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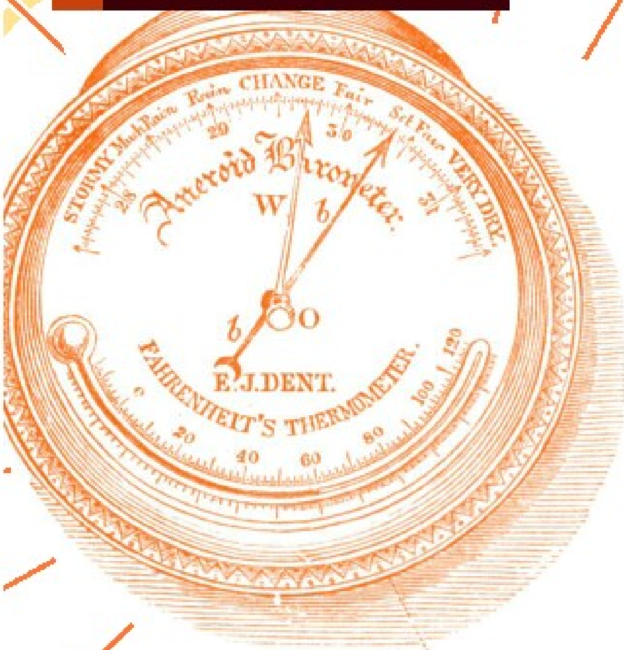

CLIMATE CHANGE IMPACTS ON COASTAL AND MARINE BIODIVERSITY IN THE INSULAR CARIBBEAN

Report of Working Group II, Climate Change and Biodiversity in the Insular Caribbean

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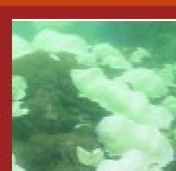

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EXECUTIVE SUMMARY

This report, prepared by a small group of Caribbean experts, is one of three produced within the framework of the project Climate Change and Biodiversity in the Insular Caribbean (CCBIC), a project implemented by the Caribbean Natural Resources Institute and supported by the John D and Catherine T MacArthur Foundation. (The other two reports focus on climate scenarios and terrestrial ecosystems). The overall objective of CCBIC is to develop a research agenda for the next ten years to inform biodiversity management in the insular Caribbean whether for conservation, sustainable livelihoods, resilience building or vulnerability reduction in the light of climate change impacts. This report is based on a desk study of published and unpublished literature relating to climate change and its impact on coastal and marine biodiversity in the insular Caribbean.

The natural resource base of the Caribbean islands is critical for the region's socio-economic development and the livelihoods of Caribbean people are intimately linked with biodiversity whether through social and cultural connections, economic exploitation or traditional use. Yet these very resources are already seriously stressed by anthropogenic activities and climate change is likely already adding another level of stress.

Following a summarised overview, supported by a detailed bibliography, of the known and/or likely impacts of climate change on coastal and marine ecosystems, this report identifies several constraints and gaps in the existing knowledge:

1. The large variation in the availability of data relating to the spatial extent of coastal and marine ecosystems, inventories of flora and fauna, and the monitoring of ecosystem changes;
2. The intricate linkages among species and systems within the overall marine ecosystem which comprises the Caribbean Sea and adjacent water bodies;
3. The effects of temperature change on the circulation of the Caribbean Sea and likely changes in upwelling and downwelling and their effects on marine flora and fauna;
4. Information on the rate of sea level rise is only available in four islands; and the impact of increased sea surface temperature on biota in seagrass and coral reef areas is little understood;
5. The impacts of high concentrations of carbon dioxide in the oceans;
6. Information on coral diseases and invasive species in the region and how they are influenced by climatic factors;

7. Trends in algal blooms and plankton distribution patterns in the region and their responses to changes in temperature, salinity, pH, and other climatic factors;
8. The state of ecosystem remediation techniques suitable for national and regional situations, and the efficacy of potential applications;
9. Basic biology and assessments of little-studied species, including seabirds, waterfowl, and key cetacean species in the Caribbean region, and the influence of climatic factors on them;
10. Physiology and ecology of marine and estuarine fishes and how they will react to climate change disturbances.

Learning from past activities and projects, this report develops a research agenda for the next ten years that focuses on these knowledge gaps. Since climate change is going to affect the lives of everyone in the insular Caribbean, there is a need to involve all society in learning about the issues, sharing information and taking appropriate measures. The research agenda has therefore been designed to involve persons from all walks of life, including youth, the general public, government professionals and scientists. The agenda includes research, monitoring of change, information sharing, and specific activities focused on conservation and ecosystem-resilience building.

Existing institutional capacity and the policy framework for biodiversity conservation and climate change are also discussed.

This present report with its assessment of the current state of knowledge regarding the impact of climate change on coastal and marine biodiversity also provides a qualitative baseline against which future progress can be assessed.

INTRODUCTION

1.1 Background

Climate change is one of the most critical issues facing biodiversity conservation in the world today. The impact of climate change, in terms of rising sea levels, increasing mean temperatures and changes in rainfall and weather patterns, is likely to be particularly severe for the ecological systems of the Caribbean islands, where in many cases, the whole island can be considered a coastal zone, and therefore, especially vulnerable. The likely increasing severity and frequency of natural hazards related to climate change is also of serious concern in the Caribbean islands.

For the purposes of this report, the insular Caribbean is the ring of islands enclosing the Caribbean Sea and related bodies of water and includes Trinidad and Tobago, the Lesser Antilles (both the Windward and Leeward groups of islands), the Bahamas group, the Virgin Islands, the Greater Antilles, the islands east of Central America, and the islands off the north coast of South America, (see Figure 1). These islands and the adjacent sea areas are immensely varied, ranging from low sandy cays to high volcanic islands with land areas of less than 1 km^2 to more than 100,000 km^2, while offshore the topography ranges from deep ocean trenches to extensive barrier reefs.

Figure 1: Map of the Caribbean Islands

The natural resource base of the Caribbean islands is critical for the region's socio-economic development. Tourism is the major economic driver in the insular Caribbean (Rivera-Monroy *et al*., 2004), and for some islands it is the prime industry. The industry is to a large extent located close to the coast and is heavily dependent on the existence of a tropical climate and the presence of sandy beaches and scenic coastal areas with clean, clear seas free from pollution and abundant in marine life. Dive tourism has developed in many islands, and Bonaire and Saba are among those exploiting this market. Migratory species such as whales, turtles and birds are also becoming the focus of niche tourism activities. In addition, most of the islands' major cities, towns and villages are located near the coast – the area most vulnerable to the effects of climate change.

Fishing (subsistence and commercial) is another important marine-based industry in these islands. Indeed, the livelihoods of Caribbean people are intimately linked with biodiversity whether through social and cultural connections, economic exploitation or traditional use.

Despite the economic importance of biodiversity, the anthropogenic degradation of coastal and marine resources is a serious problem in every Caribbean island (Richards & Bohnsack, 1990; Ogden, 1987). Activities such as beach sand mining, removal of mangroves, destruction of seagrass beds and coral reefs, and overfishing have become serious issues in almost every Caribbean island over the last several decades. Efforts are underway by governments, civil society, regional organisations and others, to reduce the level of degradation, yet as human populations increase, the rate of anthropogenic change may rise above current levels. Furthermore, it is difficult to separate, in a systematic and quantitative manner, the natural changes from those due to man's actions in most of these ecosystems. This is a very important consideration because climate change will likely add a third level of change, yet it may be difficult or impossible to separate out the climate change component.

The Caribbean islands are vulnerable to events such as hurricanes, floods and droughts; these are natural events that have been taking place for centuries. However, they are likely to become more frequent and severe as climate changes due to global warming.

Climate change due to global warming is already taking place. The Caribbean region experienced on average a mean relative sea-level rise of 1 mm year^{-1} during the 20th century, although there was extensive local variation (IPCC, WGII, 2007). Also, during the last century there have been multi-decadal fluctuations in hurricane activity in the Atlantic Basin and

Caribbean Sea with a marked increase in activity since 1995; although the record is insufficient to indicate whether these fluctuations are linked to climate change.

Table 1: Climate Predictions for the Insular Caribbean
(Based on global predictions from IPCC WGI, 2007)

Climate parameter	**Predicted change**
Air temperature	Increase of 1.8 – 4.0°C by 2099
Global sea level	Rise of 0.18 – 0.59 m by 2099
Carbon dioxide	Reduction in pH of the oceans by 0.14 - 0.35 units by 2099
Hurricanes	More intense with larger peak wind speeds and heavier precipitation
Precipitation	Unclear

Given the inevitability of climate change and the importance of biodiversity to the Caribbean region, there is an urgent need to learn about their interaction in the coming decades so as to design and implement appropriate adaptive measures to protect the region's biodiversity.

This report is one of three produced within the framework of the project Climate Change and Biodiversity in the Insular Caribbean (CCBIC), a project implemented by the Caribbean Natural Resources Institute (CANARI) and supported by the John D and Catherine T MacArthur Foundation. The MacArthur Foundation plans to support projects to identify and mitigate the threat from global climate change on species and their habitats in the insular Caribbean. The CCBIC project will provide a foundation for guiding the MacArthur Foundation's future funding in the area of climate change and Caribbean biodiversity. The other two reports produced within the framework of the CCBIC will focus on (1) Trends and scenarios for climate change in the insular Caribbean and (2) Impacts of climate change on tropical forests and other terrestrial ecosystems.

1.2 Methodology

Literature surveys were conducted by two postgraduate students between June and August 2007. Ms. Ivana Kenny from the University of the West Indies (UWI), Jamaica, reviewed published and unpublished literature relating to the impact of climate change on all aspects of coastal and marine ecosystems. Her list of more than 100 references has been incorporated into the overall bibliography of this report. The second postgraduate student, Ms. Amy Heeraman, reviewed the literature on the impact of climate change on emergent coastal wetlands, and her review is included in Annex 1.

A small working group, comprising four regional experts, was convened in June 2007 (Annex 2 contains short biographical sketches of the working group members). The literature reviews provided a starting point for the experts when they met in Jamaica in August 2007 to discuss the likely impacts of climate change on coastal and marine biodiversity. This report represents the outcome of the working group's collaboration. It is presented here as a draft that will be reviewed by the CCBIC Steering Committee, circulated to a wider group of experts at the beginning of 2008, and considered at a regional meeting of experts in mid-2008. It is anticipated that the report will be finalised during the second half of 2008.

1.3 Report Organisation

Based on an extensive, although not exhaustive, literature review and on the expert knowledge of the working group, this report develops a research agenda for the next ten years intended to inform biodiversity management in the insular Caribbean whether for conservation, sustainable livelihoods, resilience building or vulnerability reduction in the light of climate change impacts. Thus, the focus is essentially an applied one, and the research agenda does not attempt to address the entire scientific scope of work required to understand the impacts of climate change on Caribbean biodiversity.

Section 2 of the report provides a summarised overview of the known and/or likely impacts of climate change on coastal and marine ecosystems based on the literature reviews and the expert knowledge of the working group. The impact of climate change on the overall coastal and marine ecosystem is discussed, as well as the impact on each sub-system (emergent coastal wetlands; coastal forests; beaches, dunes, cliffs and rocky shores; seagrass beds; coral reefs; coastal and pelagic fish species; sea birds and coastal waterfowl; marine mammals; sea turtles). The detailed bibliography provides a record of the published and unpublished literature that has been consulted in the preparation of this overview. Section 3 identifies and discusses the main knowledge gaps, while a research agenda is outlined in Section 4 and regional capacity is the subject of Section 5. Finally a discussion on regional policy is included in section 6.

2. IMPACTS OF CLIMATE CHANGE ON COASTAL AND MARINE BIODIVERSITY

2.1 Linkages within Coastal and Marine Ecosystems

The high biodiversity found in Caribbean coral reefs is strongly influenced by the presence of adjacent mangrove forests and seagrass beds. These three ecosystems form strongly coupled habitat complexes, which are not completely understood along the coastal seascape (Koch & Madden, 2001; McKee *et al.,* 2002; Mumby, 2006). There is a continuum across these ecosystems in which complex nutrient exchanges define the spatial and temporal distribution of mangroves, seagrasses and coral reefs and negative impacts in one ecosystem can cascade across the coastal seascape, affecting other areas.

Some of the interactions across the seascape are as follows:

- Nurseries: Mangroves and seagrass beds are considered important juvenile habitats for a variety of fish and invertebrate species that spend their adult life on coral reefs or offshore habitats (Ogden *et al.,* 2005);
- Foraging movements and migration: Diurnal and nocturnal feeding migrations among habitats are a common feature of juvenile and some adult fish (Nagelkerken *et al.,* 2000a, 2000b; Beets *et al.,* 2003). As a result of these migrations, fish can function as vectors of organic material from seagrass beds to reefs, enhancing the growth rates of corals (Meyer *et al.,* 1983);
- Physical interactions: Healthy coral reefs act like hydrodynamic barriers dissipating wave energy and creating low energy environments conducive to mangrove and seagrass colonisation while at the land-sea boundary, coastal forests, mangroves and seagrasses act as buffers, which intercept freshwater discharge, stabilise salinity, and trap and bind sediment (Ogden *et al.,* 2005);
- Exchange of particulate and dissolved organic matter: Mass balance studies in a range of mangrove systems generally support the assertion that mangroves export organic matter in both particulate and dissolved forms (Lee, 1995; Robertson & Alongi, 1995).

The buffering capacity of coastal ecosystems is threatened by the projected rate of sea level rise under scenarios of global warming (Ogden *et al.,* 2005). While healthy coral growth may keep pace with sea level rise, weakened reefs may be unable to grow sufficiently to enable them to continue their coastal protection function. These zones will become inundated and subjected to erosion by progressively larger waves. Seagrass and mangrove communities will be eroded and will become less effective buffers, releasing nutrients and sediment and further slowing coral reef growth rate and negatively impacting coral reef health. In addition, changes in the structure and functioning of communities may occur as species respond differently to climate change, e.g. sponges may respond better than corals to increasing particulate matter in the water.

There is also the issue of connectivity between Caribbean coral reefs. Most reef species have pelagic larval stages that can potentially interconnect distant populations through dispersal by ocean currents. If these larvae disperse as passive propagules on advective current flow, they will be transported among both near and distant island populations (Roberts, 1997). In the Caribbean, coral reef habitat is largely spatially heterogeneous, with fragmented shallow water patches separated by deep water gaps between islands and coastlines, representing a complex landscape (Cowan *et al.,* 2000). The degree to which such a landscape facilitates or impedes movement among reefs is mainly driven by oceanographic regimes at various scales, i.e. daily to inter-annual variability in coastal and oceanic currents among coral reef patches (Cowan *et al.,* 2000).

Connectivity can be estimated from passive transport of virtual floats (or particles) within currents derived from oceanic and coastal models. However, connectivity among marine populations can only be estimated by the probability of successful dispersal, which is largely a function of species-specific life history traits e.g. adult productivity, spawning time and location, larval duration, larval behavior and mortality rate, and settlement habitat preferences. A numerical biophysical model has been developed to generate quantitative estimates of larval dispersal patterns, effective geographical dispersal distances, and ecologically significant levels of recruitment within and among regions in the Caribbean (Cowan *et al.,* 2000). A number of studies on gene flow and genetic variability among reef species are also being conducted.

Other linkages, besides the coral reef/seagrass bed/mangrove forest linkage, exist in the coastal and marine environment, e.g. the linkage between water quality/sediment quality/plankton and nekton. However, there is less research on the impact of climate change on these systems.

2.2 Emergent Coastal Wetlands

2.2.1 Definition

Emergent coastal wetlands are wetlands that emerge above sea level and are influenced by astronomical tides. They include tidal freshwater marshes, salt marshes, mangrove swamps, and tidal flats. Tidal freshwater marshes are found upstream of estuaries where the tide still influences water level, but the water is predominantly fresh. Brackish and salt marshes are found closer to the coast and are subjected to periodic flooding by the sea. Mangroves represent a large variety of plant families that have genetic adaptations which enable them to colonise saline coastal environments (Field, 1995). Tidal flats are depositional formations found near estuaries and in front of mangroves.

2.2.2 Status

Emergent coastal wetlands, particularly mangrove forests are widespread and an important resource in the insular Caribbean (Spalding *et al.,* 1997). These ecosystems support biological diversity by providing habitats, spawning grounds, nurseries and nutrients for a number of organisms including several rare and endangered species ranging from reptiles, mammals and birds (FAO, 2007). Despite the attempts to protect them by implementing coastal management and planning programmes and declaring them Wetlands of International Importance or Ramsar sites (see Annex 3 for a list of Ramsar sites in the insular Caribbean), there is still a net loss of mangroves and salt marshes in the insular Caribbean (Bacon, 2000). Of the 195 wetland sites investigated by Bacon in 1991, some 47% showed evidence of serious resource degradation resulting from human impact and all sites showed some damage (Bacon, 1991; 1995). A range of impacts were identified with the most important being:

- Landfill and solid waste dumping;
- Vegetation clearing, particularly unregulated cutting for timber or charcoal production;
- Reclamation for agriculture, including some fish pond construction;
- Hydrological alteration, particularly by roadways or flood diversion schemes;
- Pollution by factory and domestic effluent.

2.2.3 Climate Change Implications

Global climate change is expected to exacerbate the loss and degradation of mangrove forests and the loss or decline of their species, and to harm the human populations dependent on their services (Millennium Ecosystem Assessment, 2005). Coastal wetlands in

Small Island Developing States are especially vulnerable to impacts from relative sea level rise since they have a limited capacity to adapt, including limited space to accommodate landward migration of mangroves and other coastal ecosystems. After surveying over 200 coastal wetland sites in the insular Caribbean, Bacon (1994) suggests that responses to sea level rise would be quite variable since there is a wide range of wetland types and geomorphic settings in the region.

Sea Level Rise

The potential impacts are:

- Probable loss of total mangrove area due to erosion of the seaward margin of the mangroves and loss of protective lagoon bars and sea barriers;
- Relocation and migration of mangroves inland, rather than overall loss. This landward migration can be obstructed if the landward margin of the mangrove area is steep or if there are seawalls and other developments, thereby reducing the areas of coastal ecosystems;
- Change in mangrove forest structure. Landward replacement of black mangrove (*Avicennia*) by red mangrove (*Rhizophora*) and possible increased growth and productivity of the mangrove area;
- Increase in mangrove area and changes to associated wetland community types and distribution. Saline intrusion into inland freshwater wetlands and rejuvenation of salinas and scrub mangrove sites.

Mangrove forests in the Insular Caribbean are of four main functional types (Lugo & Snedaker, 1974) based on edaphic and hydrologic conditions: riverine, fringe, basin and scrub. Bacon (1994) stressed the importance of site-specific analysis and recommended that more attention be paid to site physiography, hydrology and ecology in predicting responses of tropical coastal wetlands to sea level rise. If the sedimentation rate keeps pace with rising sea level, mangrove forests would remain largely unaffected (Snedaker, 1993; Ellison, 1996).

Changes in Salinity

Increases in salinity can be due to sea level rise, groundwater depletion owing to reduced freshwater flux, ground water extraction or reduced rainfall. This can result in reduced seedling survival and growth, and decreased photosynthetic capacity (Ball & Farquhar, 1984). Loss of freshwater wetlands with saline intrusion is documented in Florida (Ross et al., 1994).

Increased Temperature

Combined with higher atmospheric carbon dioxide levels, increased temperature is expected to increase mangrove productivity, by increasing growth and litter production and expansion of the geographical range of some species (Ellison, 1996).

Water temperature in excess of 35°C can cause thermal stress in Rhizophora mangle (Banus, 1983). Diversity of invertebrate root communities was much reduced, and seedling establishment prevented over 38°C (Banus, 1983).

Increased Carbon Dioxide

An increase in productivity in mangrove and more efficient water use due to reduced stomatal conductance is expected (Warrick *et al.,* 1987).

Precipitation Changes

Changes in rainfall patterns will have a significant effect on mangrove ecosystems (Snedaker, 1995). Increased rainfall should result in reduced salinity and exposure to sulphates and an increase in the delivery of terrigenous nutrients. The extent of mangrove areas can be expected to increase, with colonisation of previously unvegetated areas at the landward fringe. The diversity of mangrove zones and growth rates should increase (Ellison, 1996). Decreased rainfall and increased evaporation is expected to result in reduced mangrove area, particularly with loss of the landward zone to unvegetated hypersaline flats and a decline in growth rates (Ellison, 1996).

Tropical Storms and Hurricanes

Studies in Anguilla before and after Hurricane Luis in 1995 showed that the mortality rate of the mangroves varied between 68 and 99% as a result of the category 4 hurricane (Bythell *et al.,* 1996).

2.3 Coastal Forests

2.3.1 Definition

On a typical lowland coast, the coastal forest lies immediately behind the beach or rocky shore, and in some cases there may be a clear zonation from the herbaceous beach vegetation to a band of shrubs to the coastal forest. A similar vegetation succession may be present if there are sand dunes behind the beach, although coastal forests also exist where there are no sand dune formations. Plants occupying these zones have to survive very sunny, windy, dry and salty conditions. Herbaceous beach vegetation may be found above high water mark and usually consists of perennials with deep tap roots; typical plants include creeping vines such as beach morning glory (*Ipomea pes-caprae)* and grasses such as seashore dropseed (*Sporobolus virginicus*). The shrub zone consists typically of plants such as cocoplum (*Chrysobalanus icaco L*.) and sea lavender (*Tournefortia gnaphalodes*). Coastal forest trees may be stunted and wind blown, but the trees themselves are deep rooting and help to hold the sediment in place. Typical tree species are seagrape (*Coccoliab uvifera*), seaside mahoe *(Thespesia populnea*), manchineel *(Hippomane mancinella), and* West Indian almond *(Terminalia Catappa).* The coconut palm (*Cocos nucifera),* while not native to the Caribbean and not deep rooting, is also a common tree in the coastal forest. The coastal forest with its different zonation from the beach vines to the mature trees acts as a protective barrier against high waves and storm activity. In addition, dune vegetation serves to trap windblown sand (UNEP, 1998). The coastal forest provides an important habitat for several species of seabirds, land birds, reptiles and crabs.

2.3.2 Status

Coastal forests have received less attention than other coastal ecosystems. There is little quantitative information on their areal extent, for while figures exist on changes in total forest cover, the coastal forest is not differentiated. Coastal zones are extensively used in the Caribbean islands for tourism, fisheries, residential and commercial development, thus coastal forests, where they have not been completely destroyed, have been reduced to narrow bands of trees, shrubs and plants. Anthropogenic impacts include: cutting and clearing for construction, for creating clear views to the sea, and for sand mining; cutting of vegetation for barbecues and fires; replacing of native with foreign species; removal for the creation of accesses to the beach (Cambers, 1998). Undoubtedly, the clearing of coastal forests for tourism purposes is the main threat, given that the Caribbean tourism image is one of an unimpeded view to the sea with perhaps some palm trees in sight.

Over the last century, coastal forests in some islands of the Caribbean and Pacific have been converted to commercial plantations of coconut thereby reducing the coastal protective function of natural coastal forests (Merlin, 2005). In the Caribbean some of these plantations are succumbing to the effects of diseases such as Lethal Yellow coconut palm disease (Meyers, 2007).

Coastal forests may exist in conjunction with coastal dunes. Dunes are especially under threat in the Caribbean since they also represent a source of construction sand. Sand mining, although reduced, still takes place under permit and illegally in many of the Caribbean islands including Puerto Rico, Antigua and Barbuda, and St. Lucia.

2.3.3 Climate Change Implications

Sea Level Rise

Where space permits, coastal forests may be able to retreat inland together with associated systems such as beaches and sand dunes. However, where sea defence structures and coastal infrastructure impede their migration, the seaward margin in particular will be eroded and the areal extent will decrease. Studies of coastal forests in the Gulf of Mexico (Williams *et al.,* 1999) show that the forest may be replaced by sand dune, beach or ocean depending on the tolerance of the trees to burial by sand, increased salt spray and wetting of roots. Exposure to salt spray is an important factor controlling the morphology and zonation of coastal shrubs and trees.

Changes in Salinity

Relict stands may be a response to sea level rise because tree seedlings are more sensitive to salt, flooding and burial by sand than mature trees (Williams *et al.*, 1999).

Tropical Storms and Hurricanes

Coastal forests, like emergent coastal wetlands, are extremely vulnerable to the high winds, storm waves and sea surges experienced during tropical storms and hurricanes. During Hurricane Luis in 1995 the vegetated dune edge at Meads Bay in Anguilla retreated inland 30 m (Bythell *et al.,* 1996).

2.4 Dunes, Beaches, Cliffs and Rocky Shores

2.4.1 Definition

A beach is a zone of loose material extending from the low water mark to a point landward where either the topography abruptly changes or permanent vegetation first appears (Cambers, 1998). A wider definition of a beach includes the nearshore zone extending to a water depth of about 12 m where the waves are no longer able to move sediment on the bottom. A beach may consist of sediment ranging in size from clay to boulders. Beaches are very dynamic systems changing size, shape and even material composition from one day to another.

A dune is an accumulation of wind blown sand forming a mound landward of the beach and usually parallel to the shoreline.

A cliff is a high, steep bank at the water's edge composed primarily of rock.

Beaches provide habitat for a variety of worms, crustaceans and mollusks. Common species include the ghost crab (*Ocypode*), the chip-chip (*Donax*) and the sand dollar (*Mellita quinquiesperforata*). Seeds, jellyfish e.g. Portuguese man of war (*Physalia*) and tennis ball jellyfish (*Stomolophus*), and other species sometimes wash up on the beach. Birds associated with beaches and coastal areas include herons, oyster catchers, sandpipers, pelicans, boobies and frigate birds. Hawksbill, green and leatherback turtles nest on Caribbean beaches; hawksbill turtles nest in the coastal forest, while the others nest on the open beach.

Rocky shores and the lower sections of cliffs provide a variety of habitats for marine plants and animals (Bacon, 1978). Animals and plants include barnacles, snails, mussels, crabs, sea eggs, and green, red and brown algae.

2.4.2 Status

Globally it has been shown that 70% of the world's sandy beaches are eroding (Bird 1985, 1987). This statistic is repeated in the Caribbean. Based on regular monitoring at 200 sites in nine eastern Caribbean territories over the period 1985-1995, 70% of the measured beaches were eroding and 30% were stable or accreting (Cambers, 1997). Average erosion rates varied between 0.27 and 1.06 m/yr, with islands impacted by hurricanes showing the highest rates. Specific beaches retreated inland by as much as 18 m during Hurricane Luis in 1995. Beach erosion is not a regular occurrence, sometimes several years may elapse with only seasonal changes, followed by significant erosion during a particular storm event. The erosion in the insular Caribbean is attributed to anthropogenic factors, e.g. sand mining and poorly planned coastal development and sea defences; and to natural causes such as winter swells and hurricanes. Sea level rise is also another causative factor (Bruun, 1962). Tropical storms and hurricanes appeared to be the dominant factor influencing the erosion, with beaches failing to return to their pre-hurricane levels. Indeed between 1995 and 1999, a period of severe hurricane activity for the islands of the northeastern Caribbean, it appeared that these numerous high-energy events introduced a certain vulnerability to the beach systems making recovery slower and less sustained, (Cambers, 2005). This loss of physical habitat has serious implications for the dependent flora and fauna. Dune retreat and disappearance has also been widely documented in the Caribbean islands. Extensive black sand dunes, 6 m high, in St. Vincent and the Grenadines, were mined at Diamond Bay in the 1980s, leaving a flat coastal lowland devoid of vegetation and vulnerable to flooding (Cambers 1998, 2005). Cliff retreat and changes in rocky shores are less well documented, although associated with the widespread beach erosion there appears to be an increase in the exposure of beachrock ledges (Cambers, 1998).

2.4.3 Climate Change Implications

Sea Level Rise

The Bruun Rule (Bruun, 1962) predicts that as sea level rises, sand is eroded from the upper beach and deposited on the offshore bottom so as to maintain an equilibrium profile. This results in beach retreat so that for every 1 cm of sea level rise, the beach retreats inland 1 m, see Figure 2.

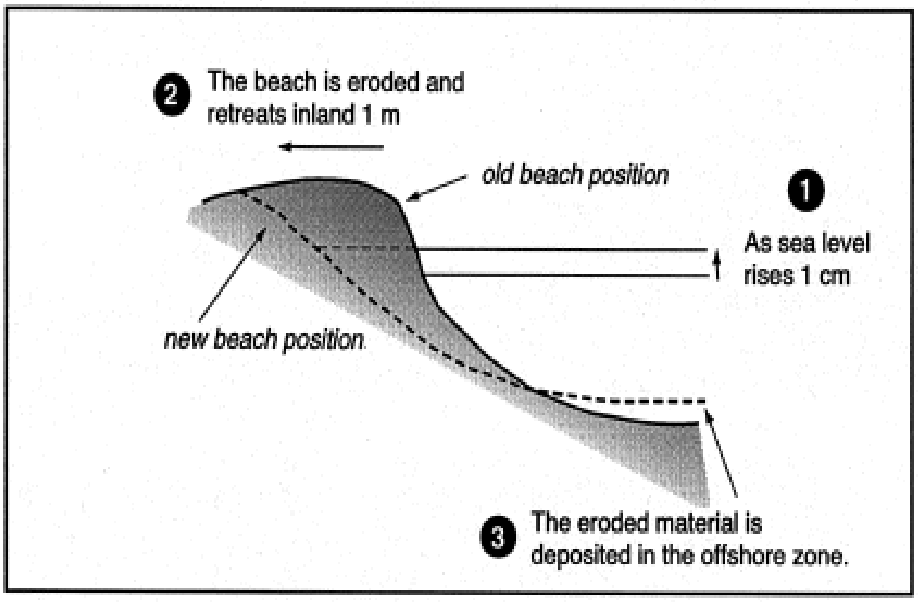

Figure 2 Beach Retreat due to Sea Level Rise
(Cambers, 1997)

However, such erosion may not take place regularly, but may come sporadically during storms (Williams *et al.,* 1999). Thus, as the rate of sea level increases, the rate of beach erosion will increase. Where beaches cannot retreat inland because of other infrastructure or geological features, the rate of beach disappearance will increase. This will have implications for related systems such as dunes, coastal forests and emergent coastal wetlands.

Decreased beach area will reduce the availability of habitat for beach fauna and flora. A study by Fish *et al.* (2005) showed that a 0.5 m rise in sea level in the Caribbean would cause a decrease in turtle nesting habitat by up to 35%. The impacts go beyond marine fauna, e.g. species of land crabs, *Gecarecinus lateralis* (black land crab) and *Cardisoma guanhumi* (blue land crab), depend on reaching the sea to wash their eggs from their legs. Decreased beach area and an increase in protective sea walls are already causing problems for these crabs in Dominica.

Increasing Temperature

Increasing sand temperature influences the sex ratio of turtle hatchlings (see Section 2.10 for more discussion). A simulation model study (Svensson *et al.*, 2006) showed that increased sea surface temperature caused faunal community shift and heightened the possibility of invasive species among species of barnacles. Mollusks, particularly the earlier life stages, are particularly vulnerable to changes in UV radiation, pH, and water temperature (Przeslawski *et al.,* 2005).

Increasing Carbon Dioxide

Many Caribbean beaches are composed of coralline sand derived from coral reefs and other marine organisms. As the oceans become more acidic, calcium carbonate exposed to sea water may dissolve, thereby reducing the supply of sand to the beaches. Similarly, the beachrock ledges that form protective barriers near the low water mark on many of the region's beaches consist of calcium carbonate cementing sand grains together – a process also likely to be impacted by ocean acidification.

Tropical Storms and Hurricanes

As these events become more intense, the rate of beach erosion is likely to increase (Cambers, 1996).

2.5 Seagrass Beds

2.5.1 Definition

Seagrasses are aquatic flowering plants that grow in the soft or sandy bottoms of estuaries and along the coastal margins of tropical, temperate and sub-arctic marine waters (den Hartog, 1970; McRoy & Helfferich, 1977). They are found throughout the insular Caribbean growing in reef lagoons between beaches and coral reefs, or forming extensive meadows in more protected bays or estuaries (Creed *et al.,* 2003). *Thalassia testudinum* is the most abundant species (Phillips & Meñez, 1988) growing in monospecific beds, or intermixed with *Halodule wrightii*, *Halophila spp*. or *Syringodium wrightii* and macroalgae.

Seagrasses form extremely complex ecosystems that are highly productive, faunally rich and ecologically important (Zieman, 1982). By providing substratum for epiphytic algae, shelter for invertebrates and fishes, and foraging areas for a variety of organisms including endangered species such as green turtle (*Chelonia mydas*) and manatees (*Trichechus manatus*), they significantly contribute to the biodiversity of coastal water (Duffy, 2006). Seagrass beds have been recognised as productive fishery areas in the Caribbean (Muehlstein *et al.*, 1989; Sturm, 1991). They are important breeding grounds and nurseries for finfish and shellfish population (Thayer & Chester, 1989; Van der Velde *et al.*, 1992; Nagelkerken *et al.*, 2001). The plants filter suspended sediments, and nutrients from coastal waters, stabilise sediments, dissipate wave energy, and remove carbon dioxide from the ocean-atmosphere system which could play some role in the amelioration of climate change impacts (Creed *et al.*, 2003).

2.5.2 Status

Population growth, increased urbanisation and the rapidly expanding agricultural and tourist-industrial sectors in the insular Caribbean have increased pressure on the coastline and their seagrasses (UNEP, 1997). While most studies have focused on how physical disturbance alter the structure and function of seagrass habitats, only recently have human impacts on seagrass food web been given attention. The presence of green turtles for instance may have had substantial ecological and evolutionary effects by increasing the productivity of seagrasses in the same way as grazers in terrestrial grasslands (Moran & Bjorndal, 2007).Changes in temperature, nutrient levels, and salinity as well as a 93-97% reduction in the green turtle population in the Caribbean compared to its size prior to human contact (Jackson et al., 2001), have been implicated in die-off of seagrass throughout the region (Robblee et al., 1991; Fourqurean & Robblee, 1999).

At La Parguera, Puerto Rico, increased traffic of ships and recreational vessels are causes of anchor damage, trampling, propeller scarring, detrimental shading by marinas and piers, and damage by dredging (Creed *et al.,* 2003). Seagrass beds near industrial area in Cuba, Trinidad, Jamaica are highly impacted (Thorhaug *et al.,* 1985; UNEP, 1994; Juman & James, 2006). In the smaller islands, seagrass beds were damaged by illegal sand mining which suspends sediments and alters local hydrodynamics. In St Lucia, seagrass beds have been destroyed by dynamite fishing (Creed *et al.*, 2003). Seamoss (*Gracilaria spp.*) is cultivated in seagrass areas in St. Lucia.

Seagrasses are subjected to nutrient pollution mainly from land-based sources, particularly sewage and grey water (UNEP, 1994; Juman, 2005). Increased sediment loading as a result of deforestation, urbanisation and agricultural activities has caused major damage to beds. Extensive seagrass beds in the Archipelago Sabana-Camagüey, Cuba, have been impacted by increased salinity in the inner water bodies, due to anthropogenic changes in the hydrological regime (Alcolado, *et al*., 1999; Claro *et al.,* 2001a). Indirect activity such as overfishing of wrasses and triggerfishes off Haiti and the US Virgin Islands resulted in an explosion of sea urchins which then destroyed seagrass bed by overgrazing (Creed *et al.*, 2003). Seagrass beds in the US Virgins were also damaged by Hurricane Hugo and from overgrowth of bluegreen alga, *Schizothrix sp*. (Muehlstein *et al*., 1989).

2.5.3 Climate Change Implications

Climate change represents a relatively new threat, the impacts of which on seagrasses are largely undetermined. Potential threats from climate change may come from rising sea level, changing tidal regime, localised decreases in salinity, damage from ultraviolet radiation, and unpredictable impacts from changes in the distribution and intensity of extreme events. Higher carbon dioxide concentrations may, however, increase productivity.

Sea Level Rise

Changes in light attenuation, wave energy, substrate type, and assuming no concomitant increase in grazers due to sea level change will influence seagrass beds (Maul, 1993).

Changes in Salinity

Changes in the river flow regimes and sediment transport may lead to increased sediment loading, thereby burying seagrass beds, and in localised salinity changes. Some seagrass species have a narrow tolerance for salinity changes, which can trigger major shifts in species composition (Lirman & Cropper, 2003). Salinity in association with nutrient enrichment can also become a stressor when freshwater inputs are drastically reduced.

Increased Temperature

Only meadows occurring in thermally stressed environments, like thermal effluence, could be affected by a 1.5˚C change in temperature. However, temperatures of 35˚C or more can prevent some species, from rooting (Vincente *et al.*, 1993).

Increased Carbon Dioxide

The increased carbon dioxide will increase the productivity of the grasses. Coupled with the slight increase in temperature, these chemical changes will increase the biomass of seagrasses, and thus, the detritus-based trophic level (Harley, 2006).

Tropical Storms and Hurricanes

Increased storm and tidal surges, changes in storm intensity and frequency, and subsequent change in river flow regimes and sediment transport will impact seagrass beds (Millennium Ecosystem Assessment, 2005). Seagrasses grow in low energy environments, and thus, increased turbulence from storms and tidal surges will dislodge the grasses.

2.6 Coral Reefs

2.6.1 Definition

Coral reefs are unique ecosystems in that they are defined by both biological ("coral" community) and geological ("reef" structure) components (Buddemeier *et al*., 2004). Coral reefs are made of limestone (calcium carbonate) which is secreted as skeletal material by colonial animals (coral polyps) and calcareous algae. Reef building coral polyps house single-celled microalgae, called zooxanthellae, within their body tissues. This symbiotic relationship benefits both partners, in that, the coral obtains food from the plant photosynthesis and the microalgae benefit from nutrients released as waste by the coral. Further, the two have complementary effects on carbon dioxide exchange that is believed to account for the rapid rates of coral skeletal growth. Due to their high biodiversity and uniqueness, these structures are some of the most studied marine ecosystems.

2.6.2. Status

Coral reefs provide a number of values to humans, as well as the health of the biosphere. Reefs support fisheries, and reef structures provide natural breakwaters that protect shorelines, other ecosystems, and human settlements from wave activity. Humans use reefs and their products extensively for food, building materials, pharmaceuticals, the aquarium trade, and other uses. In addition, due to their beauty and novelty, reefs have become a major part of the tourism product for the region. As such, coral reefs form part of the economic foundation of the region.

Unfortunately, these valuable ecosystems are being degraded rapidly by human activities such as coastal development, dredging for ports and marinas, sedimentation, overfishing, lost and discarded fishing gear, and marine pollution. Interestingly, approximately 36% of Caribbean coral reefs lie within 2 km of the coast and this makes them highly susceptible to pressures arising from coastal populations (Burke & Maidens, 2004).

The following provides an indication of some stresses affecting coral reef systems:

- It is estimated that less than 20% of sewage water generated in the Caribbean region is treated before entering the ocean (Burke & Maidens, 2004). Untreated sewage is a major source of nutrients entering coastal waters which, under normal circumstances, would be devoid of nutrients. High nutrient conditions favour algal growth at the expense of the corals (Souter & Linden, 2000), since coral reefs thrive in low nutrient (oligotrophic) waters.

- The tourism industry, a sector of major importance to the regional economy, also threatens the reefs in a number of ways. Dive boats can damage reef structure with their anchors, divers also cause physical damage, and resort development and operation increase pollution and sewage in coastal waters, as does the construction of tourism infrastructure (roads, marinas, airports).
- The conversion of land to agriculture increases soil erosion and sediment delivery to coastal waters, bringing with it pesticides and nutrients. Nearly a quarter of all the land area draining into the Caribbean is agricultural land (Burke & Maidens, 2004). Increased sediment causes stress on coastal ecosystems in a variety of ways. It screens out the light needed for photosynthesis, decreases the amount of suitable substrates for juvenile corals, and in extreme cases, can completely smother corals. Traditionally, sediments and nutrients coming from the land were filtered by mangrove forests and seagrass, however, the loss of these important areas is widespread throughout the Caribbean (Jameson *et al.*, 1995).
- Marine-based sources of pollution, including oil discharge and spills, sewage, ballast and bilge discharge, and the dumping of other human garbage and waste from ship, are a cause for great concern in the Caribbean region (Burke & Maidens, 2004).
- Fisheries also impact coral reefs. Fishermen typically target the largest fish on the reef since these have the highest market value. The depletion of larger fish leads to a reduction in the average size of the targeted species, and can cause fishermen to fish for lower valued species, removing even more components of the coral reef food web (McManus *et al.*, 2000). The removal of certain species can significantly alter the reef structure. For example, herbivorous fish are responsible for controlling algae growth on the reef and if these fish are removed from the system, algae can flourish and reduce coral cover (Bohnsack, 1993).
- Hurricanes can cause extensive damage to coral reefs (Stoddart 1985, Harmelin-Vivien, 1994, Salazar-Vallejo, 2002), for example as described for Hurricane Gilbert in Jamaica (Bacon 1989), for Hurricanes David, Frederick and Hugo in the US Virgin Islands (Rogers *et al.*, 1982), for Hurricane Hugo in Guadeloupe (Bouchon *et al.*, 1991), for Hurricane Lenny in St. Lucia (Wulf, 2001) and for Hurricane Mitch in the Mexican Caribbean (Bahena *et al.,* 2000). Hurricanes reduce the physical complexity of coral reefs and the abundance of living corals (Steneck, 1994). These effects are greatest at shallow depths where wave action is greatest. However, shallow corals are adapted to wave action and hurricanes can cause considerable damage in deeper water where corals seldom experience wave action under normal conditions (Harmelin-Vivien & Laboute, 1986).

Consequently, coral reefs are considered to be in crisis, and this is well-documented and has stimulated numerous publications on the future of coral reefs (e.g., Hoegh-Guldberg, 1999;

Knowlton, 2001; McClanahan *et al.*, 2002) and their vulnerability to environmental change (e.g., Bryant *et al.*, 1998; Hughes *et al.*, 2003). The causes of this crisis are not only caused by the above mentioned stress factors, but are a complex mixture of both human-imposed and climate-related stresses, and include factors such as outbreaks of disease, which have suspected, but unproven connections to both human activities and climate factors. Notably, by 1998, an estimated 11% of the world's reefs had been destroyed by human activity, and an additional 16% were extensively damaged in 1997–98 by coral beaching (Wilkinson, 2000).

2.6.3 <u>Climate Change Implications</u>

Although climate change has the potential to yield some benefits for certain coral species in specific regions, such as the expansion of their geographic ranges to higher latitudes, most of the effects of climate change are stressful rather than beneficial (Buddemeire & Klypas, 2004). The following summarises some of the expected negative impacts on coral reef systems:

Sea Level Rise

It should be noted that healthy coral growth may keep pace with sea level rise, but weakened reefs may be unable to grow sufficiently to enable them to continue their coastal protection function. Thus, while coral reefs may be fairly resilient ecosystems, the cumulative effects of the threats discussed are taking an alarming toll on coral reefs throughout the Caribbean. McClanahan *et al*. (2002) discusses issues of coral reef resilience.

Increasing Temperature and Coral Bleaching

The most direct evidence of climate change's impact on coral reefs comes in the form of coral bleaching, which refers to the loss of a coral's natural colour due to expulsion of the zooxanthellae. In the absence of the zooxanthellae, corals lack the necessary nutrients for reef building and growth. As small an increase as 1.0°C can trigger a bleaching event (Buddemeire & Klypas, 2004). Based on current data, it is believed that coral bleaching will become an annual event by the year 2020 (Hoegh-Guldberg, 1999). Notably, no incidents of mass coral bleaching were formally reported in the Caribbean before 1983 (Glynn, 1996). However, according to Reefbase (2004) since the early 1980s more than 5000 observations have been reported. One of the earliest incidences was during the 1982-3 El Niño-Southern Oscillation (ENSO). Further, bleaching incidents have also been recorded for 1987 and throughout the 1990s (Burke & Maidens, 2004). More recently, in 2005, Caribbean reefs again experienced mass bleaching. Massive decline of corals across the entire Caribbean basin has been shown, with the average hard coral cover on reefs reduced by 80%, from about 50% to 10% cover, in three decades (Gardner *et al.,* 2003).

Mass bleaching of corals in the past two decades has been clearly linked to El Niño events (Hoegh-Guldberg, 1999; Glynn, 2000). El Niño events have increased in frequency, severity, and duration since the 1970s (Stahle *et al.*, 1998; Mann *et al.*, 2000). This combination (warming and intense El Niño events) has resulted in a dramatic increase in coral bleaching (Glynn, 1993; Brown, 1997; Wilkinson, 2000). A rising baseline in warm-season sea-surface temperatures on coral reefs (Fitt *et al.*, 2001; Lough, 2001) suggests that physiological bleaching is at least partly to blame in some bleaching events (e.g., in the Caribbean in 1987 and 2005).

Field data indicate that coral bleaching was much worse during the 1982-83 El Niño than in 1997-98, although temperature extremes during the two events were similar (Glynn *et al.*, 2001; Guzmán & Cortés, 2001; Podestá & Glynn, 2001). The difference in responses to these two comparable events offers some support for the idea that corals or communities can adapt to higher temperatures over decades, either through adaptive bleaching (Baker, 2003) or through evolutionary selection for more heat/irradiance-tolerant corals that survive bleaching events (Glynn *et al.*, 2001).

There was a major coral bleaching event in the Caribbean in 2005. As a result, mean coral cover had decreased by 61% up to the end of 2007 in the US Virgin Islands (USGS, 2008) and *Acropora palmata* bleached for the first time on record.

Apart from the impact of coral bleaching, discussed earlier, thermal expansion of the ocean and ice melt water will result in an increase in the pressure gradient which could cause changes in upwelling patterns (Bakun,1990). In the Caribbean, upwelling areas off the Guianas-Brazil Shelf, downstream of island passages, and off Venezuela are known to influence fishery production. Changes in upwelling or other circulation patterns could affect the dispersal and transport of larvae and nutrients, affecting the distribution of corals and associated reef species.

While there is not much information available on how increased temperatures will affect metamorphosis, survival rate and other aspects of larvae or juvenile reef species, increased temperatures may negatively impact these (Bassim & Sammarco, 2002, 2003). Nozawa and Harrison (2007) found two different effects of elevated temperature on the early stages of recruitment process of scleractinian corals; a positive effect on larval settlement and a negative effect on post-settlement survival under prolonged exposure. Studies on species such as the sand dollar, show that temperatures of or greater than 31°C negatively affect larvae and juveniles (Chen & Chen, 1992).

Increased Carbon Dioxide

Photosynthesis and respiration by marine organisms also affect seawater carbon dioxide concentration, but the overwhelming driver of carbon dioxide concentrations in shallow seawater is the concentration of carbon dioxide in the overlying atmosphere. Changes in the carbon dioxide concentration of seawater through well-known processes of air-sea gas exchange alter the pH (an index of acidity) and the concentrations of carbonate and bicarbonate ions. Surface seawater chemistry adjusts to changes in atmospheric carbon dioxide concentrations on a time scale of about a year. Projected increases in atmospheric carbon dioxide may drive a reduction in ocean pH to levels not seen for millions of years (Caldeira & Wickett, 2003).

Many marine organisms, including corals, use calcium and carbonate ions from seawater to secrete calcium carbonate skeletons. Reducing the concentration of either ion can affect the rate of skeletal deposition, but the carbonate ion is much less abundant than calcium, and appears to play a key role in coral calcification (Langdon, 2003). The carbonate ion concentration in surface water will decrease substantially in response to future atmospheric carbon dioxide increases, reducing the calcification rates of some of the most important calcium carbonate producers, including corals.

However, calcification rates of corals also depend on other factors such as temperature. Kleypas *et al.* (1999) estimated an average decline of reef calcification rates of 6–14% as atmospheric carbon dioxide concentration increased from pre-industrial levels (280 ppmv) to present-day values (370 ppmv) (Buddemeire & Klypas, 2004). However, studies have shown that calcification rates of large heads of the massive coral *Porites* increased rather than decreased over the latter half of the 20th century (Lough & Barnes, 1997, 2000; Bessat & Buigues, 2001). Temperature and calcification rates are correlated, and these corals have so far responded more to increases in water temperature (growing faster through increased metabolism and the increased photosynthetic rates of their zooxanthellae) than to decreases in carbonate ion concentration (Buddemeire & Klypas, 2004). In order to boost calcification, however, the temperature increase must remain below the corals' upper thermal limit.

Precipitation Changes

Climate change is expected to bring about changes in precipitation. Increases in precipitation can lower salinity and increase sediment discharge and deposition near river mouths, sometimes leading to mass mortalities on nearby coral reefs (van Woesik *et al.*, 1991;

Coles & Jokiel, 1992). Supporting this are findings from other studies, which have shown that algal biomass is highest in the nearshore, especially in the vicinity of river mouths (Roberts, 1997).

The frequency and intensity of droughts are also expected to increase, which may cause changes in vegetation cover and land use that can lead to erosion and sediment stress when rains return (Buddemeire *et al.,* 2004).

Tropical Storms and Hurricanes

Kjerve *et al.* (1986) point out, that our perception of the ability of coral reefs to withstand hurricane damage may depend largely on how long it has been since the previous hurricane. According to Gardner *et al.* (2005) Caribbean reefs now require about eight years to recover from a storm.

However, climate change will result in increases in the frequency and intensity of storms and changes in ENSO and precipitation patterns (Shapiro, 1982 as seen in Maul, 1993). These will in turn affect turbidity, salinity and runoff; altering the oceans on a large scale, changing their circulation patterns, chemical composition and increasing advection (Harley *et al.*, 2006), negatively impacting coral reefs. Increased storm activity and intensity will hinder the ability to coral reefs to recover. In fact, some studies conducted in the region already show that while some recovery of reef in deeper waters occurs after storms, there is no noticeable recovery in nearshore areas (Roberts *et al.*, 1997).

Diseases

The most profound and widespread changes in Caribbean coral reefs in the past 30 years have been attributed to disease, however, the reasons for this sudden emergence and rapid spread are not well known (Buddemeire & Klypas, 2004). Twenty three diseases and syndromes affecting corals have been identified in the Caribbean, and in most cases, the pathogen causing the disease is not known (UNEP-WCMC, 2001). Disease outbreaks and consequent mortality among corals and other reef organisms have been a major cause of the recent increase in coral reef degradation (Epstein *et a*l., 1998; Harvell *et al.*, 1999; Rosenberg & Ben-Haim, 2002). Although diseases and syndromes of corals and other reef organisms remain incompletely characterised (Richardson & Aronson, 2002), they are known to be caused by both bacterial and fungal agents. These diseases are commonly lethal, but they exhibit a wide range of rates of progression. Most appear to affect some species more than others, but few, if any, are species-specific (Buddemeire & Klypas, 2004).

Two specific outbreaks have radically altered the ecology of Caribbean coral reefs (Richardson & Aronson, 2002). One disease killed more than 97% of the black-spined sea urchin (*Diadema antillarum)* (Lessios, 1988), some populations of which are now beginning to recover (Aronson & Precht, 2000a; Miller *et al.*, 2003).

Another disease, white band disease (WBD), has killed much of the elkhorn (*Acropora palmata*) and staghorn (*A. cervicornis*) coral throughout the Caribbean. These were dominant reef-building corals in the Caribbean for tens of thousands to hundreds of thousands of years (Aronson & Precht, 1997; Aronson *et al.*, 2002), but since 1972, WBD has helped reduce these species to candidacy for listing under the Endangered Species Act (Aronson & Precht, 2000b). WBD caused an unprecedented change in community structure in the Bahamas (Greenstein *et al.*, 1998).

Other bacterial diseases of Caribbean corals, including black-band disease, “plague,” and “white pox,” have caused significant coral mortality (Patterson *et al.*, 2002). A disease caused by a fungus of terrestrial origin, *Aspergillus sydowii* (Geiser *et al.*, 1998), has killed large numbers of sea fans and sea whips (Kim & Harvell, 2001).

Prior to the 1980s, the most important reef herbivores in the Caribbean were parrotfish, surgeonfish, and the black-spined sea urchin (*Diadema antillarum)* but in many areas the fish populations had been greatly reduced (Hughes, 1994). When a disease outbreak destroyed most of the *Diadema* populations throughout the Caribbean in 1983–84 (Lessios, 1988), acute episodes of coral mortality (due to hurricanes and other factors) combined with the absence of crucial herbivores to convert coral-dominated Caribbean reefs to seaweed-dominated communities (Hughes, 1994; Aronson and Precht, 2000a).

Climate change in the basins of the large South American Rivers, notably the Amazon and Orinoco Rivers, will affect the volume and seasonality of their discharges in ways that are difficult to predict. These river inputs contribute considerably to the offshore marine production systems of the Caribbean. The dispersal of these discharges will in turn be affected by winds and currents. In 1999, a fish kill that affected several countries in the south-eastern Caribbean was linked to increased water temperatures and the transport of a pathogen thought to be in the Orinoco discharge.

Warming can increase the virulence of pathogens, since optimal water temperatures for those infectious agents for which data are available are at least 1°C (2°F) higher than the optima of their coral hosts (Harvell *et al.*, 2002). Recent increases in the frequency and virulence of disease outbreaks on coral reefs are consistent with this prediction, suggesting that the trend of increasing disease will continue and strengthen as global temperatures increase (Buddemeire & Klypas, 2004).

Dust from Arid Regions

Events, such as coral diseases, appear to coincide with African dust production as well as other factors. According to UNEP/GPA (2006), based on data recorded in Barbados, the years of highest cumulative dust flux occurred in 1983-1985 and 1987. This has also been linked to increasing aridity and desertification in Northern Africa (Prospero & Lamb, 2003). Various peaks in the dust record at Barbados and else where in the western Atlantic coincide with benchmark perturbations events on reefs through the Caribbean (UNEP/GPA, 2006).

The mechanism by which dust may affect corals include direct fertilisation of benthic algae by iron or other nutrients interacting with ammonia and nitrite, as well as nitrate-rich submarine ground water and by broadcasting of bacterial, viral and fungal spores. Sahara dust as a source of pathogens is supported by Shinn *et al.* (2000) and Garrison *et al.* (2003).

2.7 Coastal and Pelagic Fish Species

2.7.1 <u>Definition</u>

Coastal fish resources in the Caribbean are linked with mangrove, seagrass beds and coral reef habitats. They include lobsters, crabs, shrimps, queen conch, a great variety of estuarine and reef fishes, coastal pelagics (clupeids, carangids) and fishes inhabiting the shelf slope (mainly deep-water snappers and groupers). Coastal fisheries in the insular Caribbean have been defined as reef fisheries. Estuarine environments are not extensive in the insular Caribbean, with the exception of Cuba and Hispaniola. Offshore fish resources are considered to be those caught off the islands shelves, these include small pelagics, mainly sardines, which are also found in coastal waters, and are associated with upwellings and highly productive waters more common off continental shelves; medium or large size pelagic predators and migratory fishes (tunids, swordfishes, billfishes, sharks); demersal fishes (mainly groupers and snappers); and bathypelagic fishes inhabiting offshore banks and oceanic cays (fished mainly by Puerto Rico and Hispaniola fishers).

2.7.2 Status

Most of the fishery resources of the island shelves (reef and estuarine fish, lobster, shrimp, conch and others), as well as the deeper demersal resources (mainly snappers and groupers) are considered to have been overexploited since the 1980s, and are coming under increasing fishery pressures throughout the region and are in need of rehabilitation in several islands (Mahon, 1987; 1993; Appeldoorn & Meyers, 1993; Aiken, 1993; Baisre, 1993; 2000; 2004; Claro *et al.*, 2001b). Moreover, many of these resources have been seriously affected by coastal development, pollution and habitat loss (Rogers, 1985; Hunte, 1997; Bouchon *et al.*, 1987; Mahon, 1993; Claro *et al*, 2004; 2007). On the other hand, some research suggests that following the Caribbean-wide mass mortality of herbivorous sea urchins in 1983-1984 and consequent decline in grazing pressure on reefs, herbivorous fishes have not controlled algal overgrowth of corals in heavily fished areas although they have restricted algal growth in lightly fished areas. Differences among islands in the structure of fish and benthic assemblages suggest that intensive artisanal fishing has transformed Caribbean reefs (Hawkins & Callum, 2002).

The fish resources of deep slopes and banks, which are based on fewer species than those on the island shelves, are in a better situation and in some cases, like in Cuba, they are underexploited. Large offshore pelagic fish resources are generally considered to hold the greatest potential for development in the islands. The catch consists of several species with a wide variety of life histories: tunas, billfishes, dolphin fish, wahoo, king mackerel and sharks. Most of these species show a marked seasonal availability in the whole region. Flying fish are also exploited in some of the islands of the Lesser Antilles. The status of offshore pelagic fish resources is highly variable depending on the species. The most important resources (skipjack and other small tuna, and swordfish) are heavily exploited in most areas, but little information is available for stock assessment. The existing information about resource assessment and management of the main fisheries in the Caribbean islands is patchy and much of the information is extrapolated from studies on the same species and types of fisheries elsewhere in the Wider Caribbean.

2.7.3 Climate Change Implications

Increasing Temperature

Claro *et al.*, (2007) showed that a significant decrease of fish density and biomass in the coral reefs of the Archipelago Sabana-Camagüey, Cuba, was a result of coral cover reduction by several bleaching events, and subsequent increase of algal overgrowth. Similar results have been reported by Jones *et al.*, (2004) for New Guinea reefs. These studies suggested that fish biodiversity is threatened wherever permanent reef degradation occurs.

Climate change is predicted to drive species ranges toward the more cold waters (Parmesan & Yohe, 2003) potentially resulting in widespread extinctions where dispersal capabilities are limited or suitable habitat is unavailable (Thomas *et al.*, 2004). For fishes, climate change may strongly influence distribution and abundance (Wood & McDonald, 1997) through changes in growth, survival, reproduction, or responses to changes at other trophic levels. These changes may have impacts on the nature and value of commercial fisheries and show that the distribution of both exploited and non-exploited North Sea fishes have responded markedly to recent increases in sea temperature, with two thirds of species shifting in mean latitude or depth over 25 years. Further temperature rises are likely to have profound impacts on commercial fisheries through continued shifts in distribution and alteration in community interactions. There is a lack of information on how tropical fish will respond to temperature increases.

Climate change will affect individuals, populations and communities through their physiological and behavioral responses to environmental changes (Boesch & Turner, 1984). Extremes in environmental factors, such as elevated water temperature, low dissolved oxygen, changes in salinity and pH, can have deleterious effects on fishes (Moyle & Cech, 2004). Suboptimal environmental conditions can decrease foraging, growth, and fecundity, alter metamorphosis, and affect endocrine homeostasis and migratory behavior (Barton & Barton, 1987; Donaldson, 1990; Pörtner *et al.*, 2001). These organism-changes directly influence population and community structure by their associated effects on performance, patterns of resource use, and survival (Ruiz *et al.*, 1993; Wainwright, 1994). Projections of future conditions portend further impacts on the distribution and abundance of fishes associated with relatively small temperature changes. Changing fish distributions and abundances will undoubtedly affect communities of humans who harvest these stocks (Roessig *et al.*).

Increasing Carbon Dioxide

"If global emissions of carbon dioxide from human activities continue to rise at current trends then the average pH of the oceans could fall by 0.5 units (equivalent to a three fold increase in the concentration of hydrogen ions) by the year 2100. This pH is probably lower than has been experienced for hundreds of millennia and, critically, this rate of change is probably one hundred times greater than at any time over this period. The scale of the changes may vary regionally, which will affect the magnitude of the biological effects" (The Royal Society, 1995).

In the Pacific Ocean, landings of anchovies and sardines, and the productivity of coastal and open ocean ecosystems have varied over periods of about 50 years. In the mid-1970s, the Pacific changed from a cool "anchovy regime" to a warm "sardine regime." A shift back to an "anchovy regime" occurred in the middle to late 1990s. These large-scale, naturally occurring variations must be taken into account when considering human-induced climate change and the management of ocean living resources (Chávez, *et al.*, 2003). Global warming may alter the response of populations to natural change in the Caribbean, but there is a lack of information necessary to assess such changes.

There is convincing evidence to suggest that acidification will affect the process of calcification, by which animals such as corals and mollusks make shells and plates from calcium carbonate. The tropical and subtropical corals are expected to be among the worst affected, with implications for the stability and longevity of the reefs that they build and the organisms that depend on them. Other calcifying organisms that may be affected are components of the phytoplankton and the zooplankton, and are a major food source for fish and other animals. Regional variations in pH will mean that by 2100 the process of calcification may have become extremely difficult for these groups of organisms particularly in the Southern Ocean. Some studies suggest that growth and reproduction in some calcifying and non-calcifying marine species could be reduced due to the projected changes in ocean chemistry. From the evidence available, it is not certain whether marine species, communities and ecosystems will be able to adjust or evolve in response to changes in ocean chemistry, or whether ultimately the services that the ocean's ecosystems provide will be affected.

With two duplicate six month manipulative experiments, Shirayama & Thorton (2005) demonstrated that a 200 ppm increase in carbon dioxide adversely affects the growth of both gastropods and sea urchins. Thus, even moderate increases in atmospheric carbon dioxide that could well be reached by the middle of this century will adversely affect shallow water marine benthic organisms.

Tropical Storms and Hurricanes

Increasing storm intensity will likely further reduce available fish habitat, e.g. mangroves and seagrasses, which are the main nursery areas for many coastal fishes and invertebrates, as well as coral reefs (Rogers *et al.*, 1982; Gelardes & Vega, 1999; Anónimo, 2005). The loss of habitat is greater in areas already affected by pollution and unsustainable use of the coastal zone.

Increase of Disease Pathogens

Mass mortalities due to disease outbreaks have affected major taxa in the oceans. For closely monitored groups like corals and marine mammals, reports of the frequency of epidemics and the number of new diseases have increased recently; this has been discussed in detail in Section 2.7.2. The role of coral community structure and diversity in maintaining productive fish and invertebrate populations is well documented, but links between these aspects and coral diseases are generally unstudied.

Increase of Harmful Algal Blooms

The Caribbean coastal waters periodically experience extensive blooms of algae that impact living resources, local economies and public health. Impacts of harmful algal blooms include human illness and death from ingesting contaminated shellfishes or fish, mass mortalities of wild and farmed fish, and alterations of marine food chains through adverse effects on eggs, young, and adult marine invertebrates (e.g. corals, sponges), sea turtles, seabirds, and mammals. Harmful algal blooms are increasing worldwide in frequency, distribution and impact, with significant threats for the insular Caribbean (Sierra-Beltrán *et al.*, 2004). Recently, blooms have occurred in new coastal areas and new species have appeared (GEOHAB, 2001; 2005). Harmful algal blooms are usually associated with upwelling systems, and wind is the main driving force in upwellings. So, variations in the wind regime due to climatic changes could cause short-term variation in upwelling-downwelling cycles (GEOHAB, 2005).

2.8 Seabirds and Coastal Waterfowl

2.8.1 <u>Definition</u>

The Caribbean is known for its rich abundance of seabirds, both resident and migratory, and its unusual mix of northern and southern species. These birds depend on the sea for food and the islands and cays for rookeries and nesting habitats. The coral-dependent sea life of the

Caribbean is a critical part of the food web for bird species. According to Schreiber and Lee (1999), conservation of Caribbean seabirds has largely been overlooked. These authors state that most tropical seabirds in the West Indies now exist at modest to relatively low densities and they normally feed at sea at great distances from breeding sites, and typically produce just one slow-growing chick per year. The combined result is that seabirds are more vulnerable at their breeding sites than most land birds because of the protracted period of nest occupancy and the concentration of complete regional populations in a few sites (Schreiber & Lee, 1999). Furthermore, populations are slow to recover from disturbance because of their low reproductive output and the entire populations of most sea birds reproducing in the Caribbean consist of only several thousand pairs (Schreiber & Lee, 1999).

2.8.2 Status

Schreiber and Lee, (1999) state that the breeding seabird fauna of the West Indies consists of three Procellariiformes (one of these, the **Jamaican petrel** [*Pterodroma caribbea]* is possibly extinct, and another, the **Black-capped petrel** [*P. hasitata*] is highly endangered), seven species of Pelicaniformes (pelicans and their relatives) and 12 Laridae (gulls and terns). The **Jamaican petrel** and **black-capped petrel, Audubon's shearwater** (*Puffinus lherminieri),* w**hite-tailed tropicbird** (*Phaethon lepturus)*, **brown pelican** (*Pelecanus occidentalis)*, **Cayenne tern** (*Sterna eurygnatha*) and **bridled tern** (*Sterna anaethetus)* are all represented by endemic subspecies. The **roseate tern** (*Sterna dougallii)*, is regarded as threatened by the US Fish and Wildlife Service with perhaps as much as **40%** of the world's population breeding in the West Indies (Schreiber & Lee, 1999). Populations in many outlying islands and islets have not been fully surveyed.

2.8.3 Climate Change Implications

In general, literature on seabirds and coastal waterfowl, and possible impacts of climate change focus on North America and Europe. However, bird life cycles and behaviour are closely related to changing seasons, and thus, according to DEFRA (2005), it is expected that climate change will generally have the following effects:

- The shifting of bird seasonal responses (phenology);
- Changes in egg laying dates: approximately 60% of studies on egg laying show long term advance in laying date, consistent with patterns of global warming (Dunn, 2004);
- Changes in migratory timing: migratory birds may be adversely affected by changes in wind patterns and increased frequency of storms. Increased frequency of storms in the Caribbean already appears to be reducing the number of some birds reaching their breading grounds (DEFRA, 2005). Hurricanes can have both direct and indirect effects on bird populations.

Direct effects include mortality from exposure to winds, rain, and storm surge; and geographic displacement by winds. Indirect effects are those that occur in the aftermath of the storm (days, months, and even years after) and include loss of food supplies and foraging substrates; loss of nests and nest or roost sites; increased vulnerability to predation; microclimate changes; increased conflict with humans.

- Mortality from wind, rain and flooding are best documented in aquatic birds, brown pelicans [*Pelecanus occidentalis*], and clapper rails [*Rallus longirostris*]. Geographic displacement by winds is commonly documented in seabirds blown inland.
- Mismatches between behaviour and environment.
- Loss of habitat, particularly wetlands.
- Vulnerability of long distance migrants.

Further, El Niño-Southern Oscillation variability, the persistence of multi-year climate-ocean regimes and switches from one regime to another have been recognised, and changes in recruitment patterns of fish populations have been linked to such switches (IPCC 2001). Similarly, changes in the survival of seabirds are also related to inter-annual and longer term variability in several oceanographic and atmospheric properties and processes (IPCC 2001), especially since the abundance and distribution of sea birds' prey may change.

2.9 Marine Mammals

2.9.1 Definition

A marine mammal is a mammal that is primarily ocean-dwelling or depends on the ocean for its food. There are five groups of marine mammals, with two Orders currently being present in the Caribbean region: Order Sirenia (e.g. West Indian Manatee) and Order Cetacea (whales and dolphins).

2.9.2 Status

The following is an excerpt taken from Reeves (2000) which provides a summary status of marine mammals in the Caribbean region:

The marine mammals documented in the region include six species of baleen whale (mysticete), twenty-four species of toothed whale (odontocete), one sirenian - the West Indian manatee - and a pinniped, the Caribbean monk seal. The latter is now considered extinct by the International Union for Conservation of Nature (IUCN), with the last confirmed sighting in 1952. Of these, seven species are classified as endangered or vulnerable by the IUCN. Although some species have been studied extensively elsewhere, data concerning the basic biology, life history, zeoogeography, and behavior of most cetacean (whale and dolphin) species in the Caribbean are scarce.

The mysticetes, or baleen whales, comprise the majority of large whale species. Baleen whales recorded from the region include the blue whale, fin whale, humpback whale, sei whale, Bryde's whale and minke whale, and there are occasional extra limital records of the critically endangered Northern right whale.

Twenty-four species of three toothed whale (odontocete) families have been reported at one time or another throughout the year. The oceanic dolphin family Delphinidae is represented by twelve genera and seventeen species. All three known species of sperm whales within the Physeteridae and Kogiidae families have been reported from the region. The beaked whale family, probably the least-known of all the Cetacea, is represented by at least four species.

Some species of cetacean may be resident in the Caribbean year-round, while others, such as the humpback whale, are known to engage in long-distance migrations between summer feeding grounds in the higher latitudes and winter breeding grounds in the tropical waters of the Caribbean. While certain species may range widely throughout the region or between islands, there are some indications that pilot whales may make seasonal movements within the Caribbean. Tracking studies suggest that some sperm whales move through deep waters between Guadeloupe and the southern Grenadines. Repeated sightings of individually identified sperm whales, both within and between years, indicate that certain individuals may be at least temporarily resident off these islands.

Several reports present information on the distribution and abundance of cetaceans based on sightings in the northern Gulf of Mexico. There still is insufficient data to assess the occurrence of many species of cetaceans in most parts of the region. Similarly, the distribution, abundance and behaviour of most species, especially the sperm whales, beaked whales and the smaller odontocetes have been poorly documented throughout the region.

Manatees are present in nineteen countries of the Wider Caribbean, but most populations are estimated at below one hundred individuals. Present distribution is fragmented because of local extinction or habitat unsuitability.

Directed fisheries for cetaceans have existed intermittently through the Caribbean since the late 1800s, capturing a range of species including sperm and humpback whales, pilot whales, beaked whales, killer whales, tucuxi and dolphin species. Subsistence whaling is still practiced in some parts of the region where meat and oil are consumed locally and such traditions are considered integral to their cultural heritage. In the southeaster Caribbean, humpback whales are still hunted in Bequia, Saint Vincent and the Grenadines. The target species of directed hunts in Barrouallie, Saint Vincent, and occasional catches off Dominica and Saint Lucia are generally pilot whales and nearly all other smaller odontocetes.

2.9.3 Climate Change Implications

For the most part the literature, regarding climate change and marine mammals, focuses on marine mammals inhabiting the polar regions and indicate that these are more likely to be affected (IPCC, 2001; Harwood, 2001). However, other literature indicates that the effect of climate change on the marine environment has the potential to have, and in some cases has already had, a considerable impact on the marine ecosystem and species (DEFRA, 2005). These effects include changes in abundance, distribution, timing and range of migration, community structure, the presence and species composition of competitors and predators, prey availability and distribution, timing of breeding, reproductive success and, ultimately, survival (DEFRA, 2005). The following provides some information on climate change and its impacts as these relate to the Caribbean region.

Population Abundance and Distribution

Literature in this area is scarce; however, in general, information indicates that migratory marine species, by traveling large distances and being subject to a wide range of environmental influences, are particularly likely to be affected by climate change at some point of their life cycles. While some species may increase in abundance or range, climate change will increase existing risk of extinction of some more vulnerable species (DEFRA, 2005).

Food Supply

One of the greatest threats to marine mammals probably comes from changes in their food resources, as a result of climate change. Many prey species such as fish, cephalopods and plankton appear to rely on, and are influenced by, particular sets of environmental conditions (Harwood, 2001). Any changes in the geographic distribution of these oceanographic conditions as a result of climate change will affect the abundance and distribution of prey species (DEFRA, 2005). Notably, apart from species residing within the region, it appears that other long ranging migratory species may depend on the region for food supply. Reeves (2000) states that at least one species of baleen whale depends on the wider Caribbean region for food resources, namely the common Bryde's whale, *Balaenoptera* cf. *brydei*; however, whether it migrates seasonally into and out of the region remains to be determined.

Diseases

Information on diseases and marine mammals in the Caribbean is limited; however, information pertaining to other regions suggests that there is an increase in diseases affecting marine mammals and that this may be, in part, due to temperature changes (Marine Mammal Commission, 2005).

2.10 Sea Turtles

2.10.1 Definition

Sea turtles (Family Cheloniidae; Family Dermochelyidae) are turtles found in all the world's oceans except the Arctic Ocean. There are seven living species of sea turtles, six of which are known to nest in the Caribbean region: green, hawksbill, Kemp's ridley, leatherback, loggerhead and olive ridley turtles.

2.10.2 Status

Sea turtle populations are severely depleted from historic abundances; many continue to decline. World-wide concern for the declining status of sea turtles had led to all species of sea turtle being classified as threatened to various degrees. Green, loggerhead and olive ridley turtles are considered to be "Endangered", while the hawksbill, leatherback and Kemp's ridley turtles are classified as "Critically Endangered". These terms are used by the IUCN RedList to characterise species which have exhibited declines of more than 50% and more than 80%, respectively, throughout their global ranges over the course of three generations, which for most species of sea turtle is about 100 years.

Bräutigam and Eckert (2006) provide detailed information on individual species, along with general trends and management issues. The following summarises issues affecting sea turtles:

- Exploitation and use at the national level; for example, most countries in the Wider Caribbean region have moratoriums protecting sea turtle populations, however, large and unmonitored legal fisheries remain and poaching (eggs, turtles) is a challenge region-wide;
- Illegal international trade, despite the fact that trade in this species is strictly regulated by the Convention on International Trade of Endangered Species (CITES);
- Predation of eggs by domestic, feral and wild animals;

- Loss of nesting habitat due to erosion caused by storms, sea level rise or sand mining activities, in addition to widespread losses due to coastal development in general;
- Loss of foraging areas (e.g. coral reefs and seagrass beds) to recreation, coastal development, coral disease, and disruption to the seabed (e.g. dredging and anchoring);

2.10.3 Climate Change Implications

Interestingly, in 2005, the IUCN Marine Turtle Specialist Group identified climate change as one of five key hazards to sea turtles worldwide, making the issue a high priority for further study.

Sea Level Rise

Fish *et al.*, (2005), conducted research to predict the impact of sea level rise on Caribbean Sea turtle nesting habitat. These researchers concluded that nesting habitat lost from expected sea level rise would have serious implications for sea turtle populations in the region. Sea level rise is also expected to impact on foraging grounds such as seagrass beds, coral reefs and the open ocean. Further, climate change is expected to result in more intense storms, which in turn, would compound the impacts of sea level rise, furthering eroding and altering the topography of beaches. Fish *et al*., (2008) conducted research on the use of coastal development setbacks to reduce the impact of rising sea levels on nesting beaches.

The increase in tidal height may also flood eggs from underneath. If the sand is saturated by storm-driven waves or subsurface flooding and does not drain adequately, the embryos will drown. It is worth noting that sea turtles have adapted to rising sea levels in the geological past, however, the current pattern of coastal development that prevents beaches from retreating inland naturally is potentially devastating for turtle populations.

Increasing Temperature

In marine turtles, sex is determined by temperature in the middle third of incubation with female offspring produced at higher temperatures and males at lower temperatures within a thermal tolerance range of 25–35°C (Ackerman, 1997). A mixture of sexes is produced within the threshold range of temperatures with 50% of either sex at a ‘pivotal temperature’ (Mrosovsky, 1988). According to Glen and Mrosovsky (2004), air temperatures in Antigua have increased by 0.7^{o}C over the last 35 years. These authors further state that measurements in both the sand and the clutches laid by hawksbill turtles at Pasture Bay, Antigua, show that for important parts of the nesting season temperatures are already above the level producing 50% of each sex (pivotal level); and it was estimated that fewer males were produced in 2003 than in the previous years.

From 1989 to 2003, the annual number of nests in their study area fluctuated between 13,000 and 25,000 without a conspicuous trend; however, based on a regression analysis, the median nesting date occurred earlier by approximately 10 days. The Julian day of median nesting was significantly correlated with nearshore May sea surface temperatures that warmed an average of 0.8 ^{O}C over this period.

Sea level rise and coastal development in Barbados have forced turtles to nest closer to the sea and this therefore impacts nest temperatures as well (Horrocks & Scott, 1991). Increasing temperature affects incubation length and hatching success.

In general, it is not clear precisely how great the effects of climate change on sea turtle reproduction will be. Comprehensive long-term data sets are needed to fully research the matter; and until then, how sea turtles will respond to climatic change remains a matter of speculation.

The long distance movement of marine turtles is one of the wonders of the natural world, with satellite tracking and recapture techniques showing how some species move thousands of kilometers across the ocean on an annual basis. Research suggests that migration routes are strongly influenced by two factors: sea surface temperature and chlorophyll concentrations. As such climate change has the potential to impact migratory patterns of sea turtles. Studies show that temperature can affect severity of infection (Haines and Kleese, 1977) and may also increase outbreaks of disease in sea turtles. Moreover, many disease outbreaks peak during El Niño events, suggesting a significant climatic influence on the interactions among hosts, pathogens, and the environment. Anomalous (unusually warm or cold) sea surface temperatures can displace food sources, reduce host defenses and alter the growth of disease pathogens. Intense rains and flooding (extreme weather events) can provide pulses of nutrients, chemical pollutants and pathogens, all of which can promote disease outbreaks.

3. KNOWLEDGE GAPS RELATING TO THE IMPACT OF CLIMATE CHANGE ON COASTAL AND MARINE BIODIVERSITY

3.1 Background

Some general comments regarding the published and grey literature are as follows:

- At this stage, much of the information is very generic both for the habitats and species. The ability to define boundary conditions for different species and different climate scenarios is still a long way away. Work on indicator species is only just beginning, e.g. a recently (2007) started project by the World Wildlife Fund on using the hawksbill turtle as an indicator species with which to measure the biological effects of climate change.
- There are many conflicts in the available information sometimes for the same site and this may be due to the different methods by which the data is collected. In many instances the methodology and metadata are not provided.
- Much of the information in the literature is based on modeling studies alone, with insufficient ground checking.
- There is only limited information available for the insular Caribbean and especially for the smaller islands.
- It is known that there is a large volume of unpublished information relating to marine and coastal biodiversity held in government agencies across the insular Caribbean, sometimes compiled as statistics and reports; also in baseline studies prepared by consultants for environmental impact assessments. Considerable time and effort, together with visits to the individual islands, is required to access this information. There are several incentives for researchers working in academia to publish their results; however, there is less incentive for those researchers working in government and private consultancies.
- The amount of research varies according to the particular sub-system, e.g. there is much more literature available on the impacts of climate change on coral reefs than on seagrass beds.

3.2 Major Gaps Relating to Biodiversity Management

Whilst it is recognised that further research work is required on all species of marine flora and fauna, their habitats and the processes affecting them, this section identifies major gaps relating to biodiversity management in the light of expected climate change in the insular Caribbean.

3.2.1 Long Term Monitoring of Changes in Coastal and Marine Ecosystems

There is large variation in the insular Caribbean in the availability of data relating to the spatial extent of coastal and marine ecosystems, inventories of flora and fauna, and the monitoring of ecosystem changes. Some islands have quite sophisticated data collection systems in place, while other islands have limited or non-existent systems. Even where there are sophisticated data collection systems it may not be easy to access the information, e.g. government agencies in Barbados and Trinidad & Tobago have long-term (more than 20 years) data on beach changes, but publications on the results and trends are not easily accessible. The CARICOMP network of marine laboratories has long term data on emergent coastal wetlands, seagrass beds and coral reefs with a data management centre at UWI Jamaica; however, this network is not geographically representative of the Caribbean since its monitoring stations are limited to sites easily accessible from marine laboratories. Some islands e.g. the British Virgin Islands have mapped the spatial extent of marine ecosystems on GIS, however, on other islands there is minimal knowledge of the spatial extent of the reefs, seagrass beds and emergent coastal wetlands.

3.2.2 Connectivity between Systems in the Insular Caribbean

Few studies have been conducted in the region to investigate connectivity and interrelationships from the perspective of the Caribbean Sea as a large marine ecosystem. One such study (FAO project: Scientific basis for ecosystem-based management in the Lesser Antilles, including interactions with marine mammals and other top predators, 2002-2007), examined interrelationships among some key pelagic species in an effort to improve management of shared marine resources. While this study only focused on the eastern Caribbean, it underscored the importance of understanding the intricate linkages among species and systems within a large marine ecosystem. It is essential that studies be conducted to examine connectivity and interrelations that exist within the Caribbean large marine ecosystem. Further, it is important to also to begin to understand connectivity of the Caribbean large marine ecosystem with other regions.

The process affecting the recruitment and retention of propagules, larva and pelagic juveniles of coral reef organisms is not yet fully understood. Some of the research indicates that reef organisms depend mainly on self-replenishment with retention of recruits from parental reefs or nearby reefs, so that large-scale connectivity by ocean currents is not a major factor (Ayre & Hughes, 2004; Barber *et al*., 2000; Cowen *et al.,* 2006; Jones *et al*., 1999; Swearer, *et al*., 1999). Whilst other research indicates larvae of reef organisms can disperse large distances and replenish populations on distant coral reefs (Domeier, 2004; Mora *et al.,* 2003; Roberts, 1997; Veron, 1995). Further studies are required to examine the role that larval transport, recruitment, post-recruitment survival, and connectivity play in networking coral reef environments, particularly as they relate to the siting and management of marine protected areas.

Studies need to be conducted to determine life cycles and interconnectivity of key coral and associated species at national and regional levels, including the understanding of links between species diversity and ecosystem function.

3.2.3 Modeling of Circulation Changes in the Caribbean Sea, Gulf of Mexico and South North Atlantic due to Climate Change

Modeling of the effects of temperature change on the circulation of the Caribbean Sea and likely changes in the sites of upwelling and downwelling is needed to understand how this will affect marine flora and fauna, especially migratory patterns of fish, the dispersion of coral and fish larvae, and the migratory routes of marine mammals and turtles inhabiting or migrating through the region; as well as on their prey.

3.2.4 Sea Level and Sea Surface Temperature Data for all the Insular Caribbean

One of the goals of the Caribbean Planning for Adaptation to Climate Change project (1996-2001) was to install a tide gauge network in all the CARICOM islands for the measurement of sea level rise. This goal was not achieved due to various complexities including the maintenance of the equipment and the need to measure land uplift so as to determine relative sea level change (d'Auvergne, 2004). A 2005 study by Henson assessed the status of all the installed tide gauges in the region, see Annex 4 for a summary of the results. It appears that as of January 2005, there were only six operating tide gauges in the insular Caribbean: two in The Bahamas, two in Cuba, one in Curaçao and one in Puerto Rico. The Mainstreaming Adaptation to Climate Change project (MACC) is planning to install new sea level sensors in some islands of the English-speaking Caribbean, although it is not clear whether the earlier issues regarding equipment maintenance have been fully addressed. Especially since rising sea levels are likely to impact many coastal and marine ecosystems, there is a need to have a well maintained, operating monitoring network as an urgent priority. While long term monitoring is not always the most attractive activity either for governments or donor agencies, its importance cannot be over-emphasized.

Specific information on sea level rise in the insular Caribbean is needed to understand how rising water levels will affect coastal biodiversity. For example, if sedimentation rates keep pace with rising sea level, the frequency of inundation of mangrove species zones will remain largely unaffected. However, if the rate of sea level rise exceeds the rate of sedimentation the system changes (Ellison, 1996).

In addition, it should be noted that long term data records on sea surface temperature, especially at the local and national levels are also inadequate.

3.2.5 Ocean Acidification

Research into the impacts of high concentrations of carbon dioxide in the oceans is in its infancy and needs to be developed rapidly. Critical gaps include the calcification response to increased carbon dioxide in key species; changes in calcification rates and their effect on the ecology and survivorship of key organisms; mechanisms of calcification within key calcifying groups of the region; and understanding of the diurnal and seasonal cycles of the carbonate system on coral reefs (adapted from Kyepas *et al*., 2006).

3.2.6 Diseases and Invasive Species

There has been much effort to document coral bleaching events and link this to temperature changes; however, more information is required on coral diseases in the region and how these respond to temperature changes. There is some data available to indicate that some species may be more temperature tolerant than others; however, further studies are needed to determine the level of tolerance of key coral and associate species for factors such as salinity, temperature, turbidity and pH.

In general, limited information is available on the diseases affecting Caribbean marine mammals and turtles or of the influence of temperature and other climatic factors on these diseases.

An inventory of marine invasive species in the region is needed; and further work is required as to how they are influenced by climatic factors. For instance, the presence of the lion fish (*Pterois volitans*), a species from the Pacific Ocean, has recently been reported on many reefs in the Caribbean (Puerto Rico, Cuba, Florida). It is not known how the invasion of this species may alter reef fish communities in the Caribbean. Little is known about the abundance and distribution of marine invasive species and their impacts at the national level in many of the smaller islands.

3.2.7 Algal Blooms and Plankton

Burkeholder (1998) states that there are records of harmful algal blooms from thousands of years; however, over the past few decades, the instances have increased. Although much of the data available focuses on concerns for human health, data on trends in algal blooms for the region are available from the Intergovernmental Oceanographic Commission. In 1997, this institution recommended the formation of an IOCARIBE working group on harmful algal blooms in the Caribbean region. Studies for the insular Caribbean should be conducted to investigate current trends in algal blooms and plankton distribution patterns in the region. The influence of temperature, salinity and pH, as well as other climatic factors, on these should also be investigated.

3.2.8 Remediation Techniques and Ecosystem Resilience

The health status of coral reefs is generally poor; however, there have been a number of efforts in the region aimed at coral reef restoration and rehabilitation. Given that healthy reefs are more resilient than reefs in poor condition, studies are needed to examine the state of remediation techniques that also provide for ecosystem resilience and are suitable for national and regional situations. The same situation applies to other ecosystems, such as wetlands, coastal forests and seagrass beds.

3.2.9 Biological Research and Assessments

Data on most cetaceans, especially the smaller odontocetes in the Caribbean region is scarce and information is needed on basic biology, life history, zeoogeography, behaviour, distribution and abundance (Reeves, 2000).

In addition, information on seabirds and waterfowls of the region is generally scarce. As such, there is a need to conduct an up-to-date assessment of the status of these birds, including information relating to the status of their habitats, life history and behaviour, and the influence of climatic factors on migratory patterns, reproduction, nesting habitat and prey.

3.2.10 Species Responses to Changes in Temperature

Comparative little research has been done on the physiology and ecology of marine and estuarine fishes, particularly in the tropics. Without an understanding of how these organisms and systems function and interact, it is unknown how they will react to perturbations, including global climate change-related disturbances. These gaps lead to uncertainties about future fish stocks and the livelihoods of the people depending on them.

Some information exists to suggest that with rising temperature there is a trend of increasing number of female turtle hatchlings in clutches. However, more studies in this area are required to determine if this is a local or regional trend, and the influence of other factors such as the loss of shading from beach vegetation.

It is possible that changes in the annual temperature cycle can provoke changes in spawning time of marine organisms and those changes may influence the replenishment of fish stocks.

4. RESEARCH AGENDA FOR COASTAL AND MARINE BIODIVERSITY

This research agenda has been developed to inform biodiversity management in the insular Caribbean whether for conservation, sustainable livelihoods, resilience building or vulnerability reduction in the light of climate change impacts over the next ten years.

4.1 Background

In developing a research agenda it is important to learn from past activities – those that worked well, as well as those that did not. The CPACC project was unsuccessful in establishing a fully functional, state-of-the-art tide gauge network throughout the project's participating islands. Sometimes in such cases it is helpful to look at what is working, e.g. a simpler floating gauge has provided 40 years of data in Curaçao (Hanson, 2005). It is essential to fully understand individual island's human capacity as well as their perception of research needs. This is especially so with today's mobile professional workforce.

Many government agencies recognise the need to monitor environmental systems and there are some very professional monitoring programmes in place. However, there is an almost universal reluctance to share the information with other agencies in the same island and with other islands.

The potential exists for communities and school students to participate in simple data collection programmes, however such programmes must be carefully designed so as to address the community or school's particular interests as well as the scientific interest. Successful examples in the region include Sandwatch, a programme focusing on beaches, and Reef Check with its focus on coral reefs. These activities can supplement the more sophisticated monitoring programmes undertaken by scientists, and for some remote inaccessible ecosystems, the simple monitoring may be the only source of information available (Cambers, 2008).

Furthermore, climate change is going to affect the lives of everyone in the insular Caribbean, so there is a need to involve everyone in learning about the issues, sharing information and taking adaptive measures.

The following agenda includes activities that are solely research based, as well as some activities that include research and management.

4.2 Research Agenda

4.2.1 Long Term Monitoring of Changes in Coastal and Marine Ecosystems

The objectives are to: compile and analyse existing monitoring data on a regional basis, with the aim of determining long term trends that can be used for forecasting; and to develop a system to enhance data sharing and management.

Activity 1 (Data Compilation)

A considerable amount of data exists on recent (10-20 years) changes in coastal and marine biodiversity for the region, collected by different projects, countries and institutes. A priority is to compile and analyse this information in a comprehensive manner so as to prepare new island-level baselines against which future changes can be compared.

This will include, but not be limited to, collecting, compiling, analysing and determining regional trends from the following:

- Data covering more than fifteen years from the CARICOMP Data Centre relating to the monitoring of emergent coastal wetlands, seagrass beds and coral reefs, as well as salinity, temperature, dissolved oxygen, turbidity; (scientists in the CARICOMP network have seen the need for such an analysis, but are at present too busy to undertake this work)
- Coral reef data being collected by other groups e.g. Reef Check, International Coral Reef Network (ICRAN), Atlantic and Gulf Rapid Reef Assessment (AGRRA)
- Monitoring and inventory data collected by other groups, e.g. OBIS-SEAMAP – marine mammals, birds and sea turtles (Halpin et al, 2008); NaGISA project – a collaborative effort aimed at monitoring rocky bottom algal and soft bottom sea grass communities; University of Puerto Rico Sea Grant College Program project to assess research needs for the conservation of Caribbean coastal and marine resources
- Beach change monitoring data undertaken in some islands since 1980s through national, and regional programmes such as UNESCO's Coast and Beach Stability Project (COSALC)
- Inventory of sea turtle nesting habitats undertaken by WIDECAST and the Nature Conservancy (Dow et al, 2007)
- Unpublished data available in government agencies and NGOs relating to changes in coastal and marine systems

- Fisheries data relating to the main targeted species as well as changes in fishing effort, being collected by various government institutions responsible for fisheries management. Other entities such as the Food and Agriculture Organization, Organisation of Eastern Caribbean States, International Commission for the Conservation of Atlantic Tunas, Institute of Marine Affairs and Caribbean Regional Fisheries Mechanism may also hold data or information of interest

Activity 2 (Data Management)

Complementary to the compilation and analysis of data, is effective data management and data sharing mechanisms. While a number of national and regional institutions have accumulated relevant datasets for a variety of reasons, few of these are well managed. To ensure ready access to data in the future, the following actions would be required:

- Identifying key institutions to serve as pilots for capacity building in data management
- Building capacity for data management within these key institutions
- In collaboration with key institutions, develop a web service using end-to-end access. The objective of this service would be to create a network among relevant data holding entities to facilitate data sharing.

All activities will require the cooperation of governments to release relevant information and it is understood that some information, e.g. water quality, may be considered too sensitive in nature to be released. It is also recognised that it would be necessary to have various levels of access to information through the proposed web service.

4.2.2 Connectivity between Systems in the Insular Caribbean

The objectives are to examine connectivity and interrelationships that exist within the Caribbean large marine ecosystem; and to investigate the effects of climate change on connectivity and interrelationships that exist within the Caribbean Sea and adjacent water bodies.

Activity 1

Determine interrelationships that exist within the Caribbean large marine ecosystem. This activity should consist of reviewing existing information and past studies, and supplementing these with field studies to present a more comprehensive understanding on the subject.

Activity 2

Prepare predictive models showing changes in connectivity of ecosystems and species interrelationships in the Caribbean Sea likely to result from climate change. These models should address knowledge gaps on:

- Effects on distribution of selected species, including those that play an important role in terms of both economic benefits and environmental services, and the spin-off effects of redistribution
- Effects on predator/prey relationships

Activity 3

Examine various scenarios to predict changes to environmental services and economic benefits, and make recommendations on the most effective adaptation measures that countries could focus on.

4.2.3 <u>Modeling the Circulation Changes in the Caribbean Sea, Gulf of Mexico and North Atlantic due to Climate Change</u>

The objective is to model circulation changes in the Caribbean Sea and between adjacent water bodies.

Activities

Prepare predictive models showing circulation changes (currents, vertical water displacements) in the Caribbean Sea, Gulf of Mexico and southern North Atlantic Ocean likely to result from climate change so as to address knowledge gaps on:

- Dispersal of coral, fish and invertebrate larvae, and plankton
- Effects on upwelling patterns, fish productivity and habitat status
- Effects on migratory routes of species such as cetaceans, sea turtles and pelagic fish

4.2.4 <u>Sea Level and Sea Surface Temperature Data for the Insular Caribbean</u>

The objectives are to establish a representative network of tide gauge stations to measure sea level rise; and to establish a representative network of temperature gauges to measure sea surface temperatures.

Activity 1

Based on previous project experience and in a collaborative participatory manner, determine the optimum way to establish a functional tide gauge network taking into particular account the long term maintenance of the network. The process for establishing such a network should include:

- Selection of sites
- Identification and installation of appropriate systems at sites, giving consideration to the ongoing management and maintenance of the gauges
- Establishment of a networking system among sites, including a central node to facilitate data collection, analysis, management and dissemination.

Activity 2

In collaboration with relevant entities, design and implement an effective data temperature collection system for the region, including nearshore waters (especially in areas with coral reef and seagrass beds). The design should include site selection at the national level, along with justification for site selection. The design should also detail institutional arrangements for data collection, management and dissemination, and relevant protocols and procedures.

4.2.5 Ocean Acidification

The objective is to investigate trends in acidification in the Caribbean Sea and effects on selected species.

Activities

Acidification is potentially a very serious threat to coastal and marine biodiversity; however, the degree of this threat is not fully understood. Information on effects of ocean acidification for the region is focused on a few coral species; but there is a need to:

- Select species for research based on ecological and economic importance – species selected should include *Diadema* species, lobsters and conch
- Establish baseline and long term monitoring of ocean pH and calcification rates on coral reefs and key invertebrate species
- Determine the calcification response to increased carbon dioxide in key species
- Investigate how a change in calcification rate affects the ecology and survivorship of selected organisms
- Determine the various mechanisms of calcification within key calcifying groups of the region.

4.2.6 Inventory of Diseases and Invasive Species

The objectives are to conduct an inventory of diseases of key marine species; to conduct an inventory of invasive species (including alien species that may become potentially invasive); and to investigate correlations between diseases and climatic factors, such as temperature changes.

Activity 1

The literature review underscored the absence of data on diseases of marine species in the Caribbean region and climatic influences on them. As such, the following activities should be conducted, noting also that this information is important to the use of predictive models to determine effects of climate change on these diseases:

- In collaboration with relevant entities develop a data base of diseases affecting various species within the region.
- With the use of existing data determine present and future trends in these various diseases

Activity 2

Similar research is required for invasive species affecting the region. A number of countries have no baseline information on invasive species found within their waters.

Activity 3

Select key diseases affecting marine biodiversity in the region and conduct research on these to determine possible effects of climate change on these diseases.

4.2.7 Algal Blooms and Plankton

The objective is to understand current trends in algal blooms and plankton distribution patterns, and the influence of temperature, nutrients, salinity and pH, as well as relevant climatic factors.

Activities

- Baseline survey and monitoring of plankton which are especially important since they form the basis of the food chain
- Baseline survey of plankton at selected sites and long term monitoring

4.2.8 Remediation Techniques and Ecosystem Resilience

The objectives are to increase ecosystem resilience through the application of remediation techniques, suitable for potential applications at national and regional levels; and to promote ecosystem resilience to climate change at selected sites.

Activity 1

Compile information on ecosystem remediation from around the world; and select pilot sites to test and determine most successful remediation techniques, monitor and document results.

Activity 2

Based on the understanding that whenever possible, adaptation measures should commence as soon as possible, this activity consists of monitoring selected sites with the assistance of the wider community and then implementing measures that will strengthen the resilience of the ecosystem to climate change.

This will involve three phases:

- Site selection based on designed criteria;
- Ecosystem monitoring by communities and scientists;
- Management activities to enhance the resilience of the ecosystems to adapt to climate change.

Sites will be selected in the insular Caribbean and a new baseline of coastal and marine biodiversity will be established. The following criteria will be used for site selection:

- Hotspots for biodiversity (species richness and diversity);
- Hotspots for endemic species (high number of endemic species);
- Present and/or future anthropogenic impact;
- Proximity to community;
- Provides livelihoods for island communities;
- Important migratory habitat (birds and turtles);
- Level of vulnerability to climatic factors.

A new baseline will be prepared for each site including mapping of the spatial extent of the ecosystems at the selected sites and the preparation of species inventories. Then working with communities, schools, NGOs, governments, private sector and academic institutions, monitoring activities will be undertaken that will measure ecosystem changes, help to identify stressors, develop biological indicators and biological integrity indices for individual habitats. Monitoring could include simple monitoring that might be undertaken by communities or students, as well as more sophisticated monitoring that would be conducted by relevant institutes/government agencies.

Monitoring by communities may include:

- Localised weather data: precipitation, temperature, wind speed and direction;
- Beach erosion rates;
- Sedimentation rates (emergent coastal wetlands).

Monitoring by institutions may include:

- Sea surface temperature, salinity, pH, dissolved oxygen, turbidity;
- Sea level changes (tide gauges);
- Biological community structure, composition and health.

Management activities would involve participation by all stakeholders and might include activities such as:

- Establishing green belts and strengthening existing coastal forests;
- Establishing marine protected areas and conservation areas;
- Rehabilitation of degraded systems (e.g. mangrove planting);
- Creating buffer zones between development and beaches/coastal emergent wetlands
- Reducing land-based sources of marine pollution
- Volunteer environmental vigilance, beach clean-ups,
- Environmental education and awareness activities, and publication of environmental and conservation materials
- Stakeholder involvement in planning, socioeconomic development and biodiversity conservation.

4.2.9 Biological Research and Assessments of Selected Species

The objective is to conduct biological research and assessment of selected species.

Activities

The literature review revealed a paucity of information available on seabirds and waterfowl of the region. Potential effects of climate change are mostly speculative and basic information on these birds to support predictive models is unavailable. Given this, the following the following should be conducted:

- Selection of species for research; species selection should be based on predetermined criteria, which should include rare or threatened status and economic value. Based on the analysis in this report, selected species should include sea birds and waterfowl, and some key cetacean species
- Determine biology of selected species
- Conduct status assessments of selected species and their habitats
- Determine life histories, including phenology, relationships with other species, migratory patterns and nesting habits
- Investigate effects of climatic factors on various aspects of the life history and behavior to determine vulnerability to climate change

4.2.10 Species Response to Changes in Temperature

The objective is to investigate the response of selected species to changes in temperature.

Activities

- Select species for research based on predetermined criteria. In selecting species, consideration should be given to further researching coral responses to temperature changes and tolerance levels of various species
- Investigate response of species to temperature changes. Responses investigated should include spawning timing, behavior and distribution.

5. INSTITUTIONAL CAPACITY

There are many organisations and research institutes in the region who are working on climate change issues. Collaboration and exchange between organisations and projects about climate change is now more important than ever.

5.1 Research Institutes working on Climate Change

The following represents a list of organisations and projects working on climate change in the Caribbean region, and where available the particular area of interest or research is indicated.

- Caribbean Community Centre for Climate Change, Belize: climate modeling
- Caribbean Environmental Health Institute, St. Lucia: water resources and climate, health and climate change
- Caribbean Coastal Marine Productivity Program (CARICOMP): a network of marine laboratories in the Caribbean: monitoring of marine biodiversity
- Centre of Coastal Ecosystems Researches (CIEC), Cayo Coco, CITMA, Cuba: marine biology and coastal geomorphology
- Institute of Forestry, Puerto Rico: coastal forests and emergent coastal wetlands
- Institute of Marine Affairs, Trinidad and Tobago: biodiversity and beach dynamics monitoring
- Institute of Oceanology, Cuba: marine biology, physical oceanography, hydrochemistry, marine pollution, coastal geomorphology, beach management
- Intergovernmental Oceanographic Commission of UNESCO, Paris: global ocean observing system, coral reef monitoring, coral bleaching, ocean acidification
- IOCARIBE: planning for adaptation to climate change, management of the large marine ecosystem of the Caribbean
- Mesoamerica reef project:
- Millennium Ecosystem Assessment: synthesised assessment reports on global ecosystems, biodiversity, wetlands
- United Nations Environment Programme – Regional Coordinating Unit – Caribbean Environment Programme (UNEP-RCU-CEP), Jamaica: coral reefs, invasive species,
- University of Havana, Centre of Marine Research, Cuba: marine biology, aquaculture, genetics, physiology, biotechnology
- University of Miami, National Centre for Caribbean Coral Reef Research, USA: reef recruitment and connectivity and reef resilience under stress
- University of Puerto Rico

  Natural Hazards Prevention Centre, Mayaguez: coastal flooding, sea level rise

Marine Sciences, Mayaguez: coral reefs

- University of the West Indies

  Barbados Sea Turtle Project: sea turtle monitoring, migration and distribution, habitat protection

  Climate Change Centre, Barbados: climate modeling

  Caribbean Data Management Centre, Discovery Bay, Jamaica: biodiversity data repository for the CARICOMP network

- United States Geological Service: project on Sahara dust (at University of the West Indies and the University of Puerto Rico)
- Wider Caribbean Sea Turtle Network (WIDECAST): turtle monitoring, migration and management
- World Wildlife Fund, Belize: project on the hawksbill turtle as an indicator species of the impacts of climate change

5.2. National Capacity

National fisheries and environmental agencies in particular have ongoing activities and knowledge about climate changes. Information also exists in NGOs, e.g. the Nevis Historical and Conservation Society is building a web-based biodiversity inventory.

6. POLICY

All of the insular Caribbean, with the exception of Puerto Rico and the US Virgin Islands are parties to the Convention on Biological Diversity (CBD). This international treaty seeks to sustain the rich diversity of life on earth, as well as genetic differences within each species, the variety of ecosystems and habitats, and the large number of associated goods and services. The CBD was adopted at the 1992 Earth Summit in Rio de Janeiro. Those countries that have ratified or acceded to this convention have reporting mechanisms in place and are taking various initiatives and measures to achieve the 2010 target, which has a strong commitment to reduce the current rate of biodiversity loss. Most of the insular Caribbean, with the exception of Haiti, Jamaica, Puerto Rico and the US Virgin Islands are also parties to the Catagena Protocol on Biosafety that was adopted in 2000 and seeks to protect biological diversity from the potential risks posed by living modified organisms resulting from modern biotechnology.

The United Nations Framework Convention on Climate Change was also adopted at the Earth Summit in 1992. As the title suggests this was an attempt to consider what can be done to reduce global warming and to cope with whatever temperature increases are inevitable. All the countries of the insular Caribbean are parties to the Convention. The 1997 Kyoto Protocol strengthened the Convention by committing Annex 1 parties to individual, legally binding targets to limit or reduce their greenhouse gas emissions. (The USA has not ratified the Kyoto Protocol). Under the Convention all parties have to report on the measures they are taking to implement the Convention.

Fourteen islands have acceded to the Ramsar Convention (1971) or Convention on Wetlands and have committed to the wise use of all wetland resources through the development of national plans and policies.

Most countries in the insular Caribbean have established national climate change committees comprising local experts, whose task is to advise their governments about the different aspects of climate change and how this will affect national policy and projects.

Governments and countries both nationally and regionally need to be proactive in conserving coastal and marine biodiversity, e.g. Following the Convention on Biological Diversity's Eighth Conference of the Parties, Grenada committed to protecting 25% of both its marine and terrestrial resources by 2020, based on the completion of a national Protected Area Gap Analysis, to be undertaken with the help of the Nature Conservancy.

Coastal and marine biodiversity, while an important contributor to the economy of the insular Caribbean, is heavily impacted by development projects and other human activities. Climate change is likely to further stress coastal and marine biodiversity and countries need to ensure that the impact of climate change is fully considered in all new development proposals and projects. Recent efforts by the Caribbean Development Bank to ensure that risk management, including climate change, is integrated into the environmental impact assessment process (CDB, 2004) is an important first step, but there is still much to be done.

Islands need to work together to conserve coastal and marine biodiversity. One example of sub-regional cooperation took place in July 2007 when Cuba, Haiti and the Dominican Republic signed a tripartite agreement to create the Caribbean Biological Corridor, aimed at protecting the environment and human development. This is a defined geographical space which links landscapes, ecosystems and natural or modified habitats, all of which create the conditions for maintaining biological diversity, essential ecological processes, and the benefits they generate.

Governments need to establish national and regional policies to guide research and provide access to data along the following lines:

- Give direction to the formation and implementation of appropriate institutional arrangements pertaining to data collection and management as these relate to climate, the environment and biological diversity;
- Guide the involvement of students and other researchers in research activities, facilitating ready access to data/information collected by them;
- Provide standardisation for data collection and management, considering issues such as modeling at the national, regional and international levels;
- Enhance the availability and use of information and knowledge relevant to management and planning;
- Facilitate documentation and analysis of information on environmental status, including the country's progress in adaptation to climate change and mitigation of its impacts;
- Inform researchers of the specialised priority areas of study needed to enhance knowledge relevant to management, forward planning and adaptation;
- Increase efficiency and coordination of collection and management of environmental data, including that on climate change.

7. CONCLUDING REMARKS

Climate change is undoubtedly one of the greatest challenges facing mankind. Whilst there is still some uncertainty about the specific rate of changes, and even more uncertainty about the impact on the planet and the living world, it is generally agreed that mitigation and adaption measures must be implemented now despite these uncertainties. Against this background, it is especially important to maintain scientific rigor in the research and studies that are to be conducted. This present report with its assessment of the current state of knowledge regarding the impact of climate change on coastal and marine biodiversity fulfills the twofold function of providing the basis for a research agenda as well as providing a qualitative baseline against which future progress can be assessed.

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ANNEX 1
Literature Review on the Impact of Climate Change on Emergent Coastal Wetlands
Amy Heeraman (edited by Rahanna Juman)

This is a review of the information that exists on the mangroves and other coastal wetlands in the insular Caribbean and the likely impact of climate change on these ecosystem types.

CARIBBEAN MANGROVES AND COASTAL WETLANDS

The Convention on Wetlands of International Importance, commonly called the Ramsar Convention of 1971, defines wetlands as '*areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres.'* This definition, is broad, and encompasses inland wetlands (such as marshes, rivers, swampwood and palm forests), coastal and near-shore marine wetlands (such as mangrove forests, seagrass beds and coral reefs) and human-made wetlands (such as dams, rice fields and sewage ponds).

This review is limited to coastal emergent wetland in the insular Caribbean which is dominated by mangroves and freshwater marshes or 'swamps.' The diversity of wetland types in the Caribbean along with their structural and functional characteristics were described by Lugo and Brown (1988). At that time they identified a lack of nomenclature specific to wetlands, but attempted a categorisation based on plant associations. Their study had an emphasis on Puerto Rico, Cuba and Jamaica, the other islands (Antigua, Barbuda, Dominican Republic, Guadeloupe, Haiti and Martinique) were generalised.

Mangrove forests in the insular Caribbean are of four main functional types (Lugo & Snedaker, 1974) based on edaphic and hydrologic conditions: riverine, fringe, basin and scrub. Flora in the mangrove ecosystem can be classified based on Duke's (1992) system. Mangrove species in general are divided into the Atlantic East Pacific and the Indo West Pacific. The Caribbean region falls into the East Americas, a subdivision of the Atlantic East Pacific hemisphere. The Caribbean region has fewer mangrove species than the Indo West Pacific. According to Bacon (1993), mangroves have been reported throughout the insular Caribbean, often in extensive areas of the coastal zone, but in the smaller islands of the Eastern Caribbean their areal coverage may be restricted and mangroves have poor tree development resulting in low coastal scrub. There are seven species and one variety of mangroves in the insular Caribbean (Table 1).

Table 1 Mangrove Species in the Insular Caribbean (Bacon 1993)

Family	Species	Common name	Notes
Rhizophoraceae	*Rhizophora mangle* L.	Red mangrove	Most abundant throughout the region
	R. harrisonii Leechman	Red mangrove	Restricted to Trinidad
	R. racemosa G.F.W. Meyer	Red mangrove	Restricted to Trinidad
Avicenniaceae	*Avicennia germinans* L.	Black mangrove	Widespread
	A. schaueriana Stapf. & Leechman	Black mangrove	Not common
Combretaceae	*Laguncularia racemosa* Gaertn.	White mangrove	Rarely forms large stands
	Conocarpus erectus L.	Button mangrove	Common on wetland margins and littoral woodlands

	C. erectus var *sericeus*	Button mangrove	Restricted to the northern islands of the Caribbean, native to Bahamas and Turks & Caicos.

In 1991, Bacon conducted a survey of mangrove forest and associated wetland ecosystems in 9 insular Caribbean states, comprising 16 individual islands. The coastal wetlands surveyed (Table 2) were quite varied ecologically with 10 mangrove community types and 7 associated habitat types identified (Table 3).

Table 2: Mangrove and Associated Wetlands Sites in the Eastern Caribbean Islands (Bacon, 1995)

Country	No. of Sites	Approx. area (ha)
Antigua Barbuda	36 9	559 616
Barbados	8	10
Dominica	10	10
Grenada Grenadines	24 4	149 67
St Kitts Nevis	8 8	71 8
Montserrat	4	4
St Lucia	18	157
St Vincent St Vincent Grenadines Trinidad Tobago	4 13 38 11	2 48 7020 100

Table 3: Mangrove Community Types, Species and Associated Ecosystems in the Eastern Caribbean Islands (Bacon, 1995)

Mangrove sites		Description
A. Estuarine	1. Estuarine *Rhizophora*	Estuarine/ river mouth sites dominated by red mangrove
B. Fringe	2. Fringe *Rhizophora*	Areas dominated by red mangrove fringing open coasts
C. Basin	3. Basin *Rhizophora*	Red mangrove occupying pond margins or depressions not connected directly to the sea.
	4. Basin *Avicennia*	Black mangrove occupying low lying areas, depressions, not connected directly to the sea.
	5. Basin *Laguncularia*	White mangrove occupying pond margins or depressions

		or behind barriers separated from the sea.
	6. Basin Mixed Mangrove	Areas containing more than one forest mangrove species behind beach barriers or in depressions not connected directly to the sea.
D. Scrub	7. Scrub *Rhizophora*	Very short, but mature, red mangrove forest, with trees showing poor trunk development.
	8. Scrub *Avicennia*	As above, with black mangrove
	9. Mixed scrub mangrove	As above, with mixed red and black mangrove
	10. Scrub *Conocarpus*	As above, with button mangrove.
Associated Habitats		
1. Salt pond		Saline or hypersaline water bodies not connected to the sea
2. Salina		Areas with hypersaline soils, frequently dry with a crust of algae, subjected to seasonal inundation, unvegetated
3. Salt marsh		Areas dominated by low, salt tolerant herds, frequently interspersed with scrub mangrove
4. Freshwater marsh		Areas dominated by aquatic freshwater herbs, either rooted of floating
5. Swamp forest		Areas dominated by trees with adaptations to permanent or seasonal inundation by freshwater
6. Littoral woodland		Low, often scrub-like trees bordering the coast or on beach barrier; adapted to salt spray and sea breeze
7. Strand and Dune		Herbaceous plant communities occupying back-beach and /or sand dune areas

Of the 195 wetland sites investigated by Bacon in 1991, some 47% showed evidence of serious resource degradation resulting from human impact and all sites showed some damage (Bacon, 1991; 1995). A range of impacts were identified, the most important of which are:

- landfill and solid waste dumping
- vegetation clearing, particularly unregulated cutting for timber or charcoal production
- reclamation for agriculture, including some fish pond construction

- hydrological alteration, particularly by roadways, or flood diversion schemes
- pollution by factory and domestic effluent

After surveying over 200 coastal wetland sites in the insular Caribbean, Bacon (1994) suggests that responses to sea level rise would be quite variable since there is a wide range of wetland types and geomorphic settings in the region. The potential impacts of sea level rise are discussed below.

- Probable loss of total mangrove area due to erosion of seaward margin of mangrove site and loss of lagoon bars and sea barriers protecting mangroves
- Relocation rather than overall loss of mangrove and migration of mangrove inland. This landward migration can be obstructed if the landward margin of the mangrove area is steep or if there are seawalls and other developments, thereby reducing the areas of coastal ecosystems
- Change in mangrove forest structure- landward replacement of *Avicennia* (black mangrove) by *Rhizophora* (red mangrove) and increased growth and productivity of mangrove area
- Increase in mangrove area and changes to associated wetland community types and distribution: saline intrusion into inland freshwater wetland and rejuvenation of salinas and scrub mangrove sites

Mangrove forests in the insular Caribbean are of four main functional types and Bacon (1994) stressed the importance of site-specific analysis and recommended that more attention be paid to site physiography, hydrology and ecology in predicting responses to sea level rise by tropical coastal wetlands.

Biodiversity of wetland and mangrove types at the species level (Bacon *et al*., 1979; Ramcharan *et al*., 1982; Cook 1982) and at the ecosystem level (Bacon 1988; Lugo & Brown 1988b; Bacon 1993) were identified. Lopez *et a*l., (1988) also identified associated marine ecosystems to Caribbean island mangrove wetlands.

Wetlands and mangroves of the Caribbean have been important areas of research and interest since the 1980s, especially as a resource needing sustainable management (Bossi & Cintron, 1990). The distribution and status of mangroves has been described for the wider Caribbean in Bossi and Cintron (1990). A comprehensive assessment of the mangrove forests of the English-speaking islands of the Greater and Lesser Antilles has been undertaken by Bacon (1993). It is a review of existing information on an island by island basis from a management perspective. This very comprehensive document highlights the shortcomings of previous studies on wetlands as they lack the specific data on functional values of mangroves and areal coverage needed for meaningful management, but identifies what is available. Mangrove forest structure and productivity data was also identified as a research gap by Lopez, *et al*. (1988), but through the Caribbean Coastal and Marine Productivity Project (CARICOMP) there has been initial reports on the structure and productivity of mangrove forests (CARICOMP 1997a).

Two other studies conducted on Caribbean mangroves reviewed the existing literature; Lugo (2002) provides a review of the distribution, salient features, uses and conservation of mangroves in the Caribbean and Latin America, and Ellison and Farnsworth (1996) review past anthropogenic disturbances. According to Lugo (2002) the most recent studies of mangroves in the insular Caribbean were conducted in 1993 and the majority of recent research is for continental countries such as Brazil and Colombia. The Ellison and Farnsworth (1996) review examined past anthropogenic disturbances and their biological effects on mangals (mangrove ecosystems) throughout the Caribbean and assessed the current trends of destruction, alteration and attendant loss of biodiversity as well as conservation and management of these ecosystems and speculate on future prospects for Caribbean mangals. They provide the most recent compilation on geographic information and extent of mangrove forest in the insular and mainland Caribbean.

CLIMATE CHANGE AND MANGROVES/ WETLANDS

According to the IPCC Technical Paper V on climate change and biodiversity, globally by the year 2080, about 20% of coastal wetlands could be lost to sea-level rise. But this will vary regionally and depends on erosion processes from the sea and depositional processes from land (IPCC 2002).

RESPONSE OF MANGROVES TO SEA-LEVEL RISE

There are a number of studies that have estimated sea-level change at specific locations in the Caribbean, and this ranges from -2.3 mm per year to +9.3 mm per year (Ellison & Farnsworth, 1996). Tectonic activity and subsidence plate boundaries are responsible for this observed local variability. Although there is an absence of a regional Caribbean model for sea level rise, the most recent research estimates a projected sea-level rise for the Caribbean of 1.8 ±0.3 mm per year, which is near the mean global average (Church, *et al.,* 2004). Local level studies on climate change conducted for Trinidad and Tobago include Singh 1997a, 1997b, Miller 2005, and Mahabir and Nurse 2007.

The impact of climate change on coastal ecosystems is not a new topic. It was recognised by Titus (1985) that low lying coastal areas could experience a net loss due to relative sea level rise exceeding that caused by other stresses. The natural impact on wetlands has been identified as increased tidal flooding, wave induced erosion and salt intrusion; this natural impact is already exacerbated by human activities. According to Ellison (1994) the main impacts of climate change expected to affect mangrove ecosystems and species are sea-level rise, temperature rise, changes in precipitation, change in frequency or intensity of hurricanes and changes in productivity caused by higher levels of atmospheric carbon dioxide.

According to the IUCN's Marine and Coastal Areas Programme report on mangrove forests, climate change and sea level rise, the potential responses of mangroves at the community level to changes in hydrology were determined through analysis of past and present global distributions (Pernetta, 1993). Examples were drawn from the Indo West Pacific with a case study analysis of New Guinea. The roles of temperature and sediment in determining the distribution of mangroves were explored. The scenarios of global change were applied to the distribution of the mangrove biome. It was reported that Caribbean changes in species diversity may be less extensive than the Indo West Pacific, as there are only 7 species of mangrove. On a more regional or local level, Pernetta (1993) predicted changes in individual mangrove communities as a result of changes to other physical-chemical environmental factors (sea-level changes). It is expected that the entire mangrove ecosystem will migrate inland and replace terrestrial and freshwater swamp vegetation.

Woodroffe (1990) recognised instead displacement of mangrove floral ecological zones upwards, but this may be limited where the inland slope exceeds the seaward edge and erosion outpaces land colonisation. However, this was described as a simplistic model that may not apply to Caribbean mangroves or wetlands (Pernetta, 1993). Also the impact of a small rise in sea level will be less marked where the tidal range is large than where it is small.

The ecological implications of sea-level rise on mangroves were presented generally by Vicente, *et al*. (1993), their main suggestion was that the faunal and floral biocoenocis living on mangrove roots are ephemeral, and the effect of sea-level rise on red mangrove root community structure would probably be insignificant (as there would be floral-faunal uplift). However, temperature changes may disrupt the sexual reproductive cycles of many mangrove-root organisms that rely on these environmental cues.

An indication of the past responses of mangroves to changing climates can be derived by examining sediment and mangrove peat cores and developing the Holocene history of the coastline, wetlands and even mangrove islands (Woodroffe, 1990; Ramcharan, 2004; Macintyre, *et al.,* 2004). Due to the intertidal nature of mangroves and the fact that individual species are often restricted to a narrow range within the tidal range, the former sea level can be indicated by the presence of a particular mangrove species through studies of mangrove deposits. However, the reaction of mangroves to sea level rise is harder to predict when there is the influence of sedimentation, or if zonation is a result of factors such as water-logging or salinity. Furthermore, some studies have shown that there would be a total loss of mangroves with sea level rise; according to Alleng's (1998) projection, a 1 meter rise in sea-level could cause a complete collapse of the Port Royal wetland mangrove in Jamaica, which has shown little capacity to migrate in the past 300 years.

The response of mangroves to relative slow sea-level rise was addressed by Snedaker (1993). Sea level rise-induced changing salinity gradients would cause mangroves to retreat progressively inland along the gradient. Sedimentation affected by sea-level rise also becomes an important factor in the consideration of establishment of propagules. A third scenario for mangrove responses incorporates precipitation and catchment area freshwater runoff (Snedaker, 1993).

In the UNEP report (1994), on the assessment and monitoring of climatic change impacts on mangrove ecosystems, overviews of the possible effects of sea level rise and temperature elevations on mangroves were explored. This was a very comprehensive document that has a review of the literature and some aspects of expected global change on mangrove ecosystems and the probable effects on the exploitation of the system, with the aim of identifying policy options and suitable response measures.

The major responses by mangroves to predict climate changes were estimated based on:

- rise in global mean sea level,
- increase in atmospheric CO_2 concentration,
- increase in atmospheric temperature, and,
- changes in precipitation patterns

The UNEP (1994) report recommended that a study and monitoring programme to assess the impact of climate change on mangrove ecosystems should be implemented. This was envisioned to provide long-term data to serve to assess the actual impact of climate change on mangroves and also to serve the short-term local needs to aid in management of coastal environments. One caution was that modifications to mangrove ecosystems due to climatic change may be very difficult to discern from modifications due to anthropogenic actions and episodic natural events such as hurricanes (UNEP 1994; Roth 1997). However, the inherent merit of using mangroves as early indicators of any rise in sea level was part of the basis for this initiative in 1994, and the extent to which this can be used has been treated by Blasco, *et al.,* (1996).

RESPONSE OF MANGROVE FLORA TO CLIMATE CHANGE

Temperature Change and Floral Distribution

The latitudinal extremes for mangrove distribution correspond with a minimum sea-surface temperature of 24°C (Tomlinson, 1986). The average minimum air temperatures at these extremes are lower, but few studies were done on the lower threshold temperature for mangrove species. A rise in mean regional sea-surface or air temperatures might lead to the progression of some species of mangroves to higher latitudes depending on favourable dispersal, but may take several decades to become evident.

Temperature Change and Mangrove Phenology

In the humid tropics flowering of *Rhizophora* spp. generally occurs all the year round (Macintosh *et al.,* 1991). However, according to the UNEP report (1994), there is relatively little information on other genera of mangroves and the environmental and endogenous triggers that initiate flowering and flushes of vegetative growth in mangroves are not well understood.

Pollinating agents for mangroves include the wind, insects, birds and bats (Saenger, 1982). The production of propagules from buds may be quite low and is probably due to fungal and insect attack, and morphogenetic defects. Therefore it is difficult to predict the effect of an increase in air temperature on the reproductive capacity of mangroves. There may be a change in the seasonal patterns in reproductive sequence and length of time between flowering and the fall of the mature propagules. Climatic changes may affect mangrove pollinating agents and therefore successful pollination of flower buds. The risk of attack on developing propagules would also be affected (UNEP, 1994).

Temperature Change, Productivity and Growth

Temperature affects metabolic process such as photosynthesis and respiration. Temperature effects on leaves is better studied than the effect on root systems (as affected by soil temperature), but the information available is not specific to mangroves. It could be expected that rising temperature may cause increased rates of root respiration and increased rates of root growth, but this may reduce overall growth of the plant. In the mangrove canopy, plant temperature is the critical factor affecting canopy growth. Infrared radiation absorption by mangrove leaves may cause leaf temperature to rise (UNEP, 1994).

The optimum temperatures for photosynthesis in mangroves is 28-32°C, temperatures above this reduces photosynthesis with zero photosynthesis at 38-40°C (Andrews *et al*., 1984 as cited in UNEP 1994). Increased night-time temperatures are expected to increase dark respiration. However, temperatures would have to exceed 38°C before significant leaf drop or mass tree mortality ensues (Ellison & Farnsworth, 1996).

<u>Hydrological Change and Mangrove Flora</u>

According to Tomlinson (1986) and Clough (1992), mangroves growth rates are a reflection of the interactions between photosynthetic CO_2 exchange, evapotranspiration, plant water stress and the availability of water to the trees. Therefore soil water content and soil salinity are major factors influencing the water status of mangroves. Soil water content may only be a limiting factor to growth where tidal inundation is infrequent or irregular. Mangrove seedlings and forests however exhibit reduced growth at soil salinities above 20ppt (Clough, 1984), which is reflected by low plant water potentials (Gong, *et al.,* 1992). Clough and Sim (1989) found that the rates of photosynthesis in 19 species of mangrove decreased more or less linearly with increasing soil salinity and increasing leaf-to-air vapour pressure deficit (which drives evapotranspiration).

Changes in local or regional climatic conditions that play a key role in influencing water loss and the water balance of mangrove trees can be expected to have a significant impact on their rate of growth.

Ellison and Farnsworth (1997) examined the responses (in anatomy physiology, growth and reproduction) of individual *Rhizophora mangle* plants to changing levels of inundation expected to occur in the Caribbean within 50-100 years and found that there would in general be a reduction in the relative growth rates under inundated conditions.

Atmospheric CO_2 Change and Mangrove Flora

There remains considerable uncertainty about how mangroves will respond to very much higher levels of atmospheric CO_2. This is because mangroves may respond to increased levels of atmospheric CO_2 by reduction in stomatal conductance to minimise water loss probably without a concomitant increase in photosynthetic rates, but this may also lead to an increase in growth rate through improved plant water balance. However if stomatal conductance remains unchanged at higher CO_2 levels then photosynthesis rates are likely to increase. Ellison and Farnsworth (1996) identified physiological experiments conducted by Ball and Munns (1992) and Farnsworth *et al.,* (1995) which predicted photosynthetic rates and water use efficiency in paleotropical mangrove species. Additionally Farnsworth *et al*., (1996) examined the effect of elevated CO_2 on physiology, growth and reproduction of red mangroves (*Rhizophora mangle*)

Response of Mangrove Fauna to Climate Change

Temperature Change and Mangrove Fauna Distribution

This effect was treated by examining the effect of temperature change on geographical and local distributions. On a geographical scale the species distribution of mangrove associated faunal taxa, such as *Uca* and *Penaeus* would adjust rapidly to any temperature increases caused by climatic change. Mangroves are important areas for feeding, nesting or roosting of many bird species. Changes in mangrove areal coverage or distribution, degree and periodicity of inundation or invertebrate food organisms are also likely to influence bird populations.

On the local scale mangrove fiddler crabs and other intertidal crabs and mudskippers could probably adapt to expected increase in ambient temperature by making more frequent or extended burrow visits to avoid thermal stress. It was shown where fiddler crabs can experience temperatures of 41°C on the exposed surface of a mudflat, but retreat into their burrows where temperatures remain constant at 28-30°C (Macintosh, 1978).

Species distributions of intertidal macrofauna of the mangroves can be altered by higher shore temperatures or greater exposure to air. The effect of increased temperatures on mangrove molluscs in Singapore was studied by Hong and Chin (1983) and they concluded that several molluscs are living close to their thermal stress limits and that a 2-3°C temperature increase above the present ambient level would be detrimental to the mangrove ecosystem. Mangrove filter feeders (mainly bivalves – oysters, mussels, clams, cockles) are particularly susceptible as they are directly exposed to ambient water temperatures when feeding and have little or no ability to move to other locations. Mangrove gastropods and mangrove crabs on the other hand can use evaporative cooling to regulate their body temperatures, provided they have access to water to replenish that lost through evaporation, respiration and feeding. The effect of temperature rise on mangrove soil meiofauna is less well studied.

Hydrological Change and Mangrove Fauna

Salinity tolerances of a few species of intertidal mangrove fauna have been conducted but salinity would not seriously restrict the distribution or activities of the principal groups as the most common intertidal mangrove animals are euryhaline, and many have behavioural adaptations to reduce their exposure to salinity extremes and desiccation.

DATA GAPS

A comprehensive inventory of useful and economically important mangrove-associated fauna for the Insular Caribbean mangroves as well as their relationship with the ecosystem would be very beneficial to the identification of the impact of climate change on these resources. The UNEP (1994) paper identified finfishes and shrimps as mangrove associated fauna and went on to further highlight studies done on these fisheries. The data that exists on the impacts of climate change on mangrove fisheries is difficult to predict and measure because of natural fluctuations in fish populations and human fishing pressures in coastal ecosystems.

According to Ellison and Farnsworth (1996), in order to comprehend the magnitude of potential mangrove community change, more information on the precise areal extent of the different mangrove types, their proximity to human settlements and interspecific differences in flooding responses are needed. They also identified the need for long-term controlled factorial studies of temperature, CO_2 and tidal interactions, interspecific comparisons across ontogeny and field studies in a range of ecosystem types in order to assess the potential effects of rising CO_2 and sea level on neotropical mangroves.

Ellison and Farnsworth (1996) also identified the lack of hypothetical and experimental examination of the implications of soil warming – increased soil respiration, peat decomposition, CH_4 and H_2S release, and root turnover- for the mangal. They also noted that given mainly four structural mangrove species, with a far more diverse interstitial species assemblage, there needs to be a quantification of the ecosystem functions of each mangrove species, especially in terms of management of this resource.

There seems to be very little documentation and assessment of the impact of hurricanes on Caribbean mangrove forest structure (Ellison, 1994), but this issue was addressed for Guadeloupe and the Lesser Antilles in Imbert *et al.* 1996 and Imbert *et al*. 2000. There are also some examples of consideration of studies done on Florida mangroves (Ellison 1994) and other mainland Caribbean countries (Roth, 1997). However, this may be due to the inability of models to predict and agree on the changes in rainfall and storm frequency and intensity (Ellison & Farnsworth, 1996).

Another significant research gap for the impact of climate change on the insular Caribbean coastal and mangrove ecosystems is the lack of tide-level data which is reliable and of a significant duration for analysis.

Annex 2
Short Biographical Sketches of the Working Group Members

Gillian Cambers, PhD

- Education: BSc in Geography, University of Bristol. U.K.; PhD in Environmental Sciences, University of East Anglia, U.K.
- Major positions: Head of Coastal Conservation Project Unit in Barbados (1983-1988); Head of Conservation and Fisheries Department in the British Virgin Islands (1989-1993); Coordinator of a regional beach management project for UNESCO and the University of Puerto Rico Sea Grant College Program (1994-2002); environmental consultant affiliated with the University of Puerto Rico (2003-2007); review editor for the Intergovernmental Panel on Climate Change, Working Group II (2005-2007)
- Main areas of expertise and interest: beach management; integrated coastal management; climate change especially community adaptation; environmental education and education for sustainable development; environmental communication

Rodolfo Claro, PhD

- Education: BSc in Zoology, M.B. Lomonosov University, Moscow, USSR (1970); PhD in Biological Sciences, Institute Evolutionary Morphology and Animal Ecology, USSR Academy of Sciences (1976).
- Major positions: Senior Scientific Researcher (Marine Ecology), Institute of Oceanology, Ministry of Science, Technology and Environment of Cuba; Member of the Cuban Academy of Sciences.
- Main areas of expertise and interest: fish ecology; fisheries biology; integrated coastal management; marine biodiversity; environmental impact assessments; project management; environmental education.

Rahanna Juman, PhD

- Education: BSc in Zoology and Botany, University of the West Indies, Trinidad; PhD in Zoology (Marine Ecology), University of the West Indies, Trinidad. Post-doctoral research, University of South Carolina, USA.
- Major positions: Research Fellow (1997-2001) and Research Officer (Wetland Ecology), Institute of Marine Affairs, Trinidad and Tobago
- Main areas of expertise and interest: coastal ecology(mangroves, seagrass), integrated coastal zone management, mangrove restoration, wetland hydrology, environmental education

Susanna Scott, MSc

- Education: BSc in Biology, Saint Mary's University, Nova Scotia, Canada; MSc in Natural Resource Management, Cave Hill Campus, University of the West Indies, Barbados
- Major positions: Fisheries Biologist (1993-2000); Project Coordinator for EU funded Coastal Zone Management Project, which was assigned the task of developing Saint Lucia's coastal zone management policy and institutional structure (2001-2004); Head of the Resource Management Unit, Department of Fisheries in Saint Lucia (2005-2008); Technical Assistant to the GEF Integrated Watershed and Coastal Area national pilot project (2007)
- Main areas of expertise and interest: coastal zone management; environmental policy development; coral reef management; fisheries management; climate change especially

as it relates to coastal and marine resources; environmental education and public awareness; environmental impact assessments; project management.

Annex 3
List of Ramsar Sites in the Insular Caribbean (Ramsar website, 2007)

Country	Site	Size (ha)	Geographical Position	Date Designated
Antigua	Codrington Lagoon	3,600	17°39'N 061°51'W	02/06/05
Bahamas	Inagua National Park	32,600	21º05'N 073º20'W	07/02/97
Barbados	Graeme Hall Swamp	33	13°04'N 059°35'W	12/12/05
Cuba	Buenavista Ciénaga de Lanier y Sur de la Isla de la Juventud Ciénaga de Zapata Gran Humedal del Norte de Ciego de Ávila Humedal Delta del Cauto Humedal Río Máximo-Cagüey	313,500 126,200 452,000 226,875 47,836 22,000	22°27'N 078°49'W 21°36'N 082°48'W 22°20'N 081°22'W 22°19'N 078°29'W 20°34'N 077°12'W 21°43'N 077°27'W	18/11/02 18/11/02 12/04/01 18/11/02 18/11/02 18/11/02
Dominican Republic	Lago Enriquillo	~ 20,000	18°28'N 071°39'W	15/05/02
Guadeloupe	Grand Cul-de-Sac Marin de la Guadeloupe	20,000	16º20'N 061º35'W	08/12/93
Jamaica	Black River Lower Morass Palisadoes – Port Royal Portland Bight Wetlands and Cays	5,700 7,523 24,542	18º04'N 077º48'W 17°55'N 076°49'W 17°49'N 077°04'W	07/10/97 22/04/05 02/02/06
Aruba	Het Spaans Lagoen	70	12º30'N 070º00'W	23/05/80
Bonaire	De Slagbaai Het Gotomeer Het Lac Het Pekelmeer Klein Bonaire Island & adjacent sea	90 150 700 400 600	12º16'N 068º25'W 12º14'N 068º22'W 12º06'N 068º14'W 12º02'N 068º19'W 12º10'N 068º19'W	23/05/80 23/05/80 23/05/80 23/05/80 23/05/80
St Lucia	Mankoté Mangrove Savannes Bay	60 25		19/02/02 19/02/02
Trinidad and Tobago	Buccoo Reef / Bon Accord Lagoon Complex Caroni Swamp Nariva Swamp	1,287 8,398 6,234	11°10'N 060°57'W 10°34'N 061°27'W 10º23'N 061º04'W	08/07/05 08/07/05 21/12/92
Turks and Caicos Islands	North, Middle & East Caicos Islands	58,617	21º45'N 071º45'W	27/06/90
British Virgin Islands	Western Salt Ponds of Anegada	1071	18º43'N 064º19'W	11/05/99
Cayman Islands	Booby Pond & Rookery	82	19º40'N 080º04'W	21/09/94

Annex 4
Status of Tide Gauges in the Insular Caribbean in 2005
(Based on Henson 2005)
www.gloss-sealevel.org/publications/documents/report.pdf

Country	Location	Status
Antigua and Barbuda	Antigua: Coastguard Station, Parham Barbuda: No station	Not operating Station still standing, possibly damaged by a power surge
Bahamas	**Lee Stocking Island** **Nassau** Great Inagua	**Operating** **Operating** Damaged by storm and repaired but problems with data transmission
Barbados	Bridgetown	Gauge damaged by a vessel and repaired but problems with data transmission
Bermuda	North Shore Esso Pier	Operational Operational
Cayman Islands	Georgetown	Not operating due to hurricanes
Cuba	**Cabo San Antonio** **Guantanamo Bay**	**Operating** **Operating**
Dominica	Roseau	Not operating, damaged by Hurricane Lenny in 1999
Dominican Republic	None	No operational gauges, although there may be some difficult to access archived data
Guadeloupe	Basseterre	Unclear
Martinique	Fort de France	Unclear
Grenada	Prickley Bay	Station present but not transmitting
Jamaica	Kingston, Port Royal Discovery Bay	Not transmitting Not transmitting
Curacao	**Willemstad**	**Operating**
St. Maarten	No information	No information
St. Kitts and Nevis	Basseterre	Not operating
St. Lucia	Castries	Not operating
St. Vincent and the Grenadines	Kingstown	Not operating
Trinidad and Tobago	Charlotteville Port of Spain Guayaguayare	Not operating – damaged by a boat Not operating Station no longer there
Turks and Caicos Islands	South Caicos	Not operating
Puerto Rico	**San Juan**	**Operating**

CANARI

Caribbean Natural Resources Institute

The Caribbean Natural Resources Institute (CANARI) is a regional technical non-profit organisation which has been working in the islands of the Caribbean for over 20 years.

Our mission is to promote equitable participation and effective collaboration in managing the natural resources critical to development.

Our programmes focus on research, sharing and dissemination of lessons learned, capacity building and fostering regional partnerships.

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