Project Document

An assessment of the economic and social impacts of climate change on the coastal and marine sector in the Caribbean

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Executive summary

Climate change poses special challenges for Caribbean decision makers related to the uncertainties inherent in future climate projections and the complex linkages between climate change, physical and biological systems, and socioeconomic sectors. At present, however, the Caribbean subregion lacks the adaptive capacity needed to address these challenges.

The present report assesses the economic and social impacts of climate change on the coastal and marine sector in the Caribbean until 2050. It aims both to provide Caribbean decision makers with cutting-edge information on the vulnerability to climate change of the subregion, and to facilitate the development of adaptation strategies informed by both local experience and expert knowledge.

Climate and extreme weather hazards related to the coastal and marine sector encompass the distinct but related factors of sea level rise, increasing coastal water temperatures, and tropical storms and hurricanes. Potential vulnerabilities for coastal zones include increased shoreline erosion leading to alteration of the coastline, loss of coastal wetlands, and changes in the profiles of fish and other marine life populations.

The present report uses a modified version of the regional integrated model of climate and the economy (RICE model) (Nordhaus, 2010) to estimate the economic and social impacts of climate change. The RICE model views climate change in the framework of economic growth theory. The maximized economic and social welfare under the impacts of the three different climate change trajectories, shown below, are examined in the RICE model:

a) assuming there is no climate change (baseline)
b) under the A2 scenario/Business as Usual (BAU) [high impact scenario]
c) under the B2 scenario [low impact scenario]

The report considers the potential economic and social costs arising from damage to the coastal and marine sector as a consequence of tropical storms and hurricanes. The model employed assesses the impacts of tropical storm or hurricane strikes based, among other variables, on the power dissipation index (Emanuel, 2005), which computes the frequency, duration and intensity of hurricanes (Elliott, Lorde and Moore, 2012).

Potential adaptation and mitigation strategies for the sector are discussed and cost-benefit analyses of selected options undertaken.

Results indicate that sea level rise would lead to the definitive loss of land each year in the Caribbean. By 2050, the area totally inundated would be just over 3,900 square kilometres under the A2/BAU climate change scenario and close to 3,500 square kilometres under B2. The value of the land lost by 2050 has been estimated at US$ 624 billion and US$ 406 billion, under A2/BAU and B2, respectively, accounting for between 0.6 per cent and 0.7 per cent of total land mass. Loss of land is loss of capital, with negative consequences on output. Such a loss would affect the tourism sectors in the Caribbean severely.

In addition to market economic impacts (tourism and real estate), climate change in the Caribbean is predicted to have a devastating impact on marine ecosystems and natural habitats. By 2050, there would be an almost virtual collapse in coral-reef-associated ecosystems (reefs, seagrasses, reef fisheries). Those ecosystems have provided important services, from the purely recreational and biodiversity protection to breeding zones for fish, tourism attractions and natural protection from storm surges. Under A2/BAU, the value of those ecosystems would fall, to an estimated value of US$ 2.7 billion in 2050 from a high of US$ 64.7 billion in 2030; under B2, the decline would be smaller, but still very severe, falling to US$ 36.3 billion in 2050.

Total cumulative climate damage to the coastal and marine sector increases exponentially under both A2/BAU and B2 scenarios. The cumulative value of the damage is expected to be US$ 798.7 billion by 2050 if A2 occurs, and US$ 471.7 billion if B2 occurs. Total cumulative damage to the coastal and marine sector by 2050 induced by climate change is valued at 159 per cent and 98 per cent of gross domestic product under A2/BAU and B2, respectively.

The overall decline in welfare by 2050 compared to the baseline scenario ranges from 1.2 per cent to 1.5 per cent under B2, and 2.4 per cent to 2.8 per cent under A2/BAU, depending on the discount rate. While the differences in welfare among the three scenarios appear to be relatively small, the same monetary loss would have very different consequences within countries and across the Caribbean.

The model showed that the impact of hurricanes and storms on the coastal and marine sector of the Caribbean would be high. Cumulative losses to fisheries in the subregion to 2050 would range from US$ 13.3 million to US$ 18.2 million for the worst-case scenario, and US$ 7.5 million to US$ 13.3 million for the best-case scenario. The cumulative losses to the coral reef ecosystem would be very high under a worst-case scenario, over US$ 900 million per decade in 2010, 2020 and 2030. In 2050, the cost of the potential hurricane damage would drop significantly to US$ 39.3 million, reflecting the almost complete collapse of the coral reef ecosystem by 2050. Built coastal assets would be severely damaged under both the best-case and worst-case scenarios. Predicted damage would be around US$ $ 0.5 billion in a best-case scenario and over US$ 1 billion under a worst-case scenario. These results are reinforced by existing trends, with coastal areas becoming more densely populated in response to trends in economic structure and lifestyles. Confronted with growing populations, land scarcity and infrastructural gaps, more marginal and higher-risk land is urbanized in the Caribbean every year. Moreover, land loss due to sea level rise would amplify these trends.

In general, the Caribbean has limited capacity to rebuild after extreme weather events; if the subregion were to be affected regularly, it would not have enough time to rebuild between events, and could end up in a state of permanent reconstruction, with all resources devoted to repairs instead of to new infrastructure and equipment. This obstacle to capital accumulation and infrastructure development could lead to permanent underdevelopment.

Implementation of adaptation strategies on a regional level should be increasing the flexibility of institutions and decision processes so that the public and private sectors can adjust more readily to climate impacts as these occur. More flexibility may be needed to accommodate uncertainties associated both with climate change with non-climatic stresses, such as changes in population growth, economic trends, resource demands, the legal landscape, and economic trends.

Adaptation to sea level rise should take a hybrid approach. Under the threat of rising sea levels, strategies for the Caribbean should consider the balance between protecting, on the one hand, individual safety and socioeconomic activity and, on the other, the habitats and ecological functioning of the coastal zone. Coastal infrastructure—such as sea walls—may threaten the tourism industry vital to the Caribbean, by depreciating landscapes, ecosystem health and beach leisure attractions. Hard protection has been shown to contribute to the depletion of fish stocks by damaging coastal ecosystems further (Clark, 1996). As a consequence, hard protection should no longer be considered an option for the Caribbean.

Lessening the impacts of higher temperatures in Caribbean waters due to global warming would require strategies that increase the overall resiliency of ecosystems. Placing greater emphasis on habitat protection and ecosystem-based management approaches to managing fisheries, coral reefs, and other coastal resources would establish an important foundation on which to cope with the multitude of stressors affecting those resources. Furthermore, it would be important for researchers to continue monitoring coastal water temperatures closely, and to develop swift, strategic management responses to deal with extreme events such as mass coral bleaching and disease outbreaks.

There are several measures that could be taken to reduce the risk of extreme weather events. Examples include the adoption of early warning systems and better forecasting of extreme weather events, risk communication between decision makers and local populations, improved land-use planning, improved ecosystem management and restoration, better health response initiatives, and improved sanitation, drainage, and building codes. Local populations have an important part to play through integrating local knowledge in hazard-reduction and risk-management strategies.

Benefit-cost analyses have indicated that justifiable adaptive strategies for extreme weather events for the Caribbean subregion include reforestation of mangrove swamps in coastal areas, monitoring of all coastal waters to provide early-warning alerts of bleaching and other marine events, the development and implementation of programmes aimed at the protection and rehabilitation of degraded fisheries habitats and ecosystems—and the environment generally—and the development of national evacuation and rescue plans.

Many adaptive actions could create cost savings through damage avoidance. Many of the changes required will take time to implement. Waiting for climate change to “arrive” will be too late, in some cases, and significantly more costly, in others.

I. Introduction

The Caribbean is already experiencing impacts resulting from climate change, which are projected to increase with further warming. The region's geographical diversity means that a wide range of effects will be experienced. On the one hand, there may be opportunities to explore new crops and new markets associated with higher temperatures and shorter, or longer, growing seasons. On the other hand, higher temperatures have the potential to increase the risks of greater incidence of heat stress caused by more frequent and intense heat waves, greater incidence of heavy rainfall events affecting crop yields, natural ecosystems and water resources, and sea level rise, leading to storm surge-related flooding and enhanced vulnerability of critical infrastructure located in coastal areas, such as transportation, telecommunications, national security and medical facilities. Climate change may exacerbate existing stresses on the people and activities of the Caribbean. Some populations will be especially vulnerable to specific impacts due to their location and lack of resources.

Climate change poses special challenges for Caribbean decision makers, related to the uncertainties inherent in future climate projections and the complex linkages among climate change, physical and biological systems, and socioeconomic sectors. At present, however, the Caribbean subregion lacks the adaptive capacity to address these challenges. Therefore, the present report aims to provide Caribbean policymakers with cutting-edge information on its vulnerability to – and ability to derive benefits from – climate change, and to facilitate the development of adaptation strategies informed by both local experience and expert knowledge. It proceeds from an acknowledgement that the unique combination of natural resources, ecosystems, economic activities, and human population settlements of the Caribbean will not be immune to the impacts of climate change, and that local communities, countries and the subregion as a whole need to plan for, and adapt to, these effects.

The primary objective of the present report is to assess the economic and social impacts of climate change on the coastal and marine sector in the Caribbean. Further objectives of the report are to highlight areas related to climate change that warrant additional research, and to identify data gaps and monitoring needs in order to help guide future efforts. This assessment is but one in a series of studies on the impacts of climate change on the agricultural, energy, health, tourism, and water sectors of Caribbean countries.

This assessment is focused on areas closer to the ocean: that is, up to a 30-metre depth in the sea and within 10 kilometres of the coastline on the landward side. Climate and extreme weather hazards related to the coastal and marine sector encompass the distinct but related factors of sea level rise, increasing coastal water temperatures, and tropical storms and hurricanes. Potential vulnerabilities for coastal zones include increased shoreline erosion leading to alteration of the coastline, loss of coastal wetlands, and changes in fish and other marine life populations.

Due to the Caribbean's large and relatively diverse geographical spread, special emphasis has been placed on integration and coordination so that climate change impacts and potential responses could be addressed coherently. Four key themes have been considered: climate; vulnerability; economic and social costs associated with climate change impacts; and adaptive measures.

The present report produces estimates of the economic and social impacts of sea level rise and increased temperatures arising from climate change that affect the coastal and marine sector in the Caribbean.

A. The coastal and marine sector in the Caribbean

Two of the biggest challenges in the current assessment are to determine (1) the factors driving the definition of the coastal and marine sector, and (2) the selection and articulation of an analytical framework needed to identify critical indicators and assessment tools for analysing the impact of climate change.

The coastal and marine sector in the current assessment is taken to mean the 'coastal zone' defined by the United Nations Environment Programme (UNEP) as 'the area of land subject to marine influences and the area of the sea subject to land influences'. More specifically, the coastal zone is defined to have three main subsystems: the 'sea', the 'beach', and the 'land behind the beach'. The *sea*, or offshore area, extends seaward from the low-water mark and covers the shallow marine habitats off the coast, such as the seagrasses and the coral reefs. The *beach* zone extends from the low-water mark to the seaward edge of the coastal vegetation and, in some cases, the base of a cliff or a dune may mark the end of this highly-changeable environment. The third component of the coastal zone, the *land behind the beach*, is the adjoining coastal land extending landward for some distance from the end of the beach. The definition of the length of this distance may vary according to each country. As with all environmental systems, there are no clearly-defined and universally-accepted boundaries to the coastal zone. Where the land is flat, the coastal zone may extend for a considerable distance inland, and may consist of sand dunes, swamps or lagoons. Where the land is steep, the coastal zone may be very narrow.

The three subsystems described previously interact in many ways, and the boundaries between them may fluctuate. The coastal zone is not an isolated system. Rivers and waterways may carry pollutants and sediments resulting from inland activities to the coast, where they have an impact on coastal zone habitats. Agricultural and forestry practices, for example, have been known to bring increased sediment and chemicals to the marine environment, where they may degrade the health of coral reefs. Water currents may carry pollutants from one the coastal zone of one country to that of another. The coastal zone is a complex, highly productive environment, and the health of one ecosystem is tied intimately to the health of the other ecosystems in the area and, often, to areas some distance away.

The Caribbean coastal and marine sector contains many productive, biologically-complex ecosystems. The economic importance of these ecosystems lies in their value to the fisheries and coastal tourism industries. The present section provides information on the Caribbean coastal and marine sector which forms the basis of the current study.

1. Physical and geological description

The Caribbean Sea is a semi-enclosed basin of the western Atlantic Ocean, delimited by the coasts of Central and South America on two sides and by the Antilles island chain on the other. It covers an area of about 2,754,000 km^2, a volume of nearly 6,56106 km^3, and over 13,500 km of coastline, and is home to 26 countries as well as 19 dependent territories of France, the Netherlands, the United Kingdom, and the United States of America. Toward the east and northeast, the closely-spaced chain of islands, banks, and sills of the Antilles Islands arc separates the Caribbean from the Atlantic Ocean and acts as a sieve for the inflow of Atlantic water (Andrade and Barton, 2000), whereas, toward the northwest, the Caribbean is linked to the Gulf of Mexico by the Yucatan Channel.

The form of the coastline around the Caribbean Sea is extremely varied, determined by local geological history. Coasts adjacent to mountain ranges may have steep cliffs and deeply indented bays. Coasts in areas adjacent to major stable plates, in contrast, may be generally flat and consist of recent sediment. Where there is plate collision or subduction, coastal form varies, partly from volcanic activity and partly from the elevation of deposits of marine origin, including paleoreefs, ancient reefs, beach rock, and sandstones.

The ecology of the Caribbean is greatly affected by the massive quantities of fresh water and sediment entering the Sea from three South American river systems: the Amazon, Orinoco, and Magdalena rivers. Although a large part of the outflow of the Amazon is taken eastward across the Atlantic, a significant quantity flows northward around the coast of the continent into the Eastern Caribbean and, together with the waters of the Orinoco river, creates plumes of buoyant freshwater across wide stretches of the ecosystem (Muller-Karger and others, 1988). In the Western Caribbean, the plume of the Magdalena River extends north and eastward under the influence of a current known as the Panama-Colombia Gyre.

The Caribbean Sea is characterized by high biological productivity along its coasts—providing rich feeding grounds for fish near coral reefs, seagrass beds and mangroves—but low productivity in the deep ocean regions (UNEP/UNECLAC, 1984). Most island and mainland coastlines drop precipitously to depths of 2,000 metres within a few kilometres offshore, although there are substantial shallow water areas of Belize, Cuba, and, most notably, in the Bahamas. Thus, the total area of coastal waters (shallow water less than 200 metres deep) on which humans are most dependent for food—and the zone most susceptible to human influence—is relatively small (UNEP/UNECLAC, 1984).

While local climate may vary because of other factors such as topography or deforestation, the subregion experiences a distinctive hurricane season from June to November. The Caribbean subregion is also influenced periodically by the El Niño/Southern Oscillation (ENSO), a multi-year cycle involving variations in sea surface temperatures and salinity, due to the changes in rainfall patterns on the South American continent. Some of the hurricane activity is generated far out to the east in the Atlantic Ocean, but may also originate in the Caribbean Sea.

2. Major coastal and marine ecosystems

(a) Coral reefs

Coral reefs are one of the most important coastal resources in the Caribbean, and are among the most productive. There are around seventy species of coral in the Caribbean. Seven per cent of the world’s coral reefs are located in the Caribbean (Burke and Maidens, 2004). Fringing and patch reefs are most common around islands, on the side facing the prevailing winds. Longer barrier reef systems are found off Belize (approximately 220 km) and the Bahamas (Andros barrier reef is approximately 176 km). Bank or bank-barrier reefs are moderately common. Atoll-like structures are found in Belize and the Bahamas.

Coral reefs in the Caribbean Sea are prolific providers not only of ecosystem services, including food, but also of protection from storms, recreational value and therefore tourism income, and medicinal products. It is estimated that the potential fisheries yield from coral reefs amounts to 10 tonnes per km^2 per year, which could provide up to six per cent of global fisheries if properly managed (Burke and Maidens, 2004). Commercially valuable species fished on coral reefs include snappers, groupers, and jacks, while less valuable species include parrot fish and surgeon fish. Important shellfisheries include those for conch, lobster and sea urchins for their eggs.

Other reef resources include live ornamental fishes harvested for the aquarium trade, coral skeletons and shells of other creatures collected for jewellery and ornaments, reef rock, coral heads, and coral sand mined for construction, and potential biological inputs prospected for the pharmaceutical industry (Agard and Cropper, 2007).

The Caribbean tourism industry owes much to the opportunities coral reefs provide for diving and snorkelling. Reefs contribute through the attraction of calm waters and blue-green lagoons, protection against beach erosion, and the role of coral skeletons in forming the white sands of Caribbean beaches.

Shoreline protection is a very important service provided by coral reefs, and an assessment of their value should include the replacement cost of beaches, buildings and developments close to shore—a service likely to become increasingly important, according to models which predict both rising sea levels and more destructive storm activity.

Caribbean coral reefs are already greatly degraded, having declined, in some cases, from more than 50 per cent live cover to less than 10 per cent cover over the last two decades (Gardner and others 2003). This degradation is due to a combination of impacts, including damage by hurricanes, disease, pollution, sediment runoff, overfishing, as well as more directly through boat anchoring, setting of fish traps, groundings of ships, dredging activities, collecting of corals, and dynamite fishing. Gradual and consistent increases in sea surface temperatures have also yielded increasingly frequent bleaching events (1993, 1998, 2005), the latest of which caused wide-scale bleaching throughout the Caribbean region (Donner, Knutson, and Oppenheimer, 2007). Under conditions anticipated by the Intergovernmental Panel on Climate Change (IPCC), increased temperatures in the Caribbean are likely to lead to a collapse of the coral biome during the twenty-first century (IPCC, 2007).

(b) Seagrass beds

Seagrasses are flowering plants that flourish in shallow, sheltered, marine environments, such as lagoons near mangroves or coral reefs or just offshore from beaches. The Caribbean has six species of seagrass, the most common of which is turtle grass (Agard and Cropper, 2007).

The beds formed by seagrass perform a number of important roles in the Caribbean Sea ecosystem, including the stabilization of sediment, reducing the energy of waves approaching the shore, and the provision of a nursery habitat for organisms that, as adults, live in other ecosystems. Seagrass beds provide food for species such as parrot fish, surgeonfish, queen conch, sea urchins, and green turtles. The seagrass blades enhance sedimentation and reduce erosion by slowing down waves and currents, while the roots and rhizomes[1] bind and stabilize the sediment surface.

Threats to seagrass beds in the Caribbean include their removal from shallow water to improve bathing beaches, dredging to allow access to shipping or to lay cables, pipes, and other submarine structures, burying by sediment from nearby dredging and filling activities, and pollution from nutrients, such as nitrogen which causes excessive growth of epiphytes (Agard and Cropper, 2007). Nutrient pollution can overstimulate the growth of the seagrass itself, leading to difficult decisions on whether or not to clear beds which have expanded into previously unsettled sandy areas (Agard and Cropper, 2007).

(c) Mangroves

A mangrove is a tree or shrub adapted to colonize sheltered tropical coastal environments between the high-water and low-water marks. Mangroves reach their greatest development in estuaries, where they may form extensive forests. The term mangrove is also used to describe the complex community of animals, plants, and microorganisms adapted to life in a muddy, saline environment. In the Caribbean, there are three common mangrove species: red, black, and white (Agard and Cropper, 2007).

Mangroves are found along sheltered coastlines of almost all countries and territories surrounding the Caribbean Sea, and fulfil important socioeconomic and environmental functions. These include the provision of a large variety of wood and non-wood forest products, coastal protection against the effects of wind, waves, and water currents, conservation of biological diversity, including a number of endangered mammals, reptiles, amphibians, and birds, protection of coral reefs, seagrass beds, and shipping lanes against siltation, and the provision of habitat, spawning grounds, and nutrients for a variety of fish and shellfish, including many commercial species (Agard and Cropper, 2007). Mangroves could provide income as ecotourism attractions for viewing birds, manatees, crocodiles, and other fauna and flora.

High population pressure in coastal areas has led to the conversion of many mangrove areas to other uses, including infrastructure, aquaculture, rice, and salt production. Mangrove loss has been occurring at about 1 per cent per year in a real cover since 1980 (Agard and Cropper, 2007). In other words, about 413,000 hectares of mangroves have been lost in the Caribbean over this 30-year period.

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[1] A rhizome is a plant stem which grows beneath the soil or sediment surface.

(d) Beaches

Beaches are deposits of sand between the high and low tide marks, transported to shore and moulded by waves. Beaches are dynamic, the sand being constantly subjected to deposition (accretion) or loss (erosion). Storms, offshore reefs, sand shoals, currents, and onshore dunes play important roles in controlling deposition and erosion on a beach. The stability of a beach, whether eroding or accreting, depends on a balance, over time, between the supply of sand and the rate at which it is transported away.

Beach and dune sands serve as one of the world's major sources of construction aggregate. Non-calcareous sand is used to produce minerals and ores for various industries, including electronics. However, beaches in the Caribbean are best known for their importance to tourism: the quality of the beach is cited by most tourists as the main feature of a successful holiday (Uyarra and others 2005). In addition to their economic importance in attracting overseas visitors, beaches provide areas of recreation and enjoyment for local people throughout the Caribbean and, therefore, have great cultural value.

Beaches are important habitats for sea turtles, which nest in the zone above the high-tide mark. This can create conflict between the use of a beach for recreation and its contribution to the biodiversity of the Caribbean Sea ecosystem. However, beaches could provide income, community employment, and educational opportunities through well-managed ecotourism.

A number of threats linked to human activity are causing beach erosion and polluting coastal waters, compromising the ability of Caribbean beaches to continue providing ecosystem services. Unregulated sand mining, for example, causes loss of sand and prevents the natural replenishment of other beaches through material being carried around the coast by tides and currents.

Another key threat stems from the tourism industry itself, despite its reliance on beaches to attract visitors. Many poorly-planned developments are too close to the edge of the sea. They frequently lack adequate waste-disposal facilities resulting in contamination with sewage and other effluents, causing a health hazard and badly diminishing the aesthetic value of beaches. Failure to set buildings back 50 metres or more from the shore also exposes them to storms and damages dunes which are part of the dynamic system stabilizing beaches. In addition, constructions on beaches could alter patterns of water currents which, in turn, could increase erosion.

It has been estimated that 70 per cent of beaches on the islands of the Caribbean are eroding at rates of between 0.25 metres and 9 metres per year (Cambers, 1997). It is possible that the decline in Caribbean coral reefs (a source of much of the calcareous sand) has reduced both protection from wave action and the supply of sand, thereby increasing erosion.

3. Other ecosystems

Coastal lagoons are an important mainland feature in the Caribbean subregion. Shallow tidal ponds or salinas are common to many islands. Both systems protect reefs by trapping sediments, serving as nurseries for fish, and providing wetland habitats for birds, crocodiles and manatees.

4. Species diversity

(a) Invertebrates

A wide range of invertebrates are found in the Caribbean subregion including jellyfish, lamp shells, sponges, molluscs and crustaceans, chordates, sponges, echinoderms, arthropods, coelenterates and bryozoans.

(b) Fish

The Caribbean Sea supports a diverse range of fish species, from tropical coastal species to pelagic and benthic species. Reefs play a major role in supporting the artisanal fisheries of many island and mainland States. The main fisheries throughout are of small pelagic species (menhaden, flying fish and mackerel), large pelagic species (tuna, billfish and shark), reef fish (snapper and grouper), coastal demersal fish (drum, weakfish, croaker), crustaceans (shrimp, lobster, crab) and molluscs (oyster, scallop, and conch). Underutilized resources include cephalopods (squid and octopus), small pelagic species, deepwater shrimp, and deepwater snapper (The Food and Agriculture Organization of the United Nations (FAO), 2011).

(c) Reptiles

Turtle species found in the Caribbean include the green, hawksbill, Kemp's and Olive Ridley, leatherback, and loggerhead. The largest turtle nesting areas are in Suriname, but may be found throughout the Caribbean subregion. Crocodiles, including the Spectacled Caiman, Brown Caiman and the American Crocodile are found on many islands, whose wetlands house breeding populations. There are several species of iguanas: rock iguanas species include Allen's Cay, Andros Rock, Bertsch's Rock, Crooked/Acklins, San Salvador, Central Exuma and White Cay Iguanas.

(d) Birds

Various species of waders and seabirds are native to the Caribbean subregion: one species of shearwater, two of petrels, two tropic birds, one pelican, one frigate, three boobies, eight terns, one gull, numerous egrets, herons and flamingos, and many species of migratory waders (shore birds).

(e) Mammals

The West Indian Manatee is at home in wetlands and shallow seas primarily in the Greater Antilles and coastal areas of the South American continent. Sperm whales have been sighted in Dominica, Saint Vincent and Grenada. Humpback, orca, bryde's and pilot whales in addition to some beaked whales, false and pygmy filler whales, and pygmy sperm whales as well as dolphins (spotted, spinners, bottlenose, Risso's, and Frasers, and have also been sighted.

B. Socioeconomic importance of the coastal and marine sector

1. Fisheries

The living marine resources of the Caribbean Sea constitute the most important ‘provisioning’ service of the ecosystem. Fisheries have always been a source of livelihood and sustenance for the people of the Caribbean subregion, contributing towards food security, poverty alleviation, employment, foreign-exchange earnings, the development of rural and coastal communities, recreation, and tourism.

The fisheries of the Caribbean Sea are, with few exceptions, multi-species, small-scale fisheries conducted by low-capital, labour-intensive operators. The sector is dominated by small, artisanal boats constructed of fibreglass and wood. These may be powered by outboard engines, oars, or sails, or a combination of all three. There are approximately 25,000 artisanal boats, 5,000 medium-sized boats, and 1,500 industrial vessels in the region.[2] Hook and lines, gillnets, and traps are the main types of gear used (FAO, 2011).

Fisheries play a very important role in providing nutrition and food security within the Caribbean subregion. Fish is a vital source of animal protein and minerals in the diet of Caribbean people, particularly the poor and vulnerable members of society. Per capita consumption of fish in the subregion is approximately 15 kilograms per year (Agard and Cropper, 2007). Consumption in several countries is higher than local production and has to be satisfied by high levels of imports. The high diversity of species of different shapes and sizes, the variation in taste and texture, and broad range in the commercial value of fish mean that fish is generally available at affordable prices to both rich and poor throughout the year.

Fisheries make a significant, positive contribution to the balance of trade of the Caribbean subregion, even though the quantity of imports by weight considerably exceeds that of exports. According to statistics

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[2] Fishery Information, Data, and Statistics Unit (FIDI), FAO 1998.

from the FAO of the United Nations, approximately 360,000 tonnes of fish and fishery products, worth some US$ 410 million, were imported in 2000, while exports amounted to around 200,000 tonnes, worth US$ 1.2 billion. This apparent anomaly is due to the fact that exports are dominated by high-value products such as shrimp, spiny lobster, tuna, snappers and groupers, and queen conch, which command premium prices on the international market.

Perhaps one of the most important roles of fisheries is the employment which the sector provides to hundreds of thousands of people, in a region where high levels of unemployment and under-employment continue to be a major concern. The fisheries sector provides stable, full-time and part-time, direct employment (as fishers) to more than 200,000 people, and jobs for an estimated additional 100,000 in processing and marketing (Agard and Cropper, 2007). Indirect employment is provided by boat-building, net making and other support industries. People engaged in fishing often have low levels of formal education, limited access to capital, and limited occupational and geographical mobility. It is estimated that each person employed in the fisheries sector has five dependents, suggesting that in excess of 1.5 million people in the Caribbean rely on fisheries for their livelihood (Agard and Cropper, 2007).

Within the Caribbean subregion, the fisheries sector is important, not only as a source of food and employment for commercial and subsistence fishers, but also for a growing number of people involved in recreational fishing, defined as fishing conducted for the purpose of pleasure and relaxation rather than for commercial gain or subsistence for the fisherman. Dozens of international, regional, and national fishing tournaments are held each year throughout the Caribbean. In most Caribbean countries, sport fishing is promoted by tourism interests and is neither monitored nor regulated by national fisheries administrations. There is, therefore, a strong link between the management of Caribbean fisheries and the value and impacts of tourism, which are described later in the present report. This link is evident in the economic value of the diving industry, which depends on the abundance of varied populations of coral reef species of fish and other marine life.

2. Tourism and recreation

The natural setting of the Caribbean, a product of its marine and coastal ecosystems, constitutes an asset of immense value due to the positive association it invokes around the world. Recreation and tourism-related jobs and income are linked to the amenity value or cultural services provided by the Caribbean Sea ecosystem.

As the fastest-growing economic activity in the Caribbean and, indeed, in many individual countries, the tourism sector contributes much by way of employment, foreign-exchange earnings, and, in some countries, important economic linkages with other sectors such as agriculture and construction. Relative to its size, the insular Caribbean is the most tourism-driven region in the world (World Travel and Tourism Council (WTTC), 2011). The contribution of tourism to jobs and export income is nearly double the global average, and accounts for more than one fifth of all capital investment in the Caribbean.

Cruise-ship arrivals represent the fastest-growing segment of the industry and will soon rival the hotel sector in bed/berth capacity (McElroy, 2004). In their shore visits, cruise passengers provide a major source of direct income for small entrepreneurs such as taxi drivers and handicraft vendors, as well as the informal sector. This contribution to the development of entrepreneurial activity can be as important as that of the stay-over sector, whose link to the local economy is often limited by the enclave nature of the accommodation.

II. Literature review

A. Non-climate stressors

In any complex system, there are multiple forces interacting to produce the observed behaviour. Often, it is difficult to attribute the response of the system to any particular forcing function; therefore, it is necessary to mention briefly some of the non-climate stressors impacting the various coastal components in the coastal and marine sector. Many of these stresses are associated with human consumption of natural resources and land-use practices.

A number of human-induced factors – including sewage discharges and contaminated storm water runoff from developed and agricultural areas – cause pollution and pathogenic outbreaks that can lead to the closure of nearshore fisheries. In addition to stresses related to water quality, fish stocks, as well as other marine ecosystem components, may be affected by harvesting practices, diseases that are not necessarily climate-related, and normal population dynamics, such as predation, competition, and recruitment variability.

Intense development along the coast increases both vulnerability to inundation and the demand for groundwater, which could lead to drawdown of aquifers and increased saltwater intrusion. Such changes, produced by urbanization and other forms of human land-use, can lead to habitat fragmentation, namely, the breaking-up of large, connected terrestrial or aquatic habitats. Habitat fragmentation constrains plant and animal dispersal patterns across habitats, alters plant and wildlife community composition, and increases vulnerability to pathogens, insect pests, and invasive species. It can reduce nesting habitat for birds and increase rates of predation and parasitism. Coastal infrastructure inhibits natural geographic migration of wetlands (Nicholls and Lowe, 2006). The control of the majority of coastal land by private landowners has implications for developing adaptive management strategies for coping with climate change or other environmental changes.

Invasive species are those species that are not native to a country’s ecosystems and cause harm to the economy, environment, or human health. Increases in global commerce and human travel have led to increasing rates of species invasion (Mack and others, 2000) that show no signs of slowing down in the future (Tatem, 2009). The economic impacts of invasive species can be as profound as the ecological impacts. Specifically, invasive species pose serious economic threats to various industries, for example, fishing, tourism and recreation. Although the specific outcomes of invasive species/climate-change interactions may be difficult to predict, it is virtually certain that the combinations of species composing a country’s ecosystems will look and interact differently than they do presently.

B. Climate hazards

Two climate risks are considered to be of particular importance to the coastal and marine sector: rising sea levels and increasing temperatures.

1. Sea level rise

The anticipated global sea level rise due to climate warming will greatly amplify the risks to coastal populations of the Caribbean, leading to permanent inundation of low-lying areas (including wetlands), more frequent flooding by storm surges, and the potential for increased beach erosion. Saltwater could reach further up estuaries, while increased water depth could alter the propagation of both the tide and storm surges up rivers. These hazards will continue to be exacerbated by development of the coastal zone.

The IPCC concluded in 2007 that global sea level will likely rise between 7 inches and 23 inches by the end of the century (2090-2099), relative to the base period (1980-1989), not counting unexpected, rapid changes in ice flow from the Greenland and Antarctic ice sheets (IPCC, 2007). These projections, however, may be too low, as they did not consider the uncertainty associated with ice sheet melting processes or cover the full probable temperature range given in the IPCC Fourth Assessment Report (up to 6.4° C) (Rahmstorf and others, 2007). Most of the observed current climate-related rise in global sea level over the past century could be attributed to the expansion of the oceans as they warm; however, it is anticipated that the melting of land-based ice may become the dominant contributor to global sea level rise in the future.

When compared to other climate factors, it is fairly certain that global sea level rise will continue beyond the twenty-first century, irrespective of future greenhouse gas emissions (Nicholls and Lowe, 2004). It takes centuries to millennia for the full ocean depth to adjust to surface warming, resulting in ongoing thermal expansion. This inevitable rise has been termed the *'commitment to sea level rise.'* If global warming continues to occur and passes key, but uncertain, thresholds for the irreversible breakdown of the Greenland or West Antarctic Ice Sheets, the committed rise could be 13 to 15 metres, albeit over long time spans (centuries or longer).

2. Increasing coastal sea temperatures

Sea temperature plays a dominant role in shaping marine ecosystems. As ocean temperatures continue to rise, the range of suitable habitat for many commercially-important fish and shellfish species is projected to shift northward (Brander, 2007). However, it is not clear what the national/regional production of those species would be during such transitions. Regional surface and bottom sea temperatures are influenced, in part, by large-scale oceanic and atmospheric circulation (which exhibits annual, inter-annual, and inter-decadal variability), annual cycles in solar radiation, migrating weather systems, and, more locally, by freshwater discharge.

Over the course of the twentieth century, sea temperatures have risen by more than 0.6º C. Sea temperature changes can result in shifts in faunal assemblages (groupings of organisms) that could affect marine ecosystems and economic activities in unknown ways. Every species has a thermally suitable range for habitat that, when compromised, induces a forced migration in search of another location suitable to its life cycle (Brander, 2007). Sea temperatures influence organism survival and growth, egg and larval development, and spawning and feeding behaviour. When sea temperatures rise, ecosystems become vulnerable to shellfish diseases, harmful algae blooms, and the proliferation of exotic species that force indigenous species to compete for resources, including dissolved oxygen (Kurihara, 2008). Oxygen solubility will decrease as water temperatures increase, further stressing marine organisms.

C. Other climatic factors

Higher storm surges associated with higher sea levels could periodically engulf a much greater area. Also, wave action will erode and reshape the shoreline, affecting the location and extent of storm surge inundation. The current 1-in-100-year flood (defined as a flood that has a 1 per cent chance of being equalled or exceeded in any given year) will occur more frequently, with future 1-in-100-year flood events achieving higher flood elevations. The greater frequency of severe flooding events affecting an increasing number of waterfront infrastructure may lead to the abandonment of ground floors or, ultimately, of entire buildings. Evacuation of vulnerable populations in high-risk areas during major storms may pose difficulties, in that many evacuation routes may themselves become flooded.

Low-lying coastal regions throughout the Caribbean subregion are vulnerable to surge (elevated water levels) from tropical storm systems. Elevated coastal water levels, strong winds, and large amounts of precipitation during these storm events result in hundreds of millions of dollars in damage. In addition to flooding, some of the more severe storms have disrupted power distribution systems.

Coastal flooding is a dynamic process, and individual storm events can exhibit large variations in water levels along the coast. However, the current absence of a confirmed link between the detailed meteorological evolution of tropical storm systems and the development of surge (atmospherically forced elevated water levels) in the Caribbean make it even more difficult to understand how storm systems and their impacts will evolve as the climate changes.

As sea levels rise, coastal flooding associated with storms will be very likely to increase in intensity, frequency and duration. Any increase in the frequency or intensity of storms themselves would result in even more frequent and damaging future flood occurrences relative to the current 1-in-100-year coastal flood events.

Low-lying coastal communities could find themselves repeatedly under water at high tide, with consequent property damage. The greater likelihood of coastal flooding (as well as heavier rainfall) would result in: an increase in street and sewer flooding; an increase in flood risk to low elevation transportation, energy, and communications infrastructure; more frequent delays on low-lying highways and public transportation; increased structural damage and saltwater exposure to infrastructure, commercial, and residential property; increased inflow of seawater to storm sewers and wastewater treatment plants and reduced ability of gravity discharge of sewer effluent overflows; encroachment of saltwater into freshwater sources and ecosystems; and increased beach erosion.

D. Critical vulnerabilities of the coastal and marine sector

1. Ecosystem services

New challenges in protecting remaining coastal ecosystems arise from accelerated sea level rise. Under an accelerated sea level rise regime, where slopes are gradual and land can accommodate the change (even at the expense of forested habitat), vegetated tidal habitats will shift inland. However, where squeezed between rising sea levels and either human infrastructure or steep slopes, these systems will diminish in size or disappear (Doody, 2004). The effect is that a previously diverse habitat lying between the deeper waters and uplands (that included the beaches, coastal shoals, mudflats, or marshes) becomes converted to a more simplified, deeper water habitat.

2. Fish and shellfish populations

A difficulty in discerning climate-driven changes in marine fish distributions is that the signal from climatic effects may be highly confounded by other factors. Even under nearly constant environmental conditions, fish distributions are not static. Population theory and observations indicate that fish populations occupy the most optimal habitats in times of low abundance but disperse into less optimal habitats at high abundance (MacCall, 1990). This means that species that are only rarely or periodically seen in numbers in Caribbean waters may occur there largely as a function of density dependence (relative population size within an area) and not because of favourable temperatures. Another source of complexity is the changes in fish and crustacean communities that occur because of ecological regime shifts, of which climate change may be a major driver.

Coral reefs have begun to suffer bleaching and mortality as a result of exceptionally warm periods (Sheppard, 2003). So far, events such as the 2005 mass coral bleaching in the Caribbean have not provided evidence of negative short-term bioeconomic impacts for coastal reef fisheries. However, in the longer term, fisheries production is likely to be affected by the loss or reduced structural complexity of coral communities, which result in reduced fish species richness, local extinctions, and loss of species within key functional groups of reef fish (Jones and others, 2004). A projected decline in pH as a result of acidification from increased carbon dioxide (CO_2) would affect coral growth adversely and hence, probably, associated fisheries.

Several studies have shown changes in the distribution and abundance of particular species, and yet, due to the fact that species are often replaced by functionally similar species, the net effect on trophic structure and fish production may be small (Brander, 2007). It is generally difficult to predict the changes in trophic structure and composition of ecosystems and therefore, one simplifying assumption is that functional replacement always occurs and that fish production is proportional to net primary production. Predicted changes in net primary production may be either positive or negative, and the aggregate impact at global or regional levels is unknown (Brander, 2007).

3. Freshwater resources

In addition to influencing storm surge propagation, sea level rise and changes in precipitation will impact the water tables of countries. Water tables will rise gradually, at approximately the same rate as sea levels rise. As a result, depending on local conditions, the geographic extent of ponds and wetlands and the carrying capacity of streams and rivers may change (Nicholls, and others, 2007). This will depend partly on the amount and timing of precipitation. Saltwater entering the aquifers (saltwater intrusion and salinization) is a slow process. Quantifying the impact that changes in sea level and precipitation patterns would have on water tables is complex, given the much larger effects of anthropogenic forces such as flood control, groundwater withdrawal, and sewerage.

4. Impact of increased carbon dioxide concentrations and ocean acidification

The ocean is becoming more acidic as increasing atmospheric carbon dioxide is absorbed at the sea surface. Models and measurements suggest that surface pH has decreased by 0.1 pH unit since 1750 (Bindoff, and others, 2007). It has been estimated that approximately half of the increased carbon dioxide emissions due to burning of fossil fuels since the Industrial Revolution has been absorbed in the ocean’s surface waters (Sabine, and others, 2004). However, continued acidification will reduce the ability of the ocean to take up atmospheric CO_2 and have potential negative impacts on finfish, shellfish, and plankton populations.

Kurihara (2008) noted that ocean acidification had negative impacts on the fertilization, cleavage, larval settlement, and reproductive stages of several marine calcifiers, including echinoderm, bivalve, coral, and crustacean species. In addition, Kurihara (2008) suggested that future changes in ocean acidity would potentially impact the population size and dynamics as well as the community structure of these species, influencing the overall health of marine ecosystems.

Although it appears that fish are able to maintain their oxygen consumption under elevated carbon dioxide levels, the impacts of prolonged CO_2 exposure on reproduction, early development, growth, and behaviour of marine fish are matters in need of urgent investigation (Ishimatsu, Hayashi, and Kikkawa, 2008). Changes in ocean chemistry might affect marine food webs and biogeochemical cycles but are less certain to occur because of their complexity (Haugan, Turley, and Portner, 2006). Important global biogeochemical cycles (of carbon, nutrients, and sulphur, for example) and ecosystem processes (changes in community structure and biodiversity) other than calcification may be vulnerable to future changes in carbonate chemistry and to declining pH levels.

5. Human settlements and social well-being

Future sea level rise will inundate coastal areas and thus lead to land loss in coastal regions. Even moderate sea level rise could have surprisingly large impacts, especially for low-lying coastal zones and deltas (Nicholls and Casenave, 2010). Changes in natural systems, such as flooding, for instance, can damage coastal infrastructure, ports and industry, the built environment, and agricultural areas, and, in the worst case, lead to significant mortality. Erosion can lead to loss of beachfront/cliff-top buildings and related infrastructure.

In addition to area losses from inundation and erosion (primary effects), sea level rise is likely to cause a variety of downstream, or secondary, effects such as the displacement and relocation of human populations from low-lying coastal regions (Nicholls and Casenave, 2010) into the hinterland (Dasgupta and others, 2009).

Other indirect impacts of climate change can include adverse effects on human health, for example, the release of toxins from eroded landfills and waste sites (Flynn and others, 1984), or mental health problems triggered by floods (Few and others, 2004). Moreover, it has been shown that such events can have long-lasting consequences on child development (Alderman, Hodditnott, and Kinsey, 2006). In addition to the huge direct impact on the well-being of affected populations, these consequences on labour productivity and health costs represent a strong obstacle to economic growth, which can affect the entire population. These indirect impacts will have economic consequences in terms of the cost of the damage (and/or the amendment of investment to fund adaptation).

Extreme climatic events cause a direct impact through loss of life and injury. Moreover, human-resource losses from migration go beyond these direct losses, and constitute a response to extreme events and disasters, especially in developing countries (McLeman and Smit, 2006). If disasters lead to outmigration, there will be consequences on economic growth; these consequences would be amplified if highly-skilled, high-productivity workers are more able to migrate than the average population.

If growth is understood broadly in terms of well-being, then other impacts of extreme events need to be considered. Lindell and Prater (2003), and World Bank and United Nations (2010), have provided a summary of these impacts. Poorer communities within a country are more vulnerable to the inequality-widening effect of extreme events (Atkins and Moy, 2005). Other impacts, including long-term local security aspects (e.g. on food security, individual security, civil unrest) clearly affect social welfare and well-being, even though they may be difficult to quantify and integrate in a single indicator.

6. Adaptation and mitigation

The two potential responses to climate change are mitigation and adaptation. Mitigation is defined as *an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases*, while adaptation is defined as *the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities* (IPCC, 2001). The two options are implemented on the same local, national or international scale, and may be motivated by local and regional priorities and interests, as well as global concerns. Mitigation has global benefits (ancillary benefits might be realized at the local/regional level), although effective mitigation needs to involve a sufficient number of major greenhouse-gas emitters. Adaptation typically works on the scale of an impacted system, which is international at best, but mostly local (although some adaptation might result in spillovers across national boundaries (IPCC, 2007). Hence, understanding and assessment of responses to climate change need to operate at multiple scales.

The fundamental goal of mitigation in the context of coastal and marine areas is to reduce the risk of crossing irreversible thresholds concerning the breakdown of the two major ice sheets and CO_2 levels, ultimately to rates that facilitate adaptation at a reasonable economic and social cost. Mitigation can slow the rise in sea level and sea surface temperatures and reduce their impacts and, given its strong inertia, has an important additional effect of stabilizing the rate of sea level rise, as opposed to the sea level rise itself (Nicholls and Lowe, 2006). Yet, sea level rise will continue, and will remain a challenge for generations to come. In essence, the commitment to sea level rise leads to a commitment to adapt to sea level rise, which has fundamental implications for long-term human use of the coastal zone (Nicholls and others, 2007).

Given that the rate of sea level rise controls some impacts, such as wetland loss or coral reef submergence, mitigation reduces the intensity of those impacts. In the case of flooding, absolute sea level rise is of more concern, and many of its impacts may be delayed rather than avoided due to the commitment to mitigating sea level rise (this commitment allows more time to adapt, which is an important benefit that includes lowering annual adaptation [and damage] costs). Hence, adaptation and mitigation are complementary policies in coastal areas (Nicholls, and others, 2007).

In some cases, the focus of climate change may help identify “win-win” situations, where adaptation measures are worthy of implementation just based on their capability to solve today’s problems (Hallegatte, 2009). Adaptation measures are more likely to be implemented if they offer immediate benefits – by reducing the impacts of short-term climate variability and other hazards – apart from mitigating long-term climate change impacts.

III. Methodology

The present report uses a modified version of the regional integrated model of climate and the economy (RICE model) (Nordhaus, 2010) to estimate the economic and social impacts of climate change. The RICE model views climate change in the framework of economic growth theory. In the standard, neoclassical optimal-growth model known as the Ramsey model, society invests in capital goods, thereby reducing consumption today so as to increase consumption in the future (Ramsey, 1928). In the variant of the RICE model used in the present report, the capital stock is also reduced by degradation due to climate change in the coastal and marine sector.

The model divides the Caribbean into the 16 countries under study.[3] It is assumed that each country has a well-defined set of preferences— represented by a social welfare function—and that its consumption and investment are optimized over time. The social welfare function is increasing in the per capita consumption of each generation, with diminishing marginal utility of consumption. The importance of a generation's per capita consumption depends on its relative size. The relative importance of different generations is measured using a pure rate of social time preference, and the curvature of the utility function is given by the elasticity of the marginal utility of consumption. The model contains both a traditional economic sector and a geophysical sector designed for climate-change modelling.

A. Economic sector

Each country in the Caribbean subregion is assumed to produce a single commodity, which can be used for consumption or investment. Each country is endowed with an initial stock of capital and labour and with an initial level of technology.

Population growth and technological change are exogenous, whereas capital accumulation is determined by optimizing the flow of consumption over time. Technological change is economy-wide. Output is determined using a Cobb–Douglas production function with biodiversity-augmented capital and population, rather than labour. Thus, output has a broader definition than gross domestic product (GDP), and includes ecosystem services and other non-marketable production.

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[3] The 16 countries are: Antigua and Barbuda, the Bahamas, Barbados, Belize, Cuba, Dominica, the Dominican Republic, Grenada, Guyana, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and Grenadines, Suriname, and Trinidad and Tobago.

B. Geophysical sector

The geophysical part of the model contains relationships that link the coastal and marine sector with climate-change indicators. Climate damage is country-specific, a function of sea level rise (1 cm per year) and temperature. The measurement of land loss from sea level rise is derived from Frankhauser (1995). The impact of climate change on marine ecosystems is based on the work of Vergara, Toba, Mira-Salama, and Deeb (2009), in which the key input in estimating the impact is the valuation of the marine ecosystem. Valuations for each country are based on an examination of the amount of economic activity which the ecosystem generates in the local economy (Pendleton, 2008). It involves looking at the revenues, taxes and jobs generated by each activity.

C. Scenarios

The economic and social impacts associated with climate change are examined, assuming the maximization of economic and social well-being, under the following three climate change scenarios:

a) assuming there is no climate change [baseline scenario]
b) under the A2 scenario/Business as Usual (BAU) [high impact scenario]
c) under the B2 scenario [low impact scenario]

The A2 and B2 climate change scenarios have been taken from the IPCC Special Report on Emissions Scenarios (SRES) (Nakićenović, and others, 2007). A2/BAU assumes resiliency and adaptation. The underlying themes of A2 are self-reliance and the preservation of local identity, with economic development being moderate and focused within the subregion. The global population under A2 is expected to increase at a higher rate than under other scenarios. Energy consumption is high and changes in land use are moderately high. Resources become increasingly scarce and technological change is fragmented and slower than in other scenarios. A2/BAU can be interpreted as complete inaction on climate change.

B2 assumes local resiliency and adaptation. It emphasizes environmental preservation and social equity, with local solutions to support economic, social and environmental sustainability. Global population is expected to increase continuously, yet more slowly than under scenario A2. Scenario B2, like A2, has a moderate level of economic development, but requires less energy and less change in land use than A2. Resources are more abundant and technological change more diverse than in A2. Under B2, there is some measure of mitigation or adaptation to climate change.

A2 is at the higher end of the SRES emissions scenarios, but is not the highest; emissions under A2 can be considered medium-high. Likewise, B2 is at the lower end of the SRES emissions scenarios, but is not the lowest; emissions under B2 can be considered medium-low. In fact, the A2 and B2 scenarios are not extremes. However, they are very different in terms of their conception of what the Earth might be like by the end of the twenty-first century. Compared with scenario B2, scenario A2 anticipates: higher CO_2 concentrations; a larger human population; greater energy consumption; more change in land use; scarcer resources; and less diverse applications of technology.

D. Extreme weather events

The present report considers the potential economic and social cost of damage to the coastal and marine sector as a consequence of tropical storms and hurricanes. The model for extreme weather events follows Elliot, Lorde and Moore (2012): the macroeconomic impact of hurricane strikes is obtained via a growth equation, where growth depends on GDP in the previous period, and the power dissipation index which encompasses the frequency, duration and intensity of hurricanes. Estimates for sectoral impacts are derived from ECLAC (2009).

An estimate of the strike probability for the Caribbean is based on the historic data of storms passing through the subregion from 1851-2010. The strike probability is calculated as the ratio of the number of named tropical storms passing within 69 miles of any country.

The worst-case scenario is based on the season with the highest number of named storms and hurricanes (28 named in 2005) and the best-case scenario, the season with the lowest number of named storms (4 named in 1983), over the period 1851-2010. The worst-case scenario thus assumes that there will be 28 storms and hurricanes in each season up to 2050, while the best-case scenario assumes that there will be 4 storms and hurricanes in each season up to 2050.

E. Limitations

The results derived from the present report have been limited primarily by the unavailability of data for valuing the coastal and marine ecosystems of Caribbean countries. When required inputs were unavailable for any country, averages for the Caribbean have been used. Fortunately, this limitation was not expected to have any significant effect on estimates, given the highly aggregated nature of the study.

IV. Results

The present section describes the impacts which the coastal and marine sector of the Caribbean are likely to face from climate change up to the year 2050. It considers: (1) the cost of the economic and social impacts of climate change under the A2/BAU and B2 scenarios; (2) the cost of extreme events; and (3) adaptation and mitigation strategies, and the benefit-cost analyses of those strategies.

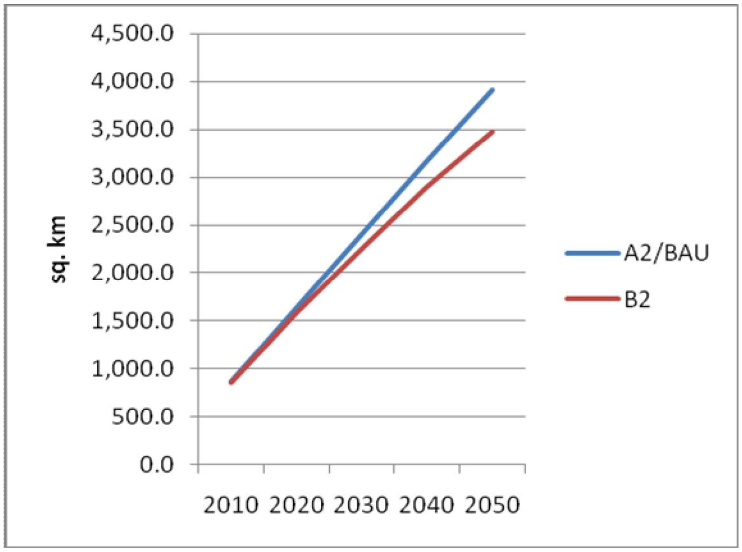
A. Economic and social costs of climate change

Sea level rise will lead to a definitive, yearly loss of land in the Caribbean (see figure 1). By 2050, the area totally inundated is just over 3,900 square kilometres under A2/BAU and close to 3,500 square kilometres under B2. The value of the land lost by 2050 is estimated at US$ 624 billion and US$ 406 billion under A2/BAU and B2, respectively (see figure 2). Approximately 0.6 per cent to 0.7 per cent of total land mass will be lost by 2050 (see table 1).

Land is a natural resource necessary for economic production. Loss of land thus represents loss of capital, with negative consequences on output. Such losses in the Caribbean will affect the tourism sector in particular. The loss of land will affect construction, especially around cities—which are all on the coast, where land is scarce and expensive—potentially leading to an increase in urban housing and land prices, which can be an obstacle to development. This aspect will exacerbate flood risks.

FIGURE 1
TOTAL CUMULATIVE LAND LOSS IN THE CARIBBEAN DUE TO CLIMATE CHANGE UNDER A2/BAU AND B2 SRES SCENARIOS, 2010 TO 2050

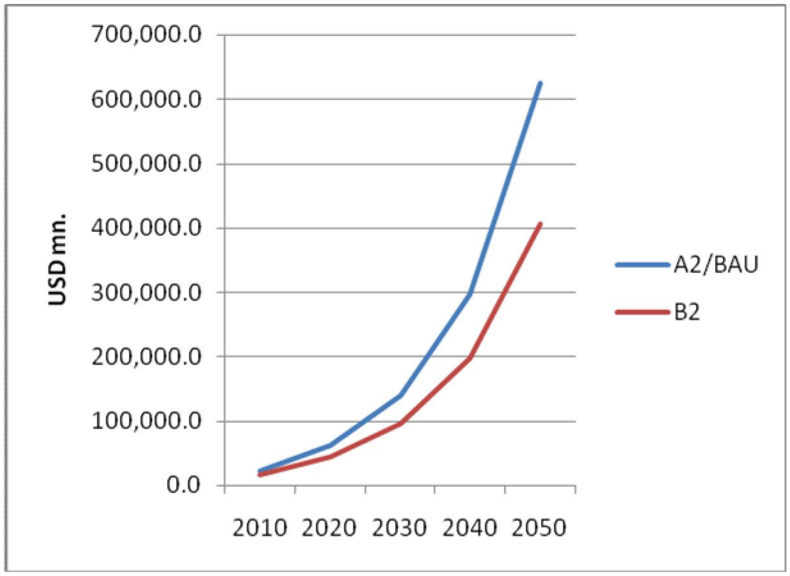
(Square kilometres)



Source: Author’s calculations

FIGURE 2
CUMULATIVE VALUE OF LAND LOSS IN THE CARIBBEAN AS A RESULT OF CLIMATE CHANGE UNDER A2/BAU AND B2 SRES SCENARIOS, 2010 TO 2050

(millions of United States dollars)



Source: Author’s calculations

TABLE 1
LAND LOSS IN THE CARIBBEAN CAUSED BY CLIMATE CHANGE UNDER A2/BAU AND B2 SRES SCENARIOS, 2010 TO 2050

(Percentage of total area)

	2010	**2020**	**2030**	**2040**	**2050**
A2/BAU	0.15	0.28	0.41	0.54	0.70
B2	0.15	0.27	0.39	0.50	0.60

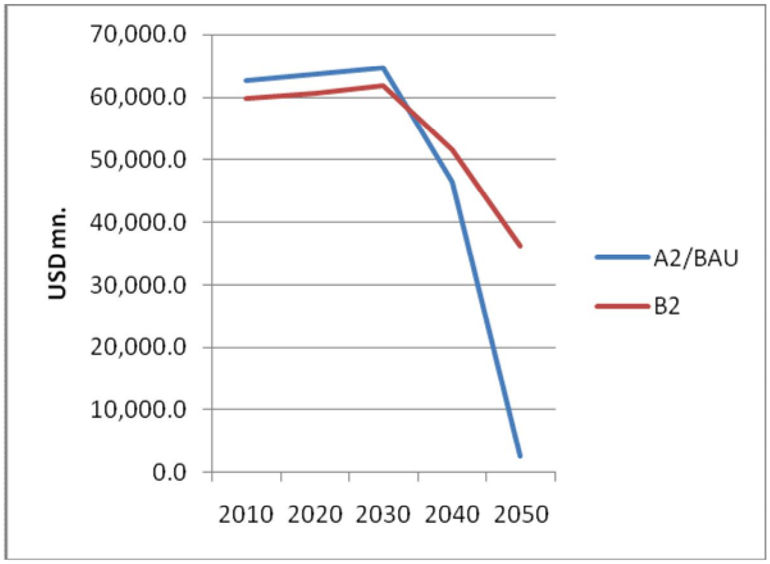
Source: Author's calculations

Loss of land means loss of infrastructure and housing as well as scarce productive capital. Inundation by sea level rise will affect the availability of drinking water, and will lead to soil salinization with severe consequences to agriculture, as coastlines recede.

In addition to market economic impacts (tourism and real estate), climate change in the Caribbean is predicted to have a devastating impact on marine ecosystems and natural habitats. Figure 3 shows that, by 2050, there will be an almost virtual collapse in coral-reef-associated ecosystems (reefs, seagrasses, reef fisheries). These ecosystems provide important services, from the purely recreational to biodiversity protection, breeding zones for fish, attractions for tourists and protection from storm surge. Under A2/BAU, the value of these ecosystems falls to US$ 2.7 billion in 2050, from a high of US$ 64.7 billion in 2030; under B2, the decline is smaller, but still very severe, falling to US$ 36.3 billion in 2050.

FIGURE 3
ESTIMATED DECLINE IN THE VALUE OF MARINE ECOSYSTEMS IN THE CARIBBEAN UNDER A2/BAU AND B2 SRES SCENARIOS, 2010 TO 2050

(millions of United States dollars)

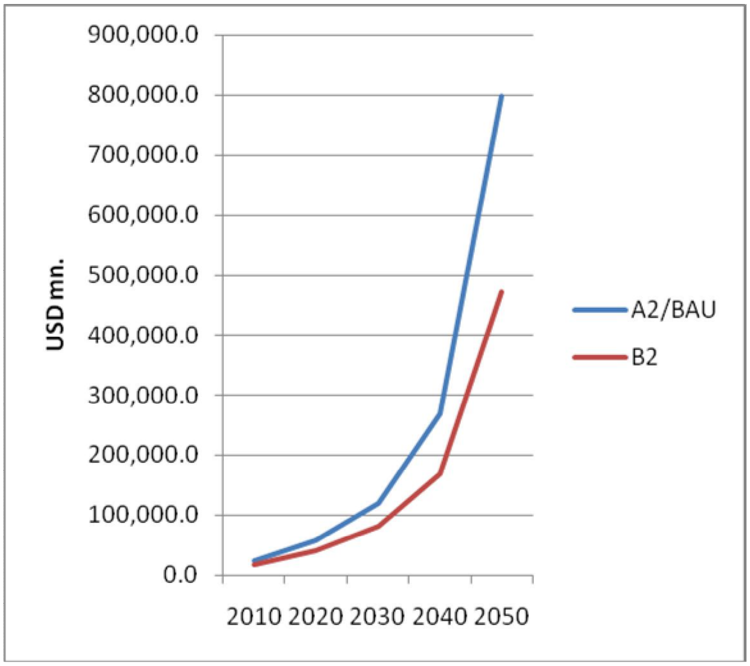


Source: Author's calculations

The total cumulative impact to the coastal and marine sector of climate change increases exponentially under both A2/BAU and B2 (see figure 4). The value of the impact by 2050 is expected to be US$ 798.7 billion if A2 occurs, and US$ 471.7 billion if B2 occurs (see figure 4). Climate damage to the coastal and marine sector by 2050 is valued at 159 per cent and 98 per cent of aggregate Caribbean gross domestic product under A2/BAU and B2, respectively (see table 2).

FIGURE 4
CUMULATIVE CLIMATE CHANGE DAMAGE TO THE COASTAL AND MARINE SECTOR OF THE CARIBBEAN UNDER A2/BAU AND B2 SRES SCENARIOS, 2010 TO 2050

(millions of United States dollars)



Source: Author's calculations

TABLE 2
CLIMATE CHANGE DAMAGE TO THE COASTAL AND MARINE SECTOR OF THE CARIBBEAN UNDER A2/BAU AND B2 SRES SCENARIOS, 2010 TO 2050

(Percentage of GDP)

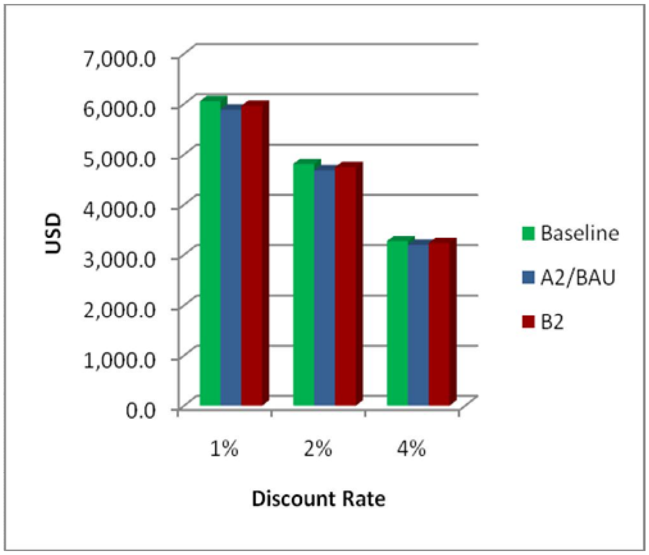
	2010	2020	2030	2040	2050
A2/BAU	8.0	15.4	26.9	54.0	158.6
B2	6.0	11.3	18.8	35.3	97.9

Source: Author's calculations

Figure 5 shows the present value of the difference in welfare, measured by consumption per capita across the Caribbean, for the baseline (no climate change), A2/BAU and B2 scenarios. Assuming a discount rate of 1 per cent, the net present value of per capita consumption is US$ 5,885 under A2/BAU and US$ 5,962 under B2, compared with US$ 6,052 for the baseline; using a discount rate of 4 per cent, the net present value of per capita consumption falls to US$ 3,195 under A2/BAU and US$ 3,233 under B2, compared with US$ 3,273 for the baseline; the predicted impact using a discount rate of 2 per cent lies between these two extremes. The decline in welfare ranges from 1.2 per cent to 1.5 per cent under B2, and 2.4 per cent to 2.8 per cent under A2/BAU, depending on the discount rate used.

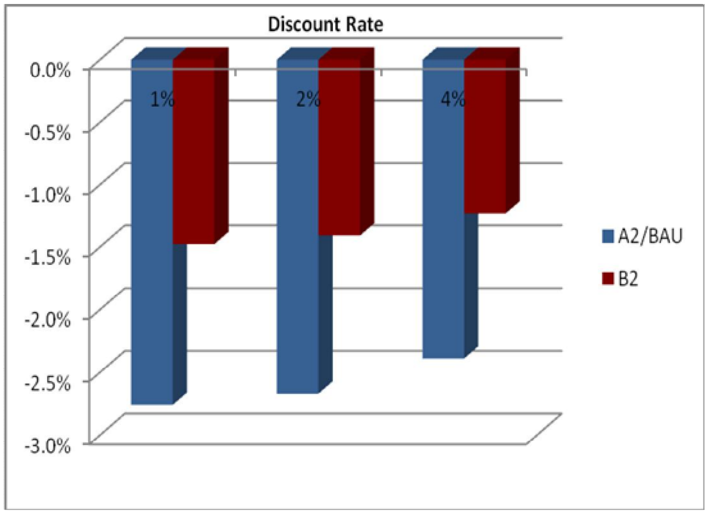
While the differences in welfare between the three scenarios for a given discount rate appear to be relatively small, the results shown in figure 5 obscure the issue of distribution within and across the countries of the Caribbean. The same monetary loss has very different consequences for poorer households, which are more vulnerable than wealthier households. The impacts are even stronger on subsistence-level populations, on whom even a minuscule monetary loss at the aggregate level has large welfare impacts. Similarly, populations living along coastlines will be more affected than those living inland. Thus, the total impact on welfare will depend on the initial situation of the affected population and the distribution of the resulting costs of impact.

FIGURE 5
NET PRESENT VALUE OF CONSUMPTION PER CAPITA IN THE CARIBBEAN UNDER BASELINE, A2/BAU AND B2 SRES CLIMATE CHANGE SCENARIOS AT 1%, 2% AND 4% DISCOUNT RATES
United States dollars ($)



Source: Author's calculations

FIGURE 6
PERCENTAGE DECLINE IN WELFARE FROM CLIMATE CHANGE IN CARIBBEAN COUNTRIES UNDER BASELINE, A2/BAU AND B2 SRES CLIMATE CHANGE SCENARIOS AT DISCOUNT RATES OF 1%, 2% AND 4%
(Percentage)



Source: Author's calculations

B. Cost of extreme weather events

The impact of hurricanes and storms on the coastal and marine sector of the Caribbean will be high (see tables 3, 4 and 5). Losses to fisheries for 2010-2050 range from a low of US$ $ 7.5 million to a high of US$ $ 13.3 million for the best-case scenario, and from a low of US$ 13.3 million to a high of US$ $ 18.2 million in a worst-case scenario (see table 3).

TABLE 3

BEST-CASE AND WORST-CASE SCENARIO LOSSES TO FISHERIES IN THE CARIBBEAN DUE TO EXTREME WEATHER EVENTS, 2010 TO 2050

(millions of United States dollars)

	2010	2020	2030	2040	2050
Best case	13.3	7.5	8.1	8.3	7.6
Worst case	13.3	16.9	18.2	18.6	17.0

Source: Author's calculations

The total losses to the coral reef ecosystem under a worst-case scenario are over US$ 900 million to 2010, 2020 and 2030. In 2050, the cost of the potential hurricane damage drops significantly to US$ 39.3 million, reflecting the almost-complete collapse of the coral reef ecosystem due to the impacts of climate change. Built coastal assets will be severely damaged under both the best-case and worst-case scenarios. Predicted damage is US$ 0.5 billion in a best-case scenario and over US$ 1 billion under a worst-case scenario (see table 4).

TABLE 4

BEST-CASE AND WORST-CASE SCENARIO LOSSES TO THE CORAL REEF ECOSYSTEM IN THE CARIBBEAN DUE TO EXTREME WEATHER EVENTS, 2010 TO 2050

(millions of United States dollars)

	2010	2020	2030	2040	2050
Best case	438.3	444.2	453.5	378.5	266.0
Worst case	919.1	934.3	949.5	681.0	39.3

Source: Author's calculations

TABLE 5

BEST-CASE AND WORST-CASE SCENARIO LOSSES TO BUILT COASTAL ASSETS IN THE CARIBBEAN DUE TO EXTREME WEATHER EVENTS, 2010 TO 2050

(millions of United States dollars)

	2010	2020	2030	2040	2050
Best case	950.2	540.7	581.5	592.9	542.0
Worst case	950.2	1,213.5	1,305.3	1,330.8	1,216.5

Source: Author's calculations

The results shown in tables 3, 4 and 5 are reinforced by existing trends, with coastal areas becoming more densely populated in response to trends in economic structure and lifestyle. Growing populations, land scarcity and infrastructural gaps have caused more marginal and high-risk land to be urbanized in the Caribbean every year. Land loss due to sea level rise will amplify these trends.

Risk perceptions influence the willingness to invest, in an economically successful future. Where investors think that natural risks are excessively high they do not invest. So, an extreme event may lead to risk overestimation by investors, and reduced economic growth, even below what is optimal.

In general, the Caribbean has limited capacity to rebuild after extreme events; it will not have enough time to rebuild between habitual events, and could end up in a state of permanent reconstruction, with all resources devoted to repairs instead of to new infrastructure and equipment. This obstacle to capital accumulation and infrastructural development could lead to permanent underdevelopment.

C. Adaptation and mitigation

Coastal development and infrastructure will face increasing threats as Caribbean beaches retreat, wetlands disappear, and storm damage becomes more severe. Tourism and fishing industries could suffer, and the insurance industry will be called upon increasingly to buffer economic losses. The Caribbean subregion must be able to adapt to these changes over the long term in a manner that is economically, socially, and environmentally sustainable.

Natural processes in the coastal and marine sector operate on time scales that are poorly understood, making effective adaptation and mitigation strategies difficult. Implementation of adaptation strategies are complicated further by the inherent inertia of relevant institutions. Thus, addressing the challenges and opportunities presented by the impacts of climate change will require both building adaptive capacity and delivering adaptive actions. These two strategies can be implemented simultaneously, although, in some cases, it may be necessary to address specific capacity needs before adaptation can be undertaken fully.

One component of increasing adaptive capacity would be to increase the flexibility of institutional decision-making processes, so the public and private sectors can adjust more readily to predicted climate impacts before these occur. More flexibility may be needed to accommodate the uncertainties associated with climate change as well as the uncertainties in non-climatic stresses, as represented by changes in population growth, economic trends, resource demands, the legal landscape, and economic trends.

Regional-scale adaptation strategies presented in the present section have assumed that the legal and institutional changes necessary for implementation can be achieved. However, depending on the objective, adaptation strategies are likely to be competing and/or conflicting, and would require a public process to achieve resolution. This section, firstly, discusses broadly some adaptation strategies and frameworks for reducing vulnerability to climate change, and then presents cost-benefit analyses of selected strategies.

1. Sea level rise

Adaptation to sea level rise involves responding to both mean and extreme rise. Given the growing concentration of people and activity in the coastal zone of Caribbean countries, autonomous[4] (or spontaneous) adaptation processes alone will not be able to address sea level rise. Further, adaptation in the coastal context is widely seen as a public, rather than a private, responsibility. Therefore, all levels of government have a key role to play in developing and facilitating appropriate adaptation measures.

Adaptation to sea level rise can be classified in a variety of ways. One widely-followed approach is the IPCC typology of planned adaptation strategies (Intergovernmental Panel on Climate Change – Coastal Zone Management Subgroup (IPCC-CZMS), 1990) (see figure 7):

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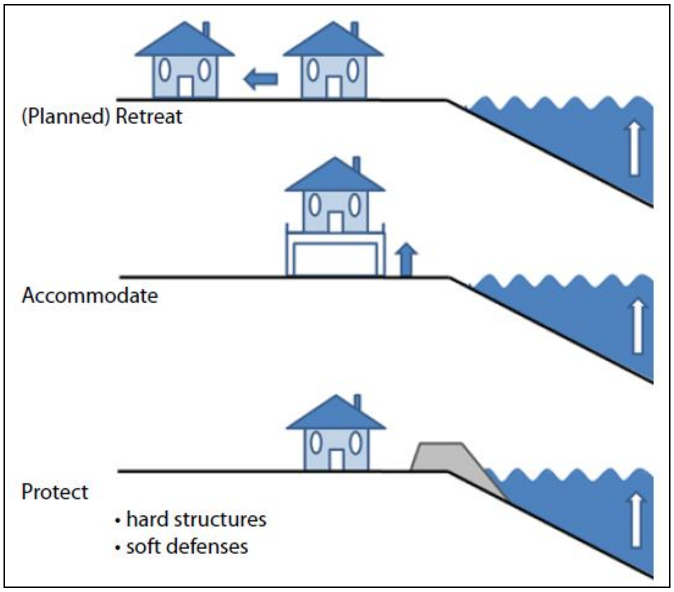
[4] Autonomous adaptation represents the spontaneous adaptive response to sea level rise (e.g. increased vertical accretion of coastal wetlands within the natural system, or market price adjustments within the socioeconomic system).

- (Planned) Retreat. All natural system effects are allowed to occur and human impacts are minimized by pulling back from the coast via land use planning, development controls, and other means.
- Accommodation. All natural system effects are allowed to occur and human impacts are minimized by adjusting human use of the coastal zone via flood-resilience measures, such as warning systems and insurance.
- Protection. Natural-system effects are controlled by soft or hard engineering (e.g. nourished beaches, dunes or sea walls), reducing human impacts in the zone that would be impacted without protection.

FIGURE 7
GENERIC ADAPTATION APPROACHES FOR SEA LEVEL RISE



Source: Intergovernmental Panel on Climate Change – Coastal Zone Management Subgroup (IPCC-CZMS, 1990)

In practice, many real-world responses are hybrid, combining elements of more than one approach. For example, when offering flood protection, the residual risk that remains for all protected areas needs to be considered, suggesting that flood protection needs to be combined with flood forecast and warning systems. Adaptation for one sector may exacerbate impacts elsewhere (Doody, 2004). Adaptation strategies for the Caribbean should therefore consider the balance between protecting socioeconomic activity/human safety and the habitats and ecological functioning of the coastal zone under rising sea levels.

Hard protection options such as bulkheads or rock walls can temporarily reduce erosion caused by wave action, but they can do little to prevent continued erosion and longshore drift, since waves rebound off the breakwater and increase the rate of beach erosion. Beach armouring, however, can cause two negative effects that act to reduce the beach area: by stopping the sediment from bluff erosion from adding to the beaches, and moving the sand offshore (Johannessen and MacLennan, 2007). Moreover, sea walls may threaten the vital tourism industry, because they devalue landscapes, ecosystem health and beach leisure attractions. Beach landscape degradation, marine ecosystem damage and loss of leisure activity (e.g. diving) would be likely to lead to a drastic reduction in tourism inflows—or, at least, to a decrease in the willingness of tourists to pay—leading, in turn, to declining local incomes. Further, hard protection has been shown to contribute to the depletion of fish stocks by damaging coastal ecosystems further (Clark, 1996). As a large fraction of fish species depend on coastal zones at some point in their life cycle, such coastal defences could have significant impact on fisheries economic activity. As a consequence, hard protection should no longer be an option for the Caribbean.

For Guyana and Suriname, two Caribbean countries which have already invested heavily in sea wall protection, accelerated sea level rise may intensify the rate and extent of coastal erosion, sea-wall breaches and lost mangroves. In response, existing hard structures, such as sea walls and mud embankments, may need to be strengthened and elevated repeatedly. The retrofitting of sea walls is estimated at US$ 6 million per km.[5] A sea defence maintenance programme should entail the following:

- Inspection, monitoring and collection of data at greater frequency on environmental conditions and structural responses.
- Ensuring that the design life of a structure is consistent with the design life of its components (reduced maintenance cost).
- Quantity surveying to establish material needs for adaptation efforts.
- Securing adequate financing for adaptation works and permanent financing for adequate maintenance.

Mangroves function as natural breakwaters along coastlines, and represent one of the most important natural sea defences available in the Caribbean. Rehabilitation and reforestation of coastlines should include the development of mangrove plantations. Filling cycles for mangroves range from 20 years to 100 years, with natural mangrove regeneration density per hectare of up to 53,350 seedlings.

Flood zone designations could be modified to incorporate expected sea level rise. Caribbean countries may choose to reduce development in hazardous coastal areas. Setback policies, and the redesignation of property lines, to move with rising mean high water, called ‘rolling easements’ by Titus (1998), can also be employed to accommodate sea level rise. Ultimately, however, the decision to retreat inland may be unavoidable as the sea level rises.

2. Higher ocean temperatures

Lessening the impacts of the higher ocean temperatures in Caribbean waters due to global warming will require strategies that increase the overall resilience of coastal and marine ecosystems to human-induced stressors, to help them resist and/or recover from impacts such as coral bleaching and disease outbreaks. Placing greater emphasis on habitat protection and ecosystem-based management of fisheries, coral reefs, and other coastal resources are crucial for coping with multiple stressors.

Decision makers should focus on protecting the diversity of species and habitat types that characterize Caribbean ecological systems, and on restoring or preserving habitat connectivity. Improving connectivity both within and between coral reefs can facilitate the distribution of larvae and maintain genetic diversity among corals (Nystrom and Folke, 2000). These should be important considerations in the establishment and management of marine protected areas, no-take reserves, and other coastal and marine conservation strategies. Furthermore, coastal water temperatures must be monitored closely, and swift strategic management responses developed to deal with extreme events.

3. Extreme weather events

Adaptation strategies for coastal flooding and storm damage reduction will depend on economic, social, and environmental factors such as the desired level of protection, level of development, presence of critical infrastructure and natural resources, and consequences to the environment and neighbouring communities. There are several measures that can be taken to reduce risk. ‘Low regrets’ measures have the ability to alter the exposure, vulnerability, and resilience of people and structures facing extreme weather events. These measures can provide other benefits, such as improving human livelihoods and well-being, and the conservation of biodiversity.

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[5] Sea and River Defence Division of the Ministry of Public Works, Guyana.

The measures might include the adoption of early-warning systems and better forecasting of extreme weather events, risk communication between decision makers and local populations, improved land use planning, improved ecosystem management and restoration, better health response initiatives, sanitation, drainage, and improved building codes. There is an important part for local people to play, by integrating local knowledge into hazard-reduction and risk-management strategies.

4. Benefit-cost of selected adaptation and mitigation strategies

Based on the general strategies discussed previously, the following are recommended for implementation at a subregional level for the Caribbean coastal and marine sector – with the exception of the option for extreme weather events, which is national in scope – and benefit-cost analyses undertaken:

a) Reforestation of mangrove swamps in coastal areas

b) Monitoring of all coastal waters to provide early warning alerts of bleaching and other marine events

c) Development and implementation of programmes aimed at the protection and rehabilitation of degraded fisheries habitats and ecosystems, and the environment in general

d) Development of national evacuation and rescue plans for extreme weather events

Costs for Options 2 and 3 were obtained from the Caribbean Community Climate Change Centre (CCCCC, 2011). All analyses were conducted for a 20-year period. Table 6 shows the benefit-cost analysis of the selected options. Benefit-cost ratios were reported positive for year 20 (2030). All adaptation options considered were justifiable; each had a benefit-cost ratio greater than 1. There was no payback period for Option 1, since it would be an ongoing strategy.

There are several other adaptation strategies for which benefit-cost analyses were not conducted (see CCCCC, 2011 for a detailed list of the options and funding available for the Caribbean). However, most importantly, one has to take into account that the decision to protect the coastal and marine sector cannot be reversed once it has been made. Indeed, if inhabitants and investors think that the area is protected, they will settle and invest there. The growth in exposure will then make it unavoidable to protect the sector, even if sea level rise becomes so large that costs soar and reach a significant fraction of available resources over the very long term.

TABLE 6
BENEFIT-COST RATIOS OF SELECTED CLIMATE CHANGE ADAPTATION STRATEGIES FOR THE CARIBBEAN

	Details	Benefit-cost ratio	Payback period (years)
Option 1	Reforestation of mangrove swamps in coastal areas	26	Not applicable
Option 2	Establish monitoring of all coastal waters to provide early warning alerts of bleaching and other marine events	906	1
Option 3	Develop and implement programmes aimed at the protection and rehabilitation of degraded fisheries habitats and ecosystems, and the environment	1,228	1

	generally		
Option 4	Develop national evacuation and rescue plans for extreme weather events	28	1

Source: Author's calculations

V. Conclusions and recommendations

Adapting to climate change will ultimately require more systematic integration of governance strategies, science, regulatory systems, policy, and economics at an international level to deal effectively with the wide range of impacts projected for the Caribbean. This integration will be shaped through formal mechanisms such as the development or modification of laws, regulations, and policies. Integration will evolve through more subtle changes in institutional culture, channels of communication, and modes of interaction that build trust among Governments, Government agencies and stakeholders.

The current report has discussed fundamental concepts of planning for climate change and has identified options for adapting to the impacts evaluated. However, the report should not be viewed as an end to the discussion on adaptation needs. That discussion is, in fact, just beginning. Areas of future research to support adaptive planning include research on institutional capacity needs and on regulatory barriers to adaptation. Improving institutional capacity to understand and better incorporate climate change impacts into planning is a “no regrets” strategy that would yield benefits regardless. The recurring need for updated information on climate impacts and other related information places a heavier reliance on the use of data collecting agencies and the best available science in the policies used to govern human and natural systems.

As has been shown in Section 4, climate change is likely to have negative impacts on the coastal and marine sector: the definitive loss of land, collapse of marine ecosystems, a decline in welfare and well-being, and adverse consequences from extreme weather events. These impacts would lead to natural capital losses, a reduction in physical capital, possible negative impacts on social cohesion or even reductions in human capital, especially if skilled workers are the first to migrate. It is difficult to quantify the overall consequences on economic and welfare growth, but sizeable impacts are very possible.

Many adaptive actions may create cost-savings through damage avoidance. Many of the changes required to develop a more climate-resilient Caribbean will take time to implement. Waiting for climate change to “arrive” will be too late in some cases, and in others significantly more costly.

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