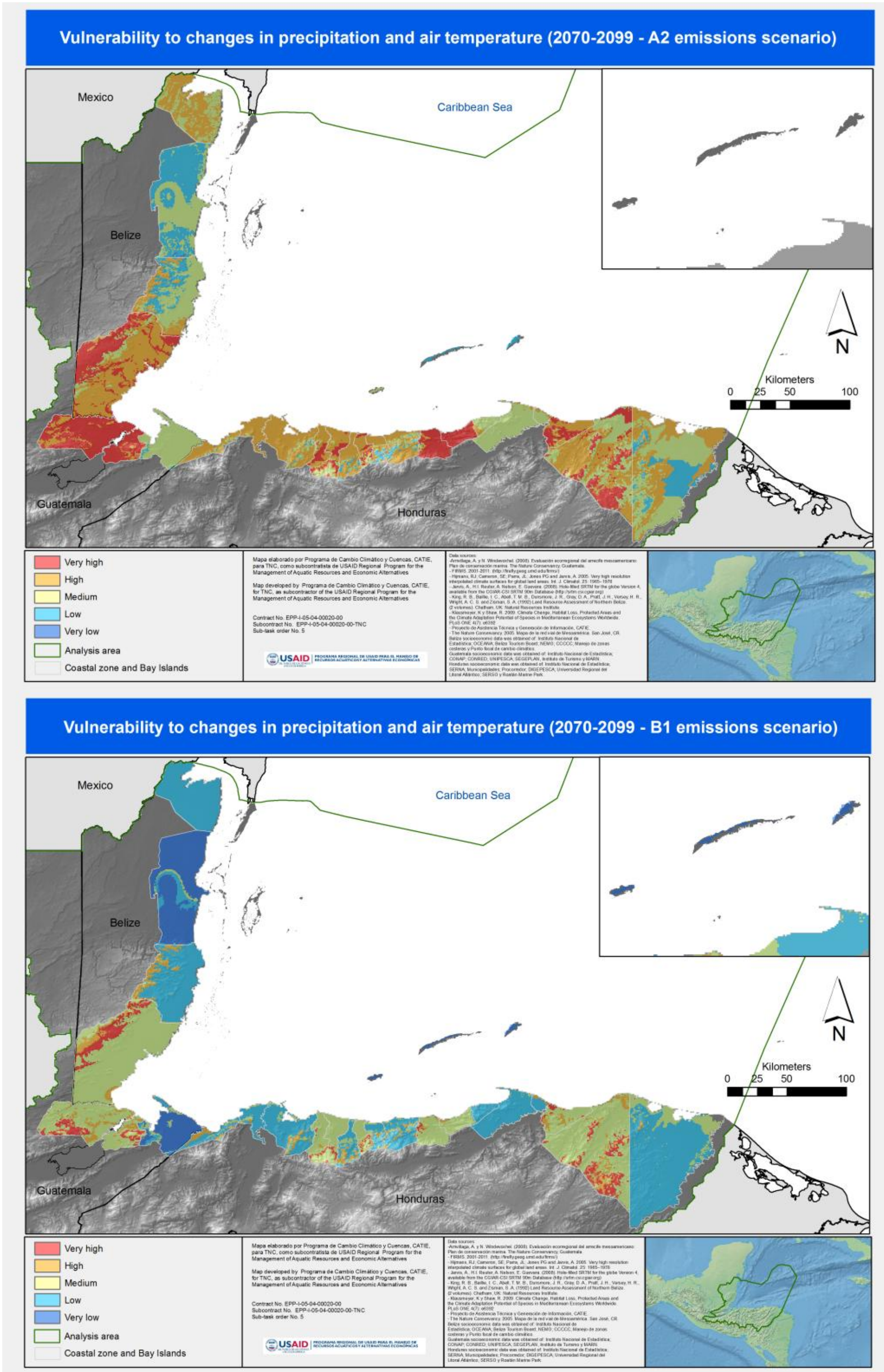


Figure 34. Vulnerability to changes in air temperature and rainfall for he period 2070-2099 according to emissions scenarios B1 (above) and A2 (below)

5.4 Integral vulnerability to the effects of climate change

Integral vulnerability to climate change was measured by combining layers of data on vulnerability to sea level rise and changes in temperature and rainfall (**Figure 35**). This perspective obviously does not consider all the aspects of vulnerability to CC, as it is limited to layers showing potential impact and the adaptive capacity indicators evaluated. A general panorama of the Caribbean is presented for the three countries with the most vulnerable municipalities. The combination of different layers of vulnerability to a large degree reflects development patterns in the region, with population centers (greatest sensitivity) and undeveloped areas (lowest adaptive capacity) standing out. Special attention should be given to the development models currently prevailing on the coast, as these also determine the social indicators that affect adaptive capacity.

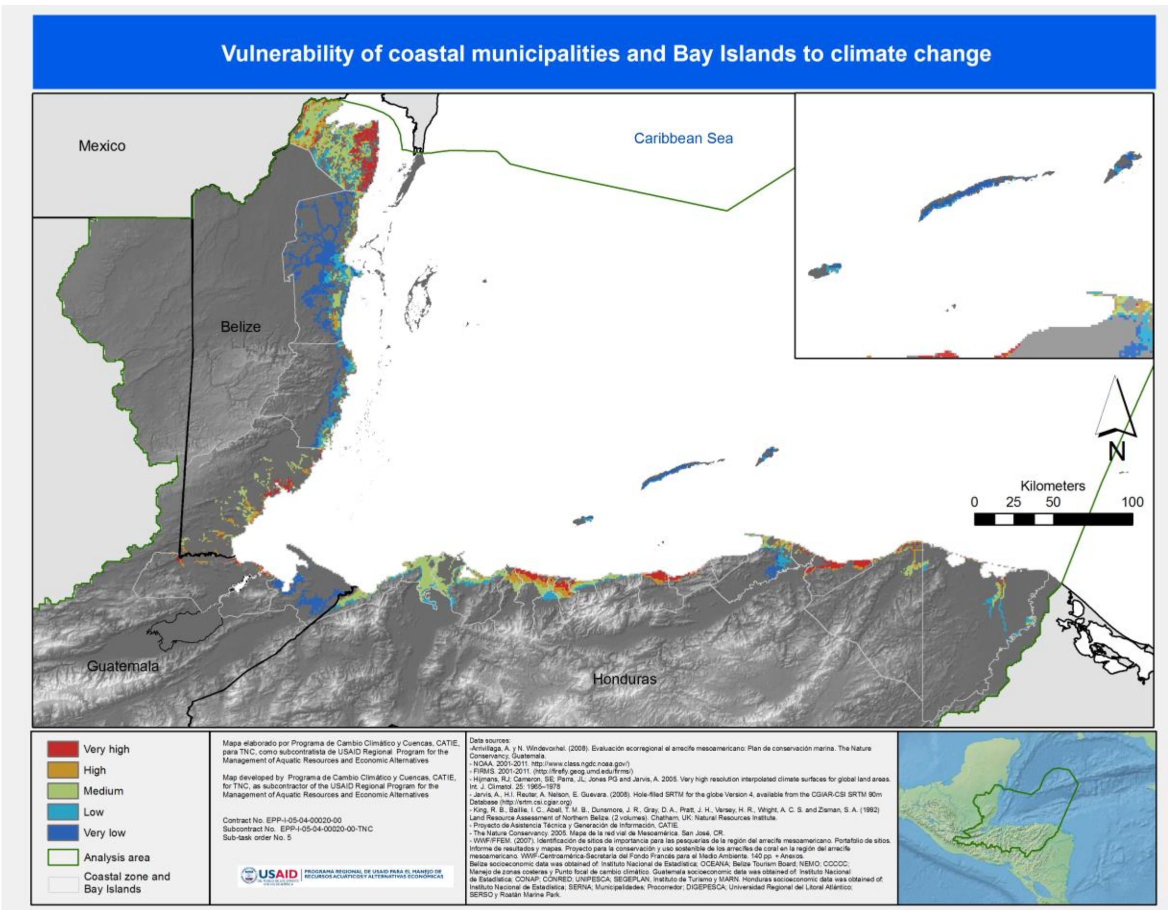


Figure 35. Current vulnerability of coastal municipalities and the Bay Islands to climate change

6 Conclusions

This vulnerability analysis should be interpreted within the context of the models and scenarios available at time of analysis, the information available (particularly social data) and the assumptions and hypothesis used. We can draw a series of firm conclusions:

1. Climate change vulnerability varies significantly through the Caribbean, determined by the differences in exposure, by the presence of sensible focal objects and by the adaptative capacity of communities. As en example, Northern Belize and Honduran Mosquitia have similar exposures (very low lands and intense hurricanes), but Northern Belize is more vulnerable because it has more inhabitants, agriculture and infrastructure.
2. Knowledge acquired through the preparation of this vulnerability analysis may be just as, if not more useful, than the results of the analysis itself for future assessments.
3. Most districts and municipalities present some areas of critical vulnerability which should be used as a starting point to initiate adaptation activities.
4. Improvements in social and economic aspects are the most cost-effective approach to to reduce vulnerability to Climate Change, and the focus of governments during the next decades. The current exposure of infrastructure or populations can be reduced only at high cost. But avoiding that future expansion be built in areas at risk and built with inappropriate techniques is relatively easy to avoid. Similarly you can avoid further deteriorating natural systems such as mangroves and coral protection.
5. Areas identified with greater impacts are closely related to human development; consequently adaptation measures should begin with changes in development patterns.

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APPENDICES

Appendix A: Vulnerability Results by Municipality

7.1 Belize

Table A-1 presents the current vulnerabilities to CC for the districts of Belize, with most of the districts showing a medium to high vulnerability, and the District of Corozal and Toledo a vulnerability of 1. Consequently 100% of the territory is highly vulnerable.

Table A-1. Current vulnerability of the districts of Belize

District	Vulnerability		
	Low	**Medium**	**High**
Corozal	-	Corozal	-
Toledo	-	Toledo	-
Stan Creek	-	Stan Creek	-
Belize	0.17	Belize	0.17

Note: Index values vary from 0-1, representing the percentage of territory in the district subject to each level of vulnerability.

7.2 Guatemala

Vulnerability values for the Municipalities of Guatemala range from low to medium, with a small portion showing a high vulnerability, associated principally to coastal areas that are highly influenced by sea level rise (Table A-2).

Table A-2. Current vulnerability of the Municipalities of Guatemala

Municipality	**Vulnerability**		
	Low	**Medium**	**High**
Livingston	-	0.78	0.22
Puerto Barrios	0.81	0.17	0.02

Note: Index values range from 0-1, representing the percentage of territory in each Municipality subject to each level of vulnerability.

7.3 Honduras

Table A-3 shows the current vulnerability value arising from the analysis for each municipality, with most municipalities showing medium to high values. Of the 12 municipalities analyzed, 8 show values over 0.7. This does not mean that the mean vulnerability in other municipalities is less important, but rather that these 8 municipalities have a greater population density with a lower socio-economic level.

Table A-3. Current vulnerability of the municipalities of Honduras to CC

Municipality	Vulnerability			
	Very low	Low	Medium	High
Balfate	-	-	-	1.00
Jutiapa	-	-	-	1.00
Arizona	-	-	0.01	0.99
Esparta	-	-	0.01	0.99
Santa Fe	-	-	0.01	0.99
Omoa	-	0.01	0.01	0.98
Puerto Cortes	-	-	0.23	0.77
Roatán	-	-	0.32	0.68
San Francisco	-	-	0.55	0.45
José Santos Guardiola	-	0.17	0.42	0.41
Tela	-	-	0.60	0.40
Utila	-	-	0.62	0.38
Trujillo	-	-	0.64	0.35
El Porvenir	-	0.01	0.69	0.30
Guanaja	-	0.35	0.40	0.25
La Masica	-	0.00	0.81	0.19
Santa Rosa de Aguan	-	0.71	0.19	0.10
La Ceiba	-	0.89	0.01	0.10
Limon	-	0.70	0.24	0.06
Iriona	-	0.98	0.02	0.00
Brus Laguna	0.68	0.31	0.01	0.00

Note: Index values range from 0-1 and represent the percentage of territory of the municipality subject to each vulnerability level.

Appendix B: Protected Area Vulnerability and Sensitivity

Tables B-1, B-3 and B-5 show the current vulnerability indices for land systems in the protected areas of the three countries; most of the protected areas present Medium to High vulnerability rates.

Tables B-2, B-5 and 24 show the current vulnerability rates for marine habitats in the protected areas of the three countries, with most protected areas showing a low to medium sensitivity.

Table B-1. Current vulnerability of the protected areas of Belize

Protected Area	Vulnerability		
	Low	Medium	High
Bird Caye	-	-	1.00
Block 127	-	-	1.00
Cerros Maya	-	-	1.00
Corozal Bay	-	-	1.00
Deep River	-	-	1.00
Gragra Lagoon	-	-	1.00
Monkey Caye	-	-	1.00
Payne's Creek	-	-	1.00
Port Honduras	-	-	1.00
Shipstern Nature Reserve	-	-	1.00
Honey Camp	-	-	1.00
Fresh Water Creek	-	-	1.00
Sarstoon-Temash	-	-	1.00
Gales Point	-	0.01	0.99
Burdon Canal	-	0.03	0.97
Grants Works	-	0.41	0.59
Mango Creek (4)	-	0.53	0.47
Cockscomb Basin	-	0.72	0.28
Mango Creek (1)	-	0.98	0.02
Manatee	0.53	0.45	0.02
Mayflower Bocawina	-	1.00	-

Note: Index values range from 0-1 and represent the percentage of land or marine territory of the protected area subject to each level of vulnerability.

Table B-2. Current sensitivity rates for Belize protected areas (marine habitats)

Protected Area	Sensitivity			
	Very low	Low	Medium	High
Monkey Caye	-	-	1.0	-
Seal Caye	-	-	1.0	-
Laughing Bird Caye	-	-	1.0	-
Block 127	-	0.1	0.9	-
Sapodilla Cayes	-	0.3	0.7	-
Payne's Creek	-	0.5	0.5	-
Nicholas Caye	--	0.7	0.3	-
Rise and Fall Bank	-	0.9	0.1	-
Port Honduras	-	0.9	0.1	-
Bacalar Chico	0.1	0.8	0.1	-
Gladden Spit and Silk Cayes	0.1	0.9	0.1	-
Santuario del Manati	0.1	0.8	-	-
Silk Cayes	-	1.0	-	-
Blue Hole	-	1.0	-	-
Caye Caulker	1.0	-	-	-
Corozal Bay	0.4	0.6	-	-
Dog Flea	-	1.0	-	-
Emily or Caye Glory	-	1.0	-	-
Gladden Spit	-	1.0	-	-
Glovers Reef	0.6	0.4	-	-
Grants Works	0.1	0.9	-	-
Guanaja	1.0	-	-	-
Hol Chan	1.0	-	-	-
Little Guana Caye	1.0	-	-	-
Los Salones	1.0	-	-	-
Northern Glovers Reef	1.0	-	-	-
Rocky Point	-	1.0	-	-
Sandbore	-	1.0	-	-
Sarstoon-Temash	-	-	-	1.0
Shipstern Nature Reserve	-	1.0	-	-
South Point Lighthouse	1.0	-	-	-
South Point Turneffe	1.0	-	-	-
South Water Caye	0.7	0.3	-	-
Swallow Caye	1.0	0.0	-	-

Note: Index values range from 0-1 and represent the percentage of marine territory of the protected area, subject to each level of sensitivity.

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Table B-3. Current vulnerability rate for protected areas (land systems) in Honduras.

Protected Area	Vulnerability			
	Very low	Low	Medium	High
Barras de Cuero y Salado	-	-	-	1.00
Cayos Cochinos	-	-	-	1.00
Sandy Bay y West End	-	-	-	1.00
Swasey-Bladen	-	-	-	1.00
Punta Izopo	-	-	0.07	0.93
Punta Sal (Jeanette Kawas)	-	-	0.07	0.93
El Higuerito	-	-	0.47	0.53
Nombre de Dios	-	0.52	-	0.48
Islas de la Bahía	-	-	0.60	0.40
Islas de la Bahía 12 millas	-	-	0.68	0.32
Turtle Harbor	-	-	0.83	0.17
Port Royal	-	0.69	0.17	0.13
Guanaja	-	0.62	0.32	0.06
Santa Elena	-	-	0.96	0.04
Río Platano	0.48	0.52	0.01	-
Barbareta	-	-	1.00	-
Utila	-	-	1.00	-

Table B-4. Current sensitivity rate for protected areas (marine habitats) in Honduras.

Protected Area	Sensitivity			
	Very low	Low	Medium	High
Bay Islands	0.7	.3	-	-
Barbareta	1.0	-	-	-
Barras de Cuero y Salado	0.8	0.2	-	-
Cayos Cochinos	0.7	0.3	-	-
Half-moon Caye	0.9	0.1	-	-
Nombre de Dios	1.0	-	-	-
Port Royal	1.0	-	-	-
Punta Izopo	0.2	0.8	-	-
Punta Sal (Jeanette Kawas)	-	1.0	-	-
Río Platano	0.7	0.3	-	-
Sandy Bay y West End	0.6	0.4	-	-
Santa Elena	1.0	-	-	-
Turtle Harbor	-	1.0	-	-
Utila	0.8	0.2	-	-

Table B-5. Current vulnerability for land systems and sensitivity of marine habitats in the protected areas of Guatemala.

Protected Area	Vulnerability of land habitats		Sensitivity of marine habitats			
	Low	Medium	Low	Medium	High	High
Barras del Rio Motagua	0.01	0.01	0.3	0.3	0.3	0.98
Bahía de Santo Tomas	-	0.20	0.8	0.1	0.1	0.80
Chocón Machacas	-	0.23	1.0	-	-	0.77
Rio Sarstún	-	0.57	1.0	-	-	0.43
Punta de Manabique	0.83	0.15				0.03
Cerro San Gil	0.24	0.74	0.2			

Note: Index values range from 0-1 and represent the percentage of continental land territory in the protected area that is subject to each level of vulnerability.