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Assessing climate change impacts on coastal infrastructure in the Eastern Caribbean

Clement Lewsey*, Gonzalo Cid, Edward Kruse

The International Programs Office, National Ocean Service, National Oceanic and Atmospheric Administration (NOAA), 1315 East-West Highway, SSMC3, Silver Spring, MD 20910, USA

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Abstract

Expected effects of changes in global climate include warmer temperatures, rising sea levels, and potentially more frequent and severe extreme weather events such as hurricanes and tropical storms. Low-lying states in the Caribbean are especially vulnerable to these effects, posing significant risks to public safety and natural resources.

This paper highlights expected trends in the Eastern Caribbean and examines the impacts of urbanization and supporting infrastructure, siting of major structures in high-hazard areas, and negative land-use practices on fragile coastal ecosystems. It focuses on the need to reduce the vulnerability of coastal infrastructure and land uses, arguing for effective linkages between climate change issues and development planning. The paper also provides general recommendations and identifies challenges for the incorporation of climate change impacts and risk assessment into long-term land-use national development plans and strategies.
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Keywords: Climate change; Coastal infrastructure; Land-use planning; Integrated coastal management; Eastern Caribbean

1. Introduction

Few areas in the world are more vulnerable to climatic variability than the low-lying island states in the Eastern Caribbean Basin. While their small land masses leave them vulnerable to hurricanes and tropical storms, that vulnerability has been exacerbated because of human activities—intensive land development, high population density in coastal zones and poorly developed coastal infrastructure are complicated by the impacts of tourism-based industries, limited human and cash reserves, and a lack of trained personnel who can address the impacts of climate variability [1].

Environmental degradation in many of these Caribbean islands has increased the risk that climate change is predicted to have on these economies, as many of them are heavily exploiting their limited natural resources. According to a 1998 Inter-American Development Bank study [2], land-use and resource allocation conflicts in the coastal zone, degradation of coastal ecosystems, fish stock reduction and declining water quality from land-based activities have been intensifying the demands on these natural resources. Such demands limit the ability of coral reefs and aquifers, e.g., to adequately adapt to climatic changes.

The climatic impacts likely to be the most significant and immediate are: (1) changes in varying rainfall regimes and soil moisture budgets, (2) potential increases in the frequency and intensity of hurricanes, and (3) changes in regional and local sea levels and patterns of wave action [1,3]. Rising sea levels, in particular, pose threats of severe ecological disruption, which will likely impact Caribbean social structures and economies in the highly concentrated coastal zone (i.e., within 2 km from the coast). Most island economies have become largely dependent on the tourism industry, which features pristine beaches, coral reef ecosystems, and other coastal amenities; to continue to attract international travelers and to remain competitive with other tourist destinations, many island states have compromised their natural assets. In the process, other economic activities such as agriculture and manufacturing industries have been jeopardized because of the strain on resources such as potable water, coral reef habitats, and fisheries.

*Corresponding author. Tel.: +1-301-713-3078x213.
E-mail address: clement.lewsey@noaa.gov (C. Lewsey).

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To develop realistic policy strategies for reducing the impacts that human activities have on sea-level rise (SLR), the Coastal Planning for Adaptation to Global Climate Change project (a 4-year project funded by the Global Environment Facility and expedited by the Organization of American States) identified distinct physical impacts that are expected to occur with climate change. They include:

- submergence of low-lying wetland and dry land areas;
- erosion of soft shores by increasing offshore loss of sediment;
- increased salinity of estuaries and aquifers;
- rising coastal water tables; and
- increased and more severe coastal flooding and storm damage.

Developing effective protection of fringe landforms—mangroves, wetlands, coastal flood plains, forests, dunes, berms—is a strategic necessity for ameliorating island vulnerability to climate change. These ecosystems serve as natural shock absorbers for protecting coastal infrastructure and land uses such as agriculture, against tropical storms and hurricanes; they also provide critical storage capacities for storm surges and floodwaters. There is increasing evidence, e.g., that strong measures to conserve and enhance their resilience to the stresses of SLR through effective land-use strategies (e.g., setback requirements, transferred development rights) can help reduce what could be a looming disaster for these small island states. Doing so will require concentrated efforts by island governments to develop coordinated policies that focus on managing human impacts of climate change, particularly SLR.

The need to act decisively in protecting coastal zones must recognize the demands of the immense tourism industry, which is likely to remain central to Caribbean island economies. The danger for Caribbean economies is that if environmental degradation continues, the islands may no longer be as attractive a destination as it now is and will lose tourism to competitors. A key challenge to the Caribbean states is how to balance the immediate economic needs that the tourism industry fills while minimizing the environmental stresses that the tourism has created. Doing so will require wide-ranging innovative policies and political will in order to reverse, as much as possible, the damages it has already caused. Meeting such challenges will be difficult, in part because economic investment generally does not project over the long term, while formulating and implementing environmental policy must. The good news is that there is great potential for reversing current environmental impacts and those projected for the future—it will take political will and cooperation among the Caribbean island states to undertake actions that can make that potential into a reality.

This paper addresses current trends in land-use planning and, in the context of climate change (in particular, SLR), their impact on the coastal ecosystems of the Eastern Caribbean small islands. The paper sets out broad policy recommendations that can help minimize the harmful impacts of these trends.

2. Background: physiology and economic development of the Eastern Caribbean

2.1. Geographic description of the Eastern Caribbean Basin

The Eastern Caribbean region encompasses an area including the marine environment of the Gulf of Mexico, the Caribbean Sea and adjacent areas of the Atlantic Ocean and the surrounding coastal regions (see Fig. 1). The two main bodies of water of the region—the Gulf of Mexico and the Caribbean Sea—form a partially enclosed sea with a total surface area of about 4.24 million km^2 [4]. This region has an ocean circulation pattern that follows an east-to-west movement in the Caribbean Sea, followed by a southeast-to-northwest movement into the Yucatan Basin and, finally reaching the Gulf of Mexico, eastward again through the Florida Straits. The region is fed by the Northern Equatorial Current, which flows northward looping into the Gulf of Mexico. Physical circulation patterns are important to note because human, or anthropogenic, impacts such as pollution and runoff, are concentrated in nearby coastal areas and can have a severe and cumulative effect on the entire region.

The surface water temperature average of some 27°C generally varies $\pm 3°$. The stability of warm water conditions has fostered the region's unique and highly productive ecosystems of coral reefs, seagrass beds and mangroves, making the areas close to the shores highly productive. Table 1 summarizes geographic details for the islands considered in this paper.

Considering the Eastern Caribbean islands' exclusive economic zone areas versus their land areas, most of these islands have very small land–water ratios, with an average for all the Caribbean of about 1:30 [5]. Due to the Caribbean Sea's unique circulation patterns, human impacts such as pollution and runoff are concentrated in nearby coastal areas and can have a severe and cumulative effect on the entire region.

2.2. Major economic activities and land-use impacts in the Eastern Caribbean

Tourism is the major economic activity in the region—an estimated 12 million tourists visit the islands each year and another eight million visit in cruise vessels [6]. Tourism accounts for between 25% and 35% of the

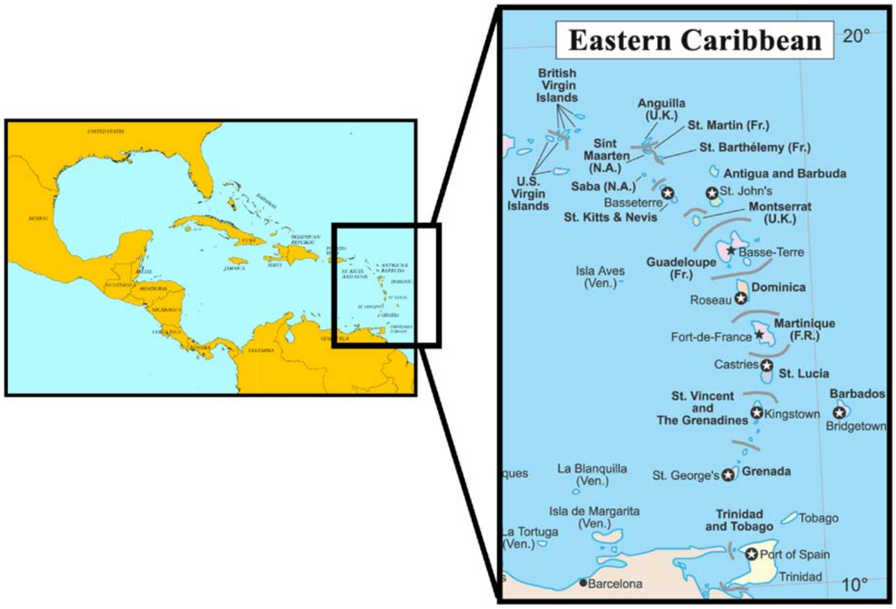

Fig. 1. Map of the Eastern Caribbean region.

total Caribbean region economy, it represents one-quarter of the foreign exchange earnings, and it provides about one-fifth of the jobs [5]. Table 2 summarizes the relative importance of tourism with respect to GNP and Exports for a sample of Eastern Caribbean countries. The Small Island Developing States (SIDS)—Program of Action identifies the tourism industry as a priority for development, and as one of the main pressures on the environment.

The small size and rugged topography of most countries in the Eastern Caribbean limit the different types of land use. The needs of tourism compete with the needs of housing, agriculture, industry, roads, and ports. According to FAO [7] data for the Eastern Caribbean, Jamaica is the largest in terms of agricultural land use, while Dominica has the most forest and woodland use. Other countries such as the Bahamas, Antigua and Barbuda, Grenada and St. Lucia have a large percentage of their land dedicated to other uses including buildings and urban facilities.

Though total forested area is virtually non-existent in Barbados and Antigua and Barbuda, and relatively small as a percentage of total island area (see Table 1), land-use management has been identified as the key issue for forestry development in the Eastern Caribbean [5]. The area of native forest in the region has declined continuously, and the average deforestation rates vary between 0.8% and 7.2% per year, although the rate of deforestation has slowed in recent years. Barbados and Antigua and Barbuda lost all their native forest to urban and coastal development, a phenomenon that has had a significant impact on polluted runoff to the near-shore environment.

Freshwater resources in the Eastern Caribbean region are generally scarce compared with other island regions in the world [5], though they differ depending on the geology, topography and size of the island. Many small islands in the region have virtually no fresh water ecosystems and depend on rain—Anguilla is one example; St. Kitts, on the other hand, has large freshwater reserves. Expansion of the tourism industry and agricultural needs have greatly increased the demand for freshwater [5].

3. Vulnerability of Caribbean Coastal Infrastructure and land uses to climate variability and change

One of the most important climate change effects on coastal communities is SLR. The Intergovernmental Panel on Climate Change [1] predicts that, on average, SLR between 15 and 95 cm by 2100 will have a significant impact on coastal infrastructure and economic development. Problems such as coastal erosion and contamination of freshwater aquifers will increase constantly in coastal areas. Changes in precipitation and temperature patterns will affect freshwater supply and agricultural activities, especially in small island states where rain is the only water source.

A common baseline scenario for the Caribbean predicts a rise in temperature of 1.5°C and a rise in sea level of 20 cm (0.5 cm/year) by the year 2025 [8]. While these estimates are conservative and based on site-specific data from south Florida, we have used them for the purpose of this analysis in order to discuss trends and recommendations.

Table 1
Descriptive indicator of some CARICOM Caribbean countries

Country	Descriptive indicators									
	Population (est. 2001)[a]	Area (km^2)[a]	Population density (Inh./km^2)	Coastline (km)[a]	Area of Continental Shelf ($\times$ 1000 km^2)[a]	Area of Mangroves (km^2)[a]	Total annual surface freshwater (km^3)[a]	Total forest area (Km^2)[a]	Mangrove area (Km^2) in 1990[b]	Mangrove area loss between 1980 and 1990 (Km^2)[b]
Antigua and Barbuda	66,970	442	152	289	2.1	13	0.1	90	1.5	7.5
Bahamas	297,852	13,940	21	11,238	79.8	2332	N.a.	1580	1419	1667
Barbados	275,330	430	640	97	0.2	<0.07	0.1	0	0.2	N.a.
Dominica	70,786	754	94	152	0.3	2	N.a.	460	0.1	N.a.
Grenada	89,227	340	262	251	0.6	2	N.a.	40	1.5	0.5
Jamaica	2,665,636	10,990	243	895	5.6	106	9.4	1750	106	+(36)
St. Kitts and Nevis	38,756	261	148	135[a]	n.a.	n.a.	N.a.	N.a.	0.2	0.3
St. Lucia	158,178	620	255	166	0.3	1	N.a.	50	1.8	1.2
St. Vincent and the Grenadines	115,942	389	298	264	1.1	<0.45	N.a.	110	0.6	0.4
Trinidad and Tobago	1,169,682	5128	228	704	22.6	<70	N.a.	1610	71	+(31)

[a] CIA, The World Factbook, 2001; World Resources Institute, Earth Trends 2001.
[b] Ref. [17].

Recent large interannual variation in oceanic and atmospheric conditions may already be affecting small islands [3]. Changes in rainfall regimes, soil moisture budgets, frequency of extreme weather events, short-term variation of local or regional sea level, and patterns of wave actions are among present manifestations of climate change. Recent data analysis indicates that the Caribbean Sea is one of the regions where the surface air temperature has increased more rapidly than the average temperature globally, causing variability in the rainfall patterns [3]. The causes of this surface temperature increase have not yet been established, but they can be attributed to multiple origins.

3.1. Major variations produced by climate change

3.1.1. Sea-level rise (SLR)

For each centimeter of SLR, the CEP [8] projects a shoreline retreat up to several meters horizontally, which translates into a loss of several thousand hectares of land. Increased flooding during storm periods will compound the problem for population centers in the poorly drained low-lying coastal plains. Coastal lagoons and estuaries in the region are likely to lose productivity, as they are subjected to saline intrusion and flooding. Mangrove forests—a unique feature of coastal lowlands in this region that stabilize soil, damper wave energy, and provide habitat—are expected to tolerate the anticipated SLR, as are seagrasses [8].

3.1.2. Temperature and precipitation

CEP [8] predicts that climate change will result in a decrease in rainfall and an increase in temperature, surface wind speed, and evaporation. This increase may trigger coral bleaching events, though most organisms are expected to tolerate the change. The agricultural sector will be more threatened by saline intrusion than by temperature change. However, overall environmental stress due to human impacts—such as erosion caused primarily by poor management practices—will be more significant than those caused by increased temperature [8]. Table 3 summarizes the projected impact in the Eastern Caribbean under the climate scenario.

Throughout the region, several over-arching forces have shaped specific trends in vulnerability, such as increasing population densities and growth rates, the rapid expansion of the tourism industry (particularly at the expense of agriculture) and the generally uncontrolled coastal development and urbanization that has resulted [4]. These trends and others, coupled with inadequate policies and enforcement of those in effect, have at times resulted in the destruction of critical ecological buffers and increased the vulnerability of coastal infrastructure and land uses in the Caribbean.

Table 2
Importance of tourism for select Eastern Caribbean SIDS

Country	Number of tourists ($\times$ 1000)	Tourists as % of population	Tourist receipts as % GNP	Tourist receipts as % of exports
Antigua and Barbuda	232	364	63	74
Bahamas	1618	586	42	76
Barbados	472	182	39	56
Dominica	65	98	16	33
Dominican Republic	2211	28	14	30
Grenada	111	116	27	61
Haiti	149	2	4	51
Jamaica	1192	46	32	40
St. Kitts and Nevis	88	211	31	64
St. Lucia	248	165	41	67
St. Vincent	65	55	24	46
Trinidad and Tobago	324	29	4	8

Table adapted from technical summary: IPCC's Climate Change 2001.

Table 3
Implications of climate change in The Eastern Caribbean: projected impacts on selected ecosystems and socio-economic sectors under the climate scenario of an SLR of 20 cm and a temperature increase of 1.5°C

Level of vulnerability	SLR of 20 cm	+1.5°C
Ecosystem		
Estuaries	M	M
Wetlands	M	M
Coastal Plains	M	L
Coral Reefs	L	M
Mangroves	M	L
Sea grasses	M	M
Fisheries	L	M
Agriculture	L	L
Forests	L	M
Beaches	H	L
Socio-economic		
Coastal Zone	L	M
Tourism	M	L
Tropical Storms	L	H
Settlements and structures	M	L

(L) Low impact; (M) moderate impact; and (H) high impact. Source: CEP, 1989.

3.2. Increasing population densities and growth rates

According to a recent FAO statistical report [9], the overall population of the Wider Caribbean region is approximately 40 million. The population of the Caribbean almost doubled between 1950 and 1995, despite relatively high levels of emigration between 1960 and 1980. Over the same period, the population below age 15 declined, while the 60 and over age group increased. This trend is expected to continue through the year 2005. Factors contributing to this trend include the marked increase in life expectancy at birth, with women living an average 4–6 years longer than men [5]. As a result of these increases, greater coastal urbanization and population densities are occurring throughout the region; this has led to an over-crowding in many Caribbean countries, which places greater stress on natural resources in the coastal zone.

3.3. Growth of the tourism industry and change from agriculture to uncontrolled coastal development

The CARICOM member countries share a common history of European colonization and slavery plantation economies that lasted until the middle of the 20th century. Until recently, the islands produced products for world exports, resulting in monocrop agriculture developed as a major economic activity.

Competitive disadvantages with other regional markets throughout the world have led to a gradual decline in some agricultural activities in the Caribbean. The geographic proximity of the Caribbean to North America and Europe has fostered a large inflow of foreign private hotel investment and aid-financed air, sea and inland transport infrastructure—the capital base of the tourism industry. The result has been a shift in the economic base of most countries from agriculture to tourism and associated services, which account for 25–35% of the total economy of the region, and 20% of all jobs [10]. This change has also increased the average per capita income and wealth of the region: between 1975 and 1995, the average per capita income in the Caribbean grew more than 30% [5].

The increasing demand for coastal tourism in the region has changed the demand for land use and increased the price of coastal lands. Trends in coastal lands have been skewed towards high-density, mass-market tourism sites close to the water's edge, which have increased the competitiveness of tourism with other activities for coastal land. The result has been a ribbon growth pattern of development along the coast, mostly due to space limitations for coastal tourism and the associated infrastructure requirements such as transport links [11]. Additionally, the growing concentration of tourist activities has increased the dependency of the Caribbean islands on tourism earnings, giving this activity priority in the use of coastal and marine resources and public infrastructure [10].

Unfortunately, the growth of tourism throughout the Caribbean in the absence of coordinated land-use planning and development controls has encouraged patterns of urbanization which have rendered coastal infrastructure vulnerable to climate variability and change. Because most of the region's tourism activities are concentrated in the coastal zone, much of the infrastructure is vulnerable to extreme weather events such as hurricanes and rising seas that are predicted to result from climate change [11].

As tourism growth has fueled intensive and uncontrolled development throughout the region, coastal infrastructure such as roads, seaports and airports by necessity expanded into more vulnerable areas [12]. For the most part this spatial distribution of coastal settlements and infrastructure has evolved with little or no land-use controls [4]. What land-use planning exists has relied upon development control mechanisms that have rarely been enforced, and have yet to successfully include building codes or standards that incorporate protections against climatic impacts. Economic instruments and incentives, which are generally far more effective for controlling land uses, have been employed in some cases but they have generally been done on a piecemeal basis and have not been coordinated among the island states [13].

Thus, current land-use planning and design guidelines in many areas of the Caribbean provide no incentives for developers to recognize or accommodate vulnerability to climate variability and change. With effective controls lacking, it should come as no surprise that the quality of coastal infrastructure is unsatisfactory in many areas. Throughout the region, there has been a trend of shifting away from traditional architectural practices to more vulnerable forms of construction, such as the squatter settlements that proliferate in many urban areas. These settlements are generally characterized by substandard infrastructure, and are particularly vulnerable to extreme weather events and SLR, as they are the least equipped to withstand high wind speeds and flooding [14]. As coastal urbanization and uncontrolled development continue to increase in the Caribbean, so too will the number of highly vulnerable squatter settlements.

Another constraint on the implementation of effective planning for reducing the vulnerability of coastal infrastructure to climate change has been the prevalence of freehold[1] ownership of land throughout the region. The comprehensiveness of freehold ownership (property rights) makes it difficult to advance a program that restricts land use. This fact will play significantly into any efforts to address impacts of SLR. Thus far, charges against non-compliant land-use practices by freehold landowners have been litigated with marginal success [13].

3.4. Location of coastal infrastructure in hazardous areas

Coastal urbanization and land-use controls have never been viewed as critical issues in the Caribbean, so lands have been inefficiently utilized under the freehold and leasehold[2] land-use allocation system. This has led to many sensitive areas being developed, particularly those lands with high environmental values such as offering watershed protection or possessing high biodiversity. Most of the coastal open space that could easily be developed has long since been built upon, and the continued growth of the population has contributed to encroachment on to hazard-prone areas such as coastal flood plains or steep slopes for settlements. A good example of encroachment onto coastal ecosystems is Rodney Bay in St. Lucia, where the development of port facilities and marinas has had negative impacts on coastal/marine resources. The Rodney Bay Marina was created by dredging and excavation of mangrove wetlands. This has altered the temperature and water circulation patterns of the bay, and has destroyed an important ecosystem in the area [15].

Currently, a majority of the population centers, agricultural areas, tourism infrastructure, ports and other major sites for industrial and commercial activity are located in the coastal zone; many in low-lying floodplains that are vulnerable to flooding from hurricanes and SLR [5]. Even islands where changes in elevation are significant, have a substantial share of their population and capital investment in vulnerable nearshore areas [16]. These development patterns and pressures can be expected to intensify with the growth of coastal urban areas, as increasing demand for housing and infrastructure result in greater encroachment into areas into hazardous zones [11]. These trends towards continued development in vulnerable nearshore areas are not merely a cause for concern, but carry terribly high risk, because such developments can only be partially ameliorated by structural measures. In general, coastal infrastructure in the region is likely to be most vulnerable to extreme weather events such as

[1] *Freehold system*: land ownership with no legal stipulations on land-use controls associated with the development of the land.

[2] *Leasehold system*: land tenure by lease and with legal stipulation on land use and development.

hurricanes, which may increase in intensity as the climate changes, and sea-levels rise. Additionally, such developments also have a large impact on coastal habitats, as evidenced by wastewater discharge, increased erosion, siltation of coastal waters and clearance of mangroves and littoral forests, all of which have been associated with urban areas and infrastructure [4]. Although accurate estimated data of mangrove loss is scarce, some data shows, for instance that, between 1980 and 1990, the Bahamas has lost approximately 54% of the country's mangrove area, and Antigua and Barbuda has lost about 83% (see Table 1) [17].

3.5. Quality of building construction and insurance incentives

The number of insurance agencies in the region is disproportionately large for the small volume of property risk underwriting that actually occurs in the region. In addition, the proportion of the risk of extreme weather events that is retained by the companies in the region is small, estimated at 15%, with the remainder being ceded to reinsurers outside the region. As a consequence, competition for agency fees and reinsurance commissions tends to drive the underwriting practice, at the expense of sound appreciation for the risk of buildings and structures to extreme weather events and future climatic changes [18].

Because few insurers provide incentives for property owners and builders to adopt measures that would mitigate the effects of extreme weather events and SLR, and few property owners do so voluntarily, the quality of buildings and structures throughout the Caribbean is not adequate. In the absence of sound financial incentives and stronger building codes and standards, cost competition prevents developers, designers, and contractors from building safer and less vulnerable structures. This trend towards building vulnerable structures is exacerbated by a low public perception of risk and vulnerability to climate variability and change in many countries [18].

The standard product offered by the insurance industry to the average property owner is expensive; more than half of the premium paid by the insured is allotted to commissions, profit, marketing, and administrative expenses. The underwriter pays little attention to catastrophe risk and vulnerability to climate variability and change, and the industry does not offer the insured any incentive to reduce that vulnerability. A substantial part of society is uninsured (i.e., squatter settlements and informal housing), and this applies not only to the lower-income sectors but also to a large majority of government-owned properties [18].

3.6. Destruction of ecological buffer systems (beaches, mangroves, reefs and wetlands)

A diverse array of stresses resulting from coastal infrastructure and land-use choices are increasing the vulnerability of natural systems in the Caribbean and reducing their effectiveness as buffers against extreme weather events and SLR. Deteriorating water quality of coastal zones is threatening the health of both reef and mangrove systems and rendering them more vulnerable to extreme events [19]. For example, shoreline construction of harbors, dikes, channels and other related activities have all resulted in excessive sediment loads to the coastal waters, reducing the ability of seagrasses and coral reefs to get the light they need for photosynthesis.

Mangroves have been cleared in large measure throughout the Caribbean to accommodate coastal development. For example, most mangroves in St. Lucia are not protected, and many have been lost along the west coast to tourist developments [15]. Similarly, in Belize mangroves are being lost to urban expansion for residential development and coastal subdivisions [20]. The loss of mangroves deprives coastal infrastructure and land uses in the Caribbean of much-needed ecological buffers to flooding. Furthermore, where mangroves have been cleared the oxidation of peat can lead to a decline in land level, making such areas even more susceptible to flooding. Similar to mangrove areas, many wetlands throughout the Caribbean have been filled and destroyed for the construction of tourism and residential developments [4].

Beaches throughout the Caribbean—among the great attractions of the tourism industry—are increasingly at risk from sand mining activities, which exacerbate erosion of these landforms and increase the vulnerability of coastal infrastructure to flooding. Traditionally in the region, sand used to fill coastal wetlands and lowlands has come from beaches, but now the current demand in many countries far exceeds the capacity of the beaches to provide it, particularly without increasing erosion [20]. This trend should be of great concern to land-use planners, because in order for coastal infrastructure in many communities and countries to withstand rising sea levels, a constant supply of large volumes of sand and sediment will be required. However, sand mining for coastal construction is significantly reducing one of the major sources of this sediment, and rapidly increasing the vulnerability of coastal infrastructure and land uses to flooding from hurricanes and SLR [20].

3.7. Continued reliance on top-down approaches to land-use planning

Land-use planning in the Caribbean is often sector-oriented, with little capacity to respond to local level needs and conditions. These top-down institutional approaches to land-use planning have largely been inherited from previous colonial experiences; they generally do not accommodate community responses to climate variability and change. In many cases, development choices are made with little or no consultation with affected stakeholders, and often result in settlements and structures in vulnerable or hazardous areas. Throughout the Caribbean there is a need to strengthen the links between local communities and national governments so that the communities increasingly gain a voice in planning and land-use decisions.

3.8. Climate change impacts on agricultural land in the Eastern Caribbean

Climate change predictions, such as changes in rainfall intensity and extreme weather events that increase the scale of flooding, landslides and soil erosion—in conjunction with the conversion of agricultural land to other uses—can seriously damage agricultural capacity. [7].

While few studies have been conducted specifically on the effects of climate change on agriculture in small islands [1], some suggest that although CO_2 uptake might have a beneficial effect, the net impact of climate change is unlikely to be beneficial [1]. The expected increased frequency of natural disasters induced by climate change will have several effects on agriculture on small islands; some of these are summarized in Table 4.

3.9. Climate change effects on forests

According to the IPCC [1], tropical forests on small islands have a greater probability of being affected by human forces than by climate change per se, as long as deforestation continues at its current rate.

The 1997 IPCC report on the Regional Impact on Climate Change [1] indicates that tropical forests on small islands are more likely to be affected by climate change effects from variations in soil–water availability (caused by the combined effects of changes in temperature and rainfall) than by changes in temperature alone. Forests, in general, are particularly vulnerable to extremes of water availability (drought or flooding) and will decline rapidly if conditions move toward one of these extremes. Increasing temperature and extreme events also may increase the incidence of pests and pathogens, as well as the frequency and intensity of fires.

3.10. Impact of climate change on water resources

Water supplies will be directly affected by changes in climatic conditions. Changes in rainfall amounts, intensity and frequency will directly impact the amount of water that will be available for use by the various competing sectors (urban, tourism, industrial, agricultural). While a reduction in rainfall will obviously decrease the water supply, problems will also occur if the quantity of rainfall is constant but patterns change: e.g., short, intense rainfall events result in high-runoff and low-percolation rates, which limit the recharge capability of aquifers and lower the water quality. When these intense events are followed by long dry periods, soil moisture decreases and leaves farmers with the choice of irrigating with water of poor quality or suffering reduced crop yields. The supply will be reduced directly through insufficient recharge and stream flows. It may also be reduced indirectly through potential degradation of water quality through saline intrusion from over pumping [21].

4. Recommendations to reverse human impacts on environmental degradation in Eastern Caribbean Island nations

The preceding section listed some general estimated impacts on low-lying island coasts in the Eastern Caribbean region caused by current trends in climate change, increasing human coastal settlements, damaging coastal activities, deficient urban planning (top-down decision-making process), and destruction/modification of watershed and coastal natural resources.

Reducing the potential impact of these trends requires taking specific governance interventions. A major challenge for addressing this task is the need to improve the mechanisms for stakeholder participation and outreach.

If Caribbean countries are to effectively stem widespread anthropogenic impacts on their coastal ecosystems, they will need to develop a coordinated set of enforceable policy actions that have targeted outcomes. These actions will need to include such measures as the following:

- land-use planning;
- economic and market-based incentives;
- research, monitoring and mapping; and
- public awareness and education programs.

The absence of comprehensive strategic planning within island states and among them has resulted in poor coordination and limited enforcement of policies and regulations. The following recommendations can be considered an annotated outline for a strategic process that Caribbean nations can use as a basis for planning.

The following is a list of recommendations to reduce the impacts of climate on the above trends. These are based on international and regional recommendations, plus the regional expertise of the authors. For publication restriction, these recommendations are intended to

Table 4
Expected effects on agriculture from extreme weather events (Source: CEPAL and IDB, 2000)

Disaster	Effects on agriculture
Hurricanes, typhoons and cyclones	Loss of plant cover, fallen trees, crop damage, especially wind damage to grass species Erosion affects root and tuber crops Changes in natural and man-made drainage systems Sedimentation, salinization, contamination and erosion of soils
Drought	Loss of crops and plant cover Erosion and damage to forests Depositing of sand and infertile earth Changes in crop types and cycles Growth of arid climate, drought-resistant vegetation, such as thorn bushes and cactuses
Floods	Destroys crops, alters crop types and growing cycles Localized damage in land, fields and woods Increased humidity improves quality of some land and makes it productive (albeit temporarily)

be general and informative only; at the end of this section Table 8 summarizes a list of major challenges to address these general recommendations.

4.1. Adaptive change recommendations to support coastal construction activity

As is the case with many SIDS in the Caribbean, the tourism industry is characterized by a concentration of ribbon tourism development activities and construction in coastal areas. Studies conducted worldwide have shown that strict adherence to building codes and standards reduces destruction caused by extreme weather events and climate variability. Revised building codes within individual countries could include instructions to [18]:

- improve construction techniques such as stronger connections (at the ridge board, between the joists and the top plate, between the floor and the foundation, at the foundation footing), long screws/nails, hurricane straps and strong roofing materials;
- modify engineering designs to include climate change projections, particularly for SLR, in addition to historical data typically used;
- limit the siting of new structures in hazardous areas, restricting siting of any new public buildings in such areas;
- elevate structures in high-hazard areas (e.g., on pilings) through the designation of minimum floor elevations, piling depths and bracing requirements; and
- add additional specifications to ensure that new buildings are built to better withstand wind and flooding.

Traditionally in the Caribbean, existing building and planning statutes do not specifically reference building codes; instead, legislation has focused on safeguarding health and property by proper planning and siting. An important first step towards introducing and enforcing revised building codes in individual Caribbean countries has been the introduction of the Caribbean Uniform Building Code (CUBiC), a regional building standard. In the Eastern Caribbean, a model building code, based on CUBiC, has been developed by the Organization of Eastern Caribbean States to facilitate the introduction of national codes [22]. However, given current climate change projections, the adequacy of CUBiC must be reassessed—efforts should focus on incorporating these regional standards and the specific instructions listed above into each country's regulations and land-use plans.

Strengthened building codes are of little use if they are not properly enforced; therefore, any efforts to revise codes or implement new ones must also include training programs for building inspectors.

In addition to revised building codes for the quality and siting of new structures, regulations should be introduced to plan a strategic retreat of existing development located in low-lying coastal floodplains and high-hazard areas along the coast. These regulations should consider:

- prohibiting the construction of protective structures in sensitive high-hazard areas;
- prohibiting the reconstruction of storm-damaged property in high-hazard areas; and
- conditioning land ownership in high-hazard areas to expire when a property owner dies or when sea levels reach a particular point along a map.

While most Caribbean countries have regulations governing the use of wetlands and mangroves, strengthening these measures to ensure that ecological buffers are protected must be a priority. The practice of filling wetlands, damming rivers, mining coral and beach sands and cutting of mangroves should be prohibited in order to preserve the natural storm abatement functions of these areas.

4.2. Land-use planning and land protection tools recommendations

4.2.1. Develop and implement integrated coastal management plans

While many Caribbean countries have developed or are developing integrated coastal management plans (e.g., natural resource management plans that encompass the various sectors impacting the coastal zone), such efforts should be a priority for government agencies charged with land-use planning and natural resource management. Since coastal ecosystems can serve to buffer the impacts of climate variability and change on coastal infrastructure and land uses, national and local level management plans to conserve these ecosystems should be a top priority for adaptation. Ongoing efforts at integrated coastal management should include assessments of the potential impacts of climate change and SLR. These plans should also provide a framework to balance resource allocation decisions across ministerial lines, because they seek to promote horizontal integration rather than the traditional vertical "command and control" decision-making approach. An important aspect of such plans is the institutionalization of mechanisms for shared management responsibility between government and communities, which foster stakeholder participation in the decision making processes.

However, it should be noted that there will be significant challenges in the institutionalization of integrated coastal zone management programs because top-down planning processes still dominate major aspects of national planning and development in the Eastern Caribbean.

4.2.2. Employ a "retreat approach" to planning and development in high-hazard areas along the coastline

Land-use planning must encourage a strategic retreat from development activity in low-lying coastal floodplains and high-hazard areas. Planning and development strategies should be based on retreat plans, where new structures are located on designated setback lines behind these areas. Designating a setback line begins with establishing a baseline, which could be drawn along the dune crest. For armored shorelines, the baseline may be drawn at the theoretical dune crest location—the position where the dune crest was calculated to exist if the shoreline had not been armored. For most erosional beaches with a sand deficit, this theoretical dune crest location may be significantly landward of the seawall or bulkhead [23].

Caribbean countries attempting to maintain ecological buffers against extreme weather events or to encourage retreat approaches from high-hazard areas may wish to explore one or more of the following land protection tools. Effective approaches involve the use of a combination of tools based on the unique environmental and development conditions on each island. All of these tools should fall within the framework established under a comprehensive land-use plan and would complement zoning and building codes to achieve the objectives of the comprehensive plan. These tools are summarized in Table 5.

4.2.3. Enhanced coastal protection where retreat and accommodation are not possible

For coastal urban areas with high population densities, retreat from or accommodation of SLR may not be an option. In such cases, hard structures such as sea walls may need to be designed to allow for future modification to ameliorate SLR. Integral to the design of any hard structure, a sand management study should be initiated to assess the impact on beach sand dynamics. It should be noted that hard structures are heavily capital intensive, which may deter their widespread use. Thus, consideration of hard structures should be limited only to those areas where capital development has occurred and the value of existing infrastructure far outweighs the cost of the hard structure approach [24].

4.3. Agriculture and forestry adaptive change recommendations

Erosion, land loss, intrusion of salt water into aquifers, sea flooding, and inundation of low-lying areas are the most important threats to agricultural land in small islands [7].

Climate effects on agriculture must address issues related to water supply, soils, cropping, and educational outreach. Recommendations or adaptive measures to address these issues by sector are summarized in Table 6.

Efforts should be also continued to maintain the integrity of existing forest reserves and reforestation should be carried out for areas where squatting remains a problem. Where possible, agro-forestry programs should be targeted on private lands within watershed areas. These programs should focus on the establishment of effective soil conservation techniques, appropriate vegetative cover, contour drainage, terracing and riverbank protection.

4.4. Potable water resources adaptive change recommendations

An effective public education strategy will be key to changing public attitudes to water use and the need for

Table 5
Land protection tools[a]

Land protection tools	Pro	Con
Demonstrated conservation easement	Permanent protection from development	Tax Incentives may not provide sufficient compensation
	Landowners receive tax benefits	Limited governmental control over which areas are protected
	Little to no cost to the local unit of government	
	Land remains in private ownership and on the tax rolls	
Purchase of development rights	Permanent protection from development	Costly
	Property owner paid to protect land	
	Estate and property tax benefits	
	Local units of government can target locations	
	Property remains in private ownership and stays part of tax base	
Transfer of development rights	Permanent protection	Complex to manage;
	Landowner paid to protect land	Receiving area must be willing/able to accept higher densities
	Estate and property tax benefits to landowner	
	Local units of government can target locations	
	Low cost to local units of government	
	Utilizes "free market" approach	
	Land ownership remains in private hands and on tax roll	
Land acquisition	Permanent protection from development and full public control for preservation and restoration	Costly
	Land can be managed for natural ecosystems services, including buffering capacity	

[a] Adapted from Land Resources Protection Fact Sheet #2 at 1000 Friends of Minnesota, http://www.1000fom.org/lctools2.htm.

conservation. Another strategy is the implementation of water-conservation measures that may include the use of low water fittings and appliances in commercial and residential structures. Barbados has instituted a program requiring compulsory construction of rainwater storage facilities for all homes and business above a set size [25]. Similarly, the price of water must reflect the costs of production (accessing, treating and delivering water to competing users), especially when the water supply becomes more vulnerable to the impacts of climate change. Use of levels or fiscal taxes may serve to adjust the actual production and delivery price of water and balance the competing need by the multiple users. This can also include pricing that decreases with decreasing use or implementing tax incentives to promote wastewater recycling [25].

4.5. Economic and market-based incentives recommendations

4.5.1. Market-based incentives to promote a sustainable tourism industry

The demands on natural resources to service the expanding tourism industry are having detrimental effects on coastal ecosystems, rendering these systems more vulnerable to climate change and reducing their capacity to buffer coastal infrastructure from extreme weather events and floods. To combat these trends, market-based incentives are already being used by Caribbean nations to promote a more sustainable tourism industry [26]. These incentives are wide ranging and include:

- duty and tariff relief and/or tax deductions for environmental resource protection and water-conservation equipment;
- water and sewage charges for both industrial and domestic users;
- Green award programs for hotels that display the best conservation practices or education program;
- private sector initiatives such as the Blue Flag Campaign or Green Globe 21 that are used to encourage eco-tourism and environmental resource preservation. The Blue Flag is an eco-label awarded by a non-profit organization to beaches and marinas in countries around the world, based on environmental management criteria. Similarly, Green Globe 21 is a collective body of roughly 1000 travel and tourism companies in over 100 countries that have committed to specific environmental management standards.

Table 6
Adaptation measures to impacts on agriculture (Source: CEP, 1998, Report #41)

Agriculture	Adaptation measure
Water supply	Improve efficiency of irrigation Improve land grading in targeted surface irrigation areas Install additional water storage facilities Rehabilitate drainage infrastructure Rehabilitation of areas affected by salinity and alkalinity Night time irrigation Line of open channel canals Use drip irrigation systems where soil conditions allow Use closed pipe systems where feasible Use treated wastewater effluent Improve control and management of supply network Develop environmental management system requirements, including market/economic instruments
Soils	Improve drainage Improve watershed management Increase public education and awareness Implement integrated watershed management Promote appropriate agricultural practices Promote improved soil management practices Improve crop selection and planting/harvesting practices Use reduced tillage Change mulching practices Alter timing of operations Alter crop husbandry
Crops (non traditional and domestic)	Investigate drought-tolerant crops Plant quicker- or slower-maturing varieties Use altered mix of crops Investigate drought-tolerant crops Educate farmers about improved agricultural practices
Public education	Conduct a public awareness campaign alerting stakeholders to the likely impacts of climate change Educate stakeholders on measures that can ameliorate climate change impacts in a manner that will not compromise the long-term sustainability of the resource base
Relocation of farms	Investigate moving agricultural crops inland and finding alternative use for formerly productive sites (e.g. service sector infrastructure- commercial, tourism)

4.5.2. Link property insurance with construction quality

The relatively poor quality of many built structures in the coastal zone has increased the vulnerability of these areas to climate variability and SLR. Perhaps no market-based tool can be as effective in improving the quality of such structures as insurance incentives. These incentives would include lower deductibles and/or premiums for those who invest in adaptation measures, such as homeowners and businesses who alter or upgrade properties to better withstand hurricanes-force winds. Reduced insurance premiums for policyholders to make their homes and businesses more hurricane-resistant could be based on available information, such as "Making Your Home Hurricane Resistant" and the "Professional Guide to Performance-Based Design Upgrade for Hurricane Resistant Construction," produced by an engineering firm in Barbados. Provided that insurers are able to verify that the retrofit work meets quality standards, such retrofit work and adaptation measures should benefit the insurance company. After a sufficient number of property owners at risk in the company's portfolio undertake adaptation measures, the company can expect its aggregate catastrophe Probable Maximum Loss to be lower. The primary insurer should be able to negotiate lower rates from the reinsurer for this effort, which combined with lower incurred claims on the retained risk should more than offset the reduced premium income [18].

4.5.3. Eliminate subsidies or incentives that continue to promote development in high-hazard areas

In many cases, national governments reallocate economic development loans in order to reconstruct and repair structures damaged from extreme weather events. This practice can in fact be considered a government subsidy, which on a long-term basis encourages development and land uses in vulnerable areas, as owners know that government will help repair any damages caused by a hurricane or a similar event. Over the long-term, this practice disrupts national economic development programs and reinforces a state of underdevelopment in many vulnerable island and low-lying Caribbean states. Governments are forced to borrow more funds from external donors for reconstruction and repairs following an extreme weather event, e.g., diverting funds that might have been used on national education programs. This is not to suggest that some level of disaster relief is not necessary after an extreme weather event, but continued reconstruction of buildings and structures that are located in highly vulnerable areas can be considered a subsidy for land uses susceptible to climate variability and change.

It should be noted that, because many of the most vulnerable settlements in Eastern Caribbean coastal zones are low-income, informal housing, countries should encourage the establishment of revolving loan funds to provide families with small loans for home improvement and hurricane-resistant retrofitting.

4.6. Public awareness and education

Much lip service is often given to the importance of public understanding and education in public policy issues. But public awareness and knowledge are critical in addressing the impacts of climate change and variability and changing attitudes. Governments must embark on a sustained education campaign that is part of a broad-scale communications plan designed to demonstrate that key public constituencies understand the impacts of climate variability and change on vulnerable areas and know what potential adaptation measures they can take. A knowledgeable consumer, e.g., should be reluctant to purchase property in high-hazard areas. Dissemination of targeted information also helps to ensure that various market sectors take into consideration potential impacts as well as new market growth opportunities. Central to any education program are the following: promoting awareness of climate change impacts; communicating information about vulnerable and hazardous areas; educating key stakeholders about tools and practices that can be applied to reduce impacts and encouraging participation at all levels in decision-making.

4.7. Research, monitoring and hazard mapping

4.7.1. Promote increased use of GIS and remote-sensing/spatial planning applications

Geographic information systems and databases should be promoted to provide resource managers with information on the state of resources and to assess their vulnerability to climate change. Inventories that quantify and qualify current uses of land and describe species diversity and distribution can provide the baseline information that managers need to prepare development scenarios and strategies, assess vulnerabilities to climate change, project impacts on ecosystems and land-use patterns, and predict land-use conflicts. Key to producing and maintaining this information is the development of a local capacity and skilled workforce to design and implement these databases.

4.7.2. Establish a network linking major sea-level rise and climate change monitoring institutions

A key deficiency in current climate monitoring is the lack of a capability to provide timely observations to both regional and national forecasters, observers, resource managers and governmental sectors. Coupled with the development of an information-sharing network is the development of databases generated from national and regional projects, observations and other complementary information such as growth and development trends. It should also be noted that paramount to any of the aforementioned actions is the development of national and regional capabilities for display, analysis and reporting of data and information related to climate variability and change. This "local capacity" varies widely from island to island, as do hardware and software capabilities. Development of regional or national training centers would be a first step toward promoting growth and development of data and information capabilities among small island nations.

4.7.3. Expand hazard mapping of coastal zones, based on climate change

Government agencies and research institutions should prioritize capacity building for vulnerability assessments to delineate critical hazard areas, particularly those affected by current and projected storm surge and wave action. Whether governments or research institutions perform the mapping, the results can then be integrated into the land-use planning and development process to allow agencies to identify areas for targeted retreat strategies and many of the land protection tools described previously. This process should be coupled with development of data and information clearinghouses to facilitate the exchange of information at local, national and regional levels. In particular, hazard maps based on current and future vulnerability should be a major feature of any education and information program to coastal residents and stakeholders.

4.8. Research and information needs

The accuracy of climate change forecasts is a function of the availability and accuracy of data. A Caribbean sea-level monitoring network needs to be reinvigorated and incorporated into marine meteorological data, geodetic leveling data, seawater chemistry and ancillary site-specific information. There must be a free exchange of information and data, coupled with

Table 7
Research and information needs by sector (Adapted from Bahamas' First National Communication on Climate Change, 2001)

Sector	Need
Agriculture	Assess the vulnerability of the sector to soil salinization, to loss of agricultural lands due to year-round and seasonally high water tables, and to salt-water flooding, using Geographic Information Systems (GIS) and other information sources
	Develop and evaluate agricultural production systems adapted to various levels of soil salinization, and to atmospheric CO_2 enrichment and increased temperatures
	Develop production systems to use low-quality (saline) water for irrigation
	Assess likely impact of increased temperatures on pest and disease incidence and on weeds, and monitor for changes in pests, diseases and weeds
Fisheries	Assess the impact of increased sea surface temperatures on the economically important fish species, and on sea-grass beds
	Assess the impact, for various scenarios of shifts in the strength and direction of the Gulf Stream, on migratory deep-water fish and marine mammals
	Assess the impact of increased water temperatures on the breeding behavior and performance of economically important fishes
Forestry	Assess the effects of salinization of the soil, and rising water tables, on pine forests, and monitor the changes in the biodiversity of these forests
	Assess the effects of salinization of the soil, and rising water tables on hardwood coppice forests, and monitor changes in the biodiversity of these forests
	Assess the effects of salinization of the soil, of inundation and rising sea levels, on coastal and inland mangrove communities, and monitor changes in the biodiversity of these communities
	Review the suitability of alien (exotic) saline-adapted species of timber trees
Coastal infrastructure	Geographic information systems
	From additional runs of the Sea Lake and Overland Surges from Hurricanes (SLOSH) model and Digital Elevation Models (DEM), develop digitized data sets to be maintained and managed by National Geographic Information system
	Produce digitized bathymetric and land contour maps indicating all features of land use, to facilitate the more accurate modeling of storm waves and surges
	Digitize changes in the movement of sand bodies and silting rates in shallow marine waters
	Meteorology and Oceanic Observations
	Establish additional sea-level monitoring stations at selected sites
	Establish wave recorders at selected sites to monitor the impacts of non-tropical processes that generate strong ocean swells
	Expand and upgrade the meteorological and hydrological monitoring system
Physical planning	Using GIS data, develop a national database of zoning and a series of maps based on risk assessment, for various projected scenarios through to the year 2100
	Develop draft legislation to enforce the system of zoning, and to enforce the use of risk assessment and impact analysis in project planning and environment impact assessment
Water resources and supply	Institute a systematic programme of water quality monitoring for fresh, saline and hyper-saline waters, so as to assess their vulnerability to contamination by sea-level rise and anthropogenic pollution
	Develop appropriate mitigation measures, especially for fresh (potable) water supplies
	Develop long-term national water resources plans for the entire Bahamas
	Identify water resources at risk from inundation, sea-level rise and flooding from extreme events
Tourism, Insurance and Commercial	For the tourism sector, carry out an economic impact assessment for various scenarios of climate change and sea-level rise
	For the tourism sector, prepare plans with costs, for infrastructure needs to protect properties against extreme events
	For the insurance sector, conduct a study of the insurance implications of climate change and sea-level rise
	For the commercial sector, conduct a study of the commercial implication of climate change and sea-level rise, with particular reference to the location of commercial properties, the storage of dangerous materials, local transportation and inter-island traffic, etc.

a basin-wide commitment to standardize and calibrate measurements. Establishing and maintaining a modern sea-level weather observing network is vital and necessary to document and ultimately forecast climate change impacts [8].

There are many gaps in existing data and information, and a lack of tools to assess the physical and economic impacts on the most vulnerable sectors of the economy. Some of these data needs are grouped by sectors (research and information) in Table 7. This list of information is adapted from the Bahamas' First National Communication on Climate Change [27] but it can apply equally to all the Eastern Caribbean nations (see also Table 8).

Table 8
Main expected challenges to address the proposed recommendation to reduce human and climate change impacts in the easter Caribbean Islands

Recommendations to reduce human impact in Caribbean coastal environments	Main challenge(s)
Adaptive change to support coastal construction activities	Develop mechanisms for enforcing strict building codes
	Retreat and conditioning land ownership plans for existing low-lying coastal development Promote education and public-awareness raising of need for strengthened codes Improve education/training of code enforcement officers
Develop an implement-integrated coastal management plan	Develop effective medium and long-term ICM plan with well-defined authority and budget
	Change from the traditional top-down planning to effective stakeholder participation Promote stakeholder awareness and education on natural interactions and human activities impacts on the coastal zone
Employ retreat approaches	Determine the baseline for development in coastal areas Determine the protection strategies to be implemented in the island
Enhance coastal protection	Evaluate the feasibility and impacts of artificial coastal protections vs. protection and restoration of natural buffers
Adaptive change for agriculture and forestry activities	Develop integrated watershed management programs to avoid erosion and runoff pollution
	Develop a program on education and promotion on alternative agricultural practices and techniques
Potable water resources adaptive change	Change public behavior in the use of water resources (e.g. implement recycling programs) Reduce ground imperviousness and develop programs for increasing rain water retention
Market-based incentives	Tax-reduce programs for environmental/pollution reduction activities from tourism activities Implement tax program based on tourist fee study for access to coastal resources
Link insurance and construction quality	Develop strict building codes and establish coastal construction base lines
Eliminate incentives for development in hazardous areas	Develop enforceable policy mechanisms to create and enforce urban development plans that include potentially hazardous areas in the coastal zone
Public awareness and education	Institutionalize an "SLR impact educational campaign" into the national educational system
Promote use of GIS in planning and development	Develop local capacities to implement GIS instruments
	Use GIS as a land use decision-making tool in the formulation of land use strategies
Establish a network of monitoring institutions	Enhance the existing monitoring/alert networks on SLR and climate change impacts in the Caribbean through effective training and outreach mechanisms Advocate for regional agreements on data sharing and collection
Expand hazard mapping of coastal zones	Develop coastal risk assessment studies for identifying and mapping hazardous areas Incorporate the identified areas into land use and urban development plans
Research and information	Strengthen partnership with regional research institutions to include sound science into decision-making process for coastal development and coastal resource use Develop educational material for decision/policy makers

5. Concluding remarks

We have argued in this paper that while small island Caribbean states are facing significant ecosystem alterations from global climate change, and SLR in particular, land development and related human activities over the last half century have increasingly exacerbated the ecosystem impacts that are likely to be experienced. Though countries may differ in specifics, there are common trends that are stressing coastal systems and making them more vulnerable to degradation from projected climate changes. These include:

- increasing population densities and growth rates;
- growth of the tourism industry and accompanying uncontrolled coastal development;

- location of coastal infrastructure in hazardous areas;
- compromised quality of building construction and insurance incentives;
- destruction of ecological buffers;
- continued reliance on top-down approaches to land-use planning; and
- destructive agriculture and forestry practices.

There is no longer any doubt that Caribbean states are highly vulnerable to current extreme weather events, nor that they will be severely impacted by predictions of higher temperatures, rising sea levels, changing rainfall patterns and potentially more frequent and intense extreme weather events.

To counter the impacts of environmental degradation from human activities, we have highlighted actions that Caribbean countries can undertake individually and collectively to reduce their vulnerability. Each country must assess the trends summarized above within the context of their own situation and develop a coordinated plan of action aimed at reducing the vulnerability of their coastal infrastructure.

Towards planning and implementing such a plan, we recommend an array of short- and long-term measures, numbers of which can be used in individual countries to reverse the human impact of projected trends. These include:

- strengthen regulations to protect ecological buffers;
- strengthen building codes;
- develop regulations to phase out development in high-hazard areas;
- develop comprehensive land-use plans;
- institute land protection tools for ecological buffers and vulnerable coastal lands;
- implement market-based incentives to promote sustainable tourism;
- develop reforms to link property insurance with construction quality;
- preserve and restore ecological buffers;
- develop an on-going communications plan for improving public awareness and environmental education; and
- map hazard areas in the coastal region and undertake a risk analysis related to climate change.

Once countries assess the vulnerability of their coastal infrastructure and land uses to climate change and identify the adaptive means for countering the projected impacts, it will then be possible to develop strategic plans for reducing their vulnerability. They can then evaluate their existing capacity for implementing such plans, and identify capacity and information gaps in the process. Countries might then seek assistance through regional initiatives, such as the Caribbean Community Climate Change Center (Belize) to address these gaps.

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