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THE SCIENCE/POLICY OF THE CONTEMPORARY COASTAL
CHALLENGE OF VULNERABILITY FROM CLIMATE
CHANGE ON SUSTAINABLE TOURISM:
AN ASSESSMENT OF THE WIDER CARIBBEAN
BY
FRANK JOSEPH GABLE

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
IN
MARINE AFFAIRS

UNIVERSITY OF RHODE ISLAND

2002

Abstract

This research exercise has assessed the threat of global change on select island nations of the wider Caribbean with a focus on the Lesser Antilles. That the Caribbean environment shall be impacted by climate change is certain, imposed in large part by marine affects. Changes in climate are the norm when one studies the history of the Earth. These changes include the glacial epochs and the contemporary climatic variation of the El Nino/Southern Oscillation. Accompanying global change will be variations in relative sea-level, modifications in storm climate, shifts in ocean circulation and altered precipitation patterns; science cannot determine today with certainty what will be the result of these adjustments. The Caribbean is particularly vulnerable to a projected increase in relative sea-level as it is made up largely of island nations that have far more coastal zone per unit of area than do continental countries.

In the context of this study, tourism is the most important source of external revenue for Caribbean island coastal areas, where the beaches are the principal attraction. Research assessments indicate that the majority of the world's sandy beaches are experiencing erosion. This situation has ramifications on the sustainability of Caribbean island shorelines to support coastal oriented tourism. Thus, the coastal challenge is to recognize the need for regional and local policy action as a proactive response to global change parameters despite scientific uncertainty or the absence of site-specific data. One of the policy tools uncovered in this study is the recognized and accepted international science-based standards regarding environmental auditing, investigations, and performance evaluation, by, for, or on behalf of, an organization from the International Organization for Standardization (ISO). The preceding standards could be regarded as analogous to the "dolphin safe tuna" moniker bestowed upon the tuna fishing and canning industry products some time ago.

Acknowledgments

First, I'm grateful to the Marine Affairs Department faculty for providing a multi-year student research assistantship. I also thank in particular my major professor Timothy M. Hennessey, who was involved in my overall Program of Study from the beginning. In addition, I thank dissertation committee member Professor Emeritus Lewis M. Alexander, who was my major professor from an earlier stint at URI. I also wish to express my gratitude to Professor Jon C. Boothroyd of the Geosciences Department, and presently State Geologist of Rhode Island. Thank you again for loaning me some slides for my presentation at Coastal Zone '99 in San Diego in July of 1999; the field trip to the "Outer Banks" of North Carolina for the Coastal Geologic Hazards course was a highlight. I also express my gratitude to Professor Dennis W. Nixon, the then departmental Graduate Program Director when I started the Ph.D. program and member of my examination and dissertation defense committees, who was instrumental in aiding me in gaining a seat in the program. I also duly thank the chairperson of my dissertation defense committee, Professor Steven K. Swallow of the Environmental and Natural Resource Economics Department.

Further, without being overly verbose, I also acknowledge proactive suggestions and commentary provided during my coursework and stay at URI with Professors Lawrence Juda, Gerald Krausse, Neils West who led a memorable fieldtrip in June of 1999 to Cape Cod that included a whalewatching excursion as part of the International & Domestic Coastal Management course, as well as Professor Richard H. Burroughs who led a similar field trip to the preceding location for Estuarine Management (MAF 584) while in concert with an Applied Coastal Ecology course. I also thank fellow student Dorian Bertram for her capable and amenable assistance with Excel 2000 spreadsheet software. Salutations to all my fellow students.

Preface

This dissertation is written in the standard format as designated by the University of Rhode Island (URI) Graduate School. It was presented in draft form to my committee on September 28th, 2001. It does, however, consist of elements of a manuscript format in that select peer review articles can be considered as *de facto* appendices. One concerns another Large Marine Ecosystem (the Black Sea) and can be found in *Ocean Yearbook*, 14, University of Chicago Press, pp. 420-467 (2000). The other, concerning optimal development setbacks from the water's edge, is available in *Ocean Yearbook*, 15, University of Chicago Press, pp. 299-330 (2001). In the latter I was aided by long-time colleague Steven F. Edwards who received his doctorate in Resource Economics from URI in the 1980's. Both manuscripts were concluded and published during my residency at URI and they are germane for this dissertation research. The above referenced periodical can be found in the Pell Marine Science Library in Narragansett.

The theme of the dissertation research, concerning the wider Caribbean, is a spin-off of another recent article of mine found in the *Journal of Coastal Research*, Special Issue No. 24, pp. 49-69 (1997). The above three articles are somewhat liberally cited in this dissertation as well as some other (joint) papers published in an earlier time. Thus, I have worked on "global change" issues in a regional sea setting for about fifteen years. Further, much of my interest in *marine affairs* hails from an earlier stay at URI in the 1980's when I received the Master of Marine Affairs degree.

As regards methodology, another approach attempted during my present (Program of Study) coursework at URI was the utilization of multivariate principal component analysis (PCA; also known as orthogonal functions). In a mimeograph

prepared for a core course (Ecological Statistics 550) the object was to look for similarities in a disparate data set of processed multi-colored plastic pellets uncovered along selectively grided sandy beach wrack lines in different littoral locations, *inter alia*, the Black Sea and the Caribbean Sea. Some of the plastic objects were uncovered along the beach wrack line(s) by me; others were provided by an oceanographer colleague who was then working at the Sea Education Association in Woods Hole, Massachusetts.

In effect, it was a "fingerprint" exercise while interfacing with researchers at the Massachusetts Institute of Technology nuclear reactor laboratory in the 1990's in an attempt to uncover any chemical "similarities" in the database. Several elements contained in individual plastic pellets were analyzed to see if there may be any connections in the variables (via a cluster analysis) to the pieces of plastic primarily uncovered on disparate global littoral sandy beaches. Thus, the preceding as regards a connection to the dissertation is the location for some of the field work and the idea of employing a comparative risk assessment to address nonbiodegradable hazardous materials found in the land/sea interface and what policy can be ascribed to manage it more effectively.

Since "preface" is defined as preceding, I would also like to mention that my URI Ph.D. program was built upon previous undergraduate and graduate studies at Louisiana State University in Baton Rouge, where I attained B.A. & M.S. degrees in Geography. Regarding the writing and revision of the dissertation, the bulk of the document was prepared at the Morse Institute Library in Natick, Massachusetts especially at the Donna Mary Sandler cubicle on the second floor. I also utilized the computer laboratory in the main library at URI for working in Excel. I was born and raised in Newton, Massachusetts.

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Chapter 1. Introduction and Statement of the Problem from the Proposal

The "greenhouse effect," which most U.S. opinion leaders believe is real, poses the most prominent and complex ecological risk today (Ledley, et al., 1999; Pew Center on Global Climate Change, 1998; Broecker, 1997; Knauss, 1997; OSTP, 1997; Morgan and Keith, 1995; Nordhaus, 1994; Kempton and Craig, 1993). "Global change" is defined to mean alterations in climate, land productivity, oceans and other water resources, atmospheric chemistry, or ecological systems, including global warming, which are significant enough to influence the future hospitality of the Earth, whether such changes are caused by natural cycles or by human activity, or a combination of both (see: Pernetta, 1995, pp. 1-3). Separating the likely impacts of anthropogenic induced climate change as distinguished from those emanating from natural variability remains, however, as questionably uncertain to some (Metzner, 2000; Hulme, et al., 1999a & 1999b).

The threat of anthropogenically-induced global environmental change on the coastal zones (Walker, 1984; re: *coastal belt*, see: Juda and Burroughs, 1990) of the wider Caribbean varies from place-to-place, because of: 1) differences in exposure to storms, 2) dissimilarity in local geology, including tectonics and subsidence, and, 3) the resulting regional choices in land-use practices (Inman, 1994; Figures 1 - 3; see also Table 1). Because of the large number of coastal nations involved, many having only subsistence economies and capabilities, and the impenitent advantage of determining collaboratively a comprehensive response to global change, the similarities and differences among national settings ought to be better identified to proactively mitigate against undesired environmental and ecological impacts. Comparisons from different locales within a region can form the basis for local response strategies. The common elements between countries often provide a basis for responses for similarly

situated nations, whereas differences facilitate local adaptations and mandates (see also Kasperson, et al., 1999; Kasperson, et al., 1995).

Regional seas locations such as the wider Caribbean will be impacted by climate change (Burroughs, 1999; Leatherman, 1997; Maul, 1993). Accompanying global change are regional impacts such as, alterations in the hydrologic cycle and precipitation patterns; meteorological changes in the intensity, distribution and paths of cyclonic episodic storms (see: Easterling, et al., 2000; Changnon and Easterling, 2000; Smith, 1999; Wilson, 1999; Knutson, et al. 1998; Landsea, et al., 1996; Gray, 1990; Emanuel, 1987) and, the specific focus of study here, concerns the prospective impacts of a potentially accelerating relative sea-level rise during the next several decades and its subsequent constraints on beach tourism on small island developing states (see below e.g., Ashe, 1999; Pantin, 1999; Krausse, 1995; de Albuquerque and McElroy, 1992).

Relative sea-level rise is the combination of rise of the sea and movement of the land. Studies of historical rates of relative sea-level rise in the Caribbean (see: Aubrey, et al., 1988) show that the tectonic movement in the Caribbean is large (compared to eustatic sea-level change) and spatially complex (Case, et al., 1984; Mattson, 1984). Eustatic change in sea level is the worldwide change of sea level, typically viewed as an adjustment in the volume of the ocean, as contrasted with local uplift or subsidence of the land. During the past half-century or so, relative sea levels in the Caribbean Basin have ranged from an emergence of 5.3 mm/yr. to a submergence of 9.3 mm/yr. The wider Caribbean countries are challenged with the need to develop appropriate research and planning programs to proactively establish policy responses to coastal impacts generated by global climate change, in the context of this study, especially as it

relates to maintaining viable coastal tourism (Nicholls and Branson, 1998; Volonte, 1997; Jacoby and Prinn, 1994).

From Ausubel, (1991, p. 215) taking another "look at the impacts of climate change...conventional wisdom" foretells that "the most important impacts will be on agriculture and from sea-level rise" (see also: Pitelka, et al., 1997; Sahagian et al., 1994). It is possible as Ausubel, (1991, p. 216) noted that "the impacts of sea-level rise may be scarcely apparent at all for the next 30 to 40 years." "Very probable projections (> 9 out of 10 chance...)¹ sea level rise could be substantial...long-term melting of landlocked ice carries the potential for considerably higher values, (i.e., 50 +/- 25 cm by the year 2100), but with less certainty" (Mahlman, 1997, p. 1417; see also Neumann, et al., 2000; Varekamp and Thomas, 1998; Nicholls and Leatherman, 1996; Leatherman and Nicholls, 1995; Warrick, et al., 1993; Nurse, 1992). Through hindcasting analysis historical 20th century patterns can emerge as oceanographers have principally employed data from tide gauge instruments in denoting changes in relative sea-level; future projections come from their analyses (Schneider, 1997; Douglas, 1997; Figures 4 - 18; Tables 2 - 8).

In terms of pressures, trends, and impacts in coastal zones, interactions between socioeconomic and natural systems (see: Turner, et al., 1996) could indicate that "travel and recreation may prove to be sources of jobs and revenue that are more vulnerable to climatic change than agriculture in several regions" (Ausubel, 1991, p.

1 From, *inter alia*, Mahlman, (1997); Easterling, et al., (2000); & the U.S. Global Change Research Prog. (<http://www.usgcrp.gov/>) -- terminology used in global (climate) change and policy includes:

- "virtually certain projections" = > 99% probability or chance of being true
- "very likely" or "very probable" = 90 to 99% or 9 out of 10 probability or chance
- "likely" or "probable" = 67 to ~90% or > 2 out of 3 chance of being true
- "possible" = 33 to 66% probability or chance of being true
- "unlikely" or "some chance" = 10 to 33% probability or chance of being true
- "very unlikely" or "little chance" = 1 to 10% probability or chance of being true
- "improbable" = < 1% probability or chance of being true.

215). Indeed, as Turner, et al., (1996, p. 162) indicate tourism revenues may be in jeopardy "since the late 1970's tourism has become the second most important item in world trade surpassed only by oil," this is especially so where "the use of the coast and small island states for tourism has also expanded at a very rapid rate" (see also Burger, 2000; Miller, 1993; Miller and Auyong, 1991; Miller and Ditton, 1986; Beekhuis, 1981).

Regarding sustainable tourism for island societies throughout "Oceania, the Indian Ocean, and also the Caribbean," Krausse, (1995, p. 179) states that "mass tourism is generally demand-driven whereas 'low impact' or cottage industry tourism is by definition supply-driven." It's been suggested that island community equilibrium is thus precariously balanced by disturbances from seasonal droughts, hurricanes, and even long term relative sea-level changes (Krausse, 1995). Pantin, (1999, p. 227) contends that tourism has been the fastest growing sector in most Caribbean island locales and "is concentrated on the marine environment and impacts directly or indirectly, in particular, on the beaches..." Ashe, (1999, p. 187) points out that the threat from global climate change (see: e.g., Tables 9 and 10) is "not limited to the most vulnerable islands, nor is it entirely geophysical." He postulates that "less vulnerable small island developing states (in the Caribbean) would suffer significant disruption as a result of the loss of beach tourism and recreation areas because of relative sea-level rise and, possibly, more storms causing increased beach and reef erosion" (Ashe, 1999, pp. 187-188). And, in the Caribbean islands the future viability of sustainable tourism ultimately depends "on the ecological integrity of the natural asset base" according to de Albuquerque and McElroy (1992, p. 630; see: Figures 19 - 46 and Tables 11 - 32). Hence, cascading effects from contemporary global climate change is a valid threat to small island coastal environments.

The policy aspects of this study were sought to aid in addressing constraints posed by "global change" while accounting for the United Nations Framework Convention on Climate Change (UNFCCC) in Article 4.1 (b) which requires signatory Parties to the Convention to: "Formulate, implement, publish and regularly update and where appropriate, regional programs containing measures to mitigate climate change by addressing anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, and measures to facilitate adequate adaptation to climate change." Similarly, domestic legislation can be invoked as a *raison d'être* for undertaking this study because the United States has territorial entities in the wider Caribbean Basin with, for example, the United States Virgin Islands considered a "small island developing state" (see: Ashe, 1999, p. 192).

Thus, U.S. Public Law 101-606 [S. 169]; the Global Change Research Act of 1990^{2,3} and Public Law 101-617 [S.3069]; the Environmental Research Geographic Location Information Act⁴ are pertinently related to the UNFCCC. The analysis undertaken coincided with the stated aims of the Framework Convention (and the stated domestic legislation mentioned) but concentrated specifically on recognizing challenges wrought by global change to coastal tourism from, *inter alia*, relative sea-level rise. As part of the assessment it is recognized that the Earth is continuously transformed by human action (see: Turner, et al., 1990; Walker, 1990; see also

² Global Change Research Act of 1990, Public Law 101-606 [S. 169]; November 16th, 1990 codified at 15 U.S.C. 2921 note. "An Act to require the establishment of a United States Global Change Research Program aimed at understanding and responding to global change, including the cumulative effects and natural processes on the environment, to promote discussions toward international protocols in global change research, and for other purposes."

³ Global Change Research Act of 1990, Senate Report No. 101-40, Congressional Record Vol. 136 (1990); the 13 page Legislative History provides the "purpose of the bill" as well as the "background and needs" of e.g., "understanding global change." The concept of the Act is fully considered and integrated into this study under "statement of the problem."

⁴ Environmental Research Geographic Location Information Act, Public Law 101-617 [S. 3069]; November 16, 1990 codified at 42 U.S.C. 4366a note. "An Act to provide a method of locating private and Government research on environmental issues by geographic location." Also of note here under this reference is the Legislative History under Senate Report No. 101-541 comprised of four pages.

Graedel and Crutzen, 1989). The problems discussed above relate and correspond to one of the main aspects of the multidisciplinary research initiatives promulgated by the "Man and Biosphere" Program (MAB) of the United Nations Educational Scientific and Cultural Organization (UNESCO); that is, the rational management of small island coastal ecosystems (D'Ayala, 1992). D'Ayala (1992, p. 565) emphasizes that "once the human being is included in the equation, islands become eminently complex open systems." Aspects of the UNESCO MAB program were used as a frame of reference here.

Assumptions & Hypotheses

Thus, select research assumptions which supported the study are provided as follows:

- A-1 Coastal hazards, including that posed by global change, provide problematic consequences at the local, regional and global scale(s) see: e.g., (Heinz Center, 2000; Dunn et al., 2000; David, et al., 1999).
 - A-2 Beyond the scope of this research, there is a direct causal anthropogenic effect upon the Earth's changing climate system (Santer, et al., 1996; Santer, et al., 1995) and hence the coastal environment (Nicholls, et al., 1999; Doornkamp, 1998; Woodward, 1992).
 - A-3. The international insurance industry will be confronted with a dramatic increase in the scope and challenges of coastal hazards in the 21st century (Henderson-Sellers, et al., 1998; Michaels, et al., 1997; Swiss Re, 1996; Berz, 1993).
- Hypothesis 1 - Relative sea-level rise threatens tourism sustainability in the eastern Caribbean islands. More specifically, it will effect tourist facilities (hotels) dependent upon sandy beaches.

Subhypothesis 1 - The rise in global (relative) sea level can affect coastal and marine areas (on small island developing states), particularly in relation to occupation and use of coastal land due to relative sea-level rise.

Subhypothesis 2 - The impacts of "Global Change" will include increased inundation under storm conditions in unprotected coastlines and low-lying areas.

Objectives of the Research

The primary objectives of the proposed research were to conduct a content analysis, utilizing peer review journal articles or equivalent, to identify past relative sea-level rise trends and future scenarios posed by climate change in the Caribbean (Schneider, 1994; Schneider, 1989; see also Nicholls, 1996). I examined past rates, and future scenarios of relative sea-level (regionally and globally, respectively) and empirically integrated those findings with socio-economic trends in tourism data to determine possible or potential impacts on the beaches (see: Lorenzoni, et al., 2000). A concern was how physical changes in the coastal environment, through incremental relative sea-level rise, may affect coastal tourism in the Lesser Antilles where sandy beaches are said to be the foremost *raison d'être* for holiday seekers (UNIDO, 1987; Gable, 1987).

The integration of global sea level data from, for example, Raper, et al., (1996) in comparison with regional tide gauge data from the wider Caribbean allowed for an analysis to look for a signal of, or rather, trends in the long-term rate of relative sea-level rise and how that situation may affect wider Caribbean coastlines (see: Figures 47 and 48; Tables 33-37). Further, such findings provided for a determination if sandy shorelines have been, are presently, or are "likely" (> 2 out of 3 chance) to become in

jeopardy from inundation from relative sea-level rise (see: Figures 47 and 48; Tables 33 to 37). Thus, the effect on sustainable tourism of a rise in relative sea-level from "global change" and the subsequent loss of dry sand areas on beaches can be articulated by looking at the preceding variables (relative sea-level rise, beach erosion, coastal - beach - tourism) by a measurement of similarity between and among samples from locales principally from the Lesser Antilles.

One example would ascertain, for example, storm effects on visitor stayover arrivals (Figures 49 - 52). The variables were aggregated or categorized further into socioeconomic: principal purpose of visit, vacationers' decision-making factors (e.g., use of sandy beach, etc.), visitor accommodations, (i.e., rooms), stayover tourists, visitor expenditures, hotels and restaurants contribution to Gross Domestic Product (GDP) for select countries, and natural variables: rates of relative sea-level change, beach changes (erosion) and episodic tropical storm events (Figures 49 - 60; Tables 38 - 45) , and combinations of the preceding for policy formulation.

Content analysis (see: Babbie, 1998; and subsequent sections) is analogous to "meta-analysis" in that the latter "involves combining a large number of studies on a single issue to see whether, in aggregate, they contain information that no single study provides alone" (Kammen and Hassenzahl, 1999, p. 374; see also Mann, 1990); similar in scope to content analysis (Babbie, 1998). Content analysis differs from meta-analysis in that the former is primarily centered on words (Babbie, 1998) and the latter focuses on numbers. A modified content (meta) analysis as performed here can provide adaptive management techniques to aid policy makers in discerning appropriate responses to prospective coastal challenges posed by forecasted climate change impacts, especially from relative sea-level rise, etc. (see: Jepma and Munasinghe, 1999; Inman and Brush, 1973; Tables 46 - 51).

Lemay, (1998), for example, states on page 24 of her publication that the Inter-American Development Bank's "Policy on Natural Disasters" (OP-704) refers "implicitly to the vulnerability of coastal areas to hurricanes and floods but emphasizes structural solutions such as breakwaters and revetments for disaster prevention in low-lying coastal areas" rather than more benign retreat and setback regimes. A personal objective was the critique of the preceding policy through my research findings. The likely range of responses to environmental hazards - i.e., structural vs. nonstructural responses by wider Caribbean governments to changes in relative sea-level, differences in storm regime, and altered precipitation patterns is important for agenda setting (Klein and Nicholls, 1999; White, 1996 & 1994).

I originally proposed to elucidate flexible policy responses, also known as adaptive management (Hennessey, 1998; Table 49), to climate change that can be determined through a content analysis of the literature to see how other areas of the world community have responded to coastal threats such as, *inter alia*, relative sea-level rise, coastal erosion, and inundation from a regional perspective. Preferred policy response options ascertained by the researcher (see especially Tables 50 and 51) fall under the rubric of limitation and prevention, adaptation - both passive and active, as well as intervention and mitigation. The latter encompassing, for example, if feasible, beach nourishment or the preferred optimal building development set-back policy in the coastal zone (see: e.g., Gable and Edwards, 2001).

This present study has theoretically contributed to the ongoing preparation of a sustainable strategy for coastal and marine resources management in the wider Caribbean through initiatives such as the Man and Biosphere Programme of UNESCO and, for example, the Climate Change and International Waters enterprises

of the Global Environment Facility (GEF) of The World Bank and United Nations Development Programme. In addition, Sulzman, et al., (1995) state on page 217 of their manuscript that "information on potential climate change should be integrated with the effects of other human-related stresses, such as land conversion, population pressures, and pollution (e.g., acidification, eutrophication, etc.) for a more holistic perspective on resource health and, thus, support better management and policy decisions." I have attempted aspects of an *holistic* approach (Figure 3) in my analyses.

Secondarily, the research has acted as a precursor study as an aid in providing elements for a post-graduate study of a comparative ecological risk-ranking utilizing the wider Caribbean Basin as a regional seas setting (see: e.g., Gable, 2000; Jones and Klein, 1999; Jones, 1997; Power and Adams, 1997; Shlyakhter, et al., 1995; Gentile, et al., 1993; Harwell, et al., 1992; Norton, et al., 1992; USEPA, 1990; Hunsaker, et al., 1990; Rodriguez, 1981; Tomblin, 1981). A modified content analysis research method, similar to that performed could be employed as a separate manuscript employing a relative risk-ranking matrix based on time for ecological recovery from environmental (i.e., habitat alteration of wetlands) and developmental (i.e., building infrastructure and coastal engineering devices such as groins) related stress (see: Gable, 2000). This procedure is typically intended to identify environmental policy-making options to respond to comparative risks (Morgan, 1993; Slovic, 1987; Russell and Gruber, 1987). It has not been accomplished, thus far, for this marine region.

Separately, ecological risk assessment can be employed as a tool (for vulnerability assessment) in the decision making process in order to help foster a better allocation of scarce government resources (i.e., comparative risk assessment). It is a way of utilizing science in policy making with a focus on impact analyses (see: Bolin, 1994; Bretherton, 1994). From page 453 of their article, Harwell et al., (1992) state

that "separating broad, general relationships of ecological risks from the seemingly infinite array of individual circumstances and uncertainties of ecosystems affected by human activities is fundamentally a process of expert judgement." They also state that the "synthesis ranking of ecological risks represents the ecological issues of greatest potential danger to the environment..." (Harwell, et al., 1992, p. 457; see also Fischhoff, et al., 1984).

Justification for and Significance of the Study

On most Caribbean islands of the Lesser Antilles, and in locales throughout the wider Caribbean, effectively all tourism development has occurred in the coastal areas, with beaches being the principal attraction (see also UNEP, 1997; Houston, 1996; Gable and Aubrey, 1990; Figures 20 - 24; Tables 12 -19). Tourism is a significant part of the wider Caribbean economy. The United States Department of Commerce reported that it is the fastest growing industry worldwide. They also noted that by the turn of the century, which is now upon us, tourism would likely be the world's number one industry. Coastal and marine tourism in most parts of the wider Caribbean is already a significant source of revenue and is the leading economic sector in the Caribbean as a whole (UNIDO, 1987).

In the late 1980's, throughout the wider Caribbean, annual revenues from tourism were \$7.3 billion (CTO, 1989). In 1994, this figure had increased by almost 60 percent to \$11.67 billion (CTO, 1995). By 1999, this amount had climbed to \$18.7 billion (CTO, 2001; Figure 40). Relatively few of the most intensively developed resorts have beaches broader than about 30 meters at high tide (Gable, et al., 1990), and both qualitative and quantitative assessments illustrate that most of the world's sandy shorelines are in retreat, which includes the wider Caribbean (see also Douglas,

et al., 1998). Geomorphologic research assessments indicate that about 70% of the world's sandy shorelines are experiencing erosion (Bird, 1996; Bird, 1985; Warrick and Farmer, 1990). In addition, Ausubel (1991) writes on page 216 of his article that "there is definitely a need for more systematic, thorough studies worldwide on the impacts, together with adaptation, from which it would be possible to identify the greatest vulnerabilities" from global change.

The situation of beach erosion (inundation) is likely to get worse, in part, because relative sea-level rise, an acknowledged ancillary effect of "global change," has risen by about 15 cm (1/2 foot) during the past century from an assessment of tide gauge records (Douglas, 1997; Haq and Milliman, 1996; Haq, 1994). The advancing level of the seas is projected by Intergovernmental Panel of Climate Change (IPCC) coastal specialists to increase over the next several decades (Warrick, et al., 1996; Kay, et al., 1996; Houghton, et al., 1992). With this prognosis, most shore areas of the wider Caribbean may suffer increasingly adverse effects, such as, beach erosion as well as loss of wetlands. This study remains focused on the issue of relative sea-level rise and its past, present and future relationship to Lesser Antilles coastal tourism. Could the coastal challenge posed by "global change" as manifested through relative sea-level rise or storminess stymie sustainable Caribbean island tourism?

Methodology

Initially, it is important to understand that according to Miller (1994, p. 19), who established the U.S. National Science Foundation's program on the human dimensions of global change, interactions "across the natural and social sciences is not totally new, the degree to which it is required for understanding global environmental change is unprecedented." Similar to studies undertaken in the broad field of *marine*

affairs, Miller (1994, p. 20) alleges that "research on the social and economic impacts of global environmental change is dependent upon better understanding the nature, direction, duration, and timing of physical and biogeochemical change." Miller (1994, p. 20) points out that, *inter alia*, a type of "interaction across the natural and social sciences is methodological." And "the use of a common method across disparate fields of science illustrates some of the difficulties" of interdisciplinary research.

Nevertheless, Miller (1994) mentions the "useful transfer of new methodological and analytical techniques to both" the social and natural sciences. She cites, on page 20 of her article, the work of Doll and Peto, the latter individual known for his *de facto* use of "meta-analysis" in the medical science and social behavior disciplines (see: Mann, 1990). Though, however, Miller (1994, p. 20) goes on to write that "all three types of interaction," i.e., disciplines that combine the social and natural sciences like geography; the adoption of metaphors from other fields; and the use of common methodologies spoken of earlier - "may contribute to an improved and broadened understanding of global environmental change - none provides a good model for the kind of collaboration across previously separate and differently focused research traditions that is now being suggested for research on global environmental change."

Lastly, Miller (1994, p. 21) points out that in her view "the social and economic impact of dramatic changes such as sea level rise...need to be framed more narrowly or concretely before they will be amenable to social science research." Social scientists may "partition the research problem" thus fostering little collaborative dialogue with natural scientists (Miller, 1994, p. 21). This view runs somewhat counter to Klein and Nicholls (1999, p. 183) approach that "coastal vulnerability assessment would require optimal knowledge of the spatial and temporal dynamics of

(multiple) biogeophysical effects that trigger the impacts of climate change and (relative) sea-level rise."

To meet the stated objectives, the study attempted to utilize available nearby reliable sea level tide gauge stations such as Key West, Florida, as a marker or baseline station, for similarly situated island locations primarily in the Lesser Antilles where there is a paucity of reliable long-term sea level information to determine past rates in relative sea-level rise. Existing studies from the literature provide a view of the 20th century global average relative sea-level change that is used as a proxy for the wider Caribbean because of the dearth of baseline tide gauge data available there. The aim was to potentially correlate trends in coastal (beach oriented) tourism information (e.g., visitor stayover arrivals, visitor accommodations) with that of data on rates of relative sea-level rise and beach erosion in order to test the hypotheses listed earlier.

To do this, I consulted the methodology found in Yamada, et al., (1995) that they undertook in their analyses of select Islands in the South Pacific (Oceania) referred to as the "Index Based Vulnerability Assessment." They modeled and modified their framework after the "Common Methodology for Assessing Vulnerability to Sea-Level Rise" described in Vellinga and Klein, (1993), and the vulnerability impact assessment and adaptation strategies recently developed and espoused in Klein and Nicholls, (1999). The foregoing methodologies, developed, in part, under the auspices of the Intergovernmental Panel for Climate Change (IPCC), were consulted for my analyses performed here. Based on my appraisal of the applicability of these methodologies for my analyses, this study followed a framework (flowchart) depicted in Figure 3.

Yamada, et al., (1995) mention on page 101 of their manuscript that their methodology is "flexible; it does not depend so much on data referring to natural and social conditions." Further, they employ a "semi-quantitative evaluation" typically utilizing an ordinal scale, i.e., a rank order methodology (using an expert panel approach; also utilized academically in a study on the Island of Rhodes for coastal management policy applications; see: Moriki, et al., 1996). This approach they based upon degrees of vulnerability of select variables that they list in their paper, utilizing any past vulnerability assessments for similarly situated geographic locales, scientific judgement (from the literature, *that is*, content analysis) and expert judgement. Yamada, et al., (1995) suggest on page 105 of their article that their "framework itself can be transferred" to different regions and countries. Therefore in order to fit data/information into the "steps" typically performed in the United Nations Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies (Klein and Nicholls, 1999) a modified content analysis was undertaken.

Content Analysis

Babbie (1998, p. 330) defines content analysis as referring "to the directly visible, objectively identifiable characteristics of a communication, such as specific words" principally in peer review periodicals or equivalent, concerning relative sea-level rise (a physical parameter of global environmental change), with that of meta-analysis, i.e., typically numerical (see: Mann, 1990). Babbie, (1998) highlights procedures and sources of content analysis as including, for example, newspapers, magazines and periodicals (journals). It is the latter, primarily of the peer-review variety that the present study has primarily utilized in the relative sea-level rise exercise as an aid in natural resource decision making.

The operational choice is the unobtrusive method of data collection: content analysis of communications (words and numbers/rates) of relative sea-level rise for the purpose of ascertaining past, present, and forecasted scenarios of relative sea-level rise (Figures 4 - 18; Tables 2 - 8). The suggested future scenarios depict a potential increasing rate of rise due to global climate change parameters (Taylor, 1999). Ratio measures between and among authors' published rates of relative sea-level rise indicates a trend in the level of the "means" of those data over time (French, et al., 1995). Central tendency mean calculations of data were determined for interval and ratio data (Babbie, 1998), that illustrate potential revisions of "best guess" estimates (and or trends) or range of estimates of projected eustatic relative sea-level rise to dates in the 21st century from existing studies authored during the last twenty or so years.

Traditionally, interval measures refer to those variables with attributes not only able to be rank-ordered but also separated via a uniform or equal distance (Babbie, 1998). "Ratio measures are same as interval measures except that ratio measures are also based on a true zero point" (Babbie, 1998, p. 163). Indeed, the mode (most frequent), mean (arithmetic average) median (midpoint) of all the studies combined can illustrate information that one study alone may not indicate. Analysis of published studies, for example, Gornitz, (1995) provided for a synthesis calculation of past and future scenarios in the ranges of global average relative sea-level rise. This analysis aids in determining the likelihood of beach inundation and loss of dry sand above mean high tide for tourists to recreate in the future. The variables were experimentally measured for similarity in an empirical expert judgement analysis, that, in part, utilized linear least squares regression analysis on tourism data as a tool in the assessment. Thus, adaptive policy management has resulted from the analysis of the content (meta) analysis. For example, in response to "global change" realizing that threatened and endangered species, such as sea turtles, rely upon sandy beaches in Caribbean

locations to lay their eggs, ought to be considered in any policy formulation as it relates to beach nourishment or placement of hard engineering structures at the shoreline.

Meta-Analysis

More specifically, the units in meta-analysis are relative sea-level rise rates (see: *inter alia* e.g., Raper, et al., 1996; Gornitz, 1995; Titus and Narayanan, 1995). The research plan included analyzing a body of existing textual materials with the units of analysis being a combination of themes, words and concepts as it relates to global environmental change with specificity given to relative sea-level rise. Further, the plan was designed to determine the synergistic effect of a potential rise in sea-level (physical parameter) with sustainable coastal tourism utilizing white sandy beaches (the behavioral social parameter employing available review data from the Caribbean Tourism Organization). The intent was to seek policy responses (e.g., setbacks; beach replenishment; environmental auditing procedures - see: Tables 50 and 51) to the conceivable consequences, if any, of as Bird (1996, p. 87) states: "coastal erosion is facilitated by rising sea-level, which brings wave action to progressively higher levels and permits higher waves to reach the coast through deepening near-shore waters."

Mann, (1990, p. 477) aptly describes, in a sidebar, examples of "how to perform a meta-analysis." The logic of the "odds ratio" analysis example given in Mann, (1990) was *de facto* employed in this study as it relates to ascertaining if there is a projection for a rising global average sea-level signal in the data set (see: Figures 7 - 18). A caveat regarding "testability," is that Berger and Berry (1988) state on page 163 of their article "consumers of data want a final probability; they want to know how probable it is that the hypothesis is true in light of the data...standard statistics cannot

answer this question." They go on to say that "our basic thesis has been that objectivity is not generally possible in statistics and that standard statistical methods, (such as p-values and confidence intervals), can produce misleading inferences" (Berger and Berry, 1988, p. 165). Standard statistical methods, referred to in the preceding, are not typically employed in interdisciplinary climate change studies.

In essence, employing the traditional statistical terminology found in most climate change oriented studies (see: footnote 1), is it "very likely" that the tourist beaches will eventually disappear from incremental relative sea-level rise? It is important to clarify, however, as Bird (1996, p. 87) states, in his abstract, that "the modern prevalence of beach erosion on the worlds' coastlines is not, therefore, an indication of global sea-level rise - however, if such a sea-level rise develops, perhaps as a consequence of the greenhouse effect, there will be an acceleration of existing beach erosion, and erosion will begin on many beaches that are now stable or growing." What effect this will have on sustainable coastal tourism in the wider Caribbean islands was the science-based policy decision sought in this study.

The aim was to utilize UNESCO - Intergovernmental Oceanographic Commission data sets, if available, (or existing studies employing that information) of beach erosion or progradation (accretion) rates registered in either feet or meters, or variations of both, on Lesser Antilles locales to ascertain if selected tourist oriented beaches are actively eroding (Bird, 1996). Some of these data sets, for up to the past twenty years or so, were available via publications from Puerto Rico Sea Grant (see: e.g., Cambers, 1998). These data indicate if certain tourist oriented sandy beaches are actively eroding in the Lesser Antilles (Figures 47 and 48; Tables 33 - 37).

This synergistic situation of what Bird, (1996) alluded to above, (i.e., relative sea-level rise effecting erosion/inundation of sandy beaches) would then have ramifications in the sustainability (i.e., no beach - no tourists - loss of revenue) of coastal tourism in the wider Caribbean - Lesser Antilles - under study (Gable and Aubrey, 1990). For studying past and future relative sea-level rise the use of existing empirical peer review studies were analyzed, such as, *inter alia*, Raper et al., (1996) and Gornitz, (1995); that according to Mann, (1990, p. 249) "fundamentally, meta-analysis is observational in nature, in the case of meta-analysis what is there consists of studies done by other investigators." The technique allows for easier replication by others.

For tourism data, trend or regression analysis was performed on available information from the Caribbean Tourism Organization (CTO). A comparison of past trends in relative sea-level rates and coastal tourism data will indicate if the two variables are in any way linked under terminology found in Mahlman, (1997). Coastal tourism data can be disaggregated to look at beach erosion and relative sea-level rise because data is collected indicating if the stayover visitors are partaking of activities on a beach (see: e.g., Figures 20 - 24; Tables 12 - 19). Coding of the data was operationalized primarily via (numerical) interval and or ratio measures with a sample tally sheet adopted and modified from Babbie, (1998). The base from which the counting was accomplished was determined through the review process of the documents and CTO data. "Analytical induction" (Babbie, 1998) is the outcome of the study because more than just description, relationships and patterns between variables have been found.

As mentioned earlier, in the wider Caribbean region, relatively few of the most intensively developed resorts (tourist facilities) have beaches broader than about 30

meters or so at high tide (Gable and Aubrey, 1990). Indeed, an important point is that during episodic storm events (see: Bosser, et al., 2000) erosion at beach-focused tourist facilities can have devastating financial ramifications on national (island) economies through the loss of infrastructure and subsequently revenue (Basco, 1996; see also Bier, et al., 1999; Zhang, et al., 1997). Indeed, episodic storm events maybe more relevant than incremental relative sea-level rise. Bosser, et al., (2000, p. 879) also highlight that "falling barometric pressures act to draw up the water surface producing a rise of ~13.6 mm for every 1 mb drop in atmospheric pressure. From their meteorological-based studies in parts of the French West Indies that has equated to ~1.5 to 3 feet" (Bosser, et al., 2000)!

Thus, in some locales, such as coastal zones and floodplains, waiting "to make policy and to take action will drive up the costs of response," and may further increase societal vulnerability and a reduction in flexibility to contain unwanted effects (Ausubel, 1991, p. 211). It's been suggested that the wider Caribbean islands, among others, may experience the largest relative increase in flood risk due to relative sea-level rise (Nicholls, et al., 1999). In addition, direct socioeconomic and biogeophysical impacts of climate change and relative sea-level rise will be felt on the tourism sector through an increasing flood frequency, erosion and inundation (Klein and Nicholls, 1999). As tendered earlier, my originally proposed study aimed to aid in understanding the risks of select global change parameters upon the Lesser Antilles while trying to help in fostering a coherent coastal policy and adaptive management decision making in the face of climate uncertainty (see also Pethick, 1993; Pernetta and Elder, 1992; Newman and Fairbridge, 1986; and see: Tables 7 and 8).

Resources Required

The initial investigatory research required generic data collection such as statistical reports of the CTO. These reports contain detailed statistical information on the performance and characteristics of Caribbean tourism, including, for example, country of origin, length of stay, expenditure, accommodation statistics, tourism budgets and the like for more than 30 Caribbean countries and entities. Visitor surveys that are available from the same source have augmented the data gathering procedure as it pertains to socio-economic information. For example, the CTO publications and visitor surveys include information on purpose of visit, length of stay, expenditures and accommodations and were readily available for Barbados and Anguilla, among other locales. Much of the preceding information has been utilized in previous studies (see: *inter alia*, e.g., Gable, 1997; Gable, 1991). Other publications required were pertinent conference and symposium proceedings, interdisciplinary *marine affairs* peer-reviewed and professional literature (see: Hinrichsen, 1996), various reference volumes (e.g., Krebs, 1999; Sills, 1968) and sundry technical reports, etc., available at the main campus library and/or the Pell Marine Science facility in Narragansett. In addition, because the basic aspects of the methodology employed has been utilized in other island settings, the time needed to complete the study was minimized.

Chapter 2. Overview and Framework of the Project Study

The undertaking of this study contributes to the ongoing preparation of a sustainable strategy for coastal and marine resources management in the wider Caribbean. This is accomplished in concert through initiatives such as the Man and Biosphere Programme of UNESCO and, for example, the Climate Change and International Waters enterprises of the Global Environment Facility (GEF) of The World Bank and United Nations Development Programme. It is noteworthy that, Sulzman, et al., (1995) mention that global change science information ought to be coupled with other stresses on the landscape to concoct appropriate management and policy decisions. For a more holistic approach to the assessment of coastal seashore sustainable health, natural and social science parameters are integrated. Aspects of an holistic approach can be seen throughout the manuscript.

That the Lesser Antilles in the wider Caribbean will be impacted by climate change is certain: its environment, land uses, and economies are dictated in large part by this marine influence. Accompanying global change will be adjustment in sea level, differences in storm climate, and altered precipitation patterns; basic science cannot define today with impunity what form these changes will take. Because global change is inevitable - although its magnitude, timing, and geographic distribution remain uncertain - the small island developing states (SIDS) of the wider Caribbean, especially those in the Lesser Antilles, have only recently begun the appropriate research and planning studies with adequate international donor support to set forth a proactive policy response to global change (see also Alexander, 1994).

Coastal areas attract human populations because these areas are focal points for economic growth; they account for more than half of humanity's infrastructure for

tourism, and other services (Olsen, et al., 1999; Cohen, et al., 1997). As noted in subsequent sections, on most Caribbean islands of the Lesser Antilles, and in locales throughout the wider Caribbean, effectively all tourism development has occurred in the coastal areas, with beaches being the principal attraction (see, for example, Figures 20 - 24; Tables 12 - 19; see also Leatherman, 2001; UNEP, 1997; Houston, 1996; Clark, 1991; Gable and Aubrey, 1990). As noted further in Chapter Six, tourism is a significant part of the wider Caribbean economy, especially for island entities.

The United States Department of Commerce reported that tourism is the fastest growing industry worldwide (Arey, 1993). They also noted that by the turn of the century, which is now upon us, tourism would likely be the world's number one industry. Interval scale data presented in this manuscript appears to substantiate these earlier claims. Coastal and marine tourism in most parts of the wider Caribbean has been a significant source of revenue and, according to the United Nations Industrial Development Organization, has been for sometime the leading economic sector in the Caribbean as a whole (UNIDO, 1987).

As a precursor for the undertaking of the analyses presented in this manuscript, it is important to reiterate that according to Miller (1994, p. 19), who, as earlier mentioned, established the U.S. National Science Foundation's program on the human dimensions of global change, interactions "across the natural and social sciences is not totally new, the degree to which it is required for understanding global environmental change is unprecedented." Miller (1994, p. 20) alleges that "research on the social and economic impacts of global environmental change is dependent upon better understanding the nature, direction, duration, and timing of physical and biogeochemical change." This is analogous to cross-disciplinary studies undertaken in the broad field of *marine affairs*. Miller (1994, p. 20) points out that, *inter alia*, a type

of "interaction across the natural and social sciences is methodological." And "the use of a common method across disparate fields of science illustrates some of the difficulties" of interdisciplinary research. This has been somewhat true for the present study described here as well (see: Chapter Three for further discussion).

To note again from earlier, Miller (1994) mentions the "useful transfer of new methodological and analytical techniques to both" the social and natural sciences. She cites on page 20 of her article the work of Doll and Peto, the latter individual known for his *de facto* use of "meta-analysis" in the medical science and social behavior disciplines (see: Mann, 1990). The technique of meta-analysis provides a controlled evidence-based experiment to policy formulation while utilizing the best available scientific data in evaluating multiple existing studies through a systematic review. This review can then be integrated using a defined criteria for quality control (see: e.g., Table 5) and collating the existing studies dataset by employing a variety of statistically valid techniques.

Though, however, Miller (1994, p. 20) goes on to write that "all three types of interaction," i.e., disciplines that combine the social and natural sciences like geography (which is my academic background); the adoption of metaphors from other fields; and the use of common methodologies spoken of earlier - "may contribute to an improved and broadened understanding of global environmental change - none provides a good model for the kind of collaboration across previously separate and differently focused research traditions that is now being suggested for research on global environmental change."

Lastly, Miller (1994, p. 21) makes a point that in her view "the social and economic impact of dramatic changes such as sea level rise...need to be framed more

narrowly or concretely before they will be amenable to social science research." Social scientists may "partition the research problem" thus fostering little collaborative dialogue with natural scientists (Miller, 1994, p. 21). This view runs somewhat counter to Klein and Nicholls (1999, p. 183) approach "that coastal vulnerability assessment would require optimal knowledge of the spatial and temporal dynamics of (multiple) biogeophysical effects that trigger the impacts of climate change and (relative) sea-level rise." Hulme, (2000, p. 596) concludes that "the integration of the methodologies of the natural and social sciences, including the humanities,...remains daunting." Nevertheless, I have attempted to frame my multidisciplinary analyses as tightly as possible while looking at relative sea-level change - beach tourism - sandy shoreline relationships in the Lesser Antilles.

This manuscript reviews selected tourism-oriented island economies, discusses coastal areas in the Caribbean already experiencing environmental degradation, and addresses the ramifications of anticipated climate changes on these and other areas primarily in the Lesser Antilles. What strategies (planning) ought to be taken, considering the magnitude of uncertainty that exists in the projections of global climate change (see: Schneider, 2001; Lampert and Schlesinger, 2001), is also addressed in Chapters Nine and Ten.

While at the same time it is important for the reader to understand that changes in climate are the norm when one studies the geologic record of the earth. These changes include the glacial epochs and the contemporary climatic variation of the El Niño/Southern Oscillation (Adeel and Glantz, 2001; Gable and Aubrey, 1989). Examination of paleoclimatic records illustrate considerable natural and spatial variability which makes long-term (20-100 years) forecasting of climate change parameters highly uncertain (see: e.g., Reilly, et al., 2001; Allen, et al., 2001). Future

climate (and arguably the present), however, will be influenced by anthropogenic as well as natural processes. Together, these forcings will cause future climate to evolve in uncertain ways (Kerr, 2001; Broecker, 1995; Schneider, 1987).

Regional seas locations such as the wider Caribbean may be being presently impacted by aspects of climate change (Burroughs, 1999; Leatherman, 1997; Maul, 1993). Accompanying global change are regional impacts such as, alterations in the hydrologic cycle and precipitation patterns; meteorological changes in the intensity, distribution and paths of cyclonic episodic storms (see: Easterling, et al., 2000; Changnon and Easterling, 2000; Smith, 1999; Wilson, 1999; Knutson, et al. 1998; Landsea, et al., 1996; Gray, 1990; Emanuel, 1987; see also Chapter Eight) and, the specific focus of study here, concerns the past and prospective impacts of a potentially accelerating relative sea-level rise during the next several decades and its potential constraints on beach tourism on small island developing states, especially those in the Lesser Antilles (see below e.g., Ashe, 1999; Pantin, 1999; Krausse, 1995; de Albuquerque and McElroy, 1992) more fully articulated in Chapter Six.

Physical and Cultural Attributes

The Caribbean Sea, an arm of the Atlantic Ocean, is bounded by the West Indies on the north and east, South America on the south and the isthmus of Central America on the west. The Caribbean connects with the Gulf of Mexico to the northwest through the Yucatán Channel (Figure 1). The Caribbean Sea and the Gulf of Mexico, the world's largest Gulf, cover an area of 3.48 million square kilometers (1.35 million square miles). Within this wider Caribbean region, defined here as the coastal and open waters of the Caribbean Sea proper, the Gulf of Mexico, and adjacent waters of the Atlantic Ocean, there are 33 countries (see: Maul, 1993). It includes an

area of 1,049,500 square miles. Several oceanographic and atmospheric currents pass through in an east-west direction. Contained within the wider Caribbean region is the largest concentration of small developing countries in the world (UNIDO, 1987). The "Caribbean Basin" is comprised of about 33 countries (plus additional territories) within and around the Caribbean Sea (UNIDO, 1987).

Included in this figure are political entities known as "overseas departments," "territories," "independent and associated states," "commonwealths" and "colonies." Political entities encompassing the wider Caribbean, which contains the largest concentration of small developing countries in the world, range in type and size from small islands such as Anguilla, measuring 91 square kilometers (35 square miles), to continental nations such as the United States, measuring 9.37 million square kilometers (3.61 million square miles).

The Caribbean countries display diversity of character and form, though they collectively face similar (climate change) and inter-related (climate change and the nearshore environmental stress) problems. Their resource base - particularly for the island entities - is limited in scale and scope, yet some of the most biologically productive and complex ecosystems (e.g. corals) found in the world exist in the Caribbean coastal zone (UNIDO, 1987; USAID, 1987).

The economic importance of coral reefs, beaches, seagrass beds, mangrove forests, and coastal estuarine ecosystems derives mostly from their linkage to other resources, especially coastal tourism and fisheries (USAID, 1987). These coastal and marine habitats contribute a large percentage of income, especially to the Greater and Lesser Antilles economies. Relatively recent economic performance of many Caribbean countries depicts tourism, construction and agricultural production (e.g.,

bananas) as the leading sectors in gross domestic product (GDP), particularly in the smaller, less - developed economies in the region (UNIDO, 1987).

Introduction to Natural Hazards

Many locations along wider Caribbean coasts are subject to natural hazards ranging from flooding from episodic storms to erosion from increasing relative sea-level rise. These events, along with accretion and deposition also occur seasonally or at various times. Today, in many Western Hemisphere sites the ocean coasts are experiencing widespread economic and environmental damage from flooding and erosion (Platt, 1994). Lee, (1993) has recently suggested, however, that these issues and their associated manifestations are the real estate developer's obstacle and not principally planning issues. As a consequence, this supposition has led to development along the coast that is haphazardly strewn oftentimes in at-risk settings (see: Heinz Center, 2000a,b). This development has in turn also exacerbated the "economic demand" or necessity in the wider Caribbean for coastal or shoreline protection defenses as described in LeMay, (1998). Most of these defenses are primarily funded through public proceeds, in the case of island entities international donor agencies, once the threats from natural hazards to "private property" become apparent. Public acknowledgement to such coastal hazards, as flooding and erosion, has evolved haphazardly in response to particular disasters.

The potential increasing effects of relative sea-level rise as a "natural hazard" has heightened the growing concern over the effectiveness of the existing legal and administrative frameworks operating in the coastal zone. In the United States, for example, of particular significance has been the concern about the lack of coordination between and among local - state - federal initiatives to coastal (development) planning

and engineering structures. At the federal level in the United States, the permits for structures are issued by the U.S. Army Corps of Engineers, an agency within the Department of Defense. This permit conflict is often coupled with the prevailing attitude that hazards, such as, coastal erosion and flooding are not proactive planning issues dealt with, at least, at the local or regional level but more formally as a "civil defense" issue (Platt, 1994). Rather, only during times of emergency such as when a hurricane approaches does local or regional planning of the known consequences of these storm events really begin in earnest.

The wider Caribbean may be significantly affected by global changes due to atmospheric trace gas loading, including warming and the subsequent rise in ocean levels (for a discussion see: *inter alia*: Diez, 2000; Etkins and Epstein, 1983; Hansen, et al., 1983; Robock, 1983; Etkins and Epstein, 1982). The wider Caribbean region includes many islands that have far more coastal zone per unit of land area than do continental areas (see: Table 1), and changes of relative mean sea level are beginning to concern more and more governments and government planners (Nurse, 1992). Governments and international aid and relief agencies make important economic and environmental decisions about coastal projects based partly upon assumptions about climate (Boesch, et al., 2000).

Many of the decisions assume that past climatic data, without modification, are a reliable guide to the future. This assumption may no longer be valid (Field, et al., 2001), since suggestions have been put forth that climate change may accelerate in the future due to anthropogenic influences. For the wider Caribbean region, several aspects of climate change and its ancillary affects appear most critical: temperature increase, relative sea-level rise, precipitation changes, and storm climate. Indeed, Grevemeyer, et al., (2000) illustrate an evidence-based increase in waveheights over

the past twenty years on select Atlantic Basin shores. They go on to mention in their article on page 351 that "it seems reasonable to propose that greenhouse forcing affects the ocean's wave climate and hence coastal surf and storm surges..." A selection of these elements is discussed in more detail in later sections.

Analogous to forecasted effects from global change research assessments have indicated that about 70% of the world's sandy shorelines are experiencing erosion (Warrick and Farmer, 1990; Bird, 1987; Bird, 1985); this is particularly true for the Caribbean region where relatively few of the most intensively developed resorts (tourist facilities) have beaches broader than about 30 meters or so at high tide.

This assertion is important because of the current environmental hypothesis of global climate change, a premise that presents far-reaching multidisciplinary scientific challenges (Broecker, 1995; Warrick, et al., 1993; Houghton, et al., 1992; Broecker, 1975). While changes in climate are the norm, it has become increasingly suggested that anthropogenic activities, for example, emissions of greenhouse gases typically from human industrial activities, have become an agent of that change (Trenberth, 2001; Barnett, et al., 2001; Vitousek, et al., 1997; Santer, et al., 1995). Consequently, environmental problems associated with the potential impact of climate changes are an important concern for governments and planners in the wider Caribbean region and elsewhere and are thus addressed more in-depth in subsequent sections.

With this in mind, public, scientific and governmental interest in global warming and the ancillary effect of rising sea level may be rising faster than sea level itself. Numerous international (e.g., Intergovernmental Panel on Climate Change; United Nations Environment Programme) and U.S. (National Academy of Sciences)

scientific committees have looked into this problem, and in the past several years newspapers and popular magazines also have displayed increased interest (e.g., Bjerklie, et al., *Time*, April 9th, 2001; *The Economist*, 1995a,b). Government-sponsored legislation, particularly in the United States (see: e.g., Global Change Research Act of 1990 - Public Law 101-606 [S. 169]; November 16th, 1990 codified at 15 U.S.C. 2921 note) was introduced to research and deal with the causes of global climate change. This increased interest alluded to above is even more the case since both broadcast and written media reports have circulated describing the present (and former) U.S. administration's intention not to fully participate in the proceedings and demands of the Kyoto Protocol (see: Chapter Ten).

Briefly, from an international policy perspective concerning the mitigation of climate change effects, from whatever source, in general, the Kyoto Protocol to the 1992 United Nations Framework Convention on Climate Change (UNFCCC), whose target is the stabilization and reduction of atmospheric concentrations of six greenhouse gases (Ledley, et al., 1999; Chapters Four and Ten). Any mandated cuts by developed nations in these emissions, however, will be swamped by allowable increases in emissions by developing nations for the foreseeable future (Malakoff, 1997).

The United States, which contributes up to 38 percent of the world's emissions of greenhouse gases, has sought to gain emissions credits by trading with Russia and Ukraine, whose emissions are already below 1990 target levels of the UNFCCC Treaty (Masood, 1997). Nevertheless, the atmospheric buildup of these trace gases is transboundary and will effect all regions of the world. And, for example, because of the continuing change in government structure in Russia and Ukraine, among others in that region, coupled with the likelihood of further development of Caspian Sea oil

fields will no doubt lead to higher concentrations of greenhouse gas emissions from this region.

Nevertheless, governments appear to be increasingly aware of the risks associated with contemporary climate change that may occur during the coming decades. This is particularly true for low-lying small island developing nation-states (Ashe, 1999; Gable, 1987). Coastal developments should therefore be cautiously planned and positioned in locales that will be least disturbed from such environmental stress. Perhaps adequate understanding of global change as defined cannot be garnered without a fresh analysis of the scope of environmental stress arising from it or the causes and consequences of anthropogenic activities in specific regions (see: e.g., Maul, 1993; Gable et al., 1991; Gable, et al., 1990).

The concomitant global warming from anthropogenic trace gases already disbursed in the atmosphere from human-induced industrialization and agricultural practices will likely mean significant, though uncertain, changes in regional climate (Wigley and Santer, 1993). The major problems facing the marine and adjacent coastal areas will result from the additive effects of human environmental modification coupled to current environmental stress combined with those, in part, associated with climate change, such as relative sea-level rise. The latter coming, for example, from an increase in the volume of the ocean and the runoff of retreating alpine glaciers from atmospheric warming. The present and projected use of coastal and nearshore areas of the wider Caribbean region for economic development, tourism, fisheries and mariculture, waste disposal, mining of non-living resources, harbor development and municipal growth (USAID, 1987) highlights the urgency of adopting and implementing effective policies to deal with projected impacts resulting from global change.

In addition, my overall graduate school program of study research has acted as a precursor study to aid in providing elements for a study of a comparative ecological risk-ranking utilizing the wider Caribbean basin as a regional seas setting (see: e.g., Gable, 2000; Jones and Klein, 1999; Jones, 1997; Power and Adams, 1997; Shlyakhter, et al., 1995; Gentile, et al., 1993; Harwell, et al., 1992; Norton, et al., 1992; USEPA, 1990; Hunsaker, et al., 1990; Rodriguez, 1981; Tomblin, 1981; see also Chapter Eleven). A comparative ecological risk-ranking has not been accomplished for this regional sea within the Caribbean Large Marine Ecosystem (LME; see: Alexander, 1993).

A modified content analysis research method can be employed separately employing a relative risk-ranking matrix based on time for ecological recovery from environmental (i.e., habitat alteration of wetlands) and developmental (i.e., building infrastructure and coastal engineering devices such as groins) related stress. This procedure is typically intended to identify environmental policy-making options to respond to comparative risks (Morgan, 1993; Slovic, 1987; Russell and Gruber, 1987). A similarly structured content analyses has been undertaken in another LME location in the Northern Hemisphere, the Black Sea. The findings contained therein can be utilized as a policy tool guide; a peer-reviewed copy of said document can be found at the Pell Marine Science Library in Narragansett in *Ocean Yearbook* 14, University of Chicago Press, pp. 420-467 (2000).

Comparative ecological risk assessment can be employed as a tool (for vulnerability assessment) in the decision making process in order to help foster a better allocation of scarce government resources. It is a way of utilizing the best available science in policy making with a focus on impact analyses (see: Bolin, 1994;

Bretherton, 1994). Harwell et al., (1992) state on page 453 of their article that "separating broad, general relationships of ecological risks from the seemingly infinite array of individual circumstances and uncertainties of ecosystems affected by human activities is fundamentally a process of expert judgement." They also state that the "synthesis ranking of ecological risks represents the ecological issues of greatest potential danger to the environment..." (Harwell et al., 1992, p. 457; see also Fischhoff, et al., 1984).

Chapter 3. Methodology

The primary objectives of this research have been to conduct a content analysis, utilizing peer review journal articles or equivalent. This was performed in order to begin to identify in-part, through a synthesis and the technique of meta analysis (see: e.g., Crouch, 1995; Mann, 1990), global average relative sea-level rise trends and future scenarios posed by climate change in the wider Caribbean (Schneider, 1994; Schneider, 1989; see also Nicholls, 1996). Here an examination of past rates, and future scenarios of global average eustatic relative sea-level was conducted with a view towards a regional and worldwide figure, and integrating those findings with socio-economic trends in tourism data. This was attempted as an aid in determining possible or potential impacts on the beaches (see: Lorenzoni, et al., 2000). A concern is how physical changes in the coastal environment, through incremental relative sea-level rise, either has or rather, may affect coastal tourism in the Lesser Antilles where sandy beaches are quantified as being the foremost *raison d'être* for holiday seekers in the Lesser Antilles (UNIDO, 1987; Gable, 1987; see: Chapter Six).

The integration of global relative sea-level data from, for example, Raper, et al., (1996) in comparison with regional tide gauge data from the wider Caribbean will allow for an appraisal to look for a signal of, or rather, the central tendency for trends in the long-term rate of global average eustatic relative sea-level rise (future) and how that either has, or may affect wider Caribbean coastlines, if at all. Further, such findings has allowed for a determination if sandy shorelines have been, are presently, or are "likely" (>2 out of 3 chance) to become in jeopardy from inundation from relative sea-level rise, or may exhibit patterns of erosion over time (see: Chapter Seven).

The use of descriptive statistics of location allows one to find so-called central tendency of a data set of observations (Sills, 1968). Central tendency provides for the most salient features of the data set to be expressed compactly. Sills, (1968, p. 232) points out that "descriptive statistics may usually be thought of as sample descriptive statistics for very large hypothetical samples, so large that sampling variability becomes negligible." Here, in the present study what has been primarily utilized (in conjunction with meta analysis) is the sample average and generalized arithmetic mean. Thus, Sills, (1968, p. 232-233) determined that a "generalized mean satisfies intuitive restrictions including: (a)...must take values between the lowest and highest observations, (b) it must be unchanged under reordering of the observations, and (c) if all the observations are equal (which is a general requirement of meta-analysis too), the generalized mean must have their common value." The principal reasons for choosing so-called central tendency include, for the available sea-level oriented published data set, from Sills, (1968, p. 233): "a tradition of use, they are computationally reasonable, and provide useful interpretations."

The scales of measurement for which synthesis observations may be made in this study is under the rubric of interval data. The sea-level data set from one location among many (or one study among many) to another is that one object is so many units (i.e., centimeters or millimeters) more than another (Babbie, 1998; Sills, 1968). The difference in the study at-hand between interval and ratio scale, is that the interval data have a *meaningful* and measurable unit (centimeters and millimeters) but not necessarily an intrinsically meaningful origin. Sills, (1968) indicates that ratio scale data has both. Traditionally, according to Babbie, (1998) indexed interval measures refer to those variables with attributes not only able to be rank-ordered but also separated via a uniform or equal distance. "Ratio measures are same as interval

measures except that ratio measures are also based on a true zero point" (Babbie, 1998, p. 163).

Interval scale allows for an increased degree of stringency where ordinal scale (Likert survey data, see: Babbie, 1998) and nominal scales (classification into categories) are weaker methods of measurement (Sills, 1968). Where sea-level data sets provided more than one integer then the median of the observations, defined as the middle number of the ordering was initially employed (see: Babbie, 1998;). Traditionally, the median cuts the set of observations in half according to order (Sills, 1968).

The "concept of the typical is associated with the mode," (Sills, 1968, p. 237) in general, and that was not employed to the interval scale data set. The mode is generally utilized with nominal scale and frequency tables information. In addition, dispersion measures using order statistics, such as the nonparametric range, was generally not employed in this appraisal (but see: Table 2). This is because of "the disadvantages that the range is fixed by the two extremes alone, outliers often occur" (Sills, 1968, p. 239; see also Babbie, 1998). The use of interpercentile range or semi-interquartile range and similar data would only introduce subjectivity into the observations on the part of the researcher and is not recommended in studies employing the technique of meta-analysis.

Lastly, Sills, (1968, p. 239) writes that the "variance and standard deviation may be computed from a table of grouped observations in a manner analogous to that for the arithmetic mean." Variance, which may be attempted in future research, could be assumed in the historical rates of relative sea-level from tide gauges, it allows for the additive property of sums of observations similar to that used in meta-analysis.

Thus, the effect on sustainable tourism, in part, utilizing the definition of Kates, et al., (2001, p. 641) "the interaction of global processes with the ecological and social characteristics of particular places and sectors" of a rise in relative sea-level from "global change" and the subsequent loss of dry sand areas on beaches can be articulated by looking at the preceding variables (relative sea-level rise, beach erosion, coastal - beach - tourism) by a measurement of similarity between and among samples from locales in an experimental cluster (graph) analysis (see: Culhane, 2001; Krebs, 1999). From Wall, (1997, p. 486) a definition of sustainable tourism is "tourism which is in a form which can maintain its viability in an area for an indefinite period of time." Wall, (1997, p. 486) goes on to say, however, that the preceding idea "places the emphasis on the perpetuation of tourism to the neglect of other potential uses of scarce resources." That is, it may or may not be a multiple-sector approach to sustaining other activities.

In my analysis, previous publications in the literature are treated as data and are referenced accordingly (see: e.g., Figures 5 - 18). Further, similar in scope to my analyses, Culhane, (2001) describes aggregated archival data as well as natural science and index measurements to be examples of quantitative methods. The tourism data sets fit well into Culhane's description as I have utilized linear regression trend analysis with percentages to calculate information contained in the aggregated tables. The variables chosen have been aggregated or categorized further into, *inter alia*, the estimated contribution of hotels and restaurants to Gross Domestic Product (GDP), visitor stayover arrivals, purpose of visit, visitor expenditures, visitor accommodations, natural hazards such as trends in coastal erosion, and episodic tropical storm events, as well as patterns in global average relative sea-level rise.

Content analysis (see: Babbie, 1998) is analogous to "meta-analysis" in that the latter "involves combining a large number of studies on a single issue to see whether, in aggregate, they contain information that no single study provides alone" (Kammen and Hassenzahl, 1999, p. 374; see also Mann, 1990); similar in scope to content analysis (Babbie, 1998). Warwick and Clarke, (1993) state on page 222 of their article that "meta-analysis refers to a combined analysis of a range of individual case studies which in themselves are of limited value but in combination provide a more global insight into the problem under investigation." When conducting a meta-analysis there is no precedent of choice of functional form (Rosenberger and Loomis, 2000). Content analysis differs from meta-analysis in that the former is primarily centered on words (Babbie, 1998) and the latter focuses on numbers. A modified content (meta) analysis as performed here can aid policy makers in discerning appropriate responses to prospective coastal challenges posed by forecasted climate change impacts, especially from relative sea-level rise (see: Jepma and Munasinghe, 1999; also Inman and Brush, 1973).

Concerning other studies use of the technique of meta-analysis, on their economics based study on "using meta-analysis for benefit transfer..." Rosenberger and Loomis, (2000, p. 1097) utilized this methodology in order to study whether "benefit transfer is the (appropriate) application of values and other information from a 'study site' with data to a 'policy site' with little or no data," to see if what exists for that "other" site was of any value. They stated in their introduction on page 1097 that while primary research is expensive, time-consuming and a "first-best strategy," the use of the technique of meta-analysis for benefit transfer studies can be "very important in many management contexts as a 'second-best strategy.'"

Rosenberger and Loomis, (2000, p. 1097) results suggested to them that "application of meta- analysis for benefit transfers is promising considering limitations imposed by inconsistent data reporting of original studies." They utilized meta-analyses on a database composed of studies conducted from 1967-1998 "to forecast benefits at unstudied policy sites." They feel that their application of meta-analysis techniques provided them the wherewithal to "project estimates for new or unstudied activities for regions in which no studies were conducted" in a reasonable manner. Meta analysis was, in part, utilized here on a database composed of studies on sea-level conducted from 1980 to the present. This approach was used to decipher and forecast rates of rise, if any, to dates in the future for prospective policy planning (see: e.g., Figure 4).

Warwick and Clarke, (1993) utilized a meta-analysis of marine macrobenthic community data on the Northeast Atlantic Continental Shelf from an ordination of data they placed in a "production matrix." This was derived from the merging of pollution/disturbance data at the phylum level with biomass data abundance. They concocted what they termed a non-metric Multi-Dimensional Scaling (MDS) technique of all their benthic species data combined into a single meta-analysis. The scale of perturbation was determined by meta-analysis from the many samples present in their "training" dataset (Warwick and Clarke, 1993).

In another study, this one on tourism demand, Crouch, (1995) utilized the technique of meta-analysis coupled to Bayesian regression approaches on ascertaining - via a more thorough synthesis of findings in the literature - the effect of country-of-origin and country-of-destination on the estimated determinants of international tourism demand. According to Crouch, (1995, p. 106) a study two decades ago by social science organization executives and a group of journal editors determined that

"no articulated set of procedures and methods of study review and integration existed" across the literature. The traditional narrative review (narrative-discursive method) of literature was employed to integrate results across studies and that this procedure is quite subjective with conclusions framed by ascertaining patterns (Crouch, 1995). Hence, meta-analysis appears, in part, borne out of the narrative-discursive method. In general, from his analysis on page 114, Crouch, (1995) discovered that the "demand for sunlust destinations is likely to be more price sensitive" than other types of international travel. A point important for Lesser Antilles locales.

To meet the stated objectives, utilizing available information on nearby reliable sea level tide gauge stations such as Key West, Florida, (another island locale; see: Chapter Five) as a marker or baseline station, to ascertain likelihood or "goodness of fit" for similarly situated island locations, from an atmospheric or meteorological perspective, primarily in the Lesser Antilles where there is a paucity of reliable long-term sea level information to determine past rates in relative sea-level rise or to project a future plausible rise from any source. The aim has been to potentially correlate trends in aggregated/archival coastal (beach oriented) tourism information (e.g., visitor stayover arrivals, visitor accommodations) with that of data on rates of prospective global average eustatic relative sea-level rise and beach erosion in order to test if the variables presently constrain one another.

In order to foster a *marine affairs* oriented mutidisciplinary approach, the preceding was done in a proactive effort to ferret out the "best management practices" policy steps to achieve sustainability of the resource base. A variation of the "Index Based Vulnerability Assessment" methodology (found in the appendix beginning on page 114) of Yamada, et al., (1995) that they undertook in their analyses of select Islands in the South Pacific (Oceania) was attempted. They modeled and modified their

framework after the "Common Methodology for Assessing Vulnerability to Sea-Level Rise" as a 30-year time horizon described in Vellinga and Klein, (1993, p. 252), and the vulnerability impact assessment and adaptation strategies recently developed and espoused in Klein and Nicholls, (1999). The foregoing methodologies, developed under the auspices of the Intergovernmental Panel for Climate Change (IPCC), have been consulted for my analyses, though not employed in their mechanistic multistep format, in order to implement aspects of peer reviewed acceptable practices for (sensitivity) vulnerability analysis. Moreover, however, the broad based Common Methodology is considered "prescriptive in the choice of scenarios, but gives little detailed discussion of specific tools and techniques to conduct the actual analysis (Klein and Nicholls, 1999, p. 184).

Briefly, Klein and Nicholls, (1999, p. 182) elaborated in their paper that "coastal zones are considered to be highly vulnerable to the effects of climate change, including relative sea-level rise." Since about 1990 a number of significant efforts have been undertaken to develop guidelines and methodologies to assess the vulnerability. In 1992, the former Coastal Zone Management Subgroup of the Intergovernmental Panel on Climate Change (IPCC) published its latest version of a Common Methodology for Assessing the Vulnerability of Coastal Areas to Sea-Level Rise. Vulnerability of coastal zones has been defined as "the degree of incapability to cope with the consequences of climate change and accelerated sea-level rise" (Klein and Nicholls, 1999, p. 183).

More recently, the IPCC developed Technical Guidelines for Assessing Climate Change Impacts and Adaptations. Typically, these guidelines offer a generic framework, consisting of several suggested steps of analysis, that are designed to be applicable to any natural and socioeconomic system potentially affected by climate

change. Milliman, et al., (1989) developed their own interdisciplinary natural and socioeconomic based methodology in their study of vulnerability in deltaic environments to the effects of climate change with a focus on relative sea-level rise.

The Common Methodology was developed specifically for application in coastal zones. The problem definition and the selection of the method is only implied in the Common Methodology. Of note, is that testing the method is not included as an explicit step in the Common Methodology (Klein and Nicholls, 1999). Further, "the Common Methodology is prescriptive in the choice of scenarios, but gives little detailed discussion of specific tools and techniques to conduct the actual analysis" (Klein and Nicholls, 1999, p. 184). Traditionally, researchers can select the tools and techniques that are most appropriate for their specific situation. Scenarios may be selected in a similar fashion, thereby allowing for sensitivity analysis (see: e.g., Milliman et al., 1989). This last citation I have direct first-hand working knowledge.

The Common Methodology has contributed to understanding the consequences of relative sea-level rise while at the same time encouraged thinking about coastal zones in the long-term. Nonetheless, according to Klein and Nicholls, (1999) a number of weaknesses have been identified. Problems with the Common Methodology can be summarized to include the following issues. From Klein and Nicholls, (1999, p. 184) "many case studies that have used the Common Methodology have faced a shortage of the accurate and complete data necessary for impact and adaptation assessment. In particular, it has often been difficult to determine accurately the impact zone in many countries owing to the lack of basic data, such as the coastal topography. Many studies have been directed towards a single global scenario of sea-level rise (1 m by 2100), often owing to a lack of more detailed data on coastal elevations, while most studies have ignored the spatial distribution of relative sea-level

rise and other coastal implications of climate change, owing largely to a lack of regional climate scenarios."

Further, according to Klein and Nicholls, (1999, p. 184) "although the Common Methodology encourages researchers to take into account the biogeophysical response of the coastal system to (relative) sea-level rise, lack of data and models for describing the complicated nonlinear coastal processes have hindered detailed quantitative impact assessment. Many case studies have carried out a simple linear, first-order assessment by shifting the coastline landward by an amount corresponding with the sea-level rise scenario. As to adaptation, the Common Methodology has been less effective in assessing the wide range of technical, institutional, economic, and cultural elements present in different localities. There has been concern that the methodology stresses a protection-oriented response, rather than consideration of the full range of adaptation options. Market-evaluation assessment frameworks, as applied in the Common Methodology, have proved inappropriate in many subsistence economies and traditional land-tenure systems. Unfortunately, these problems are quite fundamental for any approach to vulnerability assessment and cannot be solved overnight."

Also presented is the conceptual framework for vulnerability assessment of coastal zones to relative sea-level rise as suggested by Klein and Nicholls, (1999). According to these authors (p. 182) "this framework has been developed based on a combination of (i) the Common Methodology and similar approaches, including the practical experience gained with the execution and evaluation of more than 45 vulnerability assessment studies, and (ii) other methods for coastal vulnerability assessment, which have been developed in response or in addition to the Common Methodology."

Yamada, et al., (1995) state on page 101 of their article that their methodology is "flexible; it does not depend so much on data referring to natural and social conditions." Further, they employed a "semi-quantitative evaluation" typically utilizing an ordinal scale, i.e., a rank order methodology (also utilized academically in a study on the Island of Rhodes for coastal management policy applications; see: Moriki, et al., 1996), based upon degrees of vulnerability of select variables that they list in their paper. They further utilized any past vulnerability assessments for similarly situated geographic locales, scientific judgement (from the literature) and expert judgement.

Yamada, et al., (1995, p. 105) suggest that their "framework itself can be transferred to different regions and countries." Therefore in order to fit data/information into the several "steps" typically performed in the United Nations Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies (Klein and Nicholls, 1999) an overall content (meta) analysis was undertaken. Though, however, the data used in the present study was either interval or ratio scale in nature and does not provide a good fit for the Index found in Yamada, et al., (1995) which was based more on their own expert judgement concerning degrees of the vulnerability of each system under study. Consequently, information was gleaned from their work in the Pacific island archipelagoes and "grided" to the Lesser Antilles as a proxy where appropriate. Ordinal scale subjectivity was purposely avoided in the present appraisal as much as possible.

In terms of being a part of a values jury, or expert panel (see: Brown, et al., 1995), I have previously served on a United Nations Environment Programme initiated task team study under the auspices of the Regional Seas Programme in cooperation with the Intergovernmental Oceanographic Commission of the United

Nations Educational Scientific and Cultural Organization (UNESCO). That study, *Climate Change in the Intra-Americas Sea* (see: Maul, 1993), had specific "terms of reference" to follow for the assessment. One of these included the examination of the possible effects of relative sea-level changes on coastal ecosystems and on socio-economic structure and activities (Maul, 1993; see also *inter alia* Gable, et al., 1991; Gable, 1987). I have chosen to concentrate and focus in on aspects of climate change primarily in the Lesser Antilles as enunciated in Chapters One and Two.

The point here is that I have already served as an invited "task team" member of an expert (values) jury based on first-hand experience (see: Brown, et al. 1995) and have traditionally utilized and incorporated as Maul, (1993) writes in his preface on page v that "the best available existing knowledge about and insight into the problems relevant to the subject of the study" while employing "assumptions accepted at the International Conference in Villach, Austria" in October of 1985 (Maul, 1993).

At that time, in Villach it was assumed that an increased temperature of 1.5 degrees C would foster a concomitant eustatic relative sea-level rise of 20 - 140 cm before the end of the 21st century (Maul, 1993). The present study appraises the potentiality of those original assumptions in the Terms of Reference we, as a "task team" values jury had to go by (see: e.g., Chapter Five). Further, Maul, (1993, p. v) wrote that there was an "understanding that these estimates will be revised on the basis of regional scenarios yet to be developed." The present study aids in providing a reassessment of those original sea-level estimates to the best available existing knowledge readily accessible (see: Lamb, 1987).

Babbie (1998, p. 330) presents content analysis as referring "to the directly visible, objectively identifiable characteristics of a communication, such as specific words." As used for this study the analysis is principally taken from peer review periodicals or equivalent, concerning relative sea-level rise (a physical parameter of global environmental change), with that of meta-analysis, i.e., typically numerical (see: Crouch, 1995; Mann, 1990). Babbie, (1998) highlights procedures and sources of content analysis as including, for example, newspapers, magazines, books, and periodicals (journals). It is the latter, best available existing knowledge, principally of the peer-review variety that the present study has primarily utilized in the global average relative sea-level rise exercise as an aid in natural resource decision making (see: Brown, et al., 1995).

The operational choice was the unobtrusive method of data collection: content analysis of communications (words and numbers/rates) of relative sea-level rise for the purpose of ascertaining past, present, and forecasted scenarios of relative sea-level rise. The past rates as tabulated from pertinent studies of tide gauge data. These are then presented in tabular and figure format (Figures 4 - 18; Tables 2 - 7). The suggested future scenarios may depict a potential increasing rate of rise due to global climate change (Taylor, 1999; Figure 4). Central tendency measures between and among authors' published rates of global average eustatic relative sea-level rise indicate trends in the level of the "means" of those data over time (French, et al., 1995). Medians and mean calculations of data, have been calculated for indexed data (Babbie, 1998), that illustrates a reassessment of "best guess" estimates (and or trends) or span of estimates over time of projected global average eustatic relative sea-level rise to points in the 21st century from studies accomplished during the last twenty or so

years. The choice of studies commencing in 1980 is because there were few studies of (global average) relative sea-level rise prior to the frenzy of the "greenhouse effect" which was only introduced and discussed, more or less, in a contemporary scientific manner by Broecker, (1975).

Analysis of a cadre of published studies such as Gornitz, (1995) and similar manuscripts, has provided for a central tendency determination of future scenarios in the ranges of global average eustatic sea-level rise, and an overall synthesis of past rates. This appraisal performed in this study and elaborated on further in subsequent chapters has aided in determining prospective policy responses for the likelihood of beach inundation and loss of dry sand above mean high tide for tourists to recreate in the future. The variables can be experimentally measured and displayed for similarity in an aggregated cluster (graph) analysis which is a term applied to the techniques utilized to develop classifications (see: Krebs, 1999). Policy information has resulted from the cluster (graph) analysis of the content (meta) analysis (see: Chapter Nine). For example, realizing that threatened and endangered species such as sea turtles rely upon sandy beaches in Caribbean island locations to lay their eggs, ought to be considered in any policy formulation and response to "global change" via a hardening of the shore by engineering structures.

Meta-Analysis & Regression Analysis

For this study the units in meta-analysis are global average eustatic relative sea-level rise rates primarily calculated in either millimeters or centimeters (e.g., per 100 years) (from: *inter alia* e.g., Raper, et al., 1996; Gornitz, 1995; Titus and Narayanan, 1995). The research plan has been to analyze a body of textual materials with the units of analysis being a combination of themes, words and concepts (such as those

synthesized and depicted in Tables 2 - 6, for example) as it relates to global environmental change with specificity given to average eustatic relative sea-level rise. Further, the plan has been to determine the effect of a potential rise in relative sea-level (physical parameter) with coastal tourism utilizing sandy beaches (the behavioral social parameter utilizing review data of the CTO).

First, it had to be determined if visitor arrivals to the Lesser Antilles were actually on "holiday" or vacation and secondarily ascertain if they were, what were their reasons for sojourning to the West Indies (see: Figures 19 - 24; Tables 12 - 19 further reviewed in Chapter Six). In addition, it was important to quantify any long-term trends the stayover visitor arrivals and related data may indicate. Were there more international stayover visitor arrivals coming to the wider Caribbean and more specifically the Lesser Antilles today than there were in 1970 or 1980? Those years provide a timeline prior to the greenhouse effect being prominently raised. Data archived through the Caribbean Tourism Organization provided the opportunity for this interdisciplinary assessment (*inter alia* Tables 11 - 30).

The intent was to seek policy responses (e.g., setbacks, beach replenishment, environmental audit standards) to the conceivable consequences, if any, of - as Bird (1996, p 87) states: "coastal erosion is facilitated by rising sea-level, which brings wave action to progressively higher levels and permits higher waves to reach the coast through deepening near-shore waters." "The effect of any amount of future sea-level rise will be an increased rate of coastal erosion as waves will break higher on bluffs and dunes...for any given storm intensity" (Boothroyd, et al., 1998, p. A5-9). They also state that relative "sea-level rise is the variable factor affecting projected shoreline positions" (Boothroyd, et al., 1998, p. A5-18). One policy response, development setbacks, analogously discussed at length for another coastal Atlantic Basin area, can

be found as a related proxy location sidebar presentation in *Ocean Yearbook* 15, pp. 299-300 (2001).

Mann, (1990, p. 477) aptly describes, in a sidebar in his paper, examples of "how to perform a meta-analysis." The logic of the "odds ratio" analysis example given in Mann, (1990, p. 477) has been contemporaneously employed, via a synthesis of available studies, initially to test if there exists a recent past relative sea-level *rise* signal in the tide-gauge record (see: Chapter Five), and there is (see: Figures 5 and 6; Table 2). This was done in response to several related questions posited in the literature by several researchers. For example, one question posed by Ross, (1995) on page 355 of his book *Introduction to Oceanography*, was titled "is sea level rising?" Ross, (1995) postulates that "while sea level in one area is falling, it is rising in another area, and determination is relative to the status of the land. A trend may be determinable locally, but the simultaneous trend worldwide is elusive and often confusing in direction. And there is another problem: tide gauges - devices that measure the height of sea level - have only recently been placed in many critical regions of the world."

Similarly, Gornitz, et al., (1994, p. 481) asked in their scientific note "is sea level rising or falling?" They were responding to a recently published manuscript that according to Gornitz et al., (1994, p. 481) "estimated that the net effect of groundwater mining, wetland drainage, deforestation and water impoundment in reservoirs adds 0.54 mm per year to global (relative) sea-level rise. Our calculations, however, suggest that these processes may have acted to reduce (relative) sea-level rise by an amount comparable to that observed." A couple of years earlier Shlyakhter and Kammen (1992, p. 25) weighed in with their inquiry: "sea-level rise or fall?" They were concerned with "how a change in the accepted values of parameters in climate-

change models can completely alter the conclusions, turning a predicted (relative) sea-level rise into a predicted fall."

Likewise, on a more futuristic note, Schneider (1992) asked in his commentary piece "will sea levels rise or fall?" Perhaps much of the confusion was in response to other views that suggested that the greenhouse effect would have a "reduced rise in sea level" (see: Meier, 1990, p. 115) than some earlier 1980's era studies had predicted. Or, perhaps these not so whimsical studies noted above were just responding to the contentious article by Miller and de Vernal, (1992, p. 244) titled "will greenhouse warming lead to Northern Hemisphere ice-sheet growth?" Miller and de Vernal (1992) stated on page 246 of their article that their models led them to consider the "possibilities that increased concentrations of greenhouse gases in the atmosphere might lead to ice-sheet growth and a concomitant sea level fall of up to 7 mm yr⁻¹." Schneider, (1992, p. 11) responded that "recent estimates of a global sea-level fall as a result of greenhouse warming have been uncritically accepted. A closer examination of the available data could lead to the opposite conclusion." Thus, such a closer examination by way of a synthesis was pursued in this study.

The overall importance of the preceding described situation can be seen directly affecting sustainable sandy beach oriented tourism initiatives in the Lesser Antilles of the wider Caribbean. For example, one geological scientist - Meier, (1990, p. 116) - mentions that "it does appear that a (relative) sea-level rise of one meter by 2050 is unlikely. But even a 30-cm rise will cause social and economic problems in low-lying areas: this modest rise corresponds to a retreat in shoreline of 30 m or more, unless artificial protection is established." It is unclear where Meier, (1990) got his information regarding the relationship between relative sea-level rise and "corresponding retreat in shoreline."

Much of the preceding descriptive turmoil has not been rectified in the relatively recent IPCC studies available either. Hence, the need existed to carry out an assessment of past, present, and future global average eustatic relative sea-level change, that was performed here. A caveat regarding "testability," is that Berger and Berry (1988) on page 163 of their article state "consumers of data want a final probability; they want to know how probable it is that the hypothesis is true in light of the data...standard statistics cannot answer this question." They go on to say that "our basic thesis has been that objectivity is not generally possible in statistics and that standard statistical methods such as P-values and confidence intervals can produce misleading inferences" (Berger and Berry, 1988, p. 165). With the preceding caveat I chose the methods described earlier and employed in this analysis; and utilized the terminology found in Mahlman, (1997; Footnote 1).

In essence, in the climate change community vernacular is it "very likely" that the tourist beaches will eventually disappear from incremental relative sea-level rise? Or might they disappear from other natural events possibly in synergy with relative sea-level rise? It is important to clarify, however, as Bird (1996, p. 87) states that "the modern prevalence of beach erosion on the worlds' coastlines is not, therefore, an indication of global sea-level rise - however, if such a sea-level rise develops, perhaps as a consequence of the greenhouse effect, there will be an acceleration of existing beach erosion, and erosion will begin on many beaches that are now stable or growing." This is very much a policy concern for sustainability of the natural resource base. For studying past and future relative sea-level rise the use of empirical peer review studies, such as, *inter alia*, Raper et al., (1996) and Gornitz, (1995); that according to Mann, (1990, p. 478) "fundamentally, meta-analysis is observational in

nature, in the case of meta-analysis what is there consists of studies done by other investigators," this dataset was subsequently analyzed.

Another of the original aims for the present study was to utilize UNESCO - Intergovernmental Oceanographic Commission data of beach erosion or progradation rates registered in either feet or meters, or variations of both, on Lesser Antilles locales to ascertain if selected tourist oriented beaches have been actively eroding (Bird, 1996). Most of these data sets, for up to the past twenty years or so, were available via Puerto Rico Sea Grant information available at the National Sea Grant Depository in Narragansett (see: e.g., Cambers, 1998; Cambers, 1997). These aggregated data indicate if certain sandy beaches are actively eroding. This synergistic situation of what Bird (1996) alluded to above, (i.e., relative sea-level rise effecting erosion/inundation of sandy beaches) would then have ramifications in the sustainability (i.e., no beach - no tourists - loss of revenue) of coastal tourism in the wider Caribbean (Lesser Antilles) under study (see also Gable and Aubrey, 1990; Gable, et al., 1990). This can, in part, be quantified with this present study as long as severe episodic storm data are also, so to speak, brought into the overall equation (see: Chapter Eight).

For tourism data, linear regression trend analysis has been performed on available information from the Caribbean Tourism Organization (CTO), a reliable database source. An attempt was made in a comparison of past trends in relative sea-level rates and coastal tourism data to see if there were any indications that these variables are in any way refuted. Coastal tourism data can be disaggregated to look at beach erosion and relative sea-level rise because some of the data is collected indicating if the stayover visitors are partaking of activities on a beach. This then provides a proxy for similarly situated nearby locales. The base from which the counting was done was determined through the review process of the documents and CTO data.

"Analytical induction" (Babbie, 1998) was the outcome of the study because more than just description, trends, relationships and patterns between and among variables was noticed (see: e.g., Figures 29 and 30).

Part of the trend analysis as used for tourism data in this report, incorporates the technique of regression analysis - a general and known statistical tool. Sills, (1968, p. 310) mentions that it "is applicable to situations in which one observed variable has an expected value that is assumed to be a function of other variables." In the case at hand visitor stayover arrivals depend upon sandy shorelines for their holiday pleasure. The use of simple linear regression (while utilizing spreadsheet software) is that it is traditionally desirable to plot (graph) a diagram of the points that represent the observations (see: e.g., Figures 25 - 33). The figure or graph illustrates the two parameters, slope and intercept of the line.

Regression analysis is typically used as a predictor, that is, what might the trend in the available data forecast at some chosen future date, perhaps using a 10 to 20 year planning horizon, while providing a confidence number that hypothesizes what the graphed data actually denotes. The closer the confidence number is to "1" the "maximum likelihood" (also known as least squares; Sills, 1968, p. 312) estimates of the parameters observed or described will perform similarly going into the future. That is, going forward to some set date, the future will mimic the recent past trend. Sills, (1968, p. 315) emphasizes that the application of the "regression equation is usually determined not only to provide an empirical law relating variables but also as means of making future estimates or predictions." The spreadsheet software employed for this task provides a "least squares" (or maximum likelihood) fit to the data. It is the choice by which most methods of estimation for linear models is based (Sills, 1968).

Sills, (1968) suggests that many assumptions in regression analysis can be shown by least squares; that is, the maximum likelihood estimates of the parameters. For clarification, according to Sills, (1968, p. 310) "the techniques of regression analysis may be classified into two kinds: (1) testing the concordance of the observations with the assumed model, usually in the framework of some broader model, and (2) carrying out estimation, or other sorts of inferences, about the parameters when the model is assumed to be correct." In addition, one figure of all major and minor Atlantic Basin hurricanes from 1944-2000 (Chapter Eight; Figure 60) was compiled to include a "moving average" that provided trend information that a simple average of all historical information would likely mask.

Chapter 4. Greenhouse Gases

Posing the most prominent and complex ecological risk today is the "greenhouse effect," that is the opinion or judgement of most science researchers (Ledley, et al., 1999; Pew Center on Global Climate Change, 1998; Broecker, 1997; Knauss, 1997; OSTP, 1997; Morgan and Keith, 1995; Nordhaus, 1994; Kempton and Craig, 1993). The role that an anticipated spiraling of climate change may have upon the ecology of the world in only a short period of time appears to dwarf other problems facing the Earth (Taylor, 1999; Retallack, 1997). Understanding the human dimensions of risk posed by climate change from the so-called greenhouse effect, however, is both an art and a science (Stern, 1993; Stern, et al., 1992).

"Global change" is defined as alterations in climate, land productivity, oceans and other water resources, atmospheric chemistry, or ecological systems, including global warming, which are significant enough to influence the future hospitality of the Earth, whether such changes are caused by natural cycles or by anthropogenic activity, or a combination of both (see: Pernetta, 1995, pp. 1 - 3: International Geosphere-Biosphere Programme of the International Council of Scientific Unions). Separating the likely impacts of human induced climate change as distinguished from those emanating from natural variability remains highly uncertain and quite questionable to some (La Rochelle and Spencer, 2001; Metzner, 2000; Hulme, et al., 1999a & 1999b).

The cause for concern of present and future global warming is believed due in part to anthropogenic (human-induced) buildup of increased atmospheric trace gas loading from carbon dioxide, methane, nitrous oxide, tropospheric ozone, chlorofluorocarbons (freons), and water vapor, all of which absorb infrared radiation

(Ledley, et al., 1999; Mann, et al., 1998). These trace gases individually and collectively change the radiative balance of the atmosphere and may cause a rise in global mean surface air temperature by trapping more heat near the Earth's surface. As a consequence, climatologists generally agree that significant global warming is likely.

Increases in these radiatively active atmospheric gases are due principally to their use in industrial developments such as refrigeration and air-conditioning, computer semiconductors and combustion of fossil fuels (Hall, 1989). Deforestation, however, is thought to contribute considerably to carbon dioxide buildup (Myers, 1988), and may even promote climate change (Repetto, 1990). The carbon dioxide buildup in the atmosphere increased from around 270-290 parts per million volume (ppmv) to about 355 ppmv — about a 20-25% expansion — from the turn of the century to the mid 1980's (Schneider, 1987). For example, it increased by more than nine percent during the thirty year timeframe ending in the mid-1980's (Rowland, 1988). The importance of these trace gases is related to their residence time in the atmosphere. The residence time of carbon dioxide in the atmosphere being so long while many others last for tens of years and their dispersal is global no matter where or what their source (Graedel, 1989; Tables 9 and 10).

Over the past century or so, the average global temperature rose by about 0.55°C, and the average and trend of temperature increase between the thirty year timeframe of 1958 and 1988 correlates closely with the growth in atmospheric carbon dioxide concentrations (Kuo et al., 1990). If as projected, the buildup of these trace gases continues as it has, a doubling of the concentrations of these “greenhouse” gases (relative to a pre-industrial atmosphere ca. 1860) may occur as early as thirty or so years from now. This increase may produce a global rise of surface air temperature of 1.5° to 4°C (IPCC, 1992). There is, however, a considerable lag time (generally 2 to

10 decades) before the warming appears, because of absorption of some of these gases into "sinks" such as the oceans (Bullister, 1989; Cess and Goldenberg, 1981).

Future temperature trends resulting from trace gas and carbon dioxide buildup are unlikely to be uniformly distributed over the globe (Jones et al., 1988). Although the earth was about as warm during the 1930's and 1940's as it has been quite recently, this earlier warming was concentrated at high northern latitudes, while the recent warming (not in keeping with earlier climate model predictions) has been most discernible in the southern hemisphere and parts of the tropics (Parker and Folland, 1988). Consequently, the warming since 1947 is much more significant in middle and low latitudes when year-to-year variability of real world global temperature trends, both land and marine, are considered (Jones et al., 1988). These recent trends in global warming — despite the problem of homogeneity of data (Jones and Kelly, 1988) — can be compared with a mean global warming of about 0.55° C (1°F) since 1880 and an average global temperature increase of 5° - 6° C since the last ice age.

Projected changes in global and regional climate during the next 50 or so years are likely to be controlled by alterations in the concentrations of radiatively active gases, commonly known as "greenhouse gases." Generally, trace gases individually and collectively alter the radiative balance of the atmosphere and may cause a rise in global mean surface air temperature by trapping more heat near the Earth's surface. As a consequence, climatologists commonly agree that significant global warming of the past century - about 0.5° C (Karl, et al., 1989) to 0.55° C (Kuo, et al., 1990) - is not the result of faulty interpretation of climate records such as the progressive warming due to urban growth (Kerr, 1989) though this is not without controversy as to the breadth and magnitude of such changes (Hulme, et al., 1999a & 1999b). These results, however, include some portion resulting from changes in atmospheric

greenhouse gas concentrations and aerosol loading (Stouffer, et al., 1994). Indeed, this twentieth-century warming trend is reasoned not to be a wholly natural climatic oscillation (Schneider, 1994).

In addition, many of these gases also interact in various ways and time periods with non greenhouse gases, such as carbon monoxide, smoke and sulfate aerosols (Schlesinger and Ramankutty, 1994; Kiehl and Briegleb, 1993). As their concentrations increase, there will be increased global warming coupled with an intensified hydrologic cycle. The effects of methane on the atmosphere, for example, can be hastened by its interaction with carbon monoxide, which itself has the ability to decrease the self-cleansing mechanism of the atmosphere, sort of a cascading effect. Sulfur Dioxide affects the atmosphere by reflection of solar radiation (Fuglestvedt, et al., 1994).

Forecasts of global climate changes are typically projected with General Circulation Models (GCM's) using mathematical calculations and relationships (see: e.g., Weaver and Hughes, 1994). For tropical regions during the next century, extrapolated increases in mean temperatures on the order of 0.3° to 5.0°C are anticipated (Wigley and Santer, 1993; Jaeger, 1988); however, to this day the true geographical distribution, magnitude or timing of the increases remain uncertain. In tropical low latitude regions, including nearly all the wider Caribbean, temperature increases are expected to be smaller than the average global rise. Although regional precipitation patterns are the most uncertain forecasts of the major climatic variables, studies suggest an enhancement of intense rainfall in the presently rainy low latitudes (Maul, 1993). Heavy rainfall results in a depletion of elements from surface soils by pronounced leaching and increases erosion which can contribute to sedimentation build-up at the littoral. Increased erosion may in turn increase water column turbidity

and adversely affect coral reefs through the aforementioned sedimentation process (Williams, et al., 1987). Guilderson, et al., (1994) studies of Barbados corals indicate that the western tropical Atlantic (wider Caribbean) is sensitive to climate change and is capable of changing rapidly in a geologic time scale sense. The lack of resolution of climate changes on a regional scale — even for surface hydrology, precipitation, cloudiness and contemporary warming — precludes, however, unsustainable policy actions that would favor draconian measures at present (see later).

Projected increases of these trace gases due to past, current, and expected human activities - such as the expanded use of wood and fossil fuels for combustion - have been used as inputs to mathematical models to examine global climate changes. The mathematical models are, in general, based upon imperfectly-known geophysical and geochemical relationships and data. Yet, estimates of global climate change have been made based on these models, earlier forecasts allowed for projecting increases in mean global temperatures in tropical regions of 0.3°-5°C during the next century (Ledley, et al., 1999).

Within this century, in part, perhaps as a result of anthropogenic activities, average global temperatures are projected to be warmer than any experienced during recorded history (Broecker, 1995). And generally, instability in the climate of the North Atlantic region through the millenniums is the rule rather than the exception (Dansgaard, et al., 1993). Even a small increase in the average global temperature would likely cause dramatic shifts in world agriculture production (Rosenzweig and Parry, 1994), disrupt national economies, and raise sea levels (Titus, 1993; Woodworth, 1993) flooding coastal municipalities, wetlands, and other areas. Already, human activities are producing changes unprecedented in recorded history, in

global air quality, patterns of deforestation, and abundance and distribution of plant and animal species affecting biological diversity.

Global change science research transcends the boundaries of traditional scientific disciplines and requires an interdisciplinary approach to studying the entire Earth system and its history, including the atmosphere, oceans, ice, soil and solid earth, biota, and solar influences (Kates, et al., 2001). An important goal of global change studies is to develop the capability to project significant global changes, both natural and human-induced (and the synergy that exists between the two). Later in this manuscript specifically addressed are past levels, and future projections for global average eustatic relative sea-level rise.

Associated with the global temperature warming aspect of climate change are the secondary responses, altered precipitation patterns and increases in sea surface temperature — leading to changes in storminess, longshore winds, cloudiness and changes in the aforementioned relative sea levels (Maul, 1993). Specifically associated with global warming will be changes in meteorological (e.g. storm and precipitation) and oceanographic (e.g., sea-level rise and circulation) patterns. While the magnitude, timing, and geographical distribution of these climatic changes cannot be forecasted with a high degree of certainty, generalized large scale projections of these changes have been extrapolated with the aid of general circulation models (GCMs) (Parker and Folland, 1988).

At present, none of the GCM's have the capacity to forecast meaningful regional “fingerprints” for contemporary warming (Dickinson, 1986), precipitation (Grotch, 1988), or offer detail on regional surface hydrology, notably soil moisture and runoff (Gleick, 1987). Nor do the models typically address concomitant relative

sea-level rise in concert with atmospheric warming projections (Long, 2000; but see: IPCC, 1994; IPCC, 1992). The lack of regional scale model resolution of global changes limits the ability of Lesser Antilles governments to interpret and understand the implications of climate change and respond effectively by implementing a sustainable management strategy (Smith and Pitts, 1997).

As will be elaborated more in-depth in a subsequent Chapter, for example, Aubrey et al., (1988) have ascertained historical rates of relative sea-level in the Caribbean. Their results indicate that the rates of change over the past half century or so vary from an emergence (sea-level lowering) of 5.3 mm/yr. to a submergence (sea-level rising) of 9.3 mm/yr. throughout the Caribbean Basin (see also Emery and Aubrey, 1991). The recent global rate of sea-level rise, determined from tide gauge stations may exceed 2.0 mm/yr. (Peltier and Tushingham, 1989), though for the past century it is generally believed to be 1 mm/yr. to possibly 2 mm/yr. (see: Chapter Five).

Other influences upon the coastal zone from climate change may be erosion, leading to shoreline retreat (see: Chapter Seven) tidal range alterations, leading to flooding and saltwater intrusion further inland; changes in ocean chemistry through ocean pH from atmospheric CO₂ doubling; and biological effects, leading to changes in species representation (biodiversity) and productivity in both marine and terrestrial ecobiomes (Viles, 1989). Due to the complicated nature of this subject, however, not all aspects of global change are included in this study.

Among the most effective greenhouse gases are carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), water vapor and the Chlorofluorocarbons (CFC's), all of which have been enhanced by the emissions from anthropogenic

development activities spewed into the atmosphere (Ledley, et al., 1999). Chlorofluorocarbons and bromide-containing halons are entirely anthropogenic in origin; there remains a "black market" for some of these regulated or banned chemicals. The concentration of these atmospheric radiatively active gases is clearly increasing and has coincided with all of the warmest years in the 20th century occurring in the 1980's and 1990's, with 1998 suggested as being the warmest on record thus far (Bell, et al., 1999). This trend in warmer temperatures is forecast to continue well into the next century (see: *inter alia*, Trenberth, 2001; Broecker, 1997; Nameroff, 1997).

What remains undifferentiated, however, is whether this warming trend is actually related to greenhouse gases in the atmosphere, or merely natural disturbances in weather patterns (Nordhaus, 1994; Lindzen, 1990). Many researchers have now come to believe that the "balance of evidence" suggests discernible anthropogenic influences in the climate record (Trenberth, 2001; Santer, et al., 1996; Santer, et al., 1995). Understanding the frequency and magnitude of natural climatic fluctuations is necessary to reduce the risk from climate change and to implement proper policy decisions such as the attempts being made under United Nations auspices relating to the Intergovernmental Panel on Climate Change (IPCC; Shlyakhter, et al., 1995). The IPCC is comprised of international scientists, diplomats and politicians, among others, who attempt to discern via consensus what scientific evidence exists for "Global Change" (Schrope, 2001; Skodvin, 2000). This situation can be somewhat problematic.

More of the basic tenets of the greenhouse effect and its global and regional affects upon the coastal marine environment can be found in several academic oriented writings (see: e.g., Sarnthein and Wang, 1999; Druffel, 1997; Liang, et al., 1995;

Schmandt and Clarkson, 1992; Gable, et al., 1991). An assessment of coastal vulnerability to climate change (see: Klein and Nicholls, 1999) is a relevant *marine affairs* topic for study. Moreover, Hinrichsen (1996) already depicts coasts to be in crisis irrespective of climate change effects. Further, the governance of many large marine ecosystems (see: e.g., Juda and Hennessey, 2001; Juda, 1999) will take on added dimension with potential cumulative effects problems associated with issues found in the United Nations Framework Convention on Climate Change with or without participation from the United States.

It has been projected by various scientific agencies and groups that the pre-industrial concentrations of greenhouse gases will double by the years 2025-2030, a time period for which many computer models have been formulated. General Circulation Models (GCM's) forecast a mean temperature increase of 1.2 to 2.0° to as much as 3.5-7.0° Celsius (Karl, et al., 1997; Manabe and Stouffer, 1993). It is important to remember that as yet, climate models do not have the ability to take into account air-sea interactions, changes in oceanic (and marginal sea) circulation patterns, changes in snow cover (and hence albedo) and, most importantly, changes in cloud cover, water vapor and precipitation patterns (Giorgi, 1995; Weaver, 1993).

The link between cloud micro-physics and climatic change remains one of the major areas of uncertainty, for a review see: Ramanathan, (1998 & 1988). Precipitation patterns will likely shift with range estimates suggesting that present-day precipitation/evaporation patterns will be accentuated, such that dry environments will become even drier. Even the amount of snow cover can have a dramatic effect on global climate especially if it precipitates more in polar and near-polar locales (see: Mitrovica, et al., 2001). Many of the early assumptions regarding the 21st century made in United Nations Environment Programme (UNEP) climate change studies, for

example, assumed a 2-3° C temperature change and a corresponding 25 cm increase in global average eustatic relative sea level - leaving some coastal areas vulnerable (see: e.g., Maul, 1993). These figures periodically change, especially the global average sea level forecasts identified in Chapter Five, but the general trend in the predictions remain fairly constant.

Exactly how climate will change in all regions of the world is unknown. Comparison with Greenland ice cores, however, shows that CO₂ levels shortly will surpass any seen during the late Quaternary Period (Broecker, 1997; Broecker, 1987) suggesting that some change in climate will be felt. Increased temperatures in warmer climates will likely result in greater energy demands, especially for summer cooling. For many countries with mean annual temperatures greater than 20-25°C, the relative temperature increase may be slight. Yet, locally in cooler climates (e.g. mountainous and more northern areas) the temperature rise may have greater significance. Altered patterns of precipitation and the general increase of evaporation related to elevated air temperatures, also may be an important consideration.

Climatic change caused by the greenhouse effect will be manifested in other ways than simply temperature warming. Increased air temperatures will lead to increased evapotranspiration, meaning that precipitation will need to increase in order to maintain or increase net precipitation (precipitation minus evaporation) levels. Global warming is projected to force the sub-tropical high pressure system southwards, thereby leading to decreased rainfall in many of the areas already receiving sparse amounts of precipitation. A dramatic change in net precipitation, for example, can greatly affect the success or failure of agricultural harvests and river flow, a problem that may be particularly troublesome in presently semi-arid climates. Some analyses predict dramatic change in grain yield, while others suggest that the

environment may be able to absorb gradual climatic change. It is not inconceivable that present day climatic change could bring about a mean shift of entire vegetative zonations.

Another problem relates to the frequency and intensity of storms with climate change, discussed more in Chapter Eight. It appears that storm intensity (but not frequency) may increase (Emanuel, 1988). The impact of greater storms presumably will be felt particularly in low-lying areas subject to coastal flooding (van der Vink, et al., 1998), especially with rising sea level (Milliman and Emery, 1968). Although the uncertainty is great (see: e.g., Reilly, et al., 2001) it seems plausible to many researchers to explain an approximately 12 cm global average eustatic relative rise of sea level during the past 100 years by assuming a 0.5°C increase in temperature for the same period with most of the rise attributable to thermal expansion of the volume of the sea and alpine glacial melting (see: Chapter Five). Briefly, global warming can change relative mean sea level (RMSL) in two principle ways: through increased melting of ice and the expansion of the ocean by heating i.e., thermosteric change. Ice melt includes the melting of land-locked ice, principally mountain glaciers and the Greenland and Antarctic ice-caps, as well as the Antarctic ice-shelves.

The effect of climate change on the marine environment and hence upon wind patterns over the oceans is not clear. On one hand, some models predict intensification of alongshore wind stress, which may lead to an acceleration of upwelling (Bakun, 1990), thus probably at least leading to increased biological productivity. On the other hand, since land probably will warm preferentially to the ocean, in many areas the temperature difference between land and sea will decrease, thus fostering a slackening in the strength of onshore-offshore winds.

While lack of historical scientific data in the wider Caribbean means one must accept considerable uncertainty in determining local effects of global changes, nonetheless it is possible to anticipate significant consequences. Historical temperature change contains a large amount of spatial and temporal natural variability. In regions such as the wider Caribbean where there is incomplete tidal and weather station coverage, estimates of past and future temperature changes need to rely on extrapolation from other regions (see: Wigley and Raper, 2001; Kates, et al., 2001; Gable and Aubrey, 1990). Although the earth was about as warm in the 1930's and 1940's as it is today, the earlier warming was concentrated at high northern latitudes, while the recent warming is more global (see: e.g., Hulme, 2000). It is not clear how one interprets the recent historical temperature change trends in light of these model results.

Chapter 5. Relative Sea-Level Rise (Change)

Predictions of continued global warming, albeit at an uncertain rate, suggest the potential for increases in relative sea-level rise and storm intensity in the wider Caribbean. One of the problems of these forecasts is that they lack a sense of realism and immediacy for the involved countries and populace since many projections go out three decades or much longer. Consequently, it can be difficult at times to garner the political and public support necessary for capital investitures and alterations of profitable socio-economic patterns such as tourism development to minimize potential impacts. Moreover, as described in Borgese et al., (2000, p. 756), the Intergovernmental Panel on Climate Change (IPCC) "had found that humanity's emission of greenhouse gases were likely to cause rapid climate change and that, according to climate model predictions, the global temperature would rise by about 1 degree to 3.5 degrees Celsius by 2100. If current trends continue the mean sea level is expected to rise by some 15 cm to 95 cm by 2100, causing flooding and other damage." One can view the tremendous amount of uncertainty (i.e., range), or hedging in the prognosis for both temperature and relative sea-level rise by the IPCC (see: Allen, et al., 2001).

One approach to resolving this dilemma is to identify existing local alterations in physical structures (beaches), physical processes (erosion), ecosystems (wetlands, corals, etc.) and socio-economic patterns (tourism activity data; building set-backs) to illustrate what future conditions could be from impacts related to global warming. The examples presented in this manuscript illustrate how existing human activities combined with natural processes are causing impacts in the wider Caribbean (Lesser Antilles) and offer an opportunity to study the future conditions anticipated to occur from rising relative sea level and increased storm intensity (see: Emanuel, 1999).

To set the stage it is also important to consider that the rapidly expanding population of the wider Caribbean is making increasing demands for the limited coastal resources and the space the natural resources occupy. These demands are both direct and indirect. Direct demands include, among others, encroachment of development on the coast, mining of sediment for aggregate, and construction of shore protection devices. Indirect demands include those imposed as a secondary result of human activity, examples of which are global warming and relative sea-level rise, partly resulting from local land-use practices. These human activities have combined with natural environmental variability to form some distressed areas within the wider Caribbean. Examples of these distressed areas, resulting from varying mixes of causes, are presented throughout this manuscript.

The threat of anthropogenically-induced global environmental change on the coastal zones (Walker, 1984; re: *coastal belt*, that is, interactions between inshore-onshore-offshore activities see: Juda and Burroughs, 1990, p. 28) of the wider Caribbean varies from place-to-place, because of: 1) differences in exposure to episodic storms, 2) dissimilarity in local geology, including tectonics and subsidence (Dillon, et al., 1987; Mattson, 1984; Stienstra, 1983), and, 3) the resulting regional choices in land-use practices (Inman, 1994). For the making of policy decisions, there is some confusion over the issue of the position of past sea levels in parts of the wider Caribbean when analyzing the geologic record. One problem is the inference that in the Bahamas, for example, relic (fossil) beaches, sea cliffs and coastal notches indicate the position of historical relative sea-level rise (Neumann and Hearty, 1996).

These authors conclude that "from 132 to 118 ka (thousands of years ago) sea level stayed +2m, as evidenced by maximum fossil coral elevation. A rapid rise from

this level to +6m cut bioerosive notches during the stable interval of no more than a few hundred years. Then, at about 118 ka, a rapid fall of sea level abandoned the notches, stranded reef corals..." (Neumann and Hearty, 1996, p. 778). Thus, sea level "crested at +6m for no more than a few hundred years (Neumann and Hearty, 1996, p. 776). Though, however, Marshall, (2000, p. 28) has a different hypothesis concerning the geologic evidence of higher sea levels 120,000 years ago and the placing of "unusual boulders perched 20m above sea level on the island of Eleuthera in the Bahamas."

The source of the Atlantic Basin island catastrophe was a landslide collapse in the Canary Islands off of Morocco. In another article, Hearty, et al., (1999) in the same journal as Neumann and Hearty's 1996 piece and looking at the same Archipelago, mentions on page 375 that "marine deposits at +20 +/- 3m on the tectonically stable coastlines of... the Bahamas support the hypothesis of a partial collapse of the Antarctic ice sheet during the middle Pleistocene;" about 400,000 years ago. They go on to state "our critical finding is the geologic documentation of a sea-level highstand at about +20m during the middle Pleistocene... Our multiple-method data set confirms that intertidal sediments were deposited at +20 +/- 3m at three tectonically stable sites...(including Eleuthera in the Bahamas) at the end of a long, warm, and complex interglaciation at or before 420 +/- 30 ka" (Hearty, et al., 1999, p. 377).

They continue on page 378 of their article that "in order to account for a 20m increase in ocean volume, if all of Greenland and West Antarctic ice (~12m) melted, an additional 8m water equivalent of East Antarctic ice must have also melted...This flooding of the world's ocean must have initiated a dramatic revamping of low-island ecosystems during the middle Pleistocene. If it can be established that warm and

prolonged interglaciations have a causal link with the stability of ice sheets, then the implications of present-day global warming for heavily populated low-lying coastal areas are profound" (Hearty et al., 1999).

Part of the problem is what to make of the placement of geologic evidence for higher sea level (waves) that provided boulders to be located ~20m above present sea-level in the Bahamas. A cover story ("Sea Level's Tall Tale," *Science News*, February 26th, 2000) concerning the preceding may provide more insight (see: Monastersky, 2000). Nevertheless, regarding the aforementioned geologic evidence of ~20m sea-level highstand, is it because of a tsunami as Marshall, (2000) theorizes or is it related to ice sheet melting during the Pleistocene as Hearty, et al., (1999) postulate, or a combination? How does one calculate a present-day policy response to a hypothesized higher relative sea-level of 20 +/- 3m, which some scientists postulate can happen again during an interglacial epoch that we're now experiencing?

Because of the large number of nations involved, many having only subsistence budgets, and the cost of deriving independently a comprehensive response to global change, as a proactive policy the similarities and differences between national settings ought to be identified. These comparisons then form the basis for local response strategies: the common elements between nations provide a basis for responses similar to that of other nations, whereas the differences mandate local adaptation (Kasperson, et al., 1999; Kasperson, et al., 1995).

Specific to this section is another response to continued global warming, change in relative sea-level. Regarding relative sea levels, Aubrey, et al., (1988) have ascertained historical rates of relative sea-level in the wider Caribbean from tide gauges. Their results indicate that the rates of change over the past half century or so

vary from an emergence (sea-level lowering) of 5.3 mm/yr. to a submergence (sea-level rising) of 9.3 mm/yr. throughout the Caribbean Basin (Emery and Aubrey, 1991; Table 6).

Aubrey et al. (1988) have used tide-gauge data to calculate average annual change of relative land/sea level for wider Caribbean locales. Most of the tide-gauge data depict subsiding land level (increasing relative water level) at a rate of 2.5 mm per year. Among the first of the international conferences to link relative sea-level changes to the effects of greenhouse gases was at an October, 1985 scientific conference in Villach, Austria, sponsored by the United Nations Environment Programme (UNEP), the World Meteorological Organization (WMO), and the International Council of Scientific Unions (ICSU). There, trace gases, climatic change, and associated impacts were discussed, and some of the original estimates of relative sea-level rise were projected (see: Tables 2 and 5).

The estimates were based on observed changes during the past century, though these calculations have large uncertainties (Figures 5 and 6). According to individual select studies, the historical trend in global average eustatic sea level rise is on the order of an increase of about 12 cm during the past century, (Gornitz, et al., 1982) to 15 cm during the past century, (Raper, et al., 1996; Barnett, 1984) although the data can support almost any estimate in the range of 0 to 30 cm/century (Pirazzoli, 1993; Emery and Aubrey, 1991). Church, et al., (2001, p. 641) suggest that the 20th century global average sea-level rise was in the "range (of) 1.0 to 2.0 mm/yr. (10 - 20 cm/century) with a central value of 15 cm/century." The historical rise of global average sea level has accompanied an increase in the atmospheric concentration of carbon dioxide of at least 25-30 percent since the industrial revolution (Dickinson and

Cicerone, 1986); for the thirty year timeframe since 1958, the concentration has increased by 9.5 percent at the Mauna Loa Observatory in Hawaii (MacDonald, 1988).

For the future, one study of rather imprecise projections are that global warming of 1.5° to 4.5° C would lead to a relative sea-level rise of 20-140 cm by the end of the 21st century (Broecker, 1987). It is noteworthy that while the scenarios used in the Maul, (1993) assessment suggest a gradual warming, some researchers believe that changes in the Earth's climate may be sudden rather than gradual (see: Taylor, 1999). Based on tide gauge station records, earlier original projections of relative sea level throughout the wider Caribbean ranged between 50 mm and 250 mm by 2025 (UNEP, 1988). Within the next 25 to 30 years, the average relative sea-level rise is theorized to be on the order of approximately 100 mm (UNEP, 1988).

Other early super maximum estimates of the extent of global average sea-level rise vary. The U.S. Environmental Protection Agency (EPA) estimated an average global rise of between 72 cm and 216 cm for the next century (Hoffman, et al., 1983). By 2025, the EPA projected global ocean levels will be between 13 cm and 39 cm higher than ~1980. Earlier revised estimates for the next thirty or so years (to about 2020) range between 11 cm and almost 21 cm rise in global sea level (Hoffman, et al., 1986). Hoffman et al. (1986) have estimates of global sea-level rise generated from the anticipated climatic changes ranging from greater than 100 mm to less than 210 mm by 2025. Tables 2 - 5 and their associated figures (4 - 18) provide for a better synthesized view (see: Gober, 2000) of past and future estimates of global average sea-level rise from published papers.

It is of note that estimates change often (see: French, et al., 1995). From early estimates it thus appeared that the most likely rise in global relative sea levels would

range between 0.5 m to 2.0 m during the 21st century (but see: Tables 2 - 5; Figures 4 - 18) for a more discerning figure. These estimates principally address the rise in the volume of the ocean, whereas it is necessary to be concerned with relative sea-level rise. Superimposed on this global signature is the regional tectonic or isostatic trend that may have considerable spatial and temporal variability (Figure 5; Bryant, 1988); for example, this is illustrated in the Emery and Aubrey, (1991) and Aubrey et al., (1988) data sets.

In another study, Hanson and Maul, (1993) ascertain a mean for all "Intra-Americas Seas" sea level stations (based on tide gauges) of 62 cm/yr.^{-1} . This study was heavily weighted by the large number of locales in the data set in known subsidence areas in the Gulf of Mexico. In that same study Cedar Keys (Key West, Fla.) had a 14.4 cm/yr.^{-1} rate for a forty year time record, the longest available at that time. Maul and Martin, (1993) determined a relative sea-level rise of $\sim 30 \text{ cm}$ ($\sim 1 \text{ foot}$) from a tide gauge record comprising a timeframe from 1846-1992. Indeed, they went on to write on page 1957 of their article that they "compared the shoreline of Key West (ca. 1850) with that of today's and find that the (relative) sea-level rise of 30 cm has not resulted in 'significant' shoreline regression." Maul and Martin, (1993) provide a caveat, however, by acknowledging that dredging and construction activities since the last century (1800's) increased the area of Key West Island.

Thus, Key West may not provide a good proxy locale for shoreline analysis without adequate knowledge of dredge and fill operations. Or even knowledge whether the Key West shoreline was more vegetative than sandy since there have been reports that Monroe County, Florida has brought sand from the Bahamas as beach enhancement. Some researchers hypothesize that the recent global rate of sea-level rise, determined from tide gauge stations may exceed 2.5 mm/yr. (Peltier and

Tushingham, 1989). How likely is this magnitude or rise in relative sea-level probable? Hanson and Maul, (1993, p. 210) speculate that "sea level throughout the Intra-Americas Sea on average will rise between 5 and 25 cm in the next 40 years (relative to 1990) but the spatial variability will be large."

Tide gauges are useful for measuring not only diurnal, seasonal, and episodic variations in water level but also for long-term changes. It is the long-term and episodic changes that will show how permutations from global climatic changes affect the wider Caribbean region. Tide gauges rest on coasts and depict changes in sea level relative to the adjacent land at that location. These coasts contain topographic evidence of changes of land level, both up and down in relation to sea level. If the relation of movement of land level to sea level is known, then researchers can attempt to calculate changes in eustatic sea level. For the wider Caribbean region, which is characterized by complex geology, tectonism and other geologic processes that are associated with movements of crustal plates of the earth, are understood only schematically (Aubrey, et al., 1988; Dillon, et al., 1987).

Land subsidence and uplift are associated with both natural causes due to local geologic and anthropogenic disturbances. Common natural causes that lead to subsidence include: neo-tectonism due to relative plate movements; the consolidation of fine-grained deposits subjected to the weight of overlying sediments; glacial and hydro-isostasy; and thermal cooling. Human intervention can accelerate or even induce subsidence. The most common human-induced subsidence occurs because of removal of fluids from the subsoil (Dolan and Goodell, 1986; Carbognin, 1985). Examples include groundwater withdrawal for drinking and the pumping of crude oil and natural gas. Both can result in the consolidation of fine-grain sediments. Local compaction, which causes a settling of the ground, set in motion by loading by buildings or other

engineering works and vibration on sediments (Carbognin, 1985) can cause isolated subsidence.

Biochemical oxidation of peat and other organic soils is playing a localized role in anthropogenic, that is, human-induced, subsidence in parts of the wider Caribbean (Maltby, 1986). Other examples of human impacts on coastal Caribbean resources include reclamation, land drainage, coral mining, and mineral and other forms of mining, particularly sand and gravel mining, both on and offshore. Sand and gravel mining can be detrimental because it can aggravate shore erosion (Lettsome and Potter, 1997; Wiegel, 1987) which in turn destroys features attractive to tourism, an important source of income in many Caribbean countries. Because of their narrow shelves and their distance from major areas of Pleistocene ice sheets, glacio- and hydro-isostasy was considered not to be a major source of historical relative sea-level rise in the Caribbean (Peltier, 1988). Clark, et al., (2002) now hypothesize otherwise.

Given an earlier predicted 1.5 to 3.6°C global warming by the year 2025, at Villach many researchers expect to see an accelerated rise of relative sea level. Gornitz and Solow (1991) looked for a possible acceleration but did not see it in their data set(s). Similarly, Douglas, (2001) made an assessment considering a potential relative sea-level rise acceleration but did not discover any in the data he reviewed. Maul and Martin, (1993, p. 1957) mentioned, however, that in their study "there is statistically weak but consistent evidence that the rate of rise may have increased slightly starting in the mid-1920's."

Employed as a screening assessment appraisal of global average sea level trends, the use of available published studies exhibit a rise (Table 2). Although the uncertainty is great it seems plausible to many geoscientists to explain an approximate

"central value" 15 cm rise of global average sea level during the past 100 years (Church, et al., 2001; Raper, et al., 1996) by assuming a 0.5°C increase in temperature for the same period with most of the rise being attributable to thermal expansion of the volume of the sea and alpine glacial melting. Though this is not a universal understanding of the past connection between atmospheric warming and the increase in the volume of the ocean.

Sahagian, et al., (1994) note however, that the reported rise in relative sea level would have been even larger if human factors such as storing water in reservoirs or channeling it into groundwater aquifers by irrigation works had not been done (see also Gornitz, 2001). Newman and Fairbridge, (1986) state that 0.75 mm/yr.^{-1} during the 25 year timeframe to 1982 was sequestered in interior continental basins. Gornitz, et al., (1994, p. 481) state that the "anthropogenic contributions to sea-level rise over the past 60 years" reduced sea-level rise by a total of -1.63 mm/yr.^{-1} according to their synopsis. Yet, Sahagian, et al., (1994) suggest that anthropogenic activities affect the overall water storage capabilities of forests, soils and wetlands, and that deforestation is providing the greatest overall contribution to present relative sea-level rise. This theory is difficult to replicate (but see: e.g., Gornitz, et al., 1994).

To reiterate from earlier, eustatic change in sea level is the world-wide change in the volume of ocean water as contrasted with local oceanographic effects (currents) or uplift or subsidence of the land. In the wider Caribbean region, tectonism and other geologic processes, which originate within the earth cause movement of lithospheric plates. These movements exert significant influence on tide-gauge records (Maul, 1993; Emery and Aubrey, 1991; Aubrey, et al., 1988).

Known vertical movements along some Caribbean coasts are dominantly subsiding (Haq, 1994). There is calculated uplift in the outer arc of the Lesser Antilles, including Barbados (Fairbanks, 1989; see later). Despite these geophysical tendencies in the wider Caribbean, it has been suggested that at least 30 percent of the twentieth-century sea-level rise is directly attributable to human factors (Sahagian, et al., 1994; see also Newman and Fairbridge, 1986 - Table 7). The accurate interpretation of past sea-level oscillations is important both to calibrate and to assess general circulation models (GCM) output, observations of historical, as well as to better prepare forecasts of future climate change.

It is generally accepted that global warming generates higher relative sea levels by two major processes: thermal expansion of the upper ocean layers and through an increase in meltwater from continental and alpine ice sheets (Aubrey, 1985). Historical relative sea level data, which depicts changes in sea level relative to the adjacent land, however, includes many sources of uncertainty. Variability in sea-surface measurements include glacio-isostatic tectonic changes in land masses (Aubrey et al., 1988), meteorological (e.g., atmospheric pressure, humidity, wind speed and direction) and oceanographic (e.g., currents and wave height) changes (Aubrey and Emery, 1986).

Existing float-in-well tide gauge systems and recording devices are subject to a wide range of inaccuracies and restrictions that include limited temporal and spatial scales of the data (Bossler et al., 1986), perturbations from dredging, uncertainties in geodetic datum's, local effects of exorbitant groundwater removal, and the continuous length of the data record, or lack thereof (Parker, 1991; Uchupi and Aubrey, 1988). Taken together, these sources of variability make it difficult to separate eustatic (increased volume of the sea) and tectonic (changes in land mass elevation)

contributions to relative sea level rise (Aubrey and Emery, 1986), though however, it can be done (see: Fairbanks, 1989). Several researchers, have attempted to separate eustatic, oceanographic, and tectonic components of relative sea-level change derived from tide-gauge records (e.g., *inter alia* Mitrovica, et al., 2001; Peltier and Tushingham, 1989).

The choice of the term relative sea-level rise is used because it always refers to the combination of rise of the sea and movement of the land. Studies of historical rates of relative sea-level rise specific to the wider Caribbean (see: Aubrey, et al., 1988) show that the tectonic movement in the Caribbean is large (compared to eustatic sea-level change) and spatially complex. Eustatic sea-level rise is typically regarded as a worldwide increase in the volume of the ocean, as contrasted with local uplift or subsidence of the land. As mentioned from a particular pair of studies, during the past half-century or so, relative sea levels in the wider Caribbean Basin have ranged from an emergence of 5.3 mm/yr. to a submergence of 9.3 mm/yr. (Emery and Aubrey, 1991; Aubrey, et al., 1988; Table 6). Thus, the wider Caribbean countries are challenged with the need to develop appropriate research and planning programs to proactively establish policy responses to coastal impacts generated by global climate change and the ancillary effects of relative sea-level change; and for this study - especially as it relates to maintaining viable coastal tourism (Nicholls and Branson, 1998; Volonte, 1997; Jacoby and Prinn, 1994).

Thus, taking another "look at the impacts of climate change... conventional wisdom" foretells that "the most important impacts will be on agriculture and from sea-level rise" (Ausubel, 1991, p. 215; see also Pitelka, et al., 1997; Sahagian, et al., 1994). "The impacts of sea-level rise may be scarcely apparent at all for the next 30 to 40 years" depending upon what location one looks noted Ausubel, (1991, p. 216),

this situation is borne out, for example, by Emery and Aubrey (1991). "Very probable projections (> 9 out of 10 chance...) sea level rise could be substantial...long-term melting of landlocked ice carries the potential for considerably higher values, (i.e., 50 +/- 25 cm by the year 2100), but with less certainty" (Mahlman, 1997, p. 1417; see also *inter alia*, Neumann, et al., 2000; Varekamp and Thomas, 1998; Nicholls and Leatherman, 1996; Leatherman and Nicholls, 1995; Warrick, et al., 1993; Nurse, 1992). Through hindcasting analysis historical 20th century patterns can emerge wherein geoscientists have principally employed data from tide gauge instruments for their analyses in denoting recent changes in global average relative sea-level (Douglas, et al., 2001; Schneider, 1997; Douglas, 1997). The synthesis composites provided as a "screening assessment" (Klein and Nicholls, 1999, p. 186) for this study illustrate one example for analysis into the past, present, and future potential for global average sea-level change (see: Figures 4 - 18; Tables 2 - 5).

For this study it is important to emphasize that in the wider Caribbean region, relatively few of the most intensively developed resorts (tourist facilities) have beaches broader than about 30 meters or so at high tide (Gable and Aubrey, 1990). Indeed, an important point is that during episodic storm events (see: Bosser, et al., 2000) erosion at beach-focused tourist facilities can have devastating financial ramifications on national (island) economies through the loss of infrastructure and subsequently revenue (Bier, et al., 1999; Zhang, et al., 1997; Basco, 1996; see also nominal scale data found in, for example, Tables 20 - 24. Indeed, as will be demonstrated and discussed in a subsequent chapter, episodic storm events maybe more relevant, at present, for sustainably based science/policy planning than incremental relative sea-level rise (see: e.g., Figures 49 - 60; Tables 38 and 45). Bosser, et al., (2000, p. 879) also highlight that during storm events "falling barometric pressures act to draw up the water surface producing a rise of ~13.6 mm for every 1 mb drop in atmospheric

pressure." For their analyses in parts of the French West Indies of the Lesser Antilles that equates to ~1.5 to 3 feet (Bossert, et al., 2000), with subsequent erosional processes taking hold on sandy shores!

Changes described by greenhouse gas processes will continue to result in thermal expansion of sea water and alpine glacial melting; though the response of the polar (Greenland and Antarctica) ice sheets to climatic change is quite contentiously debated and unclear (e.g., Clark, et al., 2001, at p. 246; Oppenheimer, 1998, at p. 325). Perhaps approximately half of the earlier suggested global rise in relative sea level by the year 2030 (~12-18 cm) will be accounted for by the thermal expansion of the ocean, that is, by about 6-10 cm (Warrick and Farmer, 1990). Depending on the assumptions and models used, the range of predictions by geoscientists is great and increases with time (see: Tables 2 - 5) as the variables used in the different models become more speculative, few models possess realistic geography. As a consequence to the preceding, introduced here is the use of meta analysis as an aid in selecting the most proper projections while utilizing the widely accepted (and adopted) U.S. Global Change Research Program terminology (first introduced in Chapter One).

The contribution from melting ice is more difficult to predict, as it also involves absolute changes in weather patterns. For example, even if mean annual temperature increased by 3.5° C altered patterns of precipitation over Antarctica, could cause an increase in ice formation and thus contribute to a drop in sea level (Clark, et al., 2001). Whether Antarctic ice volume would decrease or increase is not yet known and may be the largest donor to the uncertainty about future eustatic sea-level rise contributions from this source. Hence the amount of corresponding global average sea-level change is quite difficult to discern; the use of the technique of meta analysis allows for some select projections or summations to be prepared (see: Figures 7 - 18; Tables 2 - 5). As

can be seen, many researchers in the past couple of decades have attempted to provide analysis of this situation (Tables 2 - 5; Mitrovica et al., 2001). Volumes of ice in the northern hemisphere, especially Greenland (Cuffey and Marshall, 2000; Hvidberg, 2000) also demonstrate instability over long periods of geologic time, though general stability during the last 8,000 years (Dansgaard, 1993; White, 1993).

The issue of global average relative sea-level rise, in part, as a consequence of climatic warming and greenhouse effect has received intense concern in recent years, especially for cascading effects upon, deltaic wetlands, flooded commercial and residential areas, and the situation of beach erosion (see: Chapter Seven) among others (Crowell and Leatherman, 1999). Rising relative sea level has serious implications on the coastal environment with such global changes as the retreat of shorelines and resultant loss of property and structures; inundated wetlands and lowlands; increased coastal flooding if storm activity also increases; increased intrusion of saline water into aquifers and increased difficulty in sewage storage and/or discharge; altered tidal ranges within estuaries; and so forth (Gable, et al., 1990). Eroding beaches in the Lesser Antilles are of especial interest in this interdisciplinary study. They are especially dealt with later in Chapter Seven.

The need to establish coastal management directives to plan for these global changes is upon us (Pernetta and Elder, 1992), yet it is not easy to accomplish, short of a "sort of" International Law of the Coast contained as an addendum amendment to the United Nations Conference on the Law of Sea (UNCLOS; the Law of the Sea Treaty entered into force in November of 1994). Indeed provisions in the UNCLOS Treaty pertaining to coastal areas...do not provide much guidance for policy making on the mechanisms to maintain intertidal sustainable shorelines especially as it relates to interdisciplinary aspects of international tourism.

To reiterate relative mean sea-level (RMSL) oscillations are related to changes in water volume, changes in sea surface shape, coastal uplift or subsidence, and large-scale crustal and subcrustal movement. As with climate, sea level has continually oscillated throughout geological and recorded history (Middelburg, et al., 1991). As recently (in geological terms) as 18 to 21 thousand years ago, sea level was as much as 120 meters lower than at present due to the large amount of water in the extensive ice sheets that covered much of the northern hemisphere. Only during the past 120 or so years, has relative sea level been monitored increasingly by calibrated tide gauges.

The actual level of the sea is continually changing in response to tides, waves, longer-term perturbations, as well as to shifts in the dynamic height (topography) of the sea in response to slight change in the path or strength of ocean currents. In addition, seasonal shifts in atmospheric pressure or in river runoff can cause significant shifts in sea level. Thus, even if sea level is averaged throughout the year, so that tides and waves are effectively canceled out, annual fluctuations are still apparent. Typically, as a result, Douglas, (1997) suggests that a continuous record of 60 or more years is needed at any tide gauge station in order to discern a meaningful long-term trend; that might include a greenhouse gas forced signal in the record. Though, however, that situation does not stop geoscientists from utilizing what they feel are valid data from shorter duration tide gauge information or using modeling techniques to extend a given data record (see: Maul and Martin, 1993).

And tide gauge stations with continuous recordings for at least sixty years or more can not be considered representative of the entire world ocean due to their lack of geographical breadth in location (see: e.g., Mitrovica, et al., 2001; Douglas, 2001; Gornitz and Solow, 1991). At present, there are no firm and unambiguous data to

suggest that the rate of relative sea-level rise has accelerated in the 20th century as a result of anthropogenic climatic warming. The balance of evidence, however, shows a gradual rise of global average sea level at coastal tidal stations with most of the eustatic sea level rise associated with thermal expansion of sea water and melting of alpine ice (Peltier and Tushingham, 1989; see also Mahlman, 1997). Though the main point here is that any overall global (and/or regional) trend in relative sea-level rise remains hidden in the tectonic, subsidence, oceanic and atmospheric noise in the data sets utilized for appraisal.

The Caribbean, much like the Pacific region (see: Yamada, et al., 1995) is particularly susceptible to changing climate and an associated acceleration of sea-level rise because within the Lesser Antilles arc in the wider Caribbean lie many islands that are low in height, some less than six meters above mean sea level. Of particular importance in controlling local relative sea-level rise is subsidence, which includes both regional and local tectonics as well as sediment consolidation. For example, if an area is rising geologically as fast as sea level, the net effect will be no apparent local rise of relative sea level, whereas an area subsiding as fast as sea level is rising will appear to have twice the eustatic rise.

There are many places, especially low-lying deltas, in which the rate of subsidence is as great or greater than the projected rates of global average sea-level rise for the next 30 to 100 years; in some localities excessive subsidence rates conceivably will outstrip even the most pessimistic scenarios for sea-level rise (see: e.g., Milliman, et al., 1989). Consequently, rising relative sea levels and increasingly landward storm surges may render some placers uninhabitable. For other inhabited islands and archipelagoes, the option to move inland to higher ground is limited (Nunn, 1997; Yamada, et al., 1995). Wells and Edwards, (1989) in their article, "*gone with the*

waves," especially point this out. In addition, many of these archipelagoes, which contain far more coastal zone per unit of land area than do continental nations, recently became independent; most rely heavily upon coastal aesthetics and marine resources both for local consumption and revenue, the latter as it relates to tourism.

Relative Sea-level Rise as a Hazard

The ocean and continent cover of the Earth's surface is 71% and 29%, respectively. The point where the ocean surface and the landscape intersect is known as the shoreline or in general, the coast. This intersect point is not fixed in time and space but continually changes. The changes are according to Moerner, (1996) caused by four main factors. These include (1) vertical changes in ocean level (eustasy and dynamics); (2) vertical changes in land level (tectonics and compaction; subsidence and emergence); (3) re-shaping of the coastal morphology (erosion and accretion/deposition); and (4) changes in sea/land interaction (tidal range, wind direction atmospheric pressure, sea surface temperature, etc.).

Factors influencing the above include long-term - century or more aspects, as well as short-term - annual to decadal - components (Hughen, et al., 1996; Moerner, 1996). Further, Moerner, (1996, p. 797) denotes that the changes in sea-level (eustasy) are many and are at least due to (1) changes in oceanic water volume; (2) changes in the ocean basin volume and the hypsometric land/sea relationship (for the latter see: for example, Giese and Aubrey, 1987); (3) dynamic height or sea-surface topography (the ocean surface is not "flat" throughout the world it has intervals of elevation and depression); and (4) rotational changes in the geoid or earth resulting in mass redistribution.

The short-term, high-amplitude "immediate" changes refer to, among others, point storms such as hurricanes and tropical storms. Today, as can be seen in the figures presented, there is not a solid agreement in the scientific community as to the rate of relative sea-level rise as a result of global climate change. Therefore, there is a huge gap in the forecasts for the rate, timing and absolute amount of the rise (see: e.g., Bryan, 1996; Figures 7 - 18, and Tables 3 - 5 demonstrate and especially make this point). The technique of meta-analysis does provide for ascertaining the central tendency of the results of existing combined studies as indicated for contributions of, for example, ice sheets and thermal expansion to future global relative sea-level rise.

For appropriate coastal zone management and resources planning, relative sea-level rise information is necessary (Kay, et al., 1996). The reasons for this vary because some global warming scenarios indicate a potential for catastrophic damage from erosion, flooding, storm surge, and associated effects, such as increasing tidal amplitude (Pethick, 1993; Titus, et al., 1991). Tidal amplitude in the Lesser Antilles, however, is not considered an important contributor due to the low range or magnitude.

Cost of Holding Back the Sea

The economic impacts of relative sea-level rise are widely considered to be all effects that the physical causes of rising sea level will have on the production and consumption of goods, services, and amenities (Gibbs et al., 1983). One of the most important economic effects for the wider Caribbean region is shoreline movement, resulting in a decrease in the availability of land for recreational, residential, or commercial purposes. Moreover, it is important to differentiate between long-term (secular) patterns in coastal accretion and erosion, and episodic or seasonal oscillations

that result from changes in atmospheric and/or wave conditions. Thus, similar to having a relatively long-term tide gauge record to ascertain relative sea-level movement, it is important to continuously measure, in a definable method (e.g., analogous to the Emery method), the beach profile over as lengthy a period of time as feasible to find trends.

Regarding flooding, coastal areas would become more vulnerable to flooding according to Titus, et al., (1991) for the following reasons including (1) a higher sea level provides a higher base for storm surges to build on in that a 1m rise in sea level would enable a 15 year storm - one whose flood levels have a 1/15 probability of being exceeded in any given year - to flood many areas that are today only flooded by a 100 year storm; (2) beach erosion would leave properties more vulnerable to storm waves; (3) higher water levels would increase flooding due to rainstorms by reducing coastal drainage capacity; and (4) a rise in relative sea level would raise water tables. In addition, a fifth factor is that saltwater intrusion would result from a rise in sea level that would penetrate farther inland and upstream in rivers, bays, wetlands, and aquifers (see also Boothroyd, et al., 1998). This in turn, would harm some aquatic plants and animals and threaten human uses of water.

For planning purposes, the expected global warming from the greenhouse effect could raise sea level 50 cm (~2 feet) or more in the next century (Clark, 1996; Titus, 1994). While global average sea-level rise rates likely (> 2 out of 3 chance) will increase from the present rate of 1.5 mm/year to possibly as much as 3.9 to 7.8 mm/year by 2100, it is noteworthy that this is a three- to eightfold increase over current sea-level rise rates on, for example, the U.S. East Coast (Daniels, 1996). The primary impacts of such a rise on the Lesser Antilles include (1) costs associated with protecting resort communities along the ocean by pumping sand onto beaches and

gradually raising the dune crests; (2) costs associated with protecting developed areas along estuarine and bayfront waters through the use of, for example, artificial dikes and bulkheads (though not advocated here); and (3) the loss of coastal wetlands and undeveloped lowlands.

Combined with development setbacks, ecological buffer strips and municipal building codes should restrict bulkheading and encourage movable semi-permanent structures. For the purposes of coastal zone management and planning, Clark, (1996) advises choosing an arbitrary relative sea-level rise rate of 150 cm/100 years and modify it as necessary. From a non-linear accelerating rise Clark, (1996) suggests using planning horizons of either 50 cm (1995-2035) or 80 cm (1995-2055) rise. Thus, Tables 2 - 5 and Figures 4 - 18, prepared as a result of sensitivity and vulnerability analysis, provide another potential planning horizon based on a compilation of available published studies.

For the United States, which includes the U.S. Virgin Islands, Titus et al., (1991) estimated that a 1m (3 ft) rise in sea-level overall would cost in protection between \$270 and \$475 billion, not taking into account future development. Similarly, the estimated loss of both wet (intertidal) and dry land from a 1m rise in sea-level is on the order of 15,000 sq. km. each (~7,000 sq. mi.). The levees and bulkheads along "sheltered" coasts would gradually eliminate most of the nation's wetland shorelines. Titus et al., (1991) feel that a major policy for the long-term survival of coastal wetlands is the gradual abandonment of coastal lowlands as relative sea-level rises. Clark, (1996) theorizes that conservative estimates of relative sea-level rise signify that rising waters threaten to affect about 60 percent of the saline and coastal freshwater wetlands in North America.

The vertical changes in sea level at a certain coastal point is the function of the combined interaction of all the variables controlling the ocean level and the land level mentioned previously. The reactions in coastal morphology to the vertical changes of the shore further determine the horizontal displacement of the actual shoreline (Moerner, 1996). The local and regional dynamic sea surface can change significantly over time periods as short as days to as long as decades. Ocean currents, such as the Gulfstream found along the western Atlantic, have what is considered to be a quiescent dynamic topography of up to 5 m or more than 15 feet. During periodic storm events, this ocean height situation can become quite menacing for the coast. This is true for open ocean coasts and equally significant for estuaries, harbors and bays where prevailing wind currents can "set-up" the sea creating a large fetch and increase tidal amplitude into storm tides.

Several practicing scientists and researchers have concluded, however, that an accelerated relative sea-level rise in the short to medium term is inevitable and that coastal zone management applications to address this will need to evolve with the rise. Moerner, (1996) states that long-term refers to a century or more aspects, while short-term is decidedly - annual to decadal - components. Changes hailed as "rapid," are those that occur in time periods of a century or less (Moerner, 1996, p. 797).

Many U.S. coasts, where there is better long-term data, have already been experiencing a long-term increase in relative sea-level. Tide gauge data along Atlantic "open ocean" locations typically indicate a historical average rate of between 27.7 cm - 30 cm (10.92" - 12") since the advent of the 20th century (Daniels, 1996). Further, suggested is that this rise may be coupled to notable recession along many miles of the beachfront. Carter, et al., (2001) state on page 340 of their manuscript that "increasing rates of (relative) sea-level rise would contribute to...reducing the extent and quality of

sandy beaches through both inundation and increased erosion associated with storm surge."

They go on to write that "at the present rate of (relative) sea-level rise, there is already a loss of 9 feet (2.7 m) of coastline due to erosion every decade in some areas" (Carter, et al., 2001, p. 340). Further, Carter, et al., (2001) stipulate that "the projected increased rate of (relative) sea-level rise would produce over 33 feet (10 meters) of erosion per decade since a typical beach erosion rate can be 150 times (relative) sea-level rise." This last point is considered of utmost controversy (see: *EOS, Transactions, American Geophysical Union*, September 19th, 2000, pp. 436-441, cited as Pilkey, et al., 2000).

Some coastal researchers, for example, Kaplin and Selivanov, (1995, p. 161) provide the caveat that "strict analytical prediction of coastal response to the accelerated (relative) sea-level rise is yet to be solved." They did mention, however, that their research indicated, in part, that among the most expressive and significant impact(s) of relative sea-level rise would be general erosion of coastal morphological features such as bluffs, marshes, and where present, coral reefs, etc. (Kaplin and Selivanov, 1995).

Coastal upland retreat typically takes two forms (1) active, through wave produced erosion; and (2) passive loss resulting from relative sea-level rise, although a rise in relative sea-level contributes to active wave produced erosion. As relative sea-level rises all corresponding measurements of tidal reference levels at the coast rise too. Though the use of tide gauges alone may not provide an accurate assessment of increases in relative sea-level rise from enhanced greenhouse warming (Hsieh and Bryan, 1996). Nevertheless, as has been demonstrated effectively in this section, tide

gauges are employed to ascertain rates of change in relative sea-level rise along the coast.

The rate of passive retreat on uplands (terrain landward of intertidal wet-land that has not been reworked markedly by coastal processes such as waves and tides) at any one location on the shoreline depends upon the rate of relative sea-level rise and the slope in elevation/topography of upland terrain. In Massachusetts, according to Giese et al., (1986) relative sea level has been rising historically at a mean annual rate of about 3 mm. On the order of about 66 percent of that total is attributed to land subsidence, therefore the contribution from eustatic changes is suggested to be one-third or about 1 mm per year (see also Giese and Aubrey, 1987). That preceding number and relationship discussed above could be a useful proxy to consider for policy making in parts of the wider Caribbean.

With respect to rapid present (late Holocene) sea-level changes on the order of decades to a century, there are small to insignificant effects from glacial eustasy (melt), tectono-eustasy and geoidal eustasy due to mass distribution (Moerner, 1996). For the wider Caribbean, among the major effects, however, these are related to (1) the dynamic redistribution of water masses via the ocean current system; (2) the deformation of the rotational ellipsoid; and (3) various local dynamic factors including a) changes in coastal current forces, b) alterations in coastal run-off, c) differences in prevailing wind directions and d) variations in meteorological pressure are all effective variables on the local ocean level position (Moerner, 1996, p. 798).

The need to investigate relative sea-level rise in the wider Caribbean is an obvious consequence of the potential for global and regional warming. To monitor sea-level changes in the wider Caribbean requires a network of tide-gauge stations.

The present data base for world-wide tide-gauge measurements is maintained by the Permanent Service for Mean Sea Level (PSMSL) in Bidston, United Kingdom and to a lesser extent the U.S. National Oceanic and Atmospheric Administration's (NOAA) National Ocean Survey. The PSMSL data base consists of approximately 33 tide gauges scattered throughout the wider Caribbean that, according to Aubrey, et al., (1988) are of sufficient quality and duration. For their study they analyzed their chosen data set as those tide gauge records that have high t-confidence levels, (the t-confidence represents the probability that the measured slope is within ± 1 mm/year of the true slope), a technique that aid researchers in attempting to distinguish between tectonism and an increase in the volume of ocean water (Aubrey et al., 1988).

The absence of adequate uninterrupted historical scientific data, however, precludes the opportunity for obtaining a complete picture of relative sea-level rise in the entire wider Caribbean region without looking at the overall global average as a proxy (see: Church, et al., 2001). This shortage of data from uninterrupted operational long-term tide-gauge stations makes present and future estimates of relative sea-level rise for the region difficult to ascertain without utilizing global stations and then employing the technique of meta analysis.

Earlier estimates by researchers concluded that the major impacts of relative sea-level rise are likely to be tidal shifts, coastline recession, salt water intrusion and the loss of coastal ecosystems (Hekstra, 1989). Briefly, one notable example of the latter is the potential alterations that increasing relative sea-level rise might cause to the fragile Caribbean coral reef ecosystem is a major concern (see: Atwood, et al., 1992). Some corals may not be able to keep pace with rising relative sea-level when subjected to other environmental and anthropogenic stress such as storm-induced turbidity, sedimentation, predation and overfishing pressures.

From a paleo-oceanographic perspective, researchers, such as Bard, et al., (1990) have used *Acropora palmata* corals from the Barbados littoral to find a chronology for the last deglaciation. These same studies attempt to measure tectonic uplift that affects the Caribbean subduction zone. Fairbanks, (1989) in his abstract on page 637 states that "coral reefs drilled offshore of Barbados provide the first continuous and detailed record of sea level change during the last deglaciation. The sea level was 121 ± 5 meters below present during the last glacial maximum," about 18,000 years before present (Fairbanks, 1989). Fairbanks' work (p. 637) "indicates that the south coast of Barbados is being uplifted at about 34 cm Kyr^{-1} ." This information (3.4 cm per 100 years) when combined with projections of global average eustatic sea-level rise (*inter alia*, Raper et al., 1996) was used to formulate Figure 4. It shows a "worst case" projection that was prepared for illustrative purposes.

If relative sea-level rise does accelerate at an increasing rate, as some researchers suggest, Caribbean reef flats could become subtidal within the next 50 or so years. "In tropical areas where reefs prevail, the beaches are entirely biogenic; constituents may include a variety of taxa or one species may dominate or be 100 percent of the sediment. Some coral and algae form the entire beach of atolls and other reef beaches" (Davis, 1985, p. 395). These changes will lead to large scale alterations in the abundance and distribution of organisms inhabiting emergent reef flats, and may result in an alteration of the nearshore hydrodynamics (Cubit, 1985).

Modern coral reef communities would be threatened if the sea level rises 3 to 5 mm (0.3 - 0.5 cm) per year (Smith and Kinsey, 1976), because they would be unable to produce skeletal material fast enough. Although "catch-up" reefs predominate in the Pacific, the condition of coral reef growth in the Caribbean is much more diversified,

with “give-up” submerged relict reefs being common on insular shelves of the leeward and windward islands, for example, on the west coast of Barbados (Guilcher, 1988). For instance, the coral *Acropora palmata*, found throughout the wider Caribbean, generally does not form an interlocking framework in depths greater than 5 m (Lighty, et al., 1982; but see: Atwood, et al., 1992). Considering projections of relative sea-level rise over the next century and observations regarding past and present rates of coral reef growth, reef growth may not be able to keep pace (Buddemeier and Smith, 1988). Implications of this situation on the biogenic beaches in the Lesser Antilles is that an increase in the recession rate of (tourist oriented) beaches could be seen - and has already been witnessed on the leeward coast of Barbados, for example (Gable, et al., 1990).

Briefly, from a societal perspective, natural coastal systems can be affected in a variety of ways. Klein and Nicholls, (1999), believe some of the most important biogeophysical effects are: increasing flood-frequency probabilities; erosion, inundation; rising water tables; saltwater intrusion; and biological effects. Other effects suggested in (Maul, 1993) include storminess and cloudiness, for example (see: Table 8). According to Klein and Nicholls, (1999, p. 183) the potential socioeconomic impacts of relative sea-level rise can be categorized to include: "direct loss of economic, ecological, cultural and subsistence values through loss of land, infrastructure and coastal habitats; increased flood risk of people, land and infrastructure...; and, other impacts related to changes in water management, salinity and biological activity."

Unlike many other anticipated consequences of climate change, global relative sea-level rise is already taking place (Klein and Nicholls, 1999; see: Figures 4 - 6; Table 2). Over the last 100 years, or so, global relative sea level rose by 1.0 - 2.5 mm

yr.⁻¹ (Klein and Nicholls, 1999; Warrick, et al., 1996). As presented in the IPCC Second Assessment Report, estimates of future eustatic sea-level rise induced by climate change, range from 20 - 86 cm for 2100, Warrick et al., (1996) indicated their best estimate of 49 cm, including the cooling effect of aerosols. This compares with the approach here utilizing the technique of meta analysis that finds a "best estimate" of 74.85 cm (Figures 15 - 18; Table 5) for future global average eustatic sea-level rise to 2100. Owing to lags in climate response, model projections out of England illustrate that relative sea level will continue to rise beyond 2100, even with an assumed immediate stabilization of greenhouse gas emissions (Klein and Nicholls, 1999). Of course, there has yet to be a stabilization of such emissions. "Dynamic ocean effects may also be important, as they will lead to regional variability in absolute changes to sea level, however, they cannot yet be modeled and predicted with confidence" (Klein and Nicholls, 1999, p. 182).

When assessing impacts of a rise in sea-level, it is the local rate of change in relative sea level that matters most. The global or regional average remains part of the signal for an overall part of any past or projected rise. Klein and Nicholls, (1999) comment beginning on page 182 of their article that "while it is affected by absolute changes in sea level, relative sea level is also influenced by vertical movements of the land, which are locally and regionally variable. These vertical movements are mostly natural phenomena, but human activities may be important as well." For example, in the wider Caribbean, in reclaimed coastal lowlands, oxidation of peat can lead to significant declines in land level (Gable and Aubrey, 1990).

Klein and Nicholls, (1999, p. 184) argue that "susceptibility, resilience, and resistance" together determine the coastal system's natural vulnerability to biogeophysical effects of relative sea-level rise. Susceptibility simply reflects the

coastal system's potential to be affected by relative sea-level rise, while resilience and resistance determine the system's stability in the face of possible perturbation. As applied in ecology, resilience describes the speed with which a system returns to its original state after being perturbed, while resistance describes the ability of the system to avoid perturbation in the first place. Susceptibility, is largely independent of human influences, resilience and resistance are often affected by human activities. The effect of human activities need not only be negative according to Klein and Nicholls, (1999); planned adaptation can serve to reduce natural vulnerability by enhancing the system's resilience and resistance and thereby adding to the effectiveness of autonomous adaptation.

"To help to structure the approach, to optimize the level of effort, and to make the likely outcome of studies more explicit, it is useful to consider initiating a screening assessment (SA). As its name implies, SA is a screening approach which, by its quick nature, focuses on one aspect of vulnerability: susceptibility" (Klein and Nicholls, 1999, p. 186). They feel that "analysis in the framework of a study should start with a screening assessment." Thus, a "vulnerability assessment will provide broad concepts and ideas concerning impacts and possible adaptation. A planning assessment might be viewed as the link between vulnerability assessment and detailed coastal planning and management." The recommendations concerning possible adaptation measures would be more precise in a planning assessment (Klein and Nicholls, 1999). Elements of the three types of assessments discussed by Klein and Nicholls, (1999) were undertaken here for the Lesser Antilles.

Klein and Nicholls, (1999, p. 186) state that "most coastal vulnerability assessments will be of a basic nature and cannot be expected to yield results that will have widespread application to day-to-day coastal zone management" (but see: Tables

50 and 51). They go on to say that "as further experience is acquired, coastal databases improve and better analytical tools and techniques are developed, more comprehensive and integrated assessments of coastal zones will become more feasible."

Accordingly, knowledge of vulnerability enables coastal scientists and policy-makers to anticipate impacts that could emerge as a result of relative sea-level rise (Klein and Nicholls, 1999). It can thus help to prioritize management efforts that need to be undertaken, for example, for sustainable tourism initiatives, to minimize risks or to mitigate against possible deleterious consequences. Making first-order assessments of potential coastal impacts of and adaptations to relative sea-level rise, this study on the Lesser Antilles served as a preparatory assessment. This study has identified the Lesser Antilles of the wider Caribbean as a priority region.

Chapter 6. Tourism in the Wider Caribbean

This section begins by mentioning that "tourism has been lightly treated in *marine affairs* literature" (Miller and Auyong, 1991, p. 75). And they state that no single subdomain of *marine affairs* encompasses the issues or problems of tourism. Miller, (1993, p. 183) points out that the "rise of coastal and marine tourism as a scientific and policy specialty is entirely warranted by contemporary world conditions." For comparative purposes, Miller and Auyong, (1991) remark that the catalytic role of world tourism (i.e., travel to locales greater than 25 miles from home) first passed the \$2 trillion figure in 1986. They state that worldwide military spending only topped the \$1 trillion barrier one year later.

In terms of pressures, trends, and impacts in coastal zones, oftentimes interactions between socioeconomic and natural systems (see: Turner, et al., 1996) indicate that "travel and recreation may prove to be sources of jobs and revenue that are more vulnerable to climatic change than agriculture in several regions" (Ausubel, 1991, p. 215). As indicated by Turner, et al., (1996, p. 162) tourism revenues may be in jeopardy from climate change related perturbations "since the late 1970's tourism has become the second most important item in world trade surpassed only by oil," this is especially so where "the use of the coast and small island states for tourism has also expanded at a very rapid rate" (see also Burger, 2000; Miller, 1993; Miller and Auyong, 1991; Miller and Ditton, 1986; Beekhuis, 1981).

Regarding sustainable tourism for island societies throughout "Oceania, the Indian Ocean, and also the Caribbean," Krausse, (1995, p. 179) states that mass tourism is generally demand-driven whereas "low impact" or cottage industry tourism is by definition supply-driven. This commentary is supported by looking at the

tremendous boom in the number of stayover tourist arrivals in the Lesser Antilles for the 1970 to 1999 timeframe (see: Figures 19 - 46; Tables 11 - 32) as well as viewing the expansion in the overall visitor accommodations (i.e., rooms, see: Figure 37). These data, on stayover tourist arrivals, visitor expenditures in U.S. dollars (millions), visitor accommodations (rooms), and estimated contribution of hotels and restaurants to GDP by percentage (Figure 42; Table 29), among others from the Caribbean Tourism Organization clearly indicate that tourism in the wider Caribbean is not a "cottage industry."

According to Miller, (1993, p. 184) "tourism has for some time qualified as the world's largest business and promises to maintain this status well into the future." This too, may be borne out by viewing the trends in wider Caribbean tourist arrivals (as well as receipts) and the projections for its continuance as measured by simple linear regression trend analysis (prepared on standard spreadsheet software found on "servers" at the University of Rhode Island computer laboratory located in the main library) found in Figures 25 - 33 and 39 - 41, and Table 20. Krausse, (1995) has also suggested that island community equilibrium is thus precariously balanced by disturbances from seasonal droughts, hurricanes, and even long term relative sea-level changes. The latter two disturbances are developed and discussed in allied section(s) of this manuscript and again bear out those suggestions. In addition, Miller and Auyong, (1991, p. 77) comment that "there is no escaping the fact that the construction of hotels, airports, and marinas, and the operation of tourist facilities fundamentally alter the coastal environment and displace communities."

Regarding tourism Pantin, (1999) contends on page 227 of his article that it has been the fastest growing sector in most Caribbean Island locales and "is concentrated on the marine environment and impacts directly or indirectly, in

particular, on the beaches..." Ashe, (1999) points out on page 187 of his article that the threat from global climate change is "not limited to the most vulnerable islands, nor is it entirely geophysical." He postulates that "less vulnerable small island developing states (in the Caribbean) would suffer significant disruption as a result of the loss of beach tourism and recreation areas because of relative sea-level rise and, possibly, more storms causing increased beach and reef erosion" (Ashe, 1999, p. 187-188). And, in the wider Caribbean islands the future viability of sustainable tourism ultimately depends "on the ecological integrity of the natural asset base" according to de Albuquerque and McElroy (1992, p. 630). Hence, cascading effects from contemporary global climate change is a valid threat to small island coastal environments; the natural asset base quantified with the beaches and climate as receiving the highest ranking (see: Ott, 1995; Ott, 1994; Figures 20 - 24; Tables 12 - 19).

Briefly, from another island locale that has high tourism penetration, Knight et al., (1997) suggest "coastal erosion control problems may continue in Bali due to the expected rise in (relative) sea level attributed to global warming." These authors go on to say that "while the actual extent of (relative) sea-level rise is debatable, any increase will undoubtedly compound existing coastal erosion conditions on beaches with protective structures, and in addition will subject more 'stable' beaches to erosion potential" (Knight, et al., 1997, p. 94; see also Chapter Seven). These authors argue that illustrating the nature and magnitude of coastal beach tourism as a force for change are the approaches and proposals for beach nourishment to not only lessen erosion but to extend beaches in resort areas to "three times their present size" (Knight, et al., 1997, p. 94).

Coastal and marine tourism in many parts of the Caribbean is a significant source of revenue and tourism is the leading economic sector as a whole (UNIDO, 1987). On the Caribbean islands, effectively all tourism development has occurred in the coastal areas, where the beaches are the principal attraction (Figures 19 -24; Tables 12 -19). Utilizing the quantitative method of aggregate/archival data - tables (see: Culhane, 2001) to indicate that most stayover arrivals to the wider Caribbean islands are in fact on holiday, and that the beaches are the principle attraction, recent data tabulated from the Caribbean Tourism Organization (of which I was a member) is presented throughout especially in Figures 19 - 24 and Tables 11 - 19. These aggregated data and the accompanying figures generated from the tables, clearly illustrate that most stayover visitors are in fact on holiday and that the principal reason for their sojourn to the Lesser Antilles was the beaches/climate (Ott, 1995; Ott, 1994).

As regards the penetration of tourism into a wider Caribbean island economy, McElroy and de Albuquerque, (1998) found that St. Maarten has the largest average number of daily visitors per 1000 population and the second biggest when looking at the number of hotel rooms per square kilometer. Both the United States Virgin Islands and the British Virgin Islands are among the highest regarding overall tourism penetration as well (McElroy and de Albuquerque, 1998). As an aside, it is of note that Dominica was found to be the least penetrated island from tourism principally because there are "no white sandy beaches," thus no hotels of 100 plus room capacity, and consequently little demand for an international airport that if it existed, could provide direct access to major markets (McElroy and de Albuquerque, 1998, p. 159). The important point in the preceding sentence is the lack of white sandy shores. Therefore, one could consider Dominica's tourism to be somewhat of a "cottage industry" (see: Krausse, 1995).

Relatively few of the most intensively developed resorts have beaches broader than about 30 meters at high tide, and most assessments indicate that most of the world's sandy shorelines are in retreat (Bird, 1996). This situation is likely to get worse, in part, because relative sea-level rise, a suggested ancillary effect of climate change (Mitrovica, et al., 2001), has risen by about 15 cm (1/2 foot) during the past century (see: Chapter Five). Both the increasing warming (about 0.5°C past 100 years), possibly due in part, to the build up of anthropogenic trace gases in the atmosphere, and the increasing level of the seas are projected by computer modellers to increase over the next several decades. With this prognosis, several shore areas of the wider Caribbean may suffer increasing adverse effects to the environment and diminishing returns to the economy (see also Dixon, et al., 2001).

As alluded to previously, the United Nations Industrial Development Organization in Vienna, Austria determined that the most important economic sector in the wider Caribbean region is tourism (UNIDO, 1987). Most recent available figures (CTO, 2001) indicate that Caribbean tourism has generated 18.7 billion U.S. dollars with an average 7.9 percent increase per annum for the timeframe of 1989-1999 (Figure 40). The overall trend in wider Caribbean receipts from tourism for the period 1980-1999 can be seen in Figure 41 coupled with a trendline for future receipts from linear regression analysis can be seen for the period ending in 2020. Tourism, a primary major source of foreign exchange and employment in much of the region may be negatively impacted by anthropogenically induced climate change.

Regarding the Lesser Antilles tourism industry, beach erosion is considered the single most important impact of climate induced relative sea-level rise, since development in most of the region is oriented towards the coast, where beaches are the principal attraction (Pantin, 1999; Ashe, 1999; ECLAC, 1986). Though, however, the

connection between beach erosion and climate induced relative sea-level rise is fraught with controversy and uncertainty (see: e.g., *EOS, Transactions, American Geophysical Union*, Forum Section, September, 19th, 2000, pp. 436-441; cited as Pilkey, et al., 2000). Nevertheless, shoreline migration landward will bring the need to seriously consider protection, replenishment, and stabilization of existing beaches, particularly those which support international tourism (UNEP, 1997; UNEP, 1988).

The running theme of this section is that tourist development in most of the wider Caribbean has been and shall likely continue to be oriented towards the coast (Gable, 1997; Rodriguez, 1981), concentrated along narrow strips, particularly in semi-enclosed bays (Gajraj, 1981). For example, Jamaica depends heavily on tourism which is centered on the beaches and inshore waters, which in turn is supported by broad real estate development close to the sea. In the Grenadines, the primary attraction for tourism development is centered along the coastlines and nearshore waters (Berwick, 1986).

In the Bahamas, the tourism sector accounts for about 33 percent of Gross Domestic Product (GDP) and directly or indirectly for 50 percent of employment (UNIDO, 1987). For the Netherlands Antilles, tourism is the second largest sector for employment and earner of foreign exchange (ECLAC, 1986). In Grenada, revenue from tourism accounts for over 35 percent of exports of goods and services (ECLAC, 1986). Within the wider Caribbean region, the tourism sector accounts for about 33% of GNP and directly or indirectly for half of employment in the Bahamas (UNIDO, 1987). In the Netherlands Antilles, tourism is the second largest sector for employment and foreign exchange earner.

For Antigua and Barbuda, tourism has directly or indirectly been responsible for over 40% of GNP — the highest in the region — and has employed greater than 50% of the labor force. This has resulted in the expansion of the construction industry for hotels and other tourism associated conveniences and industries. Tourism in Barbados has contributed to GNP by about the same amount that the manufacturing sector has, i.e., roughly 10% over the decade of the mid 1970's to the mid 1980's or so (UNIDO, 1987; see also Arey, 1993).

As far back as the early to mid 1980's, for example, tourism earnings in 1983 for St. Lucia accounted for around 45 percent of the exports of goods and services. Those tourists in St. Lucia spent U.S. 39.7 million dollars in 1983. In St. Lucia tourism provided direct employment for about 3,000 persons, and perhaps a larger number indirectly (World Bank, 1985). While in 1964 there were only two hotels in St. Lucia, with a total of only 20 rooms, by 1984 there were about 1705 rooms. In the latter part of 1984, periods of 100 percent room occupancy rates were attained (ECLAC, 1986). By 1999, St. Lucia's number of rooms had climbed to 4125, similar increases can be seen in Tables 27 and 28 for other Lesser Antillean islands. Similar examples of coastal oriented development are mirrored throughout the Lesser Antilles, as indicative of these trends, Figure 37 illustrates the story.

In the British Virgin Islands the tourist sector depends primarily on the charter and maintenance of yachts, contributing more than 50% of GNP while providing employment for roughly 30% of the populace. The yachting activity has an associated focus of snorkeling around coral reefs — a habitat already adversely impacted from environmental stress (Milliman, 1993). Similarly other Caribbean micro-states rely heavily on tourism and its associated infrastructure developments (water desalination, roads, electricity, airport improvement, waste treatment) (CTO, 2001).

Sidebar: A Glimpse of a wider Caribbean locale embracing
beach tourism development - Cuba.

On August 10th of 2001, in the United States, Cable News Network (CNN) posted on their Website (<http://cnn.com>) a very telling story. It entails the running theme throughout this section, and I repeat it here in its entirety. The broadcast of the story that I saw was on August 9th, the title is: *Tourism Expands, Sweetens Cuban Life* (Holguin, Cuba - CNN). Thus, the story unfolds: "The Cuban chefs serve Japanese food to European and Canadian tourists, while waiters serve snacks to overseas guests on white, sandy beaches. It's hard to believe this is the centuries-old heart of Cuba's sugar country. In Holguin province, where cane fields once dominated the horizon, modern apartment complexes are springing up as housing for the thousands of former farmers. They have abandoned the fields to mine Cuba's new national treasure: tourism. Today overseas visitors generate more than 40 percent of Cuba's income."

"Although the island nation is still officially off-limits to the nearby Americans, nearly 2 million tourists are expected this year. No longer is tourism limited to Varadero beach and Havana on the western side of the island. The government is opening up new hotels in joint ventures with overseas firms all along Cuba's northeastern coast. 'The tourism in Varadero is very well known, with long years of tradition and history,' said Kees Aerts, manager of Breezes Costa Verde. 'But the future will be the countryside where it is unspoiled, with beautiful beaches.' The tourists, mainly Canadian and European, see other advantages. 'Cost is an issue,' one visitor said. 'It's less expensive and it's...so natural. What you see is what you get.' For as long as anyone can remember, Cuba's economy depended on its sugar harvest.

But in the early '90s, the collapse of Soviet subsidies to the communist island made the fortunes of the already inefficient sugar industry plummet. Rather than keep betting on a losing horse, the government turned to tourism as a lifeline" (see also Figure 32 and Table 20).

The preceding commentary somewhat bolsters the storyline of Martin de Holan and Phillips, (1997) in their article titled *Sun, Sand, and Hard Currency: Tourism in Cuba*. These authors stress on page 781 of their manuscript that "for Caribbean countries like Cuba, the existence of world-class 'sun and sand' provides a basis for competitiveness in tourism, but does not guarantee development or success in the tourism industry." They mention that "Cuba as a destination is keenly competing against the Dominican Republic for Canadians, Spaniards, and Germans, and against Jamaica for Canadians, Germans, and Italians, nationalities that make the bulk of visitors to Cuba" (Martin de Holan and Phillips, 1997, p. 787). All islands in the wider Caribbean compete against each other for the revenue that international tourists provide (see: CTO, 2001). I would also like to quote from Martin de Holan and Phillips, (1997, p. 788) when they state that the "first important dimension of competitiveness involves factor conditions."

Regarding factor conditions they go on to say that "while the Cuban 'sun and sand' is clearly of world-class quality...the lack of amenities such as restaurants, shopping, and entertainment"...means that "tourists often complain that there is little to do beyond the beach in the two major tourism centers in Havana and Varadero, and that the hotels rarely meet international standards" (Martin de Holan and Phillips, 1997, p. 788). Suffice it to say that as has been shown in this manuscript, sun, sand, and surf predominate as the reasons international stayover tourists venture to wider

Caribbean islands in the first place, whether they return or not is determined by several variables (see also Figure 32; Table 20).

Thus, as has been indicated here, tourism is big business. The United States Department of Commerce reports that it is the fastest growing industry worldwide (Arey, 1993). Mentioned in the Commerce Department report is the theory that by the turn of the century, which is now upon us, tourism will likely be the world's number one industry (see also Tables 31 and 32 and Figures 44, indicating selective worldwide data on economic receipts from the tourist trade). Arey, (1993) through her analysis determined that it is the key industry in 23 of the wider Caribbean jurisdictions. She also mentioned that in the insular Caribbean (i.e. the Islands), tourism is of comparatively greater economic importance than for the continental countries of the Basin. Yet prior to the turn of the century, however, it was clear that coastal and marine tourism in many parts of the wider Caribbean was a significant source of revenue and was the leading economic sector in the Caribbean as a whole (UNIDO, 1987).

By the late 1980's, annual revenues from all tourism receipts were \$8.7 billion. For 1993, this figure has increased significantly to \$12.3 billion. And by 1999, this number has catapulted to \$18.7 billion (CTO, 2001; Figure 40). To reiterate, throughout the Greater and Lesser Antilles, as well as other wider Caribbean islands, effectively all tourism development has occurred in coastal nearshore areas, where the beaches remain the principal attraction (Gable, 1991; Gable and Aubrey, 1990; quantified in Figures 20 - 24; Tables 12 - 19).

These data are important because of the current environmental hypothesis of global climate change, a premise that presents far-reaching multidisciplinary scientific

challenges. While changes in climate are the norm, increasingly humans have become agents of that change (see: Chapter Four on greenhouse gases). Consequently, environmental problems associated with the potential impact of climate changes are an important matter for governments and planners in the wider Caribbean region.

The Caribbean countries display diversity of character and form, though they collectively face similar (climate change) and inter-related (climate change and the nearshore environmental stress) problems. Their resource base — particularly for the island entities — is limited in scale and scope, yet some of the most productive and complex ecosystems found in the world exist in the Caribbean coastal zone (UNIDO, 1987; USAID, 1987).

The economic importance of coral reefs, beaches, seagrass beds, mangrove forests, and coastal estuarine ecosystems derives mostly from their linkage to other resources, especially coastal tourism and fisheries (USAID, 1987). Ecosystem services from these coastal and marine habitats contribute a large percentage of income, especially to the Greater and Lesser Antilles economies (see: e.g., Costanza, et al., 1997). Recent economic performance of many wider Caribbean countries depicts tourism, construction and agricultural production (bananas) as the leading sectors in gross domestic product (GDP), particularly in the smaller, less - developed island economies in the region (Arey, 1993; UNIDO, 1987). Table 29 indicates the latest available estimates with a trend of the contribution of hotels and restaurants to GDP by percentage.

Culturally, the peoples of the Caribbean are a mix of African, Asian, European and native American. Table 1 provides selected socio-economic and demographic data concerning the island and continental countries and territories in the Caribbean Basin.

Most of the smaller island states have economies that are based on tourism, including the distinctive micro-states of the British Virgin Islands, Cayman Islands, Anguilla, Montserrat and the Turks and Caicos (de Albuquerque and McElroy, 1992). In addition, as indicated in selected tables throughout this section of the manuscript, Antigua and Barbuda, the Bahamas, Barbados, the Netherlands Antilles and the United States Virgin Islands (USVI) among others, now including Cuba, rely heavily upon income from tourists.

Their likely reliance in the future on tourism is indicated by Figures 25 - 33 and the linear trendlines provided through regression analysis shown in the figures for Lesser Antilles locales such as Anguilla, Antigua and Barbuda, Barbados, Guadeloupe, St. Maarten, St. Christopher and Nevis, as well as other islands like Aruba and Cuba. Typically, regression analysis can extend a trendline in a chart beyond the timeframe of the actual data to predict future values. Moreover, as a consequence, in some cases, the influx of tourists during the northern hemisphere winter season is large enough so that when averaged out tourists outnumber the year round residents. Bastin, (1984) suggests that - from an anthropological point of view - this situation could lead to a loss of indigenous cultural identity and may overshadow any monetary benefits. Nevertheless, the tourism industry and the needs of tourists has already led to the modification of the coastal and marine habitats and when coupled with anticipated changes in climate could present unfamiliar and costly solutions to those problems.

Impacts of Potential Climate Changes on Tourism

One of the fastest growing sectors of international trade, especially for small Caribbean countries and territories with limited alternative development opportunities,

is tourism. Tourism in the Caribbean has been growing both in size and complexity in an attempt to satisfy both the sophisticated international travelers and the mass marketing of the region (CTO, 2001; CTO, 1998; Waters, 1994; ECLAC, 1986).

More importantly, the link between environmental quality and tourism is evident, especially in the wider Caribbean, where the environment is the most significant part of the product. The predominant product for tourism in this region is the attraction of beaches and the appealing climate (Maul, 1993; Clark, 1991; Gable, et al., 1991; ECLAC, 1986). Clark (1991, p. 117), a noted international coastal zone management specialist, claims that the "predominant style of tourism in the region is that which is based almost exclusively on the attraction of the climate and beaches."

Moreover, while "beach tourism" has predominated in most Caribbean countries since the 1960's quantified in Figures 19 - 24 and Tables 11 - 19 and with Barbados' inception as a major destination for visitor arrivals from Canada, the U.S. and the U.K., in 1956 (Dalrymple and Greenidge, 1999), the Caribbean Basin now competes worldwide for these types of tourists. This competition is with parts of the Mediterranean coast, Africa and other exotic locations such as the Maldives and Seychelles in the Indian Ocean and the islands of the South Pacific (CTO, 1998; ECLAC, 1986). Because of the global tourism market and its important contribution to the wider Caribbean economy, the effects of anticipated climate changes on Caribbean coastal zones should not be taken lightly.

An economically based calculation or analysis of the recreational demand by international and domestic tourists for saltwater beach days in the islands is beyond the scope of this research, similar to what has been accomplished in Florida (see: e.g., Bell and Leeworthy, 1990, p. 202), where these authors concluded that "nearly 87

percent of all tourists participate in 'saltwater beach activities.'" Nevertheless, it is important to recognize that they have calculated a recreational value to just the tourist of the saltwater beach in Florida at roughly \$8.8 million per acre per year. Certainly, a similar figure for saltwater beach value (demand) can be juxtaposed to the Lesser Antilles. Beach nourishment projects and their costs in relation to the value of Caribbean beach recreation ought to be assessed in the Organization of American States - Global Environmental Facility (GEF) program (see also Edwards and Gable, 1991). Because of the global tourism market and its important contribution to the Lesser Antilles economy, the effects of anticipated climate changes on wider Caribbean coastal zones should not be taken lightly.

Beach tourism itself, has significant impacts on coastal zones. For example, construction accentuates and accelerates erosion by eliminating plant life which anchors sand dunes (ECLAC, 1986). In addition, coastal engineering works that once were envisioned as shoreline stabilizers, are now known to accelerate erosion downdrift as a result of improper planning (Walker, 1990; Walker, 1984).

Caribbean islands tourism with its large dependence on white sandy beach front locations is especially susceptible to the consequences of a rising relative sea level — inundation, erosion, increased flooding and saltwater intrusion into aquifers (Blommestein and Singh, 1987). As beaches are the prominent attraction for tourists, the loss of sandy beaches from any cause will eventually diminish carrying capacities and ultimately tourism earnings. This situation is illustrated perhaps by viewing the detrimental changes in beach width in select Lesser Antilles locales found in Tables 33 - 37 and accompanying Figures 47 and 48. Thus far, however, it does not appear that the long-term loss of white sandy beaches has brought about a decline in stayover tourist arrivals. Several locations throughout the Caribbean already exhibit periodic to

long-term trends of erosion on tourist oriented sandy beaches (Cambers, 1997; Gable et al., 1990; Cambers, 1988).

Factors such as habitat destruction, coastal pollution and shoreline alteration when coupled with relative sea-level rise reinforce beach loss (Blommestein and Singh, 1987). Besides the aforementioned problems with beach loss, tourism may be impaired by climatic changes through impacts on hotels and similar facilities, marinas and infrastructure for cruiseship dockings, sewage outfalls and waste disposal sites, and the alteration or loss of natural ecosystem attractions such as coral reefs (Blommestein and Singh, 1987; see also Landauer International, 1998).

The socio-economic impacts of relative sea-level rise are widely considered to be all effects that the physical causes of rising sea level will have on the production and consumption of goods, services and amenities (Gibbs, et al., 1983). One of the most important economic effects for the wider Caribbean region is shoreline movement, resulting in a decrease in the availability of land for recreational, residential or commercial purposes. To simplify the conversion of physical and/or ecological changes to socio-economic terms, a systematic matrix method has been employed. A suggested matrix synthesis of direct *marine affairs* oriented socio-economic impacts of climate change and relative sea-level rise on selected coastal area sectors appears in Table 8; see also Maul, 1993).

With one of the major economic activities in the wider Caribbean being tourism, negative impacts upon this sector will have detrimental reverberations for the prospect of sustainable development and economic growth, and perhaps for political stability. As of about twenty years ago, this sector provided over two million jobs basin wide and accounted for over half of Gross National Product (GNP) for some of

the smaller nations (Beekhuis, 1981). The matrix concept provides for a preliminary checklist of relevant physical and/or ecological variables cross-referenced to socio-economic variables under analysis, for example, the impact of an increased tendency of tropical storms and hurricanes (see: Goldenberg, et al., 2001) on the construction (resort) sector (Table 8).

Chapter 7. Erosion Issues

The situation of beach erosion (inundation) is likely to get worse, in part, because relative sea-level rise, an acknowledged ancillary effect of "global change," has risen by about 15 cm (~1/2 foot) during the past century ascertained from a screening assessment from a synthesis of studies analyzing global averages tide gauge records (*inter alia*, Douglas, et al., 2001; Douglas, 1997; Raper et al., 1996; Pirazzoli, 1989). The advancing level of the seas is projected by Intergovernmental Panel of Climate Change (IPCC) coastal specialists to increase over the next several decades (Warrick, et al., 1996; Houghton, et al., 1992; see also Kay, et al., 1996; Table 5; Figures 4; 15 - 18). With this prognosis, most shore areas of the wider Caribbean may suffer increasingly adverse effects, such as, beach erosion as well as loss of wetlands (Milliman and Haq, 1996). This study has remained focused on the issue of relative sea-level rise and its past, present and future relationship to Lesser Antilles coastal tourism. Could the coastal challenge posed by relative sea-level rise stymie sustainable growth in tourism?

Erosion is one of the other influences upon the coastal zone from climate change leading to shoreline retreat and thus sustainable tourism. Other similar issues from climate change upon littoral environments include tidal range alterations, leading to flooding and saltwater intrusion further inland; changes in ocean chemistry through ocean pH from atmospheric CO₂ doubling; and biological effects, leading to changes in species representation (biodiversity) and productivity in both marine and terrestrial ecobiomes (Viles, 1989). In addition, alterations in coastal ocean upwelling intensity will effect marine living resources (Bakun, 1990). Achieving a sustainable use of these marine living resources is made difficult but not impossible under all the present stress conditions in the Caribbean basin (see: e.g., Rosenberg, et al., 1993).

The majority of Caribbean coastal lowlands and their adjacent coastlines presently experience extensive damage from erosion and inundation during storms. Examples from the effect of storms can be seen by examination of the information presented in Tables 35 - 37. For example, these tables and corresponding figures of the storm-events of 1995 (Figures 49 - 52) had a noticeable impact on the estimated visitor expenditures in St. Maarten and the U.S. Virgin Islands, among other locales (Figures 35; 53 - 55). The storm events of the mid and late 1990's decreased the amount of accommodations in several Lesser Antilles islands (Figure 54; Tables 39 and 40).

It can also be ascertained and interpolated by looking at Tables 33 to 36 that several island's have experienced recent coastal erosion problems. Most beaches exhibit signs of erosion mainly because of human social and economic activities such as the construction of jetties, groins and breakwaters that interfere with littoral processes. In addition, the removal of sand from beaches and streams for use as construction aggregate has caused considerable coastal erosion in the study area (Lettsome and Potter, 1997; Gable and Aubrey, 1990; Cambers, 1987a,b).

Because of human activities, such as draining and reclamation, many natural coastal wetlands, marshes, lagoons and salinas have been permanently altered, that is, adversely impacted (Vicente, et al., 1993). Add to these problems the present and potential rise in relative sea level and it becomes imperative to adjust for and find sustainable tourism practices. That the wider Caribbean islands are affected from time to time by natural hazards such as episodic hurricanes with well-known destructive effects on the intertidal and foreshore is illustrated through the analysis presented in Tables 42, 43 and 45 and Figures 56 - 60 .

The physical nature of wider Caribbean shorelines are that they exhibit diversity. According to a United States National Research Council report issued in 1990, for example, there are several types of natural shorelines. Those primarily referred to in this analysis include (1) eroding unconsolidated bluffs and cliffs; (2) pocket beaches between headlands; and (3) barrier beaches. These shoreline types are potentially subject to measurable erosion (May et al., 1983). In addition, Schrope, (2000) asks if seaweed (algal growth) is causing some tropical beaches to disappear in the Greater Antilles?

Erosion may be defined as the landward displacement of the shoreline (mean high water line) in response to a variety of causative factors. On sandy coasts the process of shoreline change, involving either recession or accretion, is commonly known as the state of "dynamic equilibrium" (Platt, 1994, p. 267). This equilibrium, usually hinges on four variables. Depending on the location, these include (1) "the supply and loss of beach material - including sand, as well as biogenic sources of shell fragments, and coral as well as silt and flotsam; (2) energy imparted by wind, waves, currents and to a lesser extent in the Lesser Antilles - tides; (3) beach profile - slope and width; and (4) relative sea level including both eustatic sea level and local land subsidence or uplift" (Platt, 1994, pp. 267-268).

According to Platt, (1994, p. 268) it is the "interaction of these physical variables, including their possible modification by deliberate or inadvertent human intervention that determines the position of the water's edge over time" (see also Table 37). Nordstrom, (1994, p. 499) points out that in some coastal locales the "pace of development of resorts is especially rapid." He also states that "coastal tourism is a rapid-growth industry... but in many locations growth has been with little direction

and control, and construction is frequently incompatible with beach dynamics because selection of sites for resorts is based on nongeomorphological factors" (Nordstrom, 1994, p. 499; thus see: Tables 50 and 51). And for making policy management decisions episodic storm events are the dominant factor when calculating the history of a coastline (Horn, 1997). Nordstrom, (1994, p. 507) states that "scenarios for change for eroding developed coasts that do not include beach nourishment as a management option are driven by limitations in sediment availability and describe a closed system of evolution."

Nordstrom, (1994, p. 507) goes on to claim that "low magnitude, high frequency events on developed shorelines eventually convert wide beaches and wide and topographically varied dunes to truncated forms and convert multiple dune crest lines to single ridges that decrease in width and eventually are eliminated as erosion proceeds." Platt, (1994) points out that coastal erosion is not typically regarded as a "hazard" in the absence of human investment at risk (see also Boothroyd, et al., 1998), such as the tourist facilities in the wider Caribbean for instance.

Sand may be lost from the local system in several ways. It may be carried by ocean currents beyond the continental shelf into deep water and out of the "cell." Boothroyd, et al., (1998) suggest that on the order of 20% of beach sediment is lost beyond the littoral shelf. Storm waves may transport sand over or through the dune line to create outwash deposits further landward (Boothroyd, et al, 1998). Human activities may transport sand out to sea or truck it away for construction and other uses. In addition, coastal engineering works may lock up sand in bluffs or behind groins, thus interrupting the longshore flow of sand in littoral currents and cutting off the supply of beach material to portions of the shoreline (see: e.g., Boothroyd, 1985 on the role of jetties and tidal inlets). Relative sea-level rise causes most shorelines -

perhaps as many as 70 percent - to recede in the long term (Bird, 1987). Human efforts to deter this erosional process has usually resulted in making matters worse (Platt, 1994; Pethick, 1993).

The spatial incidence and magnitude of coastal erosion in the Lesser Antilles has been more recently assessed by researchers working under the auspices of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) Intergovernmental Oceanographic Commission (IOC). Though this data varies widely in resolution and reliability because it was originally a compendium of a variety of survey and mapping methodologies. Though, however, it is useful for the appraisal under study here.

It is true that broad-scale scientifically derived estimates of erosion somewhat mask the extreme variability of local erosion rates in that coasts do not uniformly respond in the same way. Local factors such as a coast's proximity to sediment from rivers, tectonic activity, the topography and composition of the land, the configuration of coastline along with the prevailing wind and weather patterns have an important influence on erosion rates. Though structures elevated on pilings may resist collapse from erosion, ultimately, they may be rendered uninhabitable because of an increasingly receding shoreline and the likely exposure and failure of on-site septic systems and or water lines or public sewers. The lot (land) itself is an expensive casualty of erosion that cannot be insured under the National Flood Insurance Program in the United States Virgin Islands territory.

Beach erosion can be approximated using topographic maps and other analyses found in the literature (Crowell, et al., 1991). The value of lost land from erosion can be typically estimated utilizing local municipal assessors records. For United States

locales, the cost of nourishing beaches over time can be derived using data collected by the Corps of Engineers, for the Lesser Antilles there is no central clearinghouse. One regional policy would be to create a databank service for just such information as an aid in determining sustainability. The costs associated with elevating land and houses and of erecting shore-protection structures can be estimated by engineers based on experience. Moreover, according to Titus, et al., (1991) the procedures for assessing shoreline retreat tend to implicitly account for flooding caused by storm surges, at least after the first foot of relative sea-level rise.

Coastal areas that are already out of equilibrium from either natural or anthropogenic disturbances or a combination of both, in terms of erosion for example, can be found throughout the eastern Caribbean. Erosion rates modify these islands considerably, depending upon their age, composition (volcanic, coralline, combination of both), geologic history, exposure to erosive forces (storm swell, wave runup), and anthropogenic impacts (sand mining, reef dynamiting, and dredging). The geography, demography, and the historical record provide insights into the potential environmental issues of the wider Caribbean islands.

One noteworthy localized Caribbean coralline island is Anguilla. It provides a representative setting where impacts of projected relative sea levels will likely have significant impacts. In one relatively recent study of a handful of beaches, the average erosion rate was measured at 0.34 m/yr. (Cambers, 1988). While the causes of this erosion were not conclusively ascertained, the increasing amounts of tourism make it a matter of immediate concern (see: Figure 47; Tables 33 and 34). With Anguilla providing a representative setting of the low islands of the Lesser Antilles as regards international tourist arrivals, like most other tourism-related activities in the Antilles,

this activity is centered around the coast, that is, the sandy beach (ECLAC, 1986; see: Figures 20 - 22, and 25; Tables 12 and 13, 15 - 18).

As an indicator of the growth of, and the reliance on tourism for Anguilla alone, the amount of (hotel) rooms over a eighteen-year period through 1998, illustrates a 597 percent increase in capacity over a relatively short period of time (Table 28). Other islands exhibit similar double to triple digit percent changes in accommodation capacity for the same time period (see: Table 27). Importantly, as yet, no specific planning guidelines or measures have gone into force or been implemented concerning the care for the coastal resources that the visitors come to partake.

On Grenada, at Sauteurs, at Levera, and at Grand Mal, rates of erosion have been on the rise since 1970, from a previously quixotic 20-year period of little change. The erosion rate at Sauteurs is 1.8 m/yr. and at Levera the rate is 3.6 m/yr. (Cambers, 1987). Cambers (1987) suggests that these rates may be due to local subsidence and relative sea-level rise, though that coupling hasn't been established. Similarly, Grand Mal, a narrow bayhead beach in Grenada, for a fifteen year timeframe had an erosion rate of 2.9 m/yr. commencing with measurements in 1970.

On the coral island of Antigua, in the Fort James area, near the capital, erosion rates were measured for a specific 26-year period that ended in 1968. That rate of erosion was calculated at 0.3 m/yr. (1 ft/yr.). Cambers (1987) reports that the probable causes of this trend are related to sand mining, winter swell, and hurricanes, where the latter atmospheric disturbances are responsible for the permanent movement of about 20 percent of longshore sediment into deep water. Also on Antigua at Parkwood beach, the erosion rate for the same period of time was calculated to be 1 m/yr. (3 ft/yr.), with the causes similar to the Fort James example. Few, if any Lesser Antilles

locales, have any complete shoreline erosion studies remotely similar to those maintained in the U.S. (see: e.g., Boothroyd, et al., 1998).

Anthropogenic effects of nearshore dredging have taken their toll on St. Thomas, U.S. V.I. At Sugar Bay beach, on the northeastern side of the island, what was once a 200 meter long by 10 meter wide sandy beach has been reduced to a cobble and stone shoreline (DuBois and Towle, 1985). Nearshore dredging of sand (placer) deposits led to a reduction in sea grass beds from increased rates of sedimentation. Sedimentation also ushered reef die-off cutting off the main source of sand replenishment for the beach. After two decades Sugar Bay beach displayed no sign of natural recovery (DuBois and Towle, 1985).

In another reef-beach system study by Hayden, et al., (1978) this one at Cinnamon Bay, St. John, U.S.V.I., suggests that high sedimentation associated with sugar cane farming of the 1700 and 1800's, reduced the rate of generation of new biogenic coral sands from fringing reefs. This situation directly fostered an erosional net export of beach sands to deep water during periods of storm waves (Hayden, et al., 1978). The size of the grains of sand also played a significant role in determining whether during storm events the breaking waves in the swash zone led to suspension of the sandy sediment. Fine sands, silts and clays with a mean diameter of <123 microns were more often lost from the beach profile out to "deep water" (Hayden, et al., 1978, p. 218). These researchers stated that during the relatively quiet tropical storm decade of the 1970's, portions of Cinnamon Bay beach, located on the northern side of St. John, had a rate of erosion on the order of approximately 2 meters per 3 years (Hayden et al., 1978). Lastly, as a policy point Hayden, et al., (1978, p. 204) suggested "that environmental modification, including engineering measures that have

minimal impact on mid-latitude sand beaches, may not be at all suitable for sand beaches fronted by coral reefs."

Another country of the eastern Caribbean experiencing coastal loss due to natural and anthropogenic influences is St. Vincent and the Grenadines. In St. George Parish, in the tourist section of the main island between Villa Point and Johnson Point on the south coast, the beaches have been eroding continuously for several years (Cambers, 1981). Recently, erosion rates for this section of St. Vincent were calculated between 0.5 m and 1 m/yr. with a significant amount attributed to hurricane swell. While Cambers (1981) suggests that these beaches should slowly build up again, I witnessed evidence of continuing severe erosion during a field trip several years ago.

In addition, high tides were reaching the building line of the hotels and guest houses with little dry sand beach remaining, undermined trees and vegetation with significant amounts of exposed beach rock were evident. Beach rock is controversially linked, in tropical areas, as indicative of an overall eroding sandy shoreline. In general, this area, important to the tourist development plans of the country, continues to experience natural and human-induced coastal degradation. With the projection of future rises in sea level, coastal vegetation will be subjected to increasing degrees of inundation.

As noted earlier, relatively few of the most intensively developed resorts have beaches broader than about 30 meters at high tide. A beachcomber survey indicates that hotels and related recreational facilities are commonly less than 20 meters from the shore at high tide in many resort locales (see also Horvath International, 1998). The set-back requirement for St. Croix, for example, is 50 feet (15 meters) from the low

tide level as set by the enabling legislation for coastal zone management. The projected rise in relative sea level of 30 centimeters over the next thirty-five years or so could erode many recreational beaches in developed areas. Some of this erosion may be mitigated by beach nourishment, however, this becomes more and more expensive as the ocean level rises. Moreover, sand resources for beach replenishment often are lacking for island countries, because of the limited sediment supply and narrow shelves.

Indeed, the Canary Islands in the eastern Atlantic off of Morocco import sand for their tourist resorts from the African continent in vessels. Beach nourishment therefore is an expensive, temporary solution that must be balanced against other alternatives (Dean, 1988). Shoreline structures (sea walls, embankments, groins, and revetments), represent one alternative; however, such structures often exacerbate beach loss while protecting the upland, destroying the very resource that attracts tourists. Proper setbacks are the alternative that ought to be considered more ambitiously, particularly in this time of rapid development of the many Caribbean coastlines (Gable and Edwards, 2001; Gable, 1997; Gable et al., 1990). Adequate land-use planning controls at both national and local levels, and a population sensitive to the problems and willing to adhere to authoritative planning controls are also needed (DeVoy, 1987).

Basco, (1996) especially made an appraisal of beach erosion on St. Maarten from Hurricane Luis and Marilyn in September, 1995. he found evidence to support "the hypothesis that Hurricane Luis was the main cause of volume loss of the subaerial beach" (Basco, 1996, p. 16). He scaled beach lengths from cartographic maps and compared that information to in-situ field methods six weeks after the event and discovered that "the nine major beaches on the Dutch side lost about one-half million

cubic meters of beach volume" (Basco, 1996, p. 18). Sustaining about 750,000 cubic meters of subaerial volume loss were fourteen French side beaches in his study (Basco, 1996). It is noteworthy to mention that St. Maarten was only reopened to international tourists three months after the event (see also Figure 50 and 54).

Basco (1996, p. 20) contends that a "major conclusion regarding hurricane beach damage on St. Maarten is that the beaches should be immediately rebuilt" as a policy outcome because of its beach-driven tourist economy. This diagnosis has important hindcasting lessons to be learned for the international reinsurance industry today (see: Berz, 2000; Michaels, et al., 1997; Berz, 1993). This is the case because there is no "Regional Emergency Management Agency," or equivalent, analogous to the Federal Emergency Management Agency in the U.S., which deals with flooding. In times of crisis the Lesser Antilles relies upon subsidies from the international donor agencies and market rates from the insurance communities, among others (including France - if one is domiciled in Guadeloupe or Martinique, for example).

North American sandy beaches and barrier islands have eroded at average annual rates of 0.8m, according to May, et al., (1983) although the Gulf coast barrier islands have receded at a mean rate of 1.6 m annually. Coasts with fine-grained sediments, mudflats, and deltas, however, have the highest mean rates of recession due to erosion: 2.0m annually. Erosion rates on islands vary considerably, depending on their age, composition, geological history, exposure to the erosive forces, and human impact. On the tourist-oriented south and west coasts of Barbados, erosion has caused a loss of 6m over the past 30 years, equivalent to 0.2 m per year (Cambers, 1987). Grand Anse is the major tourist center on Grenada; consequently, most of the hotels are situated on and behind this 2 kilometer long beach. This beach eroded at a rate of 0.7 meters per year between 1970 to 1982. The primary causes of the erosion

were ascertained to include sand mining and perhaps relative sea level rise (Cambers, 1987). Concurrent climate change impacts will likely alter the erosion outlook in the wider Caribbean.

In the face of a rising sea-level and changes in storm climate, a dune/beach system can migrate landward if sediment replenishment is available. Sand, gravel and shell mining in offshore shoals in waters that are shallower than 15 meters reduce sediment availability in the wider Caribbean region. Dredging these shoals has eliminated natural breakwaters that reduce wave energy impinging on the shoreline. Further, the artisanal mining of calcium carbonate from nearshore reefs has contributed to coastal erosion problems in several developing countries in the region.

The island of St. Lucia is one such location where mining sand and aggregate from beaches and nearshore zones has led to localized beach recession on the average of 0.6m per year (Clark, 1985). Before offshore sand extraction is undertaken, prospective alterations of the offshore bed should be examined in light of possible damage to the beach, as offshore sand deposits play a role in beach stability and sediment supply. With projected relative sea-level rise and a newly forecasted increase in storms (Goldenberg, et al., 2001) and their accompanying swells, beach stability and sand supply should remain of great concern.

The Islands of Dominica, Grenada, Guadeloupe, Jamaica, Martinique, St. Christopher and Nevis, St. Lucia and St. Vincent appear to be the most in jeopardy to these projected natural hazards, because, in part, of the level of sand mining activities that has already taken place on these islands (U.S. AID, 1987). On the windward coast of St. Vincent, beach erosion has increased following the extraction of sand and gravel from the foreshore for industrial usage. Modification of tidal inlets can also

exert significant influence on the erosional and depositional patterns of abutting beaches (for a review see: Boothroyd, 1985).

Sedimentation processes

If there is to be a forecast for the evolution of shorelines, then proper understanding of the mechanics of sediment transport is needed. At present, processes of erosion and accretion along coastlines are understood qualitatively. It is known, for example, how natural and anthropogenic processes affect the erosion and accretion of shorelines (see e.g., Horn, 1997) and we have a comprehension of the physical processes that govern the response of the coast to various activities (Nordstrom, 1994). From a purely quantitative standpoint, researchers tend not to possess the capability to provide policy guidance about the fate of sediments, or about the evolution of coasts (but see: Boothroyd, et al., 1998). Although shoreline structures, for instance, might diminish the stability of a section of coast, it is not feasible at present to forecast how fast that instability might occur, or even how far it might extend.

As they approach the shore, waves and currents mold the coast according to the severity of the physical forcing, contributing to the erodibility of the coast. There is considerable variability in the types of waves and how each kind (e.g., long, short, etc.) contributes to swash zone mechanics (see: Horn, 1997). Sandy beaches are rare for rocky shorelines that are not easily eroded, and the coast may consist of steep seacliffs, fronted at places by a narrow cobble or sand beach. A submergent coast, one that is sinking relative to sea level, may have many such rocky shorelines, as the physical processes are not allowed to work long enough to break down the seacliffs to derive enough sediment to form a beach. Areas that are submergent, but that have

abundant sediment supply, typically form extensive lagoons or estuaries, that may, for example, result in the development of mangrove wetlands.

Along emergent coasts, one that is rising relative to sea level, or along coasts consisting of more erodible sedimentary deposits, the coasts tend to have sandy beaches and related marine resources. Areas that are emergent which have good sediment sources make for building wider beaches, tend to have multiple beach ridges or other markings of ample sediment supply and stable profiles.

Anthropogenic activities can also have a significant effect on coastal morphology and stability. The type of coast that exists in an area may provide the control point in large part concerning acceptable management practices. Management plans applicable to one type of coast oftentimes are inappropriate for other types of shorelines (Olsen, et al., 1998). Differences and distinctions need to be recognized when legislative, regulatory, or policy decisions are formulated for coastal environments (see: Olsen, et al., 1997).

Mangrove wetlands are areas of critical environmental concern, because their existence relies on a balance of freshwater/saltwater balanced sediment supply, water level, and water quality (Snedaker, 1995). Significant shifts in the vegetation patterns, and on the character and stability (or mobility) of the coast can result through alteration of any of these parameters.

Physical stresses are placed on the coast by nature and by anthropogenic activities. Natural stresses include relative rise of sea level, the continual pounding of the shoreline by waves (with a possible recent increase in waveheights - Grevenmeyer, et al., 2000), fluxes brought by tides, interruptions in sediment supply by droughts

and river meanders (oxbow's) and similar events. Anthropogenic influence is similarly broad in scope, and has tended to show an increasing "fingerprint" in recent years (Ausubel, 1996).

The human influences on coastal stability are many and varied, and a selected listing includes: mining of sands from beaches and offshore; construction of shore protection structures along the coast; land reclamation resulting in loss of coastal habitat; dredging and the construction of navigation structures along the coast; submergence of land due to withdrawal of groundwater; interruption of natural river flow to enhance irrigation; and saving the upland but reducing the supply of sediment to maintain an equilibrium coast.

These physical stresses cause imbalances in the delicate equilibrium that has marked many coastlines for hundreds or thousands of years. As sea level rises globally, many coasts that are not tectonically emergent are constantly retreating; the ability of shores to retreat is essential to maintaining a stable landform (see: Titus, et al., 1991). Retreating coasts, however, are an anathema to shorefront development leading to inevitable conflict between those who would protect investments and others who choose to retreat in the face of overwhelming natural processes. Protection of investments will prevail until the total economic and insurance related costs of this subsidy are analyzed. The result is a reduced stability of the coast, a state of siege along many coasts whereby the infrastructure is constantly threatened by storms and other natural hazards (van der Vink, et al., 1998). Only by recognizing this imbalance and anthropogenic contributions to it will the shore be able to regain its natural defenses to the natural processes that constantly re-shape it. Thus, this is the "coastal challenge" that effective integrated coastal area management has to deal (Olsen, et al., 1998; Clark, 1996; Inman and Brush, 1973).

How best to preserve the coastal environment in a sound state where it is now healthy, and how to restore those areas that have been impacted adversely by human activities? This challenge must be met while keeping in mind economic constraints as well as the desire for continued and even increased human habitation and resource utilization in the coastal zone. The multiple use conflicts that pressure coastal management are difficult to resolve globally, and almost always must be addressed on a local basis. Lacking a global or regional scale resolution may render local management decisions ineffective and may result in a dichotomous framework.

Since coastal oceans disperse pollutants (including atmospheric CO₂) effectively with open waters through natural dispersion and mixing processes, the results of discontinuous management may be a degraded marine resource along the entire shore in some locales even when apparently proper management decisions have been taken. This connectivity between the coastal areas mandates a regional view (see: Alexander, 1994) for management at the least, considering the effects of management practices at one location on resources some distance away.

From time to time, several primary coastal area management issues arise. First, a precautionary principle of prevention and control strategies ought to be implemented to reduce pollution inputs. Eventually, there will be an increased need or desire to implement international controls on marine pollution, similar in scope to those contained in the United Nations Convention on the Law of the Sea Treaty. A second need is for clean-up and improvement of deteriorated environments. In most cases, this clean-up may be more expensive than point-source control devices; to be economically feasible such an effort should focus on those sources or contaminants most responsible for ecosystem degradation. This information is provided through

scientific investigation. Thirdly, a carefully-considered monitoring program needs to be provided to monitor the health of the coastal resources (see: e.g., GESAMP, 1990).

Through careful scientific analysis can a rather limited program produce unambiguous data relevant to monitoring the health of coastal resources. To achieve the efficient and effective monitoring goal, new ocean engineering technologies can be developed and calibrated to acquire the interdisciplinary measurements needed for assessment of the movement of shorelines.

Interaction between the policy, management and scientific community expressing the ideas, needs and resources of each group is mandatory. For instance, much basic science is fundamentally not able to be incorporated directly into management practice (see: Pielke, 2002), though for baseline and other reasons it still must be completed ultimately to address central management needs. The communication must be specific enough to allow policy makers to communicate their perceived needs and time requirements. The scientist needs to consider these when providing recommendations from the scientific results. Similarly, policy professionals must acknowledge that improved understanding of some essential management problems oftentimes requires years of continued investigation, with results either indirectly or directly bearing on recommendations for an improved management strategy. If successful, this type of communication will aid in assuring proper progress in science leading to applied management needs at the land-sea interface.

Chapter 8. Episodic Storm Events

Climatologic and meteorologic changes may provide one example of global environmental change. For this study such variables assume a large percentage of the reshaping of the land-sea interface. That is, as was demonstrated in an earlier chapter, the episodic severe storm-events are the principal processes that rework and reconfigure the littoral zone. Determining the regional distribution of global climate change impacts, and whether or not storminess can be depicted out of natural variability, requires accurate assessments of both the direct and associated effects of climate change on the physical environment (Schneider, 1989). The lack of in-situ historical scientific data in the wider Caribbean means one must accept considerable uncertainty in determining local effects of global changes. Though weather and climate extremes places societal infrastructure in a more precarious position which would be exacerbated by climate change (Easterling, et al., 2000). Nonetheless, it is possible to develop localized examples that capture some of the most significant anticipated consequences of global change.

Historical temperature change contains a large amount of spatial and temporal natural variability. In regions such as the wider Caribbean, where there is incomplete tidal and weather station coverage (Granger, 1997), estimates of past and future temperature changes may need to rely on extrapolation from other regions across the globe that may act as a proxy. This is also the situation when utilizing the narrow availability of physical data that does exist for the Lesser Antilles. To reiterate from an earlier chapter complete knowledge of global mean temperature change remains uncertain (Maul, 1993), even in the present era of instrumental meteorology. Researchers have calculated that global mean warming since 1880 has been about 0.55° C. More importantly, warming during the mid 1980's, for example, in 1987

was attributed to more than 0.4° C temperature rise at low latitudes (23.6°N-23.6°S), which encompasses most of the wider Caribbean (Hansen and Lebedeff, 1988).

Modeling studies, on the other hand, project that the highest increases in temperature accompanying global change will occur near the poles, with smaller temperature increases near the equator. Further complicating the problem is that global models can not as yet reliably forecast regional scale climate changes (Schneider, 1989). Further, "the merits of using current global climate models to project future changes in tropical storm frequency," for example, are actively debated (Easterling, et al., 2000, p. 2071; see also Henderson-Sellers, et al., 1998). It is not clear how one interprets the recent historical temperature change trends in light of these model results. Nevertheless, the historical trend of increasing temperature, if continued, will be expected to produce changes in precipitation patterns, water and sediment budgets, relative sea-level rise, and storm climate changes.

Storm patterns are responsive to perturbations in weather and climate, in the short and long term. As climate warms geographical gradients in atmospheric and oceanic temperatures will intensify. Storms (both tropical and extra-tropical) reacting to ocean/atmosphere interactions may change in intensity (magnitude) and track, with some areas experiencing increased incidence of severe storms (Mayfield and Lawrence, 1996; Gray, 1993).

There are suggestions that changing climate can alter the range, intensity and paths of hurricanes and tropical storms. It appears that storm intensity (but not frequency) may increase (Emanuel, 1999; Emanuel, 1988). Recently, according to one calculation, there is a combined average of eight tropical storms and hurricanes that traverse the wider Caribbean each year, comprising about 15 percent of all tropical

cyclone occurrences world-wide (Underwood, 1988). Another appraisal of major and minor hurricanes in the Atlantic Basin from Goldenberg, et al., (2001) can be seen in Figures 58 - 60 and Table 45. Record hurricane storm surges of greater than seven meters, and associated 200 kilometer per hour winds, have been recorded in the wider Caribbean within the last several decades. Generally, hurricane formation requires sea surface water temperatures in excess of 26° C (Emanuel, 1988). Since the Caribbean Sea is already on average 27° C (Levitus, et al., 2001; Underwood, 1988), even higher ocean temperatures accompanying global warming might extend and intensify the tropical storm and hurricane season. Judging from output data from general circulation models, increased storm intensity could yield as much as a 50 percent expansion in the damage potential of hurricanes in the wider Caribbean (Emanuel, 1987).

This estimate is based on mean conditions for August over the tropical oceans, and a two-fold increase in present CO₂ content resulting in a surface water temperature increase of between 2.3-4.8° C. In partially enclosed basins, such as the Gulf of Mexico, the suggested maximum damage potential of tropical hurricanes could be increased by as much as 60 percent (Emanuel, 1987). In addition, global warming may cause an increased tendency of hurricanes to form at higher latitudes within the wider Caribbean region. The potential for an increased intensity of severe storms will likely foster erosion and shoreline recession which will have potential impacts on the social and economic development of countries in the wider Caribbean, particularly on tourism.

Recently, several Lesser Antilles islands were struck by Hurricane Luis, where in St. Maarten, it caused an early estimated \$500 million in damage, including three of the island's major hotels being closed for the 1996 winter-spring season (Kurkjian,

1996; see: Figure 50; Tables 38 and 39). Indeed, according to Munich Re, a reinsurance firm, of all natural disasters the "bill" for Hurricane Andrew in 1992, at \$16 billion in claims surpasses all other single natural catastrophes of any kind to date (note Table 41). In the U.S., Easterling et al., (2000, p. 2071) report that "losses caused by catastrophes, defined by the property insurance industry as storms causing insured losses greater than \$5 million in the year of occurrence, have grown steadily from about \$100 million annually in the 1950's to \$6 billion per year in the 1990's." They also add that the annual number of catastrophes increased to 35 in the 1990's from about 10 in the 1950's (Easterling, et al., 2000).

For the Pacific region, present day El Niño/Southern Oscillation (ENSO) causes dramatic shifts in storms, reflected by more storms of greater intensity during part of the El Niño/Southern Oscillation cycle (Avila, et al., 2000). Meteorologists have also provided a suggestion or theory that ENSO plays a significant role in the formation, intensity, and even the frequency of Atlantic Basin (atmospheric waves) tropical storms and hurricanes; through an analysis of data presented in Table 43, this theory remains inconclusive and unresolved.

Another of the most powerful and catastrophic wider Caribbean storms on record was Hurricane Gilbert (with central atmospheric pressure lower than 920 millibars), one of only a handful or so "category five" storms recorded in the 20th century. This storm affected the northern wider Caribbean causing considerable damage and loss of life in Jamaica and the Yucatan peninsula, Mexico (Ratcliffe, 1989). According to reliable data it was the largest cyclonic system ever observed in the western hemisphere with a circulation pattern encompassing 25 degrees of latitude and 20 degrees of longitude, and drew moisture from the central Amazon (Eyre, 1989). Hurricane Gilbert's maximum sustained wind was 185 m.p.h. At Cozumel,

Mexico near the point of landfall, sustained winds were estimated at about 170 m.p.h. (Lawrence, 1989).

The storm surge-increased water-level on the northeast coast of Jamaica were nine feet above normal (Lawrence, 1989). While some of the effects of the storm surge were attenuated by nearshore bathymetry and coastal topography (Eyre, 1989), erosion occurred on over 50 percent of the beaches with heavy damage to coastal woodlands, with local losses of up to 60 percent for mangroves in some areas (UNEP, 1989). At the time, early damage estimates from Gilbert indicated about U.S. \$5 billion for the entire wider Caribbean (Lawrence, 1989). It is important to also point out that in addition to altering the range, path, and intensity, global warming is also anticipated to extend the duration of the hurricane season as viewed from the historical meteorological record (Emanuel, 1988).

Though, however, Landsea, et al., (1996) suggested that there was a downward trend in the frequency of intense Atlantic hurricanes in the era of aircraft reconnaissance from 1944 to 1995 (see also Henderson-Sellers, et al., 1998). They also felt that the "mean maximum intensity - averaged out over all hurricanes in a season - has decreased" (Landsea, et al., 1996, p. 1697). The peak intensity, from instrumental records, obtained for the strongest hurricane per season displays no significant change with time (Henderson-Sellers, et al., 1998). Smith, (1999) suggested that from 1900 through 1998 there was a slight increase in hurricane frequency and that land falling hurricanes indicated no increase in either frequency or intensity for the 20th century. Though even those episodic tropical storms that do not make landfall play a significant role in coastal sedimentary processes such as beach erosion.

Nevertheless, in September of 1989, Hurricane Hugo struck a path of destruction through the Lesser Antilles and Puerto Rico before moving into the Atlantic Ocean. In its wake lay an early estimated \$2 billion in property damage. Hugo, a category four storm with sustained winds reportedly of between 135-140 mph, first made landfall on Guadeloupe while eventually making its way to Puerto Rico. Widespread damage from coastal erosion to flooding of tourist facilities were reported on a number of islands, especially Montserrat and the U.S. Virgin Islands (see: Table 42 and Figures 51 and 52). Generally, the meteorological record indicates that the most intense storms for the Lesser and Greater Antilles, have occurred over the last two decades of the 20th century (Goldenberg, et al., 2001; see also Table 45). The impact of greater storms presumably will be felt particularly in low-lying areas subject to coastal flooding (van der Vink, et al., 1998), especially with rising relative sea level (Milliman and Emery, 1968).

In the wider Caribbean, as elsewhere, mangrove forests act as a buffer against destructive hurricanes and tropical storms. There is great concern about deforestation throughout the wider Caribbean as elsewhere (Repetto, 1990). Mangroves are an important resource throughout the Caribbean because they aid in nutrient removal, control local mean water levels and flow direction, and act as sediment baffles, spawning grounds, nurseries and feeding habitats for traditional and commercially important finfish and crustaceans. The prevalent practice of mangrove 'clear cutting' and filling for land and fuel results in increased siltation and eliminates the shoreline stabilization these forests provide particularly during severe storms. Data from Kurian, (2001) indicates that St. Lucia sits at number four, behind Jamaica in second place, on the list of nations losing tropical forests by percentage with 3.6 percent rate of deforestation. Jamaica's rate of deforestation for the first half of the 1990's was 7.2 percent of its entire stock (Kurian, 2001).

During the period for which written records are available Tomblin, (1981) states that more than 20 hurricanes have claimed about 30,000 lives in the Caribbean islands alone (see also Tables 42 and 43). Information from these Tables demonstrates the highly variable nature of atmospheric events on people and property in the wider Caribbean islands. The movement of the region's population and infrastructure to vulnerable coastal areas is illustrated via the development of numerous eastern Caribbean cities at or near the shore.

The extensive waterfront development, much of which is on reclaimed land, greatly increases the potential for serious storm damage. This seaward encroachment has led to an increased risk for the inhabitants because the low elevation and proximity to the sea means increased exposure to storm waves and ocean surge associated with tropical storms and hurricanes. This situation is further exacerbated by the removal of protective mangrove screens for shorefront development. While there is regional evidence for the landward encroachment of mangrove and marsh-grass communities, it is not clear whether this is the result of recent sea-level history or the anthropogenic withdrawal of groundwater resulting in increased landward saltwater encroachment (Snedaker, 1995). The Figure 8 matrix provides for a visual input-output analysis of select *marine affairs* thematic issues of the biosphere of the wider Caribbean.

Storm Effects

Crowell et al., (1993; 1991) among other researchers point out that it is important to document shoreline processes that occur during severe episodic storms in order to better cope with coastal changes that may result from global climate change. Further, it is imperative that the management mechanisms and policies enacted to

combat the resultant deleterious cumulative effects of these storms take marine geologic and other representative natural resources parameters and processes into account.

Beatley et al., (1994) suggest that landfalls of episodic tropical storms in the North Atlantic as a whole over the last three decades may only be indicative of perhaps an abnormally low level of hurricane and coastal storm activity. Gray, (1990) has forecast an increase in storminess as we return to a more volatile cycle in meteorological conditions. This theory has been more recently trumpeted by Goldenberg, et al., (2001). Further, Carnell, et al., (1996) caution that an increase in mid-latitude winter storminess and low level windiness could be one of the most damaging aspects of climate change. This may be the case since there is some general agreement that apparently computer model estimates typically under forecast more intense low pressure systems. The long-period swells generated over great distances from these storms can directly contribute to beach erosion in Lesser Antilles locales as Hayden, et al., (1978) have quantified.

Changes in storm climate would continue to impact the extensive shorelines of the Caribbean. As global ocean and atmospheric temperatures increase, atmospheric stability will change in some locales (Goldenberg, et al., 2001). Decreased atmospheric stability in turn is related to storm activity. Empirical data suggest that for the tropical west Atlantic, hurricane activity depends strongly on the size of the pool of warm water exceeding 26° C (Emanuel, 1999; Emanuel, 1988). As climate changes, the size of this warm pool will theoretically expand (see: Levitus, et al., 2001), potentially altering the intensity, range, and paths of tropical storms (Emanuel, 1999).

While increased temperatures may have ramifications for biological organisms, it is the associated effects of rising sea levels and increased storminess that are especially important to tourism activities in the Caribbean (Hendry, 1993). In relatively recent times, some quite substantial hurricanes and an increased number of tropical storms have been felt in the region (Wilson, 1999; Case, 1990; Lawrence and Gross, 1989) despite earlier commentary. For the Atlantic region in 1995, there were more tropical storms than for any year since 1933, causing several billion dollars in damages in their wake (Le Comte, 1996). Annual reviews of Atlantic hurricane seasons for the past three or so years can be found in Franklin, et al., (2001); Lawrence, et al., (2001); and Pasch, et al., (2001); none were as potent as 1995 for the islands. In general, if predictions come to pass with the dawning of the 21st century, an increased amount of episodic storms from ramifications of global warming would tend to increase erosion and shoreline recession (see: Cambers, 1997; Cambers, 1988; Figures 47 and 48).

Sidebar: A Discussion of the Effect of a Major Hurricane, Hugo on St. Croix,
U.S.V.I. and Subsequent Recovery of Select Coastal Landforms.

Poorly planned development, previously stressed coastal ecosystems, and careless recovery efforts exacerbate the overall effects of the impacts from hurricanes. It is time to learn from past experiences to brace for the future (Olsen, et al., 1998). The passage of Hurricane Hugo through the Lesser Antilles provided a unique opportunity to study the effects of severe storms on tropical coastal and marine ecosystems. In general, Aubrey, et al., (1991) tested two subhypotheses (as depicted in the next few paragraphs): the first was that coastal marine ecosystem structure is formed by severe episodic events, and the second was that the impact from these episodic events is accentuated when ecosystem stress contributes to pre-existing

degradation of the coastal environment. In other words, cumulative effects makes the impact from episodic storms that much more problematic (see: Bedford and Preston, 1988). One objective was to determine the relationship, if any, between episodic storm events and the structure of marine ecosystems, in the case at hand here, sandy beach biomes. The reasoning is in order to aid in providing proper policy tools to better manage coastal marine resources (see also Aubrey, et al., 1991).

Responding to environmental conditions on a variety of temporal and spatial scales are marine and terrestrial ecosystems. Effective risk assessment and management of tropical ecosystems is often hampered by poor scientific understanding (Aubrey, et al., 1991). Even where appropriate scientific data exists, it is often not accessible or known to policy-makers in a functional format to implement management decisions. What can be considered normal episodic disturbance and atypical prolonged disturbance and stress events? It is hypothesized that the latter may be about to occur more often (Goldenberg, et al., 2001) as episodic tropical storms increase in their intensity and come ashore upon overdeveloped coastal environments already acutely stressed from environmental degradation (see: USAID, 1987).

In recent memory, in 1989 Hurricane Hugo, exacted a property loss that was estimated at approximately \$3 billion dollars in the Lesser Antilles (see similar data from Munich Re, Table 41). Hurricane policy response was excellent based upon the relatively low loss of life from this "category four" hurricane. The in-place effective warning and response system (see: CTO, 1998) was not something that just happened when Hugo was on the horizon, rather, it was the result of years of cooperative work by governments and non-governmental agencies in the region. One atmospheric database indicates that the tumultuous 1989 season had 11 named storms, seven of which acquired hurricane level status (see also Tables 42 and 43). At that time, this

compares to a 50-year average (to ~ 1990) of 9.5 tropical storms, of which 5.5 became hurricanes (Aubrey, et al., 1991; see also Wilson, 1999 for similar calculations).

Meteorologist's have constructed a Hurricane Destruction Potential (HDP). It is a measure of a hurricane's potential for wind and storm surge destruction (Avila, et al., 2000). It is defined as the sum of the square of each hurricane's maximum winds for each six-hour period of its existence. The average HDP during a Cape Verde (African) year of the 1967-1996 timeframe was larger than the average HDP of the non-African years (see: *inter alia* Goldenberg, et al., 2001; Avila, et al., 2000; Case, 1990). Usually the most intense hurricanes are spawned by atmospheric waves exiting to the west from the African Continent just south of the Cape Verde island archipelago (see: e.g., Avila, et al., 2000; Pasch and Avila, 1999; Rappaport, 1999; Lawrence, et al., 1998; Pasch et al., 1998).

Serving as an important protective function for shoreward ecosystems and societal infrastructure is one role for beach landforms at the land-sea interface. They dissipate storm wave energy and act as barriers to storm-elevated sea levels (Boothroyd, et al., 1998). It is also of importance to consider that plant communities are familiarly connected with the development of barrier landforms as well as determining their overall effectiveness as storm buffers. The types of plants, for example, grasses and shrubs, the composition - species abundance - as well as the distribution of coastal plant communities are principally controlled by topographic elevation and hydrologic properties, substrata composition, and exposure to wind and salt (Aubrey, et al., 1991).

Researcher's from marine science organizations on Cape Cod in the early 1990's conducted two post-storm surveys that examined the response to Hurricane

Hugo of beaches and their associated plant communities on St. Croix, United States Virgin Islands in the Lesser Antilles. The focus for this sidebar is on the two beach systems, Shoy's Beach on the north coast of St. Croix and Halfpenny Bay beach on the southern shore. Giese and Burdick conducted a generalized island-wide survey of hurricane impacts on the beaches and shore vegetation of St. Croix, covering approximately 80 percent of the island's coastline (see: Aubrey, et al., 1991).

Results of transects using standard survey quadrat (1 m²) methods indicated that dune retreat amounted to approximately 20 feet, as estimated from field observations as well as from aerial photography (Table 36c). Extending more than 100 feet from the dune scarp were overwash fans that encroached into the back-barrier mangrove swamp. At Halfpenny Bay beach the dune line retreated approximately 32 feet during the hurricane. There, overwash deposits extended landward into the backwater swamp over 100 feet. These deposits added up to two feet of new sand to the dune surface (Aubrey, et al., 1991).

Table 36c. Estimates of beach retreat rates (mean distance in feet +/- standard error) for Shoy's Beach and Halfpenny Bay (St. Croix, U.S.V.I.) beach. The information is principally based on aerial photography and direct quadrat measurements from the seaward edge of the protruding roots (old dune scarp) to the new dune scarp (source: adapted and modified from Aubrey, et al., 1991).

METHOD	HALFPENNY BAY	SHOY'S BEACH
	-----	-----
Aerial photography (n=20)	33.8 ft. +/- 3.6	21.0 ft. +/- 2.0

Table 36c. (continued)

Root line to dune scarp (n=3)	32.3 ft. +/- 0.3	19.7 ft. +/- 1.7
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A general observation was that the island-wide survey indicated rapid post-storm sedimentation and natural beach replenishment at the south and southwest shores, and slower rates of recovery, if any, on the northern and northwestern shores (Aubrey, et al., 1991). For a comparison see the study by Hayden, et al., (1978). Further, the post-Hugo erosion appeared to be greater where the beach had detached from the beach rock (Aubrey, et al., 1991). This may be also due to differing rates of vegetative recovery as well.

In the study it was demonstrated that "most of the beach systems studied on St. Croix were protected by offshore reefs. Where structures such as houses or parking lots occurred near the high tide line on beaches, they were usually damaged by the storm. On beaches where the natural coastal plant communities were removed (sometimes replaced with non-native species and groomed), research suggests some of the dune building properties of the plant community were lost. It is important to maintain natural plant communities that support coastal sedimentary processes in the face of rising relative sea-level and more hurricanes" (Aubrey, et al., 1991).

From Aubrey, et al., (1991) it can be concluded that shoreline retreat was more extensive on the south coast (approximately 30 feet) than on the north coast (approximately 20 feet) as the storm emanated from a southeasterly direction. At both sites, overwash deposits raised dune surface elevations up to between one to two feet.

It also extended the landward toe of the dune into the mangrove swamp behind the beach. By the following November, about 14 months after Hugo had passed, "the beaches have regained sediment (extensively on the south coast, almost none on the north coast) from nearshore sources. Red Mangroves appeared to have been overwhelmed by the storm.

Several tree species succumbed following releafing (dune locales: Seaside Maho, swamp areas: White and Black Mangroves). Most surprising was the survival of Sea Grape trees and Coastal Dropseed grass in areas that had been dune environments but were eroded by the storm waves and now are part of the beach. The island-wide survey indicated that the areas where coastal development was impacted most severely by the storm were not protected by naturally vegetated coastal landforms. Natural vegetation will serve to trap sand on the dune during both recovery and future erosive periods" (Aubrey, et al., 1991). The preceding vernacular is just one example for the relevance of attempting to calculate optimal development setbacks (Gable and Edwards, 2001).

Chapter 9. Policy Formulation

The variable effects of global climate change, coupled with present environmental stress from human activities upon landscapes (ecosystems) illustrates the need for a proactive and less reactive cumulative impact assessment (Cocklin, et al., 1992). Further, Cocklin et al., (1992) stress the need that these cumulative environmental impact assessments be performed on a regional approach as opposed to project-based assessments. For our purposes this means that island-wide assessments and/or even basin-wide evaluations are necessary to illustrate proper accountable cumulative links of individual tourism development projects and environmental quality problems, among others. Moreover, the greenhouse effect, believed a triggering mechanism, is considered to provide disruptions to ecological processes that can change system behavior in the region (Cocklin, et al., 1992).

An attempt to evaluate the exposure, response, comparative risk and vulnerability of cultural, economic, social, biological and physiographical implications of global change and its local, basin-wide, regional and inter-regional manifestations can be described as a cumulative effects impact assessment (Bedford and Preston, 1988; Kotlyakov et al., 1988). Cumulative impacts can be defined further as the impact on the local, regional or global environment which is a consequence of the incremental impact of the action (e.g., climate change). The cumulative effects of environmental variability (including climate change) on many scales, determines the mean state of an ecosystem (McGowan, 1990).

Minor but collectively significant actions taking place over a period of time can result in cumulative impacts (Preston and Bedford, 1988). In addition, while greenhouse gases normally occur in unification, synergistic effects of interacting

combinations, superimposed upon direct effects, is also important (Parsons, 1990). A paradigm of the cumulative impacts describing interactions of anthropogenic forcings upon regional coastal landscapes was attempted for part of the western Indian Ocean (see: Gable, et al., 1991). A similar example has been extrapolated for the Caribbean Basin (Figure 3).

While it is convenient to separate and categorize the impacts from these activities individually, all categories of stress, be they local, regional and/or global, will be operating simultaneously on the same ecosystem components (e.g. coral reefs, coastal fisheries, mangroves, beaches, etc.). Because of the interaction of these stresses often cover a large area and cross political jurisdictions they represent regional and basin scale risks and subsequently, costs (Ayres, 1992).

For policy formulation, the expanding coastal population of the wider Caribbean is making burgeoning demands for the limited coastal resources and the area the natural resources occupy. These demands are both explicit and incidental. Explicit demands include, among others, encroachment of building infrastructure on the coast, mining of sediment for construction material, and placing of shore protection devices, for example, groins and breakwaters. Incidental demands include those imposed as an indirect result of human activity, examples of which are global warming and relative sea-level rise, partly resulting from local land-use practices. These human activities have combined with natural environmental variability to form some notable impacted locales within the wider Caribbean.

The policy aspects of this tome have sought to aid in addressing constraints posed by "global change" through the United Nations Framework Convention on Climate Change (UNFCCC) in Article 4.1 (b) which requires signatory Parties to the

Convention to: "Formulate, implement, publish and regularly update and where appropriate, regional programs containing measures to mitigate climate change by addressing anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, and measures to facilitate adequate adaptation to climate change." Similarly, domestic legislation can be invoked as a *raison d'être* for undertaking this study because the United States has territorial entities in the wider Caribbean Basin with, for example, the United States Virgin Islands considered a "small island developing state" (see: Ashe, 1999, p. 192), not to mention the existence of maritime boundaries of the U.S. throughout the Caribbean Sea. "Small Island Developing States" under the rubric of the United Nations Framework Convention on Climate Change are part of a trend for similarly situated entities to form a sort of independent functional marine regional organization to better foster their environmental concerns collectively (see: Alexander, 1994).

Thus, U.S. Public Law 101-606 [S. 169]; the Global Change Research Act of 1990 and Public Law 101-617 [S.3069]; the Environmental Research Geographic Location Information Act are pertinently related to the UNFCCC. The analysis undertaken has coincided with the stated aims of the Framework Convention (and the stated domestic legislation mentioned) but concentrates specifically on recognizing challenges wrought by global change to coastal tourism potentially from aspects of relative sea-level rise. Recognized throughout this body of work is that the Earth is continuously transformed by human action (see: Turner, et al., 1990; Walker, 1990; see also Graedel and Crutzen, 1989).

The problems discussed above relate and correspond to one of the main aspects of the multidisciplinary research initiatives promulgated by the "Man and Biosphere" Program (MAB) of the United Nations Educational Scientific and Cultural

Organization (UNESCO); that is, the rational management of small island coastal ecosystems (D'Ayala, 1992). D'Ayala (1992, p. 565) emphasizes that "once the human being is included in the equation, islands become eminently complex open systems." Aspects of this UNESCO MAB program have been used as a frame of reference.

Regarding decisions about coastal policy, for example, Lemay (1998) states on page 24 of her publication that the Inter-American Development Bank's "Policy on Natural Disasters" (OP-704) refers "implicitly to the vulnerability of coastal areas to hurricanes and floods but emphasizes structural solutions such as breakwaters and revetments for disaster prevention in low-lying coastal areas" rather than more benign retreat and setback regimes. An objective of the work performed here has been a critique of the preceding policy through allied research findings (see: Gable and Edwards, 2001). The likely range of responses to environmental hazards - i.e., structural vs. nonstructural responses by wider Caribbean governments to changes in relative sea-level, differences in storm regime, and altered precipitation patterns is important for agenda setting (Klein and Nicholls, 1999; White, 1996; White, 1994).

Proposed here are flexible policy responses to climate change that were, in part, determined through a content analysis of the literature to see how other parts of the world community have responded to coastal threats such as, *inter alia*, relative sea-level rise and coastal erosion and inundation. Likely policy response options to be ascertained by the researcher fall under the rubric of limitation and prevention, adaptation - both passive and active, as well as intervention and mitigation. The latter encompassing, for example, a building development set-back policy in the coastal zone (see: Gable and Edwards, 2001).

Thus, in some locales, such as coastal zones and floodplains, waiting "to make policy and to take action will drive up the costs of response," and may further increase societal vulnerability and a reduction in flexibility to contain unwanted effects (Ausubel, 1991, p. 211). Nicholls, et al., (1999) suggest that the wider Caribbean islands, among others, may experience the largest relative increase in flood risk due to relative sea-level rise. Klein and Nicholls (1999) suggest that direct socioeconomic and biogeophysical impacts of climate change and relative sea-level rise will be felt on the tourism sector through an increasing flood frequency, erosion and inundation (see: e.g., Table 8). As suggested earlier, this study has aimed to aid in understanding the comparative risks of select global change parameters upon the Lesser Antilles while trying to help in fostering a coherent coastal policy and management decision making in the face of climate uncertainty (see also Pethick, 1993; Pernetta and Elder, 1992; Newman and Fairbridge, 1986).

Concern about potential climate change accelerated by human actions has spurred policy analysis and assessment of effects for various regions of the globe. Although some may question the need for policy analysis when the scientific basis for human (anthropogenic) induced climate change is so controversial, it seems prudent, however, to identify in advance sensitive locations and issues arising from such change. Through such a sensitivity analysis, available resources can be focused on those issues and areas most demanding of attention. Such focusing is particularly necessary for sovereign Archipelagic states lacking adequate resources internally to complete comprehensive analyses of potential climate change impacts. Here, a segment of a vast, and interconnected marine region - the wider Caribbean - was examined for its sensitivity to aspects from potential climate change related impacts.

Preliminary investigation from analysis of climate changes and their direct and indirect cumulative effects on Lesser Antilles coastal and marine tourism, demonstrate that governments do have some management and policy options to consider. The following policy options were adapted and modified from Blommestein and Singh, (1987):

- Promotion of alternative styles of tourism (see: Krausse, 1995) thus reducing the primary dependence of Caribbean tourism on the beaches;
- Restoration of beaches (sand replenishment/nourishment);
- Protection and provision of shoreline space for diverse ecobiomes such as mangroves, lagoons, coral reefs, seagrass beds, shrub vegetation through the concept of "master plans;"
- Promotion for changes in insurance legislation therein requiring building setback lines to be promulgated and properly placed depending on terrain and marine conditions` (with variances through a zoning board of appeals, or equivalent, can be part of the process);
- Conceptualization of climate change scenarios (e.g., relative sea-level rise) included in the design of structures and engineering drawings;
- Determination of where are high risk areas to leave fallow - after calculating where such "high risk" areas are (from e.g., erosion) in manner similar to the potential workings of the Federal Emergency Management Agency in the United States (see: Heinz Center, 2000a,b)
- *do nothing.*

Other ways to address the human and scientific aspects of global environmental change when coupled with present environmental stress can be considered. The adoption of comprehensive coastal zone management/planning schemes is one

noteworthy example, especially in how one attempts to manage changes from relative sea-level rise (Pernetta and Elder, 1992). A few of these planning texts have been implemented in the wider Caribbean (Sorensen, 1997); however, they were promulgated because of crises that existed and not necessarily in response to global change, *per se*. Planning texts that foresee problems for a given locale and then provide mechanisms for mitigation specifically for those distressed areas would be a better approach (Sorensen, 1993). Because of the ramifications of potential climate change, convincing environmental impact assessments or audits, such as those provided under the International Standardization Organization (ISO; established 1947) 14001 environmental management standard (Oluoch-Wauna, 2001) should be performed when site analysis for tourism facilities are being planned, modified, or modernized (see: Tables 50 and 51).

Appropriate decisions can be arrived at concerning policy implementation based on knowledge of local response to the direct and indirect changes in climate along with the best available scientific findings on the magnitude and timing of human-altered climatic conditions. More importantly, however, may be the emerging late 1990's approach of an environmental audit (Gable, 1997; see: Table 50). Goodall, (1995, p. 29) states that "environmental auditing provides tourism firms with a tool to assess their environmental performance, identifying any negative environmental impacts and evaluating the opportunities to change current practices in order to improve that performance." Goodall, (1995, p. 30) writes that the emerging concept of environmental auditing "originally developed as a business management tool in manufacturing industry to address concern about compliance with legislation and regulations." It derives from the Independent System Operator or ISO, where ISO 14001 refers to environmental management operations (see: Oluoch-Wauna, 2001; Wu and Hunt, 2000).

Environmental auditing is defined as "a management tool comprising a systematic, documented, periodic and objective evaluation of the performance of the organization, management system and processes designed to protect the environment..." (Goodall, 1995, p. 30). He writes that "sustainability, however defined suggests a duty of care...at least, for the physical environment" and that "there is also the wider global dimension incorporating environmental issues such as stratospheric ozone depletion, global warming and tropical deforestation to which tourism activities contribute" (Goodall, 1995, p. 30). In practice there is a wide variety in which to undertake environmental audits, "since there are no legal requirements requiring firms to prepare environmental audits it is, therefore, a means of self-regulation" (Goodall, 1995, p. 30).

Moreover, it is quintessentially a market-oriented approach because "tourists are consumers of environment and tourism is, therefore, an environment-dependent industry reflecting the availability and quality of its primary or direct resource base, i.e. the physical environment" (Goodall, 1995, p. 29). "The overall aim is to support environmental protection and prevention of pollution in balance with socio-economic needs" (Oluoch-Wauna, 2001, p. 240). "It does not prescribe absolute requirements for environmental performance but instead only demands commitment through policy to compliance...it may be applied by any organization that wishes to implement, maintain and improve its environmental management system, assure itself that it conforms with its stated environmental policy, demonstrate such conformance to others, seek certification/registration of its environmental management system by an external organization or make a self-determination and self-declaration of conformance with it (Oluoch-Wauna, 2001, p. 240). The preferred option advocated here is for an organization or entity to seek an "external" agency to determine, through the audit

procedure, if a certificate of compliance is warranted by performance and adherence to stated policy goals.

Thus, if consumers, in the case at hand, stayover (tourist) visitors are not happy with the quality of their stay, perhaps due to hotel operations or the associated natural resource base (i.e., beaches) then they will not return nor provide the important word-of-mouth referral. In Thailand, hoteliers quickly saw the benefits of initiatives to manage and protect coral reefs and the scenic qualities of the shoreline (Olsen, et al., 1998) likely through a process known as environmental monitoring. Hence, *de facto* involvement of the private sector in coastal management is essential (Olsen, et al., 1997).

It may be imperative, therefore, to follow through to develop and/or enhance local, national and international programs and policies to address these and similar environmental issues. Such a program ought to, among others, provide further identification of the critical marine habitats/ecosystems or their components at risk (see: e.g., Gable, 1993), as well as provide an assessment of how much risk is acceptable that can be best managed by commencing environmental auditing for tourism (see: Tables 50 and 51). This audit can be a documented, objective, periodic and systematic evaluation performed with the aim designed to protect the environment (see: Goodall, 1995). Thus the audit procedure can be utilized to help ensure or safeguard tourism activities and operations that are as environmentally compatible as possible.

"The use of environmental management systems (e.g. ISO 14001) and audit as an instrument of environmental protection is in an experimental phase" (Oluoch-Wauna, 2001, p. 240). Despite the contention that either the judging criteria for assessing the effectiveness of the audit, or that there is not in place a systematic

approach to its application, does not diminish the point that it provides a fine example of an adaptive management approach to environmental policy making (see: Tables 49 - 51).

Based on knowledge of local response to the direct and indirect changes in climate along with the best available scientific findings on the magnitude and timing of human-altered climatic conditions, appropriate decisions can be arrived at concerning policy implementation. Though the uncertainties concerning the human-altered global climate change do not warrant draconian developmental and environmental regulations, it is suggested here that aspects of global climate change demands increased consideration as part of the matrix of environmental and ecological issues (Gable and Aubrey, 1990; Table 8). The indirect socio-economic effects on tourism from pollution, coral reef mortality, loss of fisheries and storm damage already are considered important problems for Caribbean officials to deal with; climate change has very likely become another.

A policy tool for continuing multidisciplinary sea-level research approach is necessary to further delineate the causes and consequences of relative sea-level changes. Tide gauge locations should be selected by national authorities with the capability to maintain them to the standards of the Permanent Service for Mean Sea Level in Bidston, U.K., (see: Woodworth, 1991) in order to monitor long-term changes in sea level. As sufficient data becomes available, emphasis by marine researchers can be placed on the interpretation, measurement, and modeling of relative sea-level changes from increased technological capacity.

Terrestrial measurement systems using space and satellite techniques have been developed to detect small changes in relative position of earth movements. Very Long

Baseline Interferometry (VLBI) and Satellite Laser Ranging (SLR) are two techniques under refinement for this purpose (Nerem, and Mitchum, 2001; Nerem, et al., 1999; Nerem, et al., 1997). Another readily transportable and less costly measuring program is based on the Global Positioning System (GPS) (Done, 1988). This device has already been employed by U.S. Department of Interior, National Park Service Personnel on St. John's U.S.V.I. While at present all of the above mentioned techniques are in the research, development, and evaluation period, they will eventually become more "on-line" in the Caribbean with donor agency funding support. All of these systems should be used in concert with available tide-gauge data in order to attempt to separate land-level from sea-level changes, for improved prediction capability (see also Eden, 1990).

In addition, the improved satellite altimetry observations and networks of tide-gauge stations surveyed with accurate geodetic positioning techniques described previously may eventually allow for extrapolation of the contemporary climate-induced signal from the background noise. The choice of which techniques should be used in the wider Caribbean will depend on local expertise, finances, and environmental factors. Regional studies must be continued to conceivably correlate coral reef evolution with relative sea-level changes and hence changes in beach profile and width as well as studies that illustrate the parallels of Caribbean sea-level histories with climatic, geologic (tectonic), and oceanographic processes (Dillon, et al., 1987; Hopley and Pirazzoli, 1985).

There are, as a matter of course, several possible policy responses that could be employed to lessen the rate and impact of climate change. In the face of the scientific uncertainties accompanying the projected impacts of climate change, emphasis ought to be focused on (1) energy efficiency and conservation, (2) alternate

fuels and industrial chemical usage, and (3) periodic reevaluation and adjustments of policy decisions (Lave, 1988). Research should be conducted on (4) science/policy issues, specifically how scientific information is used in the formulation of decisions about climate change for coastal and ocean resources policy (Lave, 1988). A policy orientation framework may be considered a "best management practice" for periodic review of *marine affairs* related strategies.

Other key policy actions might include (5) minimizing both land-use changes that contribute to the input of trace gases into the atmosphere and (6) coastal development that does not take advantage of local conditions, for example, the building of air-conditioned hotels (which have contributed to freon CFC gas emissions) instead of open-air inns. In addition (7) fostering incentives for the revegetation and reforestation of fallow land, as well as (8) developing strategies that provide for building setbacks (see: Gable and Edwards, 2001), as well as the undertaking (9) of a regional shoreline study similar to that conducted by the U.S. Army Corps of Engineers in the U.S. in 1971. In addition, (10) adaptation, mitigation and prevention (if economically and technologically feasible) of acknowledged climate change activities should be employed to halt environmental climate change in advance (Schneider, 1989). All of the preceding points can be addressed and assessed through the aforementioned environmental audit procedure (Table 50).

Christiansen et al., (1996, p. 673) posit the viewpoint that ecosystems are dynamic spatially and temporally and that "we are just beginning to understand the complexity and scales of change that occur in marine ecosystems ranging from seasonal variations in currents and sea temperature, to periodic events like the El Nino/Southern Oscillation cycle, to long-term changes and large-scale changes, such as those driven by variations in salinity and ocean temperature." The latter point of

significance for eustatic sea level change. Christiansen, et al., (1996, p. 676) state that regarding ecosystem management there remains unprecedented "uncertainty, surprise, and limits to knowledge." They go on to proclaim that uncertainties as they relate to "unknowable responses...that arise from the complex and ever-changing character of ecosystems and their response to perturbations...include ecosystem responses to unprecedented rates of climate change, carbon dioxide enrichment, or increased ultraviolet radiation" (Christiansen, et al., 1996, p. 676). For select elaboration of the elements of ecosystem management see Tables 46 - 49.

The concept of adaptive management is learning by doing including treating programs as experiments (Hennessey, 1998). Thus, embracing of adaptive management procedures should foster more movement towards the development and endorsement of environmental auditing (Gable, 1997). For this multidisciplinary *marine affairs* oriented study performed here, I apply the Christiansen, et al., (1996, p. 678) commentary that the "vastness and three-dimensionality of the marine environment combined with an historical lack of necessary research incentives present unique limitations on our ability to acquire knowledge in these ecosystems." This situation would arguably apply to the uncertainty in past absolute rates of relative sea-level rise as well as present day scenarios of future contributions of ice sheets and alpine glaciers in synergy with atmospheric carbon dioxide enrichment, for example.

Hennessey, (1998) suggests that every policy is an experimental hypothesis; does it work? He too confirms that knowledge of ecosystem process and management is incomplete and subject to alteration, thusly, we should learn from policy experiments. "This concept of management as experiment is the basis for adaptive management" (Hennessey, 1998, p. 33; Tables 48 and 49). Further, for the present study, one of the central themes of ecosystem management includes human values

(Hennessey, 1998), here, for example, as it relates to coastal tourism (Chapter Six). A dominant role in ecosystem management and goals is played out by humans, regardless of scientific information (Hennessey, 1998).

Thus at sandy shores ecosystems the value that people place on the environment, ecological services (see: Costanza, et al., 1997) and economic return from (unsustainable) international tourism appears to be at an imbalance. To better understand ecosystems' ecologies, administrators must principle themselves to "consider all natural and human components and their interactions" (Hennessey, 1998, p. 35). My study has attempted to apply this idea. Lastly, Hennessey, (1998, p. 38) mentions that "ecosystem management has the potential to bring a new focus to land use planning and to accommodate environmental objectives and development." While land use planning is not a central theme to my study (but see: Gable and Edwards, 2001), however, as it applies under the rubric of coastal management it is quite appropriately important (see: Olsen, et al., 1998).

In many instances, the projected impacts of future climate changes, however, will exacerbate environmental changes presently taking place and documented elsewhere (see: *inter alia*, USAID, 1987). While the vulnerability to climate change may be less pronounced when viewed on a regional scale, local site-specific impacts within a region may be considerable as has been illustrated in this survey.

In order to help facilitate the process of choosing proper response options, the cooperation among government administrators, policy makers, and scientists is essential. Inter-governmental organizations such as the United Nations Environment Programme and non-governmental organizations, such as the Caribbean Conservation Association can effectively pioneer the implementation process, although each wider

Caribbean country is unique in its experience and should seek its own strategy to global change problems while eliciting examples from elsewhere. Existing regional and local organizations concerned with global change impacts need to be strengthened, and should contain local participation and perspectives. To reach appropriate policy responses - data collection, dissemination, and field activities - ought to be an integral part of the governmental planning process.

There are several institutional frameworks in the Caribbean region that governments can look to for retrospective examples of coastline management schemes. One example is the U.S. Virgin Islands, Coastal Zone Management Plan (VICZMP) which was approved by the U.S. government in June 1979. From July 1, 1979, federal (U.S.) funding under Section 306 of the 1972 Coastal Zone Management Act (CZMA) in the U.S. Virgin Islands amounted to \$4,039,000 over the first decade.

The VICZMP was designed to manage all development activities in the Virgin Islands coastal zone, which includes St. Thomas, St. John, and St. Croix islands, all offshore islands and cays, and the territorial sea. The Program centers intensive management attention on development activities occurring in the "first tier," a relatively narrow coastal strip, along with all the offshore islands and cays, through the use of a general system of major and minor Coastal Zone Management (CZM) permits. A number of laws and related permits and programs administered by the Department of Public Works (DPW) controls activities within the "second tier," which includes the interiors of the three major islands.

The Virgin Islands Coastal Zone Management Act of 1978 (VICZMA) established the coastal zone permit system and the organizational structure for the VICZMP by designating the Department of Conservation and Cultural Affairs (DCCA)

as the lead administrative agency and creating the Coastal Zone Management Commission (CZMC or Commission) as having the primary responsibility for implementing the VICZMP. The VICZMA created the Bureau of Environmental Enforcement (BEE) within the Department.

The Commissioner of the DCCA is responsible for directing the activities of the DCZM, for issuing, denying or modifying all minor coastal permits, and for taking all enforcement actions arising from the implementation of the major and minor permit system. The DCCA also issues earth change permits for public entities in the second tier. The DPW retains the authority for all other earth change permits in the second tier. The CZMC (originally comprised 15 citizen members, five from each major island, who serve also on one of three separate island Committees), along with the Commissioner and the Director of the Virgin Islands Planning Office (VIPO) (both ex-officio, non-voting members), are empowered to promulgate rules and regulations and to issue major coastal permits.

The VIPO is responsible for reviewing and developing any changes to the VICZMP, reviewing and granting subdivision permits and historic district approvals, and ensuring that they are consistent with the goals of the VICZMA. The DPW has the statutory authority to grant building permits in both tiers and zoning permits in the second tier, and must ensure that they are consistent with the goals of the VICZMA. The DPW also is responsible for monitoring activities permitted in the second tier by the Soil Conservation Districts and under the Virgin Islands Earth Change Program.

The DCCA has identified eighteen Areas of Particular Concern (APC's). Eight are special management areas and ten are areas for preservation or restoration. The DCCA developed detailed site-specific plans for most of these areas. The VICZMP is

currently updating these for presentation to the CZMC. The plans give priority planning, monitoring, and enforcement status to each of these areas. The Virgin Islands Legislature may designate new APC's upon recommendation by the CZMC.

The VICZMA also provides for appeals to CZM Committee decisions on major permits through the Board of Land Use Appeals. The Act gives aggrieved parties 45 days from the committee's decision to appeal. The VICZMA (Section 907) authorizes the preparation of a Coastal Land and Water Use Plan to provide long-range guidance on coastal decision making to the CZM Commission, the Department of Conservation and Cultural Affairs Commissioner, the Virgin Islands Planning Office and other territorial agencies. Though there is no section of the U.S. CZMA as amended that specifically deals with relative sea-level rise, the Act provides the mechanism or framework for addressing impacts of sea-level changes; leading to implementation of planning or policy actions for areas that are vulnerable to shore loss.

Besides the Virgin islands plan, other institutional examples from the Lesser Antilles are available. Barbados began a Coastal Conservation Project Unit (CCPU) in April 1984, which was originally totally funded by the government (Cambers, 1987). Among the tasks of the CCPU were the monitoring of natural phenomena such as hurricanes, storm swells and relative sea-level rise. Through this program there was established and implemented a 30 meter - from the high tidemark - development setback requirement. It is somewhat unclear what parameters or variables were utilized to set that policy.

As early as 1983, the government of Grenada performed a Physical Tourism Development Plan funded by the Organization of American States. From that study a coastal monitoring Programme was begun in August of 1985. One of the four major

tasks of the Programme was to set up one or more tide gauges and initiate long term sea-level measurements. Unfortunately, that did not become a permanent reality. The examples cited above illustrate the concern of many wider Caribbean nations for their fragile environments. However, many of these nations have no equivalent governmental organizations in place to address environmental concerns. In addition, no nations in the Lesser Antilles region, have major policy or management foci on global change issues, other than those that directly relate to obligations contained in the Kyoto Protocol, which has yet entered into force.

Coastal Planning: Response to Hazards

It appears necessary that coastal zone planners at all government levels need to take account of the likely cumulative atmospheric and oceanic effects of global climate change from increasing CO₂ concentrations (Wigley, et al., 1996). According to Platt, (1994, p. 265) in the U.S. and its territories, reliance on engineered shoreline protection works (that remain commonplace policy in the wider Caribbean) has been aided by "beach nourishment, federal flood insurance, building and land use regulations, coastal zone planning and other approaches." Some of these remedies are not available to Lesser Antilles governments without international donor support.

Together with retreat to higher ground or the often used - entrench with dikes - other coastal zone management strategies should include siting standards and development limitations. Setback standards, as is demonstrated in Gable and Edwards, (2001) can limit construction in threatened areas and perhaps preclude rebuilding if a dwelling is damaged. Clark, (1996) feels that such zones should be redefined as the shoreline moves. Significantly, a recession line to govern the setback distance is important wherever a beach is receding or could become so.

A coastal manager's response to an eroding shoreline varies between coastal "retreat," making no attempt to stabilize the shoreline therein allowing the beach to migrate, and shoreline stabilization efforts, such as groins, seawalls, bulkheads and or offshore breakwaters (Houlahan, 1989). In general, the chosen response varies site-by-site and oftentimes involves economic, environmental and especially legal considerations. The preferred response from this author's perspective is adaptive management techniques that include an agreed upon statutory development setback standard that can be periodically redefined, perhaps in concert with beach nourishment applications (see: Boothroyd, et al., 1998). Here it is noted that the latter adaptive approach - beach nourishment - if performed without biological parameters being part of the "environmental audit" or impact statement can have pronounced deleterious effects on organisms (see: McLachlan, 1996 for an interesting assessment of changes in beach particle size on the benthic ecology of a bay environment).

Deficiencies are often coupled with the expressed criticisms of coastal engineering structures as a result of interference with natural sediment transport (longshore littoral drift) (Good, 1994). This is then combined with problems of reconciling "hard" coastal protection devices with "soft" beach nourishment in hazard prone areas and conservation interests. In addition, many coastal problems need to be considered in the context of the behavior of the appropriate landward geomorphologic system. Here the local planning board, or equivalent group, should be concerned with ensuring that development or redevelopment does not affect the stability of downdrift locales.

Most shorelines that were developed prior to the early 1970's were oftentimes "armored" with concrete, rock revetments, steel reinforced seawalls and bulkheads that

were "designed" to protect landward private and public parcels and structures from erosion. Through in-situ investigation of these works over time, these bulkheads more often postponed the loss of valuable real estate generally at the expense of the oceanfront beach and its offshore sand cell (Platt, 1994).

A similar yet alternative approach involved the use of sand-trapping structures such as groins along a beach and jetties at the mouths of inlets. These engineering works protruded seaward from the shoreline into the surf zone to reduce wave energy and capture sand on the updrift side at the expense of downslope side where no sand accumulates. In recent decades, coast protection has become an exceedingly contentious issue with local private property owners' interests often in direct conflict with wildlife and landscape conservation priorities.

Shoreline defenses often take the form as engineering structures placed at the land-sea interface. They have implications for other folks since these barrages typically affect the amenity and ecological value of the coast. They also give rise to greater conflict between and among private persons, local interests, public access rights and non-profit (member) conservation organizations, among others. Because of these multiple competing constituencies along the coast, there is now affirmed recognition that in many if not all circumstances, engineering based solutions to hazards are not necessarily the best available adaptive management science-based response to provide protection for vulnerable shorelines (Good, 1994).

And research indicates that anticipatory planning measures over the concern of potential impacts of relative sea-level rise at the land-sea interface are better left to "soft solutions" such as beach nourishment (Boothroyd, et al., 1998; Leatherman, et al., 1995). Thus, there needs to be a shift away from "hard" engineering based "solutions"

such as those espoused in LeMay, (1998) when describing Inter-American Development Bank policy. In addition, a move towards avoidance of known vulnerable locations would thus foster a reduction on a nation's economy, of the impact of episodic coastal hazards (Good, 1994; Lee, 1993). This ought to be coupled with the appreciation and knowledge of the broader scale of coastal littoral processes.

Because coastal planning has not always taken into account the dynamic nature of the coast therefore it is largely the result of the following two factors. These being (1) the apparent widespread view that hazards such as erosion, landslides and intermittent flooding are a matter for the real estate owner or developer and not a proactive planning issue per se; and (2) a general lack of awareness and appreciation of the - biological diversity - of the physical environment, *inter alia*, the use of, and need for sandy beaches as an integral stage of the life cycle of sea turtles, and the limited use of technical information in support of decision-making (Lee, 1993).

A peculiar problem one encounters is that few planners or developers have an earth science background and few earth scientists have a planning background, therefore, there is a large communication gap. In addition, in continental United States locales many local town or city planning boards and zoning boards of appeal, are stacked with general practice lawyers and real estate brokers with little applied earth science knowledge. While these factors are not unique to the coastal zone, the cumulative consequences of these shortcomings are more acute at the coast as stark and rapid changes are a reality for land-use planning and development. Through Professor Dennis Nixon's proactive foresight, the joint Roger Williams University - URI Marine Affairs Master's program was designed to alleviate the shortcomings of the preceding commentary. It has successfully done so.

Effective long-term coastal zone management requires the ability to assess the response of the shoreline to projected increases in sea-level (Daniels, 1996). The integration of erosion and inundation models would assist planners in forecasting the effects of climate change on the coastal zone and in developing strategies to identify and mitigate any adverse impacts (see: e.g., Boothroyd, et al., 1998). Many coastal erosion models, however, are difficult to generalize. Most marine science practitioners believe that wave action is the primary erosion producing force on open ocean shores (see: Pilkey, et al., 2000).

Today, the philosophy that coastal processes do not conveniently operate within fixed administrative boundaries is central to modern shoreline management practice. In addition, McLachlan, (1996, p. 205) states that "exposed sandy beaches are physically dynamic benthic environments which can be defined by three variables: wave energy, tide range and sand particle size." He goes on to point out that "beach state is determined by the interaction between wave energy and sand particle size if tide range is constant" (McLachlan, 1996, p. 214). Beach state refers to, *inter alia*, a dissipative shore - "a surf zone that thoroughly dissipates (scatters) the incoming waves, to form a mild smooth swash action with little turbulence over the beach face" (McLachlan, 1996, p. 213) versus a reflective shore - which in some locales is fostered by a "harsh swash climate (i.e., water movement on the beach face) and/or coarser sand" with steeper slopes (McLachlan, 1996, p. 206; see also Boothroyd, et al., 1998, p. A5-12 & A5-13).

Rather than optimizing the output of a single resource, coastal zone management is increasingly about making trade-offs aimed at resolving competing sectoral demands (Sorensen, 1997). Regarding the application of coastal management, Sorensen, (1997) recently identified more than 180 programs, projects and feasibility

studies in 90 nations. In the tropics, the majority are being funded by international donors and development banks. There is little communication among these projects or analysis of the differences in their designs and impacts (Olsen et al., 1998).

In terms of responding to climate change, integrated coastal zone management is seen as an essential institutional mechanism that can deal with all competing pressures on the coast, including short-, medium-, and long-term issues (Klein and Nicholls, 1999; Olsen et al., 1998; Sorensen, 1997). Climate change requires a more strategic perspective to managing long-term coastal change. In view of its global nature it has facilitated more international and intra-national cooperation than many other classes of coastal problems.

As shown in Milliman et al., (1989), facets of a vulnerability assessment can be conducted in areas with low-, medium-, or high-knowledge bases, and with no limited or comprehensive integrated coastal zone management in place (Klein and Nicholls, 1999). Thus, an "iterative evolution" of vulnerability assessment under the rubric of integrated coastal zone management can be envisaged, progressively drawing from and also contributing to an improved knowledge base for decision making (Klein and Nicholls, 1999; see also Olsen et al., 1997). As part of this evolution, vulnerability assessment to climate change will become embedded in wider issues, such an evolution can be seen in, for example, studies by Milliman, et al., (1989) concerning Egypt (the Nile delta) and Bangladesh (the Ganges-Brahmaputra delta), where "initial studies raised significant environmental concerns" so say Klein and Nicholls (1999, p. 187). For vulnerability assessment, models and approaches can and should be selected as appropriate, the approach is not necessarily prescriptive (Klein and Nicholls, 1999).

For the suite of problems inherent in managing the coast, managers should remain diligent to the needs of competing users of the coastal zone. They need to recognize (1) the inherent conflict between the demands to protect against erosion and flooding as well as the necessity to allow coastal landforms to adjust to coastal processes; (2) development may foster significant changes within the coastal system, especially upon downdrift locations and upon ecosystems; and (3) the cumulative effects of development may take years to become apparent (Bedford and Preston, 1988). For example, past structural responses to the threat of erosion and flooding have led to many long-term problems (Lee, 1993; Houlahan, 1989).

Effective management of the coastal zone should therefore be viewed as involving the resolution of conflicts between alternative demands on resources while ensuring that anthropogenic activity does not significantly alter or affect coastal systems or the ecosystems which they support. There are a number of key issues remaining for coastal management as a whole, including (1) the need for a regional perspective for coastal management, e.g., through a regional intergovernmental Commission (Alexander, 1994); (2) the need to take the full account of the dynamic nature of the coastal environment, particularly the avoidance of vulnerable locations; and (3) the need to reconcile economic growth with improving and enhancing the physical environment (Archer, et al., 1994; Pickering, 1994).

It is clear that with increased coastal development over the last several decades, the coast and its valuable resources are not immune to damage from poor land use practices. Construction of private docks, piers and coastal revetments has diminished public access to and along the shore. In general, planning management efforts have oftentimes segregated land based activities from coastal, waterside activities. In the United States, for instance, the proliferation of private docks and piers has encroached

even on the fisherfolk's access along the shoreline, similar stories abound in Antigua. Experience from continental U.S. areas has shown, however, that an integration of these components is necessary to ensure a balanced use and protection of both land and water resources. In addition, both natural and aquaculture shellfisheries face pressures from increased shoreline development and recreational activity.

A learning-based approach to coastal management is repeatedly recommended (Olsen, 2000; GESAMP, 1996). It assumes that coastal management is a relatively young and experimental endeavor and that practitioners do not know all the answers to problems. It further assumes that incremental progress towards effective coastal management and sustainable forms of coastal development will be made (Olsen, et al., 1998). This can be done by analyzing and learning from many years of experience. According to some, a learning-based approach calls for framing coastal management initiatives as experiments, at its most fundamental level, and subjecting them to austere scientific analysis (Olsen, et al., 1998; see also Hennessey, 1998).

Two levels of learning are in order for integrated coastal zone management (Olsen, et al., 1998). The first, which may be termed "'single loop learning,' occurs when a management tool is refined or when one management tool is replaced with another, but the fundamental hypothesis upon which the program has been constructed is not questioned. Here learning consists in making 'instrumental adjustments' to the program" (Olsen, et al., 1998, p. 612). The second can be termed "double-loop learning." It "occurs when the hypotheses upon which a coastal management program has been constructed are questioned and a management initiative is redesigned around a fresh set of hypotheses" (Olsen, et al., 1998, p. 612).

A learning-based approach to coastal management, *inter alia*, would ideally require initiatives to: "document baseline conditions and monitor relevant change in human society, ecosystem quality, and governance; periodically analyze monitoring data and draw conclusions to affirm, reject, or modify the hypotheses," e.g., relative sea-level is rising, relative sea-level will rise; and learn from experience (Olsen, et al., 1998, p. 612).

There are major problems in justifying the expense of making such an overtly scientific approach operational. Olsen, et al., (1998, p. 612) make the case that it is for "the objectives, process, and structures of governance that double loop learning is both likely and desirable." Coastal setback requirements, for example, according to Olsen, et al., (1998), are the "stock in trade for coastal management at the operational level" (see also Gable and Edwards, 2001). "Planning and management policies must be based on sound interpretations of the best available science" lament Olsen, et al., (1998, p. 613). Initial emphasis upon comprehensiveness in coastal management gave way to an issue-based approach similarly to that now found in climate change instruments. There are predictable patterns in anthropogenically driven ecosystem change. Olsen, et al., (1998, p. 613) conclude "that a learning-based approach needs to take a long-term perspective on different expressions of change."

The qualities that make the coastal zone an important resource make it one of the most desirable areas in which to live and recreate. But the incessant change of the day-to-day forces of winds, ocean currents and tide constantly reshape the littoral geography. A storm of any magnitude can work changes sufficient to render portions of the coast unrecognizable.

Regarding policy-making in response to climate change the United Nations Environment Programme (UNEP) prepared a study of the wider Caribbean through the UNEP Regional Seas Programme. Some of the objectives of the study comprised an examination of the possible effects of sea-level changes on the coastal ecosystems, including but not limited to, deltas, estuaries, coral reefs, beaches, and wetlands. Another objective has been to determine areas or systems that appear to be most vulnerable to the projected climate changes and related effects. In this regard, beach systems were determined to be among the most vulnerable areas potentially affected (see: Maul, 1993).

A clear, pervasive thread in the research agenda is the need to document past climate change and related issues within the wider Caribbean, and the response of the region to such past climate change. Then, as scientific certainty of the mode, magnitude, timing, and distribution of global climate change grows, future climate change impacts can be better estimated based on past responses. This challenge requires improved understanding of local relative sea-level rise, tectonics, ecosystem response and causes, and climate variability. In addition, satellite and airborne sensors have the potential of being valuable in the definition of coastline and beach width studies. For example, Clark and others (1986) have analyzed a part of the shoreline of Vieques Island in the Caribbean with remarkable success.

In most instances, new research facilities must be planned, funded, constructed, and staffed by trained local personnel. At the least, continued attention should be focused on global climate change by the international community through interdisciplinary conferences and workshops, as well as basic research. This has only

quite recently begun in the wider Caribbean region with the commencement of a World Bank, United Nations Development Programme and Organization of American States (OAS) Global Environmental Facility initiative (Volonte, 1997).

The application of this thesis also poses similar consequences to other regions of the world. The managing of resources for economic development (tourism) in light of looming global climate change needs to be addressed and ascertained so fluid policy responses (i.e., adaptive management) can be formulated. It should also be noted that a generic response to the effects of climate change is not likely to succeed in foreseeing local environmental stress that is presently exhibited for those same areas. Further study at specific sites concerning the linkages between environmental resources used for tourism (beaches; underwater parks; see: Agardy, 1993) and how they may be affected by likely climatic changes (increased storminess; turbidity) ought to be addressed.

Awareness of the interdependencies among nations and territories of the region in ecological, economic, social and technological terms, particularly with the theoretical advent of human-induced climate alterations, is vitally important. The indirect socio-economic effects on tourism from pollution, coral reef mortality, loss of fisheries and storm damage already are considered important problems for Caribbean officials to deal with; human-induced climate change has become another.

Now looked upon as one Large Marine Ecosystem (Alexander, 1994), especially as it relates to marine resources management (Alexander, 1993), the impacts of contemporary climate change and the ancillary effect of relative sea-level rise may affect the lives or livelihoods of many people throughout the Caribbean Basin. Through the research prepared and presented here, this study concludes from the primary

hypothesis that relative sea-level rise does threaten tourism sustainability (see: Kates, et al., 2001) in the eastern Caribbean islands. More specifically, it will "very likely" (9 out of 10 probability of being true) effect tourist facilities (hotels) dependent upon sandy beaches when synergistic effects of storm surge and erosion are taken into account.

As demonstrated in this manuscript, the rise in global (relative) sea level can and has affected coastal and marine areas (on small island developing states), particularly in relation to occupation and use of coastal land, in part, due to relative sea-level rise but more importantly at present, from episodic storm events. Thus, the impacts of "global change" will include increased inundation under storm conditions in unprotected coastlines and low-lying areas. It may be important to ensure that data and information produced as a result of global change science research and assessment activities is in a form that can be readily used by policymakers developing appropriate responses to it.

Table 52. Aspects of a Possible Policy Agenda in the wider Caribbean Regional Sea
(source: after Gable, 1997):

- Measurements necessary to document global change such as relative sea-level rise, including the standardization of measurement techniques.
- Basic and applied research to understand the nature of and the interactions among the physical, chemical, and biological processes related to global change.
- Development of quantitative (regional) computer models of the Earth system to simulate system dynamics and to allow identification and prediction of global environmental trends.

Table 52 (continued)

- Development of an information base, including necessary management systems, which will be readily usable by policymakers attempting to formulate effective strategies for mitigating and adapting to the harmful effects of global change.
- Assessments (environmental audit) of the effect of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health, and biological diversity. Such assessments may include recommendations for action.
- Measures for increasing international cooperation in global change research, monitoring, analysis, and data dissemination.
- Utilizing the "*concept of beach environments* to recognize the roles of natural and social sciences in management systems" (James, 2000a, p. 506; see also James, 2000b). The concept broadens the approach to beach management.

There is mounting evidence of global climate change. Analysis of near surface temperatures over land and oceans during the past 130 years shows marked warming during the first half of this century with relatively steady temperatures through the mid-1970's and rapid warming occurring during the 1980's. Of further significance is that the warmest decade in the record is the 1990's with some of the most pronounced warming occurring in the lower latitudes which include the wider Caribbean region. In the context of this study, the important consequences of this warming are the potential impacts associated with rising relative sea level due to thermal expansion of the oceans, melting of land-based ice sheets and glaciers and to local geologic parameters in combination with increased intensity, and seasonality of tropical storms. Rising relative sea level coupled with potential meteorological changes present the potential for increased coastal erosion, loss of wetlands, and other habitats such as mangroves

and coral reef communities. These potential impacts may have a significant impact on future land use and development practices that could alter the sustainable economic growth and development through the curtailment of sustainable tourism.

Forecasting the potential regional and local impacts of global events is not a trivial problem. General circulation models presently do not provide the necessary fine-scale resolution required for ascertaining local or regional impacts nor is there agreement between different models regarding the prediction of such fundamental climate variables as precipitation and air temperature. The absence of quality regional and local tide-gauge data of the appropriate duration necessary for calculating changes in relative sea level and henceforth probable 21st century scenarios exacerbates scientific uncertainty.

Irrespective of scientific uncertainty, the impacts represent present-day problems resulting from alterations in natural occurring processes and human activities. What is important is that these problems typify the impacts forecast as the result of global warming and that they are occurring now and not at some undefined time in the future. Illustrated in numerous eastern Caribbean cities by waterfront development, much of which is on reclaimed land, is the movement of the region's population and infrastructure to vulnerable areas, with consequent increase in storm damage potential. This seaward encroachment has led to an increased risk for the inhabitants because the low elevation and proximity to the sea means increased exposure to large waves and storm surge associated with hurricanes, and because protective mangrove screens have been removed for shorefront development.

Chapter 10. A Policy Orientation Introduction Toward the Kyoto Protocol

With an Assessment of the Coastal Challenge to Vulnerability From Global Climate Change

This section starts by posing the question, how can coastal oriented professionals use their knowledge most effectively in decision and policy processes? It has been the experience of many coastal professionals, for example, those working for, or members of nations or U.S. State and local municipalities as well as government oversight agencies, have indicated in their writings that they do not possess the insight nor the skills in the policy process that either determines or augments the future of coastal resource management. This appears to be the situation despite the fact that the profession is, by and large, good at generating technical information without necessarily having profession wide knowledge of the complexities and subtleties of the knowledge needed to solve problems as it may relate, for example, to coastal natural hazards such as relative sea-level rise and coastal erosion (Dunn, et al., 2000; David, et al., 1999; van der Vink, et al., 1998; Platt, 1994).

Further, both substantive knowledge about the resource and process knowledge concerning the decision and policy processes utilized to derive the routes of management action are required to solve coastal management related issues and problems (see: e.g., Clark, 1992). As has been provided for estuarine shores and wildlife professionals (see: respectively, Burroughs, 1996; Clark, 1992), it is the contention here that the coastal management profession when assessing the contemporary coastal challenge to vulnerability from global environmental change (see: Munn, et al., 1999; Pernetta and Elder, 1992; Pethick, 1993; Kay, et al., 1996) could significantly benefit and improve its use of "knowledge" in the policy process if it held and applied an understandable policy orientation (see: Lasswell, 1951).

Clark, (1992, p. 424) suggests that a policy orientation "means having knowledge (or intelligence) that is directly useful in the policy process, but in addition, having knowledge of the process itself." Insight into policy allows a person to understand the overall process by mapping its interactive dynamics, thereby suggesting options to participate effectively (Clark, 1992).

Lasswell, (1951, p. 3) made the contention some fifty years ago that "the pace of specialization in philosophy, natural science, biology, and the social sciences has been so rapid that colleagues...often complain that they cannot understand one another." Lasswell, (1951) commented further that perhaps broad fields of knowledge are needed in order to have a vision of the whole, thus, the policy orientation approach to global climate change embraces just such a mission especially when taken from an overall *marine affairs* perspective. And, similarly to Lasswell, (1951) it remains the contention that a policy orientation can be developed to cut across the existing global change science specializations.

The term "policy sciences" was coined by Lasswell, (1951, p. 4) for the "purpose of designating the content of the policy orientation during any given period." The methods by which the policy process is probed, the outcomes of the study of policy, coupled with findings of academic disciplines that contribute to the knowledge needs of the timeperiod under examination comprise the "policy sciences" (Lasswell, 1951, p. 4). It is a fundamental way of thinking and acting differently from the reductionistic, positivistic traditions of modern science (Clark, 1992). Understanding of human choice is but one emphasis of the policy sciences, which are in turn advanced "whenever the methods are sharpened by which authentic information and responsible interpretations can be integrated with judgement" (Lasswell, 1951, p. 4).

Lasswell, (1951, p. 4) further expounds that "the world as a whole (re: ecosystem management...intended to sustain the integrity of ecosystems; (see: e.g., Brunner and Clark, 1997) needs to be kept at the focus of attention. It is also essential to cultivate the practice of thinking of the past and the future as parts of one context, and to make use of 'developmental constructs' as tools for exploring the events in time." It is the desire, in subsequent studies, to develop the "construct tools" of policy orientation for coastal management within the context of the coastal challenges of global climate debate.

Implications of the policy-science approach further includes the "assembling and evaluating of knowledge from whatever source," in addition to the knowledge about the policy making process itself (Lasswell, 1951, p. 14). He points out that policy sciences - policy orientation can be considered as the disciplines regarded with explaining the "policy-making and policy-executing process." These are then combined with locating data and information and "providing interpretations which are relevant to the policy problems" of a given timeframe and domain (Lasswell, 1951, p. 14). In the example provided, the *marine affairs* domain is assessing the contemporary coastal challenge to vulnerability from global environmental change, under the rubric of integrated coastal management (see: e.g., Olsen, et al., 1998; Sorensen, 1997; Clark, 1996; Towfighi, 1994), the geographic scale for the analyses is the Lesser Antilles within the wider Caribbean region.

A review of the literature suggests that a policy sciences - policy orientation remains elusive under the rubric of coastal management for global climate change both in the United States and globally (see: Sorensen, 1997). This apparently remains the situation despite the fact that problems are well documented concerning land-use

development in coastal locales (Klein and Nicholls, 1999; Gable, 1997). It is too soon to conclude that it is too risky to just abandon the old ways of coastal management in the absence of a new paradigm as it accounts for climate change related perturbations. And Lackey, (1997, p. 110) writes, however, that in ecosystem management the search for a new paradigm is elusive and that "the hypothesis testing approach works well in research for narrow, mechanistic questions in science, but not for more complex (and typical) research and policy questions."

Perhaps a *policy orientation* approach to global change science could foster a beneficial coastal management related management policy science framework that has not been previously identified (see: e.g., Reynolds, 1975). Baird, (1996, p. 320) argues, regarding movements toward new paradigms in coastal resources management, that "large scale regional management plans must develop political consensus and integrate knowledge at unprecedented rates (see also Turner, et al., 1999). Significantly enhancing management performance into the public policy arena are processes that increase the degree of dissemination of scientific information (Baird, 1996). It is believed that the policy orientation approach is just such a process and movement toward a new or alternative paradigm perspective for global change science. It is the contention that a *policy orientation* for assessment of vulnerability from climate change would aid in reaching the momentum toward sustainable development while elucidating concepts contained in the precautionary principle (Watson, et al., 1997).

Policy Orientation Tools

Now, it may be advantageous to review the "policy process" described by Burroughs (1996) in his article entitled "A policy orientation toward estuarine shores."

We can also include phases in the policy process as discussed in Clark, (1992). It is generally recognized that there are at least six phases (steps) in the policy process: initiation, estimation, selection, implementation, evaluation, and termination. Real policy is often made in the implementation phase, the place where the majority of many university-associated professionals are most active (Clark, 1992); he is most interested in the implementation phase, the alleged execution of the selected policy option. Clark, (1992, p. 426) emphasizes today, the policy process is dynamic and quite fluid with a "reciprocal series of relationships between and among several groups of actors" rather than the trickle down hierarchy that runs "from the top to the bottom."

The "policy orientation" process conceptual tools may include some of the following "functional activities" for an assessment of coastal challenges from global climate change (adapted and modified after, Jones, 1984; see also: Burroughs, 1996; Clark, 1992; Olsen, et al., 1998; Pielke, et al., 1999; Thia-Eng, 1998; Juda and Burroughs, 1990; Hennessey, 1994); the functional activities include:

- **Definition of problems in society (problem definition);**
- Initiation/invention may include preliminary investigation of management concepts;
- Aggregation of concerned individuals, e.g., stakeholders, also public awareness;
- Organization, or initiation e.g., stakeholders consensus building;
- Representation, access to decision makers maintained; (continued)
- **Agenda setting;**
- **Formulation of proposals (by government);**
- Legitimation of program by government;
- Program preparation may include pilot projects as a potential pre-test;

- Estimation may include a more thorough assessment of management concepts;
- Selection may provide benefits by reducing uncertainty about various options;
- **Prediction of policy decisions in planning and managing natural resources;**
- Budgeting for government program and (formal adoption of program);
- Adoption of organizational and legal mechanisms;
- **Implementation of government program by key actors;**
- **Evaluation of program;**
- Refining and Consolidating, including, e.g., program monitoring; and
- Adjustment and/or termination, including how adjustments come about.

The bold highlighted stages above indicate "significant scientific input for this activity" (Burroughs, 1996, p. 436). Prediction as a process in fostering sound decision making comes from Pielke, et al., (1999). It too would contain significant scientific input. Legitimacy in terms of climate change strategies, calls for compliance to regulations, that all must perceive to be fair. One may notice the heavy emphasis on significant scientific input in the Kyoto Protocol concept seems to be in stark contrast, however, to Brunner and Clark (1997), who state on page 53 of their paper on a practice-based approach to ecosystem management, that "first a better scientific foundation of functional relationships is not necessary for the practical purpose of ecosystems management, as distinguished from the theoretical."

They continue with this view by stating "that the functional relationships of basic science would not be sufficient for ecosystem management decisions, even if they were improved." If one even remotely subscribes to the view of Brunner and

Clark, (1997) then a policy orientation approach (Lasswell, 1951) is a practical next step as an assessment tool in the evolutionary process for potentially tweaking the climate change treaty while attempting to prospectively solidify the role of the precautionary approach to emissions from greenhouse gases.

Clark's, (1992, p. 428) understanding of Lasswell's rendering in solving any complex problem, is that the "distinctive outlook of the policy sciences calls for: (1) contextual analysis, (2) problem orientation, and (3) synthesis of technique." All three activities are interactive and so must be carried out simultaneously in all six phases (steps). "This represents a post-positivistic style of problem-solving quite different from the positivistic, experimental science as commonly practiced by the physical and biological sciences" (Clark, 1992, p. 428). "Contextual analysis allows a person to make sense of a large, complex, and often bewildering array of potential information," (Clark, 1992, p. 428) especially in the field of global change science, or for that matter fisheries management. "Contextual analysis is a broad and in-depth identification and examination of all the factors that bear directly or indirectly on the problem at hand" (Clark, 1992, p. 428). If contextual analysis is constrained by narrow professional or bureaucratic perspectives, for example, errors and failures are likely. The process of contextual mapping and problem-solving is never complete, for example, there are in principle always more observations and interpretations to be made (Clark, 1992).

"Scientific decisions are negotiated...many of these forces and pressures at play in determining the path implementation takes are not scientifically based. Decisions are made by balancing legal requirements or technical considerations and the need for political consequences" (Clark, 1992, p. 426). Decisions are really based on a "mix of science, art, and politics and that individual attitudes, values, and professional norms weigh significantly in the process" (Clark, 1992, p. 427). The preceding

points, if often true, make climate change treaty negotiations that are allegedly based on hard science all the more perplexing and not likely implementable. Scientific decisions are usually made as a response to political controversy such as the Kyoto Protocol debacle that existed in the summer of 2001 in Washington, D.C. (see: Victor, 2001). Policy is regarded to be effectively made by the people who implement it.

Many people are interested in improving decisions and policies through scientific inquiry. The policy sciences offer a way to do just that -- they offer ways to improve programs and policies. Most preventable program and policy mistakes stem from failure to ask the right questions or to appreciate the answers (Clark, 1992). The policy sciences have a distinctive frame of reference. The policy sciences are "logically and methodologically a distinctive enterprise" with practical applications (Reynolds, 1975, p. 18). They seek to augment, by "scientific decision methods and the behavioral sciences, the process that humans use in making judgments and taking decisions" (Clark, 1992, p. 427). The policy sciences provide decision, policy, and social process models essential to problem solving, including ways to map a problem and its context. These tools recognize the practical limits of people's objectivity and rationality because of analytical tools and time and resource constraints. And the policy sciences use very few terms according to Clark, (1992).

Olsen, et al., (1998, p. 616) have concocted an integrated coastal management "policy orientation" process that "begins (Step 1) by identifying and analyzing the resource management issues posed by the stretch of coast in question, and then proceeds to define management objectives and prepare a set of policies and actions (Step 2). Next comes Step 3 of formulation through a law, decree or interagency agreement and the securing of funds for implementation. Policy implementation (Step 4) is when the procedures and actions planned in the policy formulation stage are made

operational. Step 5, too often ignored or poorly executed, is formal evaluation. In this step, the results of the management process are compared with the desired outcome(s)." Evaluation is of primary importance in natural resource policy development and decision making (Bellamy, et al., 2001).

"Purposes of a natural resource management evaluation and possible outcomes," according to Bellamy, et al., (2001, p. 412) include improving program management, transparency, accountability, and the process itself, as well as fostering learning through reduction of risk and uncertainty. Olsen, et al., (1998, p. 616) state that "a complete cycle may be termed a generation of a program." Evolving management capacity for integrated coastal management required eight to 15 years to complete a full generation (steps one through five noted above) at a national, or for U.S. state scale programs (Olsen, et al., 1998).

Olsen, et al., (1998, p. 616) argue that "the most critical transition in first-generation programs is between planning and implementation." Further, they suggest that "programs fail to obtain the political and financial support required for implementation." This was certainly true at the Congressional level in the United States regarding any support for the Kyoto Protocol. In a location such as Rhode Island, coastal management is in the implementation step of second and third generation efforts, because the origins of coastal management date back to the early 1970s (Olsen, et al., 1998). Many cycles in the double-loop policy process have taken place there.

"A hypothesis that has emerged is that anthropogenic change to coastal ecosystems follows a consistent, and therefore predictable, sequence...there is, however, great variation in how fast these cycles of change occur and when they take place historically. The most dramatic expressions of anthropogenic change are

occurring now in the tropics" (Olsen, et al., 1998, p. 618). Governance related instability and change underscores the need for an adaptive incremental approach to coastal management and is therefore not a technology transfer or refined scientific knowledge issue (Olsen, et al., 1997). A learning-based approach necessitates vigilant attention be given to documenting baselines for selected indicators of coastal ecosystem quality and monitoring for change, for example, beach erosion (Olsen, et al., 1998). "Current baselines and monitoring in most coastal management initiatives in the tropics are designed to gauge the performance of individual projects and do little to help us understand the impacts of coastal management on these larger and longer-term cycles of anthropogenically driven coastal change" (Olsen, et al., 1998, p. 619). In most developing countries, coastal management initiatives are donor-designed and donor-driven this has been typically the case in the Lesser Antilles.

This portion of this section begins with a discussion of the Kyoto Protocol and the period after, expectations of the Protocol, policy outcomes and products, and relates the story that climate change is a long-term issue. The chapter then proceeds into the policy process framework, per se, by highlighting implementation (or lack thereof) activities as it relates to the Kyoto Protocol primarily in the U.S., provides further evidence of vulnerability from climate change, a discussion section on adaptive strategies to the coastal challenge and closes with an introduction to the concept of a "policy orientation" approach to contemporary coastal climate change issues. The latter concept incorporates knowledge (comprehension/judgement) that is directly pertinent in the policy-making process together with having the wisdom and insight of the policy-executing process itself (Clark, 1992; Lasswell, 1951).

To address these issues the United Nations established the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change (FCCC), in

December of 1990 (see: Table 53). A series of negotiating gatherings culminated with more than 160 countries adopting the FCCC, which was open for signature on June 4th of 1992 at the Rio Conference in Brazil (U.S. Energy Information Administration, 1999). The United Nations Framework Convention came into force in March of 1994 when the 50th nation ratified it (Brunner, 2001). Ratification is meant to implement the objective of the Framework Convention, *inter alia*, ..."stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (from: U.S. Energy Information Administration, 1998, p. 8). In the words of the U. S. Energy Information Administration (1998, p. 9), the Kyoto Protocol to the FCCC "is the most far-reaching and ambitious international environmental agreement ever attempted."

To ameliorate potential unwanted effects from climate change upon the biosphere, in December of 1997, government ministers gathered in Kyoto, Japan to seek solutions from perturbations expected from an increase in global warming. The Kyoto Protocol defines principles to guide global action, such as the precautionary principle (Pittock, 1999) and leadership activities by the industrialized countries. Moreover, the FCCC had originally called on the industrialized countries to return their greenhouse gas emissions to 1990 levels by 2000 and committed all countries to address climate change and to report on the actions they are taking. The return of emissions to 1990 levels has not even remotely happened. According to written accounts from Kyoto, there are two immediate concerns for the ministers. One concern is how to measure and verify in detail greenhouse gas emissions, the second, is how to best devise a course of action for trading emissions among countries (Schmalensee, 1998; Masood, 1997) that was discussed in Buenos Aires. The second point is sometimes referred to as the carbon offset concept (Kosloff, 1997). The government

ministers continue to look to the scientists for answers to global change science questions (see: Reilly, et al., 1999; Prinn, et al., 1999; Ellerman, et al., 1998).

The Kyoto Protocol was adopted by a unanimous vote (on December 11th, 1997) of the Conference of Parties, including the United States. The Protocol was opened for signature on March 16th, 1998. In theory, signature is generally held to be sufficient to compel a country to an agreement, under international law (U.S. Energy Information Administration, 1998), however, U.S. domestic law truncates that theory due to the domestic constitutional requirements that the Senate provide "advice and consent" to the international undertakings of the executive branch prior to a treaty becoming a binding agreement in the United States.

Curiously, the U.S. Senate passed a "sense of the Senate" resolution (S. 38) by a vote of 95-0 on July 25th, 1997 that specifies that "the United States should not be a signatory to any Protocol to, or other agreement regarding the United Nations Framework Convention on Climate Change of 1992, at negotiations in Kyoto in December 1997, or thereafter which would," *inter alia*, "mandate new commitments to limit or reduce greenhouse gas emissions...unless...new commitments to limit or reduce greenhouse gas emissions for (applied to) Developing Country Parties within the same compliance period" e.g., 2008 to 2012 (U.S. Energy Information Administration, 1998, p. 9; see also Skolnikoff, 1997; Jacoby, et al., 1998).

Some of the Protocol's provisions are that it sets emissions targets for industrialized countries for all major greenhouse gases, which amount to an overall cut of five percent from 1990 levels (Najam and Page, 1998). Each industrialized country is required to reduce its emissions by a certain percentage, e.g., eight percent in the European Union, seven percent in the United States, and six percent in Japan

(Skolnikoff, 1999; U.S. State Department, 1998). As stated earlier, the agreement generally provides for mechanisms to increase countries' flexibility in meeting targets, namely, emissions trading, joint implementation, and the Clean Development Mechanism. Many of the details of these programs remain to be worked out even after the most recent Bonn summit in July, 2001. Most western economists believe that market-based initiatives are the best way to cut the cost of limiting climate change. One reason is that it will encourage new science/policy, and better technologies, to emerge. Another reason is that the cuts can likely be made where it costs least (Hayhoe, et al., 1999). No solution, however, had appeared as of the end of autumn of 2001 (see: Jahnke, 2001 for a discussion on a possible compromise). The UNFCCC and the Kyoto Protocol remain an intensely political issue as alluded to in the "sense of the Senate" resolution (see also Knauss, 1997; Ellerman, et al., 1998; Babiker, et al., 1999; Babiker and Jacoby, 1999). The need for the "role of a champion" for effective implementable climate change policy comes to mind (see: Khator, 1999, p. 83).

Thus, a number of American utilities have vowed to find ways to reduce the harm done to the atmosphere by their power plants. DuPont, the world's biggest chemical firm, declared in September of 1999 that it would voluntarily reduce its emissions of greenhouse gases to 35% of their level in 1990 within a decade. This is the sort of "environmental auditing" decision making that can be negotiated under adaptive management policies. If compromise can be found, it could breathe life into Kyoto's market mechanisms (see: e.g., Young, 1999). That, in turn, could provide a flexible long-term policy process framework (see: Jones, 1984) and a springboard for sensible local steps such as liberalizing energy markets, or regressive carbon taxes and ending fossil-fuel subsidies (see: e.g., Reilly, et al., 1999). Ameliorating effects from global warming could give rise to the world's next trillion dollar industry, that is, the

greenhouse-gas trade. There have been several agreements that have emerged recently, however, the details are beyond the scope of this discussion.

According to information found in Depledge (1999), 84 countries had signed the Kyoto Protocol by the summer of 1999, however, only nine had ratified it with almost all of them "small island developing states" (see: Ashe, 1999) who are overly concerned about the effects of relative sea-level rise. Relative sea-level rise also has significance for the determination of the baselines for maritime boundaries allowed under the United Nations Conference on the Law of the Sea (see, e.g., Gable and Aubrey, 1989) as well as, for example, issues concerning sustainable beach tourism in the wider Caribbean as noted earlier.

Thus, concerning a framework for analysis in a policy process, where does global change science enter the decision making apparatus, if at all? At what stage of the policy process is the world regarding stabilization of the climate? Just how will the provisions and functional activities found in the Kyoto Protocol be implemented and how? Is there a global policy process at all, or is it more like a United Nations command and control situation? What are the risks of climate change? Is there a more comprehensive approach to diverse risk problem-solving and any available decision-making methods to fill a void in the climate change policy process? Relatedly, Bugnion and Reiner (1999) pose the question can the U.S. Environmental Protection Agency regulate Greenhouse Gases prior to the United States Senate consenting to the provisions of the Kyoto Protocol, which they rejected prior to its development? This is in question since the United States is the world's leading emitter of CO₂ (see: Table 9).

This policy analysis orientation pertains primarily to an assessment of the Framework Convention on Climate Change and subsequent international (Kyoto) Protocols. For this study the *marine affairs* domain centers around the coastal challenge to vulnerability from the effects of accelerating greenhouse gases in the atmosphere and the concomitant melting of continental glaciers, polar ice sheets and the consequential increasing amount of global eustatic sea-level rise. This paper frames the coastal challenge via integrated environmental decision-making in the context of coastal management (see: e.g., Olsen, et al., 1999).

Policy Responses: Implementation

Based on knowledge of local response to the direct and indirect changes in climate along with the best available scientific findings on the magnitude and timing of human-altered climatic conditions, appropriate decisions can be arrived at concerning policy implementation. Olsen, et al., (1997) illustrate about 10 principles that have been identified as important concerning policy implementation. To highlight one of those, an important strategy is to complete the double loop process between planning and implementation as fast and often as possible, in part, to demonstrate effectiveness of policies that may be innovative (Olsen, et al., 1999; Olsen, et al., 1997).

It is argued here that provisions, especially the "tough targets and timetables" (Victor and Salt, 1995, p. 282) of the Kyoto Protocol upon the nations of the developed world (see: Bolin, 1998) are too large in scope for quick implementation. Indeed, while it can be argued that decreasing emissions of greenhouse gases back to levels below 1990 is noble, the practice of such measures for the United States is untenable for many reasons (see: Edmonds, 1999; Jacoby, 1998). Some learned analysts make the case that in order to build an effective treaty it should be more

loosely construed, *inter alia*, as regards emissions targets and timetables as "unpredictability of modern economies and policy instruments assures that international climate policies are intrinsically shrouded in doubt about what is implementable (Victor and Salt, 1995, p. 282). These authors write on page 282 of their paper that "most international environmental agreements give inadequate attention to verification." Thus, hard and fast requirements in an enforceable Protocol to a treaty is not yet the way to proceed in *atmospheric affairs* policy making.

As is stated on the front page of a Department of State fact sheet released by the Bureau of Oceans and International Environmental and Scientific Affairs dated May 26th, 1999 "Meeting the Challenge of Global Climate Change," during the Clinton-Gore administration the President made clear that he would not submit the Kyoto Protocol to the Senate without "meaningful participation of developing countries in addressing global warming." Henceforth, he never did. Consequently, implementation on a global scale of a meaningful reduction in greenhouse gases via the Kyoto Protocol is not likely without the United States (responsible for ~38% of these emissions; see: Brunner and Klein, 1999; Bolin, 1998; Romm, et al., 1998) participation. And the U.S. Senate as a whole, is not likely to participate in any implementation procedures without developing nations such as Brazil, India and China addressing their own emissions of radiatively active gases as part of the Kyoto Protocol policy process.

More specifically, Chelimsky, (1991, p. 226) puts forth the argument that "not knowing something in a key area normally means that a policy needs to be cautious and flexible and maybe even reversible" with only a small scale policy or program flowing from that unknown, that is, for this discussion, the effects of long term radiatively active gases upon the biosphere. Presently, many may argue that scientists and diplomats do not possess all the research necessary to foster inflexible decision-

making policies when it comes to implementation of especially the economic principles found in the Kyoto Protocol (Victor and Salt, 1995).

Regarding contemporary implementation research, deLeon, (1999, p. 330) contends that "the combination of a greater emphasis on a democratic (participatory) orientation to implementation, buttressed by more of a post-positivist (interpretive) orientation and methodology and a realistic assessment of what implementation can deliver" will likely produce the "policy goods." That is, the provisions of the Kyoto Protocol, depending upon ones vantage point, can be construed as undemocratic where the views of stakeholders at the national, regional, and local levels has not been extrapolated (i.e., to infer from known information). Further, neither has constituent capacity been built to support such stringent economic measures that some U.S. Congressman view as, more or less, sanctions (see double-loop learning found in: Olsen, et al., 1998; Olsen, et al., 1997).

As was seen in estuarine implementation policies in the southeastern United States, the "role of champions" in shaping expectations and perceptions of issue networks (constituents) can be extremely important (Khator, 1999, p. 83). I argue that there is not a champion, at least in the United States, pushing or pulling for the implementation of the provisions of the Kyoto Protocol here. This is witnessed, for example, by the Congressional action taken in November of 1999 for the FY 2000 consolidated appropriation bill (H.R. 3194) which specifically contains a provision not allowing any funding to attempt to implement the Kyoto Protocol to the UNFCCC Treaty into U.S. policy.

The remaining uncertainties concerning human-altered global climate change do not warrant draconian developmental and environmental regulations, however, global

climate change has demanded increased consideration as part of the matrix of both environmental and ecological issues (see: Gable, 2000; Mahlman, 1997). Hence, the Kyoto negotiations on climate change are just that, negotiations to stabilize and prevent anthropogenically derived greenhouse gas emissions in the atmosphere through what the United States would prefer to be a more encompassing worldwide participatory democratic process (see: e.g., Brewer, 1981).

Through a risk-characterization process the Science Advisory Board of U.S. EPA, and associated researchers, will likely contribute to problem formulation, analysis of characteristics of integrated environmental decision-making, and implementation and performance evaluation concerning climate change. The Board in their white paper report has taken into consideration a systematic review of environmental decisions in light of further scientific findings, changes in stakeholder preferences and societal shifts in values as well as possible cascading effects placed upon the environment by previous decisions (USEPA, 2000; white paper used with permission).

As part of the common methodology for learning and assessing aspects to progress of coastal challenges from vulnerability from global climate (environmental) change, the double-loop learning process (see: Figure 1 in Olsen et al., 1999 at page eight and not reproduced here) espoused by Olsen, et al., (1998) ought to be employed when assessing any climate change treaty too, especially as scientific information is either updated or challenged. This mechanism would allow for feedback among the policy steps which could alter the sequence (see: Jones, 1984), or necessitate repetition of some steps especially as it relates to the provisions found in the Kyoto Protocol that have ramifications to challenges along coastal environments (see also USEPA, 2000). It is quintessentially an aspect of adaptive management procedures.

In review, from a policy perspective, the Kyoto Protocol to the 1992 U.N. Framework Convention (i.e., the Climate Change Treaty), whose target was the stabilization of atmospheric concentrations of carbon dioxide and five other radiatively active gases, would seek to reduce emissions of the six recognized greenhouse gases (Ledley, et al., 1999). Any mandated cuts by developed nations in these emissions, however, will be swamped by allowable increases in emissions by developing nations for the foreseeable future (Malakoff, 1997).

The United States, which contributes about 38 percent of the world's emissions of greenhouse gases (Bolin, 1998), will seek to gain emissions credits by trading with Russia and Ukraine, whose emissions have been theoretically below 1990 target levels of the Convention (Masood, 1997). Nevertheless, the atmospheric buildup of these trace gases is transboundary and will effect all regions of the world. And, because of the continuing change in government structure in Russia and Ukraine, among others in that region, coupled with the likelihood of further development of Caspian Sea oil fields will no doubt lead to higher concentrations of greenhouse gas emissions from this region, and make them less attractive trading partners.

Global Change Review

A number of steps can be taken to mitigate or minimize the effects of global change. Yet global, regional and local considerations must include a broad-range approach to on-going (and accelerating) environmental deterioration (Bohm, 1993). For example, relative sea-level rise may have a deleterious effect on tidal and wetland areas, an ecosystem that is critical for coastal fisheries, and for protection against coastal erosion. But the increasing diversion and damming of rivers, which decreases

the flux of river water to coastal areas, plus the logging of remaining forest tracts may result in wide-spread destruction of this ecosystem long before the global eustatic relative sea-level rise problem becomes critical locally (note: Tables 50 and 51).

Moreover, proposed engineering projects, such as dams, levees and barrages, should be designed so that their environmental impact is small. Natural delta subsidence of 1 cm/year, for example, makes ten times greater a contribution to local relative sea-level rise than a global rise of 1 mm/yr. If local subsidence is accelerated by withdrawal of groundwater or petroleum, the resulting local relative sea-level rise could be catastrophic (see: e.g., *The Economist*, April 29th, 2000 "Bangkok gets that sinking feeling," p. 39). In some countries, these environmental problems can be addressed locally or nationally, but in other countries (for example where a river flows through more than one country - such as the Danube) the problem will require regional cooperation.

When considering to plan for future environmental change, Riebsame, (1990) feels that it is important to consider not only mean change but also variability and frequency of extremes. Accentuated seasonal variations, increased intensity of major storms, and occurrence of more frequent hazardous storms all must be taken into account, especially in coastal locales (van der Vink, et al., 1998). The problem, of course, is that the available climatic models give only the most general of trends in terms of the mean central tendency climate change, and even less indication of peak events.

Superimposed on regional and global climatic change, however, will be changes resulting directly or indirectly from human activities in the local and regional environment, known as "cumulative effects." Such actions as damming of rivers,

enhanced subsidence (and associated impacts on the coastal zone caused by the removal of petroleum or ground water), decreasing water quality, logging of coastal forests, mining of beach sands and coastal pollution are only some examples of activities that can dramatically accentuate environmental problems created by climate change.

By taking these changes into account, it is possible that many large marine ecosystem regions such as the wider Caribbean will undergo increased (and, at least locally, dramatic) environmental pressures in the foreseeable future (Sherman, 1991). Climate warming as well as accentuated precipitation and evaporation patterns may result in altered agricultural productivity in the next century. Perhaps the most effective reaction to potential global climate change is a mixture of prevention and adaptation formally described in the literature (e.g., Reilly, et al., 1999). Further, a fuller comprehensive approach to climate change analyses may include the utilization of Global Warming Potentials (GWP's; Skodvin and Fuglestedt, 1997). Though the utilization of this technique "has been convincingly attacked" (Victor and Salt, 1995, p. 282).

The GWP's would transform calculations of the interactions of different emissions of greenhouse gases into an equivalent scale of common greenhouse units allowing scientific assessments, and hence policy instruments, more precision. Before these decisions are made, however, it is necessary to gain an economic, societal and political assessment of future climate and environmental change, for without these assessments it is difficult, if not impossible, to gauge the "cumulative effects" of change or the cost of mitigating this change.

To be most effective, at least some of these preventing/planning efforts should be made at the national and regional level, but perhaps they can be most effectively coordinated through international nongovernmental organizations such as the International Union for the Conservation of Nature and Natural Resources (The World Conservation Union) or intergovernmental agencies such as the United Nations and the World Bank's Global Environmental Facility (GEF). For example, the Intergovernmental Panel on Climate Control (IPCC) was established by the World Meteorological Organization (WMO) and UNEP. Together they have prepared important publications on Global Change (IPCC, 1994; IPCC, 1992). Other agencies and organizations, such as UNESCO and GESAMP (Group of Experts on the Scientific Aspects of Marine Pollution) are also addressing the general problems related to the nearshore and marine environment (GESAMP, 1990).

Because nearly each country in the world's regions has its own ecological, societal and economic systems as well as different needs, problems and expectations, similar discussions and directions should be undertaken by other countries. Several policy forums have discussed adaptive policies and actions that might help mitigate relative sea-level rise in the foreseeable future (IPCC, 1992). Some examples may be of particular interest to interested parties both as specific suggestions and indications of the breadth of possibilities to be considered, though not mutually exclusive, when discussing other adaptive strategies for coastal and nearshore environmental change: (see also Tables 50 and 51)

- Making environmental impact assessments convincing (Sankoh, 1996).
- Identifying local coastal management tools and techniques that could be shared with other countries (Pernetta and Elder, 1992).

- Maximizing opportunities for saving/conserving fresh water resources, e.g., changing from ditch water irrigation to drip techniques.
- Implementing a uniform sea level monitoring network to document changes in relative sea level and to enhance predictive capability.
- Spraying marshes with cleansed dredged material slurries to allow the level of marsh to keep pace with potential relative sea-level rise. (continued)
- Developing wildlife and fisheries management plans and techniques for the changing environment, including the enhancement of aquacultural resources to produce biogenic beach sand!
- Developing an integrated process for managing a multinational regional ecosystem.
- Exploring alternative coastal resource uses with the creation of marine reserves (Agardy, 1999).
- Prohibiting subsidies for inappropriate development or compensation for damage caused by the effects of relative sea-level rise in vulnerable coastal areas.
- Negotiating bi- and multi-lateral treaties to protect important habitats as conservation areas (see also Young, 1999)
- Predetermining the value of the "ocean sector" to the world's economy (see: e.g., Pontecorvo, et al., 1980) coupled with potential coastal climate change effects.
- Seeking to establish ecological zonations in coastal areas and document changes with changing climate and sea-level.

The importance of a mechanistic relative risk assessment for climate change perturbations is that it would allow for re-interpretation in order to formulate (marine) policy from a scientific source of information (Skolnikoff, 1999). Governments and

their agents can take into account the comparative relative risk-ranking in developing present and future policies and in determining funding resources to mitigate unwanted effects. Further consideration should be given to methodologies to improve data sets and the ecological and developmental risk assessments in the future (Mendelsohn and Schlesinger, 1999).

Table 53. The First Decade of the International Climate Change Program (adapted and modified from Depledge, 1999; Skolnikoff, 1999).

- 1990 • The United Nations General Assembly adopts a non binding resolution commencing negotiations on a convention to mitigate climate change.
- 1992 • The United Nations Framework Convention on Climate Change is adopted and opened for signature at the Earth Summit (Rio Conference) in Rio de Janeiro, Brazil in June of 1992.
- 1994 • The FCCC enters into force when ratified by 50 countries.
- 1995 • The first Conference of the Parties (COP 1) took place in March/April in Berlin, Germany. Delegates to the FCCC decide that the commitments of the industrialized countries are inadequate and launch talks to negotiate a new agreement with more stringent commitments.
- 1996 • The second Conference of the Parties (COP 2) convenes in Geneva, Switzerland in July. The Geneva Ministerial Declaration, which endorses the recent findings of the Intergovernmental Panel on Climate Change (IPCC; 1995) that there is already "a discernible human impact on global climate" (see: also Santer, et al., 1995; Santer, et al., 1996) and calls for legally binding commitments that is accepted by most ministers and heads of delegation.
- 1997 • The third Conference of the Parties (COP 3) was held in Kyoto, Japan where on the morning of December 11th, the Kyoto Protocol is adopted by more than 160 countries. It enters into force when 55 countries and Annex 1 nation signatories with CO₂ emissions totaling 55% of the total emissions for all Annex 1 (Developed) nations have acceded to the Protocol.
- 1998 • The fourth Conference of the Parties (COP 4) met in Buenos Aires, Argentina in November. There, delegates identified many of the Protocol's "unfinished business."
- 1999 • The fifth Conference of the Parties (COP 5) took place in October/November in Bonn, Germany. It marked the midpoint in the negotiations over the details of the Kyoto Protocol that remain to be worked out for next year.
- 2000 • The sixth Conference of the Parties (COP 6) took place in late November in the Hague. This conference was the target date for reaching agreement on most of the details of the Protocol, including the (flexible) Kyoto Protocol mechanisms; it didn't happen. Negotiations continued intermittently throughout 2001.

Chapter 11. A Brief Introduction on Comparative Risk Assessment for the wider Caribbean

This research program, undertaken with particular emphasis on the Lesser Antilles, can act as a precursor study as an aid in providing elements for a *post-dissertation* study of a comparative ecological risk-ranking utilizing the wider Caribbean basin as a regional seas setting (see: e.g., Jones and Klein, 1999; Jones, 1997; Power and Adams, 1997; Shlyakhter, et al., 1995; Gentile, et al., 1993; Harwell, et al., 1992; Norton, et al., 1992; USEPA, 1990; Hunsaker, et al., 1990; Rodriguez, 1981; Tomblin, 1981). A comparative ecological risk-ranking has not been accomplished for this location within the Caribbean Large Marine Ecosystem (LME; see: Alexander, 1994; Alexander, 1993).

A modified content analysis research method could be undertaken as a separate manuscript employing a relative risk-ranking matrix based on time for ecological recovery from environmental (i.e., habitat alteration of wetlands) and developmental (i.e., building infrastructure and coastal engineering devices such as groins) related stress. This procedure is typically intended to identify environmental policy-making options to respond to comparative risks (Morgan, 1993; Slovic, 1987; Russell and Gruber, 1987). A similarly structured analyses has been undertaken in another LME location in the Northern Hemisphere, the Black Sea (see: Gable, 2000). As suggested above, it can be utilized as a policy tool guide.

Assessing environmental risks requires; a) knowledge and understanding of the extent and magnitude of environmental stresses (see: Wilson and Crouch, 1987); b) the co-occurrence in time and space of individual and multiple stresses with valued physical and ecological components of the environment (Woodward, 1992); and, c) a conceptual framework, often by use of a matrix, and criteria for ranking the risk of

these stresses individually and cumulatively (see: e.g., Kaspersen et al., 1999; Lindeman, 1997; Deisler, 1997; Shlyakhter, et al., 1995; Harwell, et al., 1992; Cohns and Covello, 1989; Slovic, 1987).

In essence comparative risk assessment has been utilized effectively in many disciplines as an aid in decision making (Power and Adams, 1997). Further, it can aid in identifying emerging issues for policy formulation (White, 1996; White, 1994). Appropriate use for comparative ecological risk assessment matrix development demonstrates the potential role it presents to aid in allocating scarce resources. For example, Lemay, (1998) states on page 24 of her publication that the Inter-American Development Bank's "Policy on Natural Disasters" (OP-704) refers "implicitly to the vulnerability of coastal areas to hurricanes and floods but emphasizes structural solutions such as breakwaters and revetments for disaster prevention in low-lying coastal areas" rather than more benign retreat and setback regimes.

The likely range of responses to environmental hazards - that is, structural as opposed to nonstructural responses by wider Caribbean governments to changes in relative sea-level, differences in storm regime, and altered precipitation patterns is important for agenda setting. This present study could contribute to the ongoing preparation of a sustainable strategy for coastal and marine resources management in the wider Caribbean (see: Lemay, 1998).

Methodologies for assessing ecological and coastal risks were developed as an approach for comparing, rather than measuring individual risks (Power and Adams, 1997; see also Harwell, 1998; Barnes, 1994; Harwell, et al., 1992; USEPA, 1990). Gentile, et al., (1993, p. 242) lament that "the scope of today's environmental problems are diverse, complex, and will require and integrated scientific and

regulatory policy...that will have to address the cumulative effects from multiple stresses... including the potential alteration of global climates."

As employed in the prospective research on the wider Caribbean, the development of comparative ecological risk matrices would be as a tool to help foster better allocation of research, regulatory and monetary efforts from lower to higher risk problems (Jones, 1997; Power and Adams, 1997, see also Bostrom, et al., 1994: Read, et al., 1994). Ecological risk assessment can be employed as a tool in the decision making process as a way of utilizing science in policy making with a focus on impact analyses (see: Bolin, 1994; Bretherton, 1994).

The key methodological steps to the approach for regional comparative ecological risk assessment may be borrowed, in part, from those described by Hunsaker, et al., (1990, p. 326). These steps include: (a) "qualitative and quantitative description of the source terms of potential hazards," for example, locations and rates of relative sea-level rise or the development of tourism based infrastructure; (b) identification and description of the geographic location and the time period for the risk assessment, for example, the wider Caribbean; (c) selection of the environmental entity of concern (e.g., sandy beach erosion) and the quality of the entity; (d) an estimation of the spatial and temporal patterns of exposure by using appropriate available environmental data, for example, the amount of beach habitat lost; and (e) quantification of the relationship between exposure (habitat modification) to the disruptive influence (e.g., relative sea-level rise or severe episodic storms) in the reference environment.

To reiterate from earlier, Sulzman, et al., (1995, p. 217) state that "information on potential climate change should be integrated with the effects of other human-related

stresses, such as land conversion, population pressures, and pollution (e.g., acidification, eutrophication, etc.) for a more holistic perspective on resource health and, thus, support better management and policy decisions." It is the contention here, that a comparative prioritizing of environmental and ecological risks from environmental stresses can be accomplished through the comparative methodology espoused, *inter alia*, by Harwell, et al., (1992). Examples from the literature employing, *inter alia*, the Harwell et al., (1992) techniques include similar work performed on another marine region, the Black Sea (see: Gable, 2000). Applications from the peer-review periodical *Ocean Yearbook* concerning a comparative risk assessment content analysis regarding work performed for the Black Sea Large Marine Ecosystem can be found in volume 14 of said journal from page 420 to 467 available in the Pell Library in Narragansett.

Applying this strategy to the stresses of the wider Caribbean, for example, may illustrate the concepts; ranking criteria; and most important environmental risks (see: *inter alia*: Slovic, 1987; Fischhoff, et al., 1984) as they relate to climate change and other stressors to this region within the limits of available data. Regional approaches to looking at global environmental change(s) may signify a rich tapestry of information (Kasperson, et al., 1999; Kasperson, et al., 1995; Argent and O'Riordan, 1995).

The potential for environmental effects can be estimated or ranked (high, medium or low) for each environmental stress using the following criteria or factors: (1) the potential intensity and magnitude of environmental effects, that is, the spatial and temporal scales over which the effects are or can be expected to occur; (2) the nature or type of environmental perturbations elicited by the stress and its direct or implied social value; (3) the degree of uncertainty accompanying these estimations may be used to differentiate those situations for which data, knowledge, and understanding

destruction of some coral reefs. Moreover, the recent discovery of mass bleachings on Caribbean coral reefs may be related to global warming trends through higher seawater temperatures (Porter et al., 1989) and has been suggested as potentially an early indicator of climate change (Wellington, et al., 2001; Goreau, et al., 1993; Goreau, 1990).

The general decaying of most of the coral reefs of the Caribbean Basin from overfishing, pollution, sedimentation from nearshore erosion, etc., may have reduced the capacity of coral reefs to endure climate changes (Bunkley-Williams and Williams, 1990; Williams, et al., 1987). For coral reefs, increasing seawater temperatures could be important (Williams, et al., 1999). These could adversely affect the growth potential of the coral and, thereby, its ability to keep pace with relative sea-level rise.

According to Klein and Nicholls, (1999) situational scenarios of changing rainfall patterns as well as seawater temperatures can be now obtained from general circulation models (GCMs). Though, however, "the construction of plausible scenarios using the output of GCMs is as yet impossible" (Klein and Nicholls, 1999, p. 186). They state that "sensitivity analysis using trend analysis... could be helpful in providing insight into the possible consequences" (Klein and Nicholls, 1999, p. 186). In spite of the considerable interest around the world in assessing the vulnerability of coastal zones to climate change, many such assessments are hindered by the limited availability of data. Additional problems include the use of fertilizers, pesticides and insecticides. The runoff from these chemicals into the marine environment poses serious threats. Organotins used in paints for yachts and other vessels presents a serious environmental threat to shellfish populations in coastal areas and may make their way into the food web through zooplankton and finfish posing a threat to humans (Champ and Lowenstein, 1987).

Plastic debris in the Caribbean has been a recent environmental degradation. Wilber (1987) has found oceanically-derived plastic to be a common occurrence, particularly on the beaches in the Bahamas and the Antilles. Much of the plastic present in the marine environment is likely to be deposited on sandy shores (Wilber, 1987). In addition, floating tar and oil slicks, notably the recent spill into Christiansted Harbor on St. Croix, are fouling the Caribbean coasts and having a negative impact on tourism. Increasing urbanization and industrialization are causing an increase in domestic sewage and industrial effluents, resulting in both direct and indirect impacts to adjacent marine waters (Simmons and Associates, 1994; GESAMP, 1990; Capuzzo et al., 1985). Because of poor or no sewage treatment plants, high counts of fecal coliform bacteria are often found on the beaches and adjacent waters, which of course has a negative impact on tourism.

This problem is exacerbated by the continued promotion of tourism and the construction of expansive hotels behind the beaches. The carrying capacity for a particular area can be exceeded by untreated wastes from these hotels which creates serious and recurring health problems. Therein lies the quandary, where the undoing by tourism of the environmental quality that attracted visitors and the tourist industry is now an agent in the physical damaging of a location (Murphy, 1986). Therefore, proper planning for these facilities is critically important, particularly if development is to be sustainable (see: Kates, et al., 2001). As a policy point the adoption of environmental auditing as a tool of risk assessment should be seriously considered by businesses and also governments in the Lesser Antilles (Tables 50 and 51).

The majority of Caribbean coastal lowlands and their adjacent coastlines presently experience extensive damage from erosion and inundation during storms.

Most beaches exhibit signs of erosion mainly because of human social and economic activities such as the construction of jetties, groins and breakwaters that interfere with littoral processes. In addition, the removal of sand from beaches and streams for use as aggregate has caused considerable coastal erosion (Cambers, 1997b). Because of human activities, such as draining and reclamation, many natural coastal wetlands, marshes, lagoons and salinas have been permanently altered (adversely impacted). Add to these problems the potential continuing rise in relative sea level and it becomes imperative to alter policies for sustainable tourism.

Enhanced relative sea-level changes (land subsidence) caused by underground fluid extraction, salinization of ground waters and general deforestation are other basin-wide problems. As mentioned earlier, deforestation is especially problematic in the wider Caribbean islands (Hedges and Woods, 1993). While several of these environmental problems occur to varying degrees in some countries, they may not exist in detrimental form in others. In this review, however, differentiation has not been ventured. Environmental deterioration in developing countries in general however, continues at an ominous rate (Gleick, 1989). Moreover, because of present environmental stresses, the addition of another - climate change from global warming - is an unwelcome prospect.

An omen for marine biological resources - shellfish and finfish especially - is the occurrence of ciguatera and red tides, both caused by toxic algae. These toxic organisms are known to cause illness and even death in humans. Apparent increases in red tides and toxic algal blooms may be linked to global change (Anderson, 1989). An increase in the occurrence of ciguatera or red tide as a possible secondary effect of climate change in coastal zones could have an economic impact especially through

shellfish aquaculture and fisheries that are important in providing provisions for tourists (Shumway, 1989).

While increased temperatures may have ramifications for biological organisms, it is the associated effects of rising sea levels and increased storminess that are especially important to tourism activities in the Caribbean. Recently, some unusually powerful hurricanes and a forecast for an increased number of tropical storms may be felt in the region (Goldenberg, et al., 2001). Though it is important to reiterate from Bengtsson, (2001, p. 441) that the "lack of long reliable records and a systematic classification of the storms in previous years makes it impossible to identify trends or clearly defined fluctuations."

It is important to acknowledge the dynamic interaction that takes place between natural and socioeconomic systems (Klein and Nicholls, 1999). Instead of being considered as two separate systems that exist independently of each other, natural and socioeconomic systems are increasingly viewed as developing in a co-evolutionary way. The future is, by definition, uncertain, so plausible scenarios can be constructed to assess these potential impacts. If conceivable, sensitivity analysis can be attempted by constructing more than one scenario for each relevant parameter (see: Milliman, et al., 1989). To allow for sensitivity analysis, Klein and Nicholls, (1999, p. 186) state that "relevant parameters have two degrees of freedom: environmental or socioeconomic, and climate-induced not climate-induced;" that's one published viewpoint.

Chapter 12. Conclusion(s)

This investigation has encompassed the systematic study of the human uses of coastal space while analyzing the myriad factors which influence patterns of use and development of coastal areas in small island developing states in the wider Caribbean. This multi-disciplinary undertaking has combined natural and social science parameters on the patterns of use of the land-sea interface on Caribbean island sandy beaches; that use principally being for international recreational tourism (e.g. Figures 11 to 19). In addition, this investigation applies analysis of severe episodic storms (see: Figures 56 to 60) under the concept of "focusing events" that has brought shoreline erosion and unsustainable international tourism development into the spotlight. Thus, this cause and effect situation of episodic severe storms producing widespread sandy shoreline erosion (Figures 47 and 48; Tables 33 to 37), presents the need to maintain sustainable development of the Caribbean island natural environment which is central to *marine affairs*.

It is the above mentioned storm-events that contribute to beach erosion in the wider Caribbean islands (Figures 47 and 48), producing cascading effects on stayover tourist arrivals (Figures 49 to 55). This situation when coupled with present and projected worldwide relative sea-level rise (Figures 4 to 18), presents the "focusing event(s)" that mandates the need for, and development of, integrated approaches to coastal zone and large marine ecosystem management efforts. The *marine affairs* oriented analysis in this manuscript demonstrates the pronounced need to incorporate marine science into public policy decision making.

One of those public policy decisions that should be utilized in the wider Caribbean islands is the incorporation of adaptive environmental management

techniques. Adaptive management procedures or methods to known environmental perturbations on an ecosystem basis is an example of an integrated approach to sustainability of the natural coastal and marine environment. The employment of treating adaptive management policies or techniques as experiments provides the flexibility needed when considerable uncertainty in the parameters and timing of "global change" exists (see: Tables 46 to 49).

Human intervention in shoreline management through the inflexible policy utilization of "hard" structures at the land-sea interface has resulted in failed attempts to manage finite sand resources in closed-systems that are found on insular Caribbean islands. The design and placement of "hard" stabilization devices does not take into account the need for the shoreface to be considered on a sustainable ecosystem basis. The investigative findings herein contributes to the attempts to persuade international donor agencies, whose present shoreline policy is to utilize "hard" stabilization devices, that it is time to employ more flexible adaptive approaches. These adaptive plans of action ought to incorporate beach nourishment and optimal development setbacks in the overall sustainable coastal management mix in insular Caribbean island environments.

An adaptive management technique put forth in this investigation is the utilization of emerging international environmental standards under the auspices of the International Organization for Standardization (ISO) located in Switzerland. It is suggested here, that employment of international standards of environmental management available from ISO, known as ISO 14000, can be adopted as "best available science" techniques by hoteliers and other organizations in the insular Caribbean (see: Table 51). The ISO provides for the development of cross-cultural standards and code of conduct for overall environmentally related practice. This

practice can incorporate fundamentals for tourism and performance by organizations such as hoteliers, while at the same time providing acceptable environmental auditing procedures that can lead to internationally recognized certification (see: Table 50). For this study, applicable industry sectors that are separately categorized under ISO include, construction, hotels and restaurants, engineering services, and public administration. Fishing and shipbuilding are other *marine affairs* oriented industry sectors that have their own category. Thus, this certification can be used as a marketing tool to the environmentally conscious consumer. This then can be considered to be analogous to the "dolphin safe tuna" labeling found on some seafood products sold in North America. The ISO 14000 compliant designation (certification) provides for just such a moniker for an organization, such as a hotelier, to market its environmental product. For another view on so-called eco-labeling see Swallow and Sedjo, (2000).

Characteristically, the environmental auditing procedures necessary under ISO 14000 designation, can be employed as an adaptive management tool in response to the findings of this study. This investigation concludes - from the primary hypothesis - that relative sea-level rise does threaten tourism sustainability in small island developing states. Specifically, it is "very likely" (9 out of 10 probability of being true) that relative sea-level rise - a parameter of global change - will effect tourist facilities (hotels) dependent upon sandy beaches when synergistic effects of episodic storm surge and subsequent erosion of the beach are taken into account (see: Figures 4 to 60; Tables 2 to 8 and 11 to 45). Thus, the ISO 14000 environmental management standards employed in the audit procedure, can be adopted as an insurance policy of sorts for organizations in the insular Caribbean that rely on white sandy beaches year in and year out to attract international tourists (see: Tables 50 and 51). These organizations also rely, or are dependent upon, a sustainable coastal tourism product

that incorporates the coastal environment - the white sandy beach - into their leisure offering. That overall product competes with other coastal locales worldwide for the international tourists' dollar.

Steffen, et al., (2001, p. 25) state that "nature/society interactions ... tend to come in complicated functional patterns that defy the power of standard scientific analysis." Working under this belief, this investigation has relied upon a few statistical techniques to ascertain suggested cause and effect relationships from the hypothesis. For example, *inter alia*, the use of meta-analysis as an aid to deciphering information contained in published studies for future global eustatic sea-level; linear (least squares) regression analysis for available data from the Caribbean Tourism Organization (a reliable sole source) for discerning past and future trends in stayover tourist arrivals and visitor receipts; and normative value-based judgements founded upon my experience of being on a United Nations Environment Programme Task Team for climate change analysis in the "Intra-Americas Sea," has provided the wherewithal to understand how natural and social science parameters coalesce at the land-sea interface.

In addition, Steffen, et al., (2001, p. 25) ask: "what are the most appropriate methodologies for integrating natural science and social science paradigms, research approaches, and knowledge?" This investigation has provided a research approach utilizing functional data that nevertheless, has provided an end result which is the allocation of proper flexible adaptive management based policy responses while taking into account climate science uncertainty (re: Tables 50 and 51).

"*Marine affairs* may be defined as social processes involving opportunities and conflicts arising from the uses of ocean and coastal environments, the creation and exercise of authority, and the development and implementation of substantive policies" (Miller and Broches, 1989, p. 263). "In addition to denoting special phenomena, *marine affairs* is also a label for an emerging field of inquiry defined by a knowledge base and a set of general skills. Categories of knowledge possessed by a professional of marine affairs pertain to the history of marine events, participants in the policy process, the marine environment, and marine technologies" (Miller and Broches, 1989, p. 288). Further, these authors suggest that "new policy topics such as marine tourism" constitute an "issue network" under the rubric of *marine affairs* (Miller and Broches, 1989, p. 280). That belief is central to the investigation undertaken and discussed here.

Miller and Broches, (1989, p. 263) also theorize that ... "the complex problems of *marine affairs* have sustained the attention of ... governments and diverse industries and publics since the 1960's. Thus, these authors suggest on page 263 of their article that since the 1960's, the "transformation of the law of the sea, the advent of exotic technologies, and an expanding coastal population have stimulated debate about such marine issues as energy development, ocean science, the management of living resources, the exploitation of hard minerals, environmental protection, waste management, national defense, trade and communication, port management, shipbuilding, and leisure in addition to the installation and operation of an array of residential, industrial and other structures required for modern life."

The contribution to this evolutionary menagerie from the investigation provided in this manuscript expands the above list to formally include aspects of "global change," which encompasses more than climate change, into the above definition. Thus, the above list from Miller and Broches, (1989) serves as only part of what comprises the evolutionary aspects of *marine affairs* over time. Specific to the specialization's of the University of Rhode Island's marine affairs program, this study falls under the rubric of "coastal zone management" combined with "international marine policy and law." The "law" in this article gives particular reference to the ramifications of the United Nations Framework Convention on Climate Change (UNFCCC), which was negotiated in June of 1992 at the United Nations Conference on Environment and Development, concerning coastal policy decision making and implementation. Specific regard about this subject of inquiry can be found in Chapter Ten of the manuscript which provides some specificity to international agreements (i.e., Treaties and Protocols) that play a part in how decisions are made that can affect coastal sustainability.

As for policy development, along with the aforementioned ISO 14000 discussion, this investigation also provides for the inclusion of comparative risk assessment tools and ideas into the evolving ingredients of the *marine affairs* pie. It introduces the concept of comparative risk assessment for a large marine ecosystem, the wider Caribbean. It is briefly introduced in Chapter One with more formal elaboration in Chapter Eleven as a "future direction" initiative or a discussion on where would holistic ecosystem based research go from here. Moreover, the manuscript also provides reference to a similar peer reviewed publicly validated assessment found in *Ocean Yearbook* 14, (2000, pp. 420-467) which provides analyses utilizing the tools from the concept of comparative risk assessment in another large marine ecosystem, that is, utilizing the Black Sea as a comparable proxy marine region.

Similarly, for policy development, the dissertation also provides reference to another article found in *Ocean Yearbook* 15 (2001, pp. 299-330) that introduces the concept of optimal development setbacks as a tool in adaptive coastal zone management decision making in the face of uncertainty. It is suggested that future direction or further investigation on insular wider Caribbean shorelines should consider the adoption and implementation of building setbacks as a form of adaptive management. Thus, Chapter Nine discusses the (marine) policy orientation means by which researchers from different disciplines can collaborate with other "stakeholders" who can then cooperate to find and utilize the "best available science" in decision making under uncertainty. Therefore, it is suggested that the concept(s) of optimal development setbacks and comparative risk assessment presently provide opportunities at including "best available science" techniques in coastal cadastral and marine management that is essential to fostering the sustainability of insular Caribbean island natural environments.

The human-induced environmental modification that is seen taking place on sandy shorelines in the insular Caribbean to accommodate international tourism facilities also broadens the interdisciplinary aspects of *marine affairs*, while at the same time illustrating the intensification of coastal zone usage on several wider Caribbean small island developing states. From a historical event perspective, in the United States, for example, as a response to "noticeable" coastal erosion patterns, Congress passed Public Law 90-483 approved on August 13th, 1968 which authorized the Corps of Engineers to conduct an investigation over three years of national shoreline erosion while at the same time providing further initiative to identify and locate suitable deposits of material for fill and beach restoration.

Thus, a suggestion found in this manuscript is for international donor agencies, for example, the Inter-American Development Bank, to provide the long-term economic support needed for a similar comprehensive profile on shorelines of insular small island developing states in the wider Caribbean. Surveys of local human-induced shoreline modification coupled with adaptive types of remedial responses possible, along with cost estimates under a scenario of global change, can provide effective baseline information. As an example, the international donor agency funding could be funneled through agencies such as the International Oceanographic Commission of UNESCO or similar that has some experience at this activity in the wider Caribbean.

As can be ascertained by this investigation, the most intensive uses of the coastal zone for small island developing states in the wider Caribbean, occur at the water's edge. Here, shoreline development to accommodate international tourism has exerted and will "very likely" continue to put forth the greatest demand for shorefront property. This development runs head-long into beach erosion problems caused by episodic storm-surge and incremental inundation of the shore from global relative sea-level rise. Thus, the water's edge creeps nearer to immovable tourist facilities whose placement has not taken into account the change or movement of the shoreline over time. An attempt at sustainability of the natural environment can be garnered when environmental audit procedures that utilize the "best available science" are incorporated by organizations into their operations.

Another future direction for investigation of the kind performed here is the relationship between climate science and insurance risk (Michaels, et al., 1997). The role that private insurance companies and reinsurers, not to mention the banking industry, play in providing catastrophe capital to hotel developers in the wider

Caribbean, for example, is quite relevant to coastal zone management. As inferred in Gable and Edwards, (2001) insurance companies play a pivotal role by providing actuarial policies to private developer organizations to build or redevelop in coastal locations that perhaps would be better left fallow when using valuations incorporating climate science risk and vulnerability assessment. Indeed, if these actuaries relied upon ISO 14000 environmental audit parameters, prior to writing cadastral policies, both insured and economic losses would very likely be less over time. It would be a good proactive approach. Further, development under adaptive coastal management initiatives would be better served. Thus, the relationship of actuaries providing insurance to private organizations for coastal tourism development investments is relevant for continuing research.

FIG. 1. Sketch-map of the wider Caribbean.

Lesser Antilles

Lambert conic conformal projection

km at latitude 16 N
0 200 400

Figure 2a. Map of the Lesser Antilles

Figure 2b. Map of the Caribbean Sea

Figure 3 Global Change Paradigm Flow Chart

Source: Adapted from Gable, et al., (1991)

(Italics indicates those parameters pertinently discussed in the manuscript).

Accelerated Sea-Level Rise in the Lesser Antilles (Worst Case Scenario)

Figure 4 from Fairbanks, (1989); Raper, et al., (1996); IPCC Publication cited as Church, et al., (2001)

Estimates of Averages of Past Increase in Mean Global Relative Sea Level (cm) from Tide Gauge Records

Selected Studies Synthesis 1980 to the present

Figure 5 from Table 2

Uncertainty Estimates of Averages of Past Increase in Mean Global Relative Sea Level (cm) from Tide Gauge Records

Selected Studies Synthesis 1980 to the present

Figure 6 from Table 2

Contribution of Ice Sheets to Future Global Eustatic Sea-Level Rise to Year 2100 (cm)

Selected Studies ~1980 to the present

Figure 7 from Table 3

Contribution of Ice Sheets to Future Global Eustatic Sea-Level Rise to Year 2100 (cm)

Selected Studies ~1980 to the present

Figure 8 from Table 3

Contribution of Ice Sheets to Future Global Eustatic Sea-Level Rise to Year 2050 (cm)

Figure 9 from Table 3

Selected Studies ~ 1980 to the present

Contribution of Ice Sheets to Future Global Eustatic Sea-Level Rise to Year 2050 (cm)

Figure 10 from Table 3

Selected Studies ~ 1980 to the present

Contribution of Thermal Expansion to Future Global Eustatic Sea-Level Rise to Year 2100 (cm)

Figure 11 from Table 4

Contribution of Thermal Expansion to Future Global
Eustatic Sea-Level Rise to Year 2100 (cm)

Selected Studies ~ 1980 to the present

Figure 12 from Table 4

Contribution of Thermal Expansion to Future Global Eustatic Sea-Level Rise to Year 2050 (cm)

Figure 13 from Table 4

Selected Studies ~ 1980 to the present

Contribution of Thermal Expansion to Future Global Eustatic Sea-Level Rise to Year 2050 (cm)

Selected Studies ~ 1980 to the present

Figure 14 from Table 4

Estimates of Future Global Eustatic Sea-Level Rise to Year 2050 (cm)

Selected Studies 1980 to the present

Figure 15 from Table 5

Estimates of Future Global Eustatic Sea-Level Rise to Year 2050 (cm)

Selected Studies 1980 to the present

Figure 16 from Table 5

Estimates of Future Global Eustatic Sea-Level Rise to Year 2100 (cm)

Figure 17 from Table 5

Selected Studies 1980 to the present

Estimates of Future Global Eustatic Sea-Level Rise to Year 2100 (cm)

Selected Studies 1980 to the present

Figure 18 from Table 5

**Lesser Antilles Stayover Tourist Arrivals by Principle Purpose of Visit:
Holiday/Vacation (by %)**

1989 - 1993 - 1999

Figure 19 from Table 11

All Vacationers' Decision-making Factors: Anguilla & Barbados

Figure 20 from Table 16

**North American and European Vacationers' Decision-making Factors:
Anguilla (Stayover Visitor)**

Figure 21 from Table 18

**North American and European Vacationers' Decision-making Factors:
Anguilla (Day Excursionist)**

Figure 22 from Table 18

**North American and European Vacationers' Decision-making Factors:
Barbados (Summer '93)**

Figure 23 from Table 19

**North American and European Vacationers' Decision-making Factors:
Barbados (Winter '94)**

Figure 24 from Table 19

Anguilla: Stayover Tourist Arrivals (Thousands) 1970-2010

Year (1970 - 2010) With Linear R-squared Value Trendline

Year (1970 - 2010) Linear R-squared Value Trendline

Figure 25 from Table 21

Antigua and Barbuda: Stayover Tourist Arrivals (Thousands) 1970-2010

Year (1970 - 2010) With Linear R-squared Value Trendline

Figure 26 from Table 21

Year (1970 - 2010) Linear R-squared Value Trendline

Barbados: Stayover Tourist Arrivals (Thousands) 1970 - 2010

Year (1970 - 2010) With Linear R-squared Value Trendline

Figure 27 from Table 21

Guadeloupe: Stayover Tourist Arrivals (Thousands) 1970 - 2010
 Year (1970 - 2010) With Linear R-squared Value Trendline

Figure 28 from Table 21

St. Maarten: Stayover Tourist Arrivals (Thousands) 1970 - 2010

Year (1970 - 2010) With Linear R-squared Value Trendline

Figure 29 from Table 21

United States Virgin Islands: Stayover Tourist Arrival (Thousands) 1970 - 2010

Year (1970 - 2010) With Linear R-squared Value Trendline

Figure 30 from Table 21

Aruba: Stayover Tourist Arrivals (Thousands) 1970 - 2010
Year (1970 - 2010) With Linear R-squared Value Trendline

Figure 31 from Table 21
Year (1970 - 2010) Linear R-squared Value Trendline

Contribution of Thermal Expansion to Future Global Eustatic Sea-Level Rise to Year 2100 (cm)

Figure 11 from Table 4

Contribution of Thermal Expansion to Future Global Eustatic Sea-Level Rise to Year 2100 (cm)

Selected Studies ~ 1980 to the present

Figure 12 from Table 4

Contribution of Thermal Expansion to Future Global Eustatic Sea-Level Rise to Year 2050 (cm)

Figure 13 from Table 4

**Contribution of Thermal Expansion to Future Global
Eustatic Sea-Level Rise to Year 2050 (cm)**

Selected Studies ~ 1980 to the present

Figure 14 from Table 4

Estimates of Future Global Eustatic Sea-Level Rise to Year 2050 (cm)

Selected Studies 1980 to the present

Figure 15 from Table 5

Estimates of Future Global Eustatic Sea-Level Rise to Year 2050 (cm)

Selected Studies 1980 to the present

Figure 16 from Table 5

Estimates of Future Global Eustatic Sea-Level Rise to Year 2100 (cm)

Figure 17 from Table 5

Selected Studies 1980 to the present

Estimates of Future Global Eustatic Sea-Level Rise to Year 2100 (cm)

Selected Studies 1980 to the present

Figure 18 from Table 5

**Lesser Antilles Stayover Tourist Arrivals by Principle Purpose of Visit:
Holiday/Vacation (by %)**

Figure 19 from Table 11

All Vacationers' Decision-making Factors: Anguilla & Barbados

Figure 20 from Table 16

**North American and European Vacationers' Decision-making Factors:
Anguilla (Stayover Visitor)**

Figure 21 from Table 18

**North American and European Vacationers' Decision-making Factors:
Anguilla (Day Excursionist)**

Figure 22 from Table 18

Cuba: Stayover Tourist Arrivals (Thousands) 1980 - 2010

Year (1980 - 2010) With Linear R-squared Value Trendline

Figure 32 from Table 21

St. Christopher and Nevis: Stayover Tourist Arrivals (Thousands) 1970-2010
 Year (1970-2010) With Linear R-squared Value Trendline

Figure 33 from Table 21
 Year (1970-2010) Linear R-squared Value Trendline

Lesser Antilles Visitor Stayover Tourist Arrivals (thousands) Various Years 1970 - 2000

1970-1980-1985-1990-1995-2000

Figure 34 from Table 23

Lesser Antilles Selected Tourism Activity: Estimated Visitor Expenditures in U.S. \$ (millions)
Data Various Years 1980 - 1999

Figure 35 from Table 24

**Wider Caribbean Islands Estimated Visitor Expenditures in U.S. \$ (millions)
with Percent Change Increase Yr. 1985 - Yr. 1999**

Estimated visitor expenditures includes stayover tourists, cruise vessel passengers and other same-day arrivals

Figure 36 from Table 25

Lesser Antilles Selected Tourism Activity: Visitor Accommodations (Rooms in thousands)

1980 - 1985 - 1990 - 1995 - 1999

Figure 37 from Table 27

Wider Caribbean Stayover Tourist Arrivals: 1970 - 1999 (millions)

Figure 38

Source: Adapted and modified from Caribbean Tourism Statistical Report(s)

Wider Caribbean Stayover Tourist Arrivals: 1970 - 1999 (millions)

Year (1970 - 2020) With Linear R-squared Value Trendline

Figure 39

Source: Adapted and Modified from Caribbean Tourism Statistical Report(s)

Wider Caribbean Visitor Receipts: 1980 - 1999 U.S. \$ (billions)

Figure 40

Source: Adapted and Modified from Caribbean Tourism Statistical Report(s)

Wider Caribbean Visitor Receipts: 1980 - 1999 U.S. \$ (billions)
 Year (1980 - 2020) With Linear R-squared Value Trendline

Figure 41

Source: Adapted and Modified from Caribbean Tourism Statistical Report(s)

Wider Caribbean Islands Estimated Contribution of Hotels and Restaurants to GDP by Percentage

The Gross Domestic Product (GDP) as used in this graph, is the sum of the value added contribution of each good and service produced in the economy; visitor expenditure estimates do not take into account leakages (see: CTO Statistical Report, 2001, p. 253)

Figure 42 from Table 29 1989 - 1994 - 1999

Tourism Related Hotel Room Taxes by Percent (%) for the Year 2000

Selected Lesser Antilles Locales

Figure 43 from Table 30

Tourist Trade Receipts U.S. \$ (millions; 1995 from Kurian, 2001)

This graph provided as perspective for comparison of continental nations to small island developing states

Figure 44 from Table 31

Prospective Measure of Tourism Sustainability in the Wider Caribbean Year to Year Percent Change in Stayover Tourist Arrivals (Years 1970 - 1999)

(1986 Data Unavailable)

Figure 45

Source: Adapted and Modified from Caribbean Tourism Statistical Report(s)

Prospective Measure of Tourism Sustainability in the Wider Caribbean **Year to Year Percent Change in Stayover Tourist Receipts (Years 1980-1999)**

Figure 46

Source: Adapted and Modified from Caribbean Tourism Statistical Report(s)

Lesser Antilles Selected Average Shoreline Change (General Timeframe 1985 - 1994);
With Number of Sites Measured & Percent Locales Facing Erosion;
Erosion Measured as Mean Change in Beach Width

Selected Lesser Antilles Islands

Figure 47 from Table 34

Lesser Antilles Beach and Dune Changes Resulting Primarily from 1995 Hurricane Luis

Average Retreat of Land/Dune Edge (m) (at rear)
General Distance to Center of "Luis" (km) (at front)

Figure 48 from Table 35

Storm Effects on Stayover Tourist (Visitor) Arrivals in Guadeloupe, Years 1987 - 1999
(e.g. Hurricanes Hugo, 1989; Luis & Marilyn, 1995)

Figure 49 from Table 20

Storm Effects on Stayover Tourist (Visitor) Arrivals in St. Maarten, Years 1987 - 2000
(e.g. Hurricanes Luis & Marilyn, 1995; Bertha, 1996)

Figure 50 from Table 20

Storm Effects on Stayover Tourist (Visitor) Arrivals in U.S. Virgin Islands, Years 1987 - 2000
(e.g. Hurricanes Hugo, 1989; Luis & Marilyn, 1995)

Figure 51 from Table 20

Storm Effects on Stayover Tourist (Visitor) Arrivals in U.S. Virgin Islands, Years 1987 - 2000
 (e.g. Hurricanes Hugo, 1989; Luis & Marilyn, 1995)

Figure 52 from Table 20

Lesser Antilles Selected Effect of Episodic Storm-Events on Estimated Visitor Expenditures in U.S. \$ (millions) The Hurricanes of 1995 (Luis & Marilyn)

Figure 53 from Table 38

Lesser Antilles Selected Effect of Storm-Events on Visitor Accommodations (Rooms)
The Hurricanes of 1995 & 1998 (Luis and Marilyn; Georges)

Figure 54 from Table 39

U.S. Virgin Islands Selected Effect of Storm-Events on Visitor Accommodations (Rooms)

Figure 55 from Table 40

Wider Caribbean Islands Tropical Storms and Hurricanes 1964 - 1999

Figure 56 from Table 42

Wider Caribbean Islands Tropical Storms, Hurricanes, and Floods 1964 - 1999

Figure 57 from Table 42

Major and Minor Atlantic Basin Hurricanes 1944-2000

Figure 58 from Table 45

Source: Modified and Adapted from Goldenberg, et al., 2001

Total Major and Minor Atlantic Basin Hurricanes 1944-2000

Figure 59 from Table 45

Years (Modified and Adapted from Goldenberg, et al., 2001)

Total Major and Minor Atlantic Basin Hurricanes 1944-2000 With Moving Average Trendline

Years (Modified and Adapted from Goldenberg, et al., 2001)

Figure 60 from Table 45

Table 1. Lesser Antilles Socio-economic and Geographical Data

	Area in km ²	(miles ²)	Length of Coastline (km)	(miles)	Population (est.) 1999	Per Capita Income* \$	Carbon Dioxide Emissions Per Capita [Metric Tons (1996)] United States = 20.0
Anguilla	91	35	102	63	12,900	1,914**	9.5^
Antigua and Barbuda	442	171	153	95	70,900	8,450	4.9
Barbados	431	166	97	60	267,500	4,925**	3.2
British Virgin Islands	153	59	304	189	19,900	6,246**	9.5^
Dominica	751	290	148	92	78,100	3,150	1.1
Grenada	345	133	121	75	100,700	3,250	1.7
Guadeloupe St. Martin St. Barthelemy	1780	687	306	190	450,000	4,170**	6.2#
Martinique	1080	416	290	180	391,000	3,670**	6.2#
Montserrat	102	39	46	29	4,800	4,030**	9.5^
St. Christopher and Nevis	262	101	135	84	39,500	6,190	2.5
St. Lucia	616	238	158	98	153,700	3,660	1.3
St. Vincent and the Grenadines	389	150	84	52	112,000	2,560	1.1
U.S. Virgin Islands	342	132	175	109	116,800	7,811**	20.0

* - 1990

= France; ^ = U.K.

Source: Adapted and modified from World Bank Atlas, (2000); Gable & Aubrey, (1990)
Caribbean Tourism Organization Statistical Report(s) (2000)

Table 2

Estimates of Averages of Past Increase in Mean Global Relative Sea Level

Author	Rate (cm. Century) ± = Uncertainty	Notes and Method Stations = Tide Gauges
Emery (1980)		
Gornitz et al. (1982)	30.0	1935-1975 Selected Stations
	12 ± 1	1880-1980 Many Stations
Barnett (1983)	10 ± 1	1880-1980 Selected Stations
Hansen et al. (1983)	15.1 ± 1.5	1881-1980 Selected Stations
Robock (1983)	10 - 12 ± 5	1880-1980 Many Stations
Barnett (1984)	17.0	1935 - 1975 Selected Stations
	14.3 ± 1.4	1881-1980 Many Stations
	22.7 ± 2.3	1930-1980 Many Stations
Lambeck & Nakiboglu (1984)	12 ± 5.0	Selected Stations With Eustatic Modelling
Robin (1986)	10.5 ± 2.5	1880-1980 Many Stations
Gornitz & Lebedeff (1987)	9 - 12 ± 1 - 3	1880-1982 Selected Stations
Raper et al. (1988)	12 ± 12	1880-1980 Many Stations
Oerlemans (1989)	9.5 ± 5.5	1850-1985 Many Stations
Peltier & Tushingham (1989)	24 ± 9	1920-1970 Selected Stations

Table 2 (continued)

Pirazzoli (1989)	4 - 6 $\pm$ 0.09	1880-1980 Many Stations
	5.2	Best Estimate
Trupin & Wahr (1990)	17.5 $\pm$ 1.3	1900-1980 Selected Stations > 37 years
	11 - 19 Range	Best Estimate
Wahr & Trupin (1990)	16.7 $\pm$ 3.3	1900-1986 Many Stations
Warrick & Oerlemans (1990)	10 - 20 $\pm$ -0.5 - 22	IPCC Estimates "Last 100 Years"
	(15 $\pm$ 10.5)	Best Estimate
Douglas (1991)	18 $\pm$ 1	1880-1980 Selected Station >60 Years
Emery & Aubrey (1991)	11.0	1807-1986 Many Stations See: Pirazzoli (1993)
Douglas (1992)	18 $\pm$ 1.2	1905-1985 Selected Stations
Gornitz (1993)	10 - 20 $\pm$ 5 - 30	Last 100 Years of Tide Gauge Data From 16 Studies
Groeger & Plag (1993)	8 $\pm$ 6.2 - 9.0	1807-1991 Multiple Stations > 30 Years
Pirazzoli (1993)	5 - 30 $\pm$ 5 - 30	Many Stations and Review Of Other Studies
Woodworth (1993)	15 $\pm$ 5	Expert Panel (Values Jury) Secular Trend Last 100 Yrs.
Haq (1994)	20.0	Review From Sundry Studies

Table 2 (continued)

Gornitz (1995)	14.9 ± 5.3	Review Of Tide Gauges From 17 Studies
Mitrovica & Davis (1995)	15 ± 3.0	1880-1990 Selected Stations
Peltier (1996)	19.4 ± 5.6	1920-1970 & North American East Coast
Raper et al. (1996)	10 - 20 ± 5 - 30	1880-1990 Observationally Based Estimates
Warrick et al. (1996)	18 ± 10 - 25	IPCC Estimates "Last 100 Yrs."
Douglas (1997)	18 - 19 ± 1	Selected Stations > 60 To > 70 Yrs. In Record
Harvey (2000)	18 ± 1.0	"Observed" Different Processes
Douglas (2001)	19.40 (± 7 - 40)	1900-1997 Selected Stations > 70 Yrs. In Record
Peltier (2001)	18.67 (18.4 to 19.1)	1900-1997 Selected Stations > 70 Yrs. In Record (Range)
Proshutinsky et al. (2001)	18 (± 3 - 32)	1950-1990 Arctic Ocean
Total All Studies' Range	(8.95 - 22.55)	Range

Source: Adapted and modified from Gable et al., (1991).

Table 3 Contribution of Ice Sheets to Future Global Eustatic Sea-Level Rise

Author(s)	Alpine	Estimates (cm) Greenland	Antarctica	Notes and Comments
Gornitz et al. (1982)		20 (Melting)		to 2050
Revelle (1983)	12	12		to 2080
Hoffman et al. (1983)		28 - 230 (Melting)		to 2100
PRB (1985)	10 To 30	10 To 30	(-)10 To 100	to 2100
Hoffman et al. (1986)	12 To 37	6 To 27	12 To 220	to 2100
Robin (1986)	20 ± 12	To 10	To (-)10	to 2080
Raper et al. (1988)	4 To 10	1 To 4	(-)1 To 2	to 2030
Van Der Veen (1988)	10 To 25	0 To 10	(-)5 To 0	to 2080
Oerlemans (1989)		5	12	to 2025
Meier (1990)	16 ± 14	8 ± 12	(-)30 ± 20	to 2050
Warrick & Farmer (1990)	8.3 To 12.6	1.8 To 3.1	(-)1.9 To (-)3.3	to 2030

Table 3 (continued)

Warrick & Oerlemans (1990)	2.3 To 10.3 [7.0] 18	0.5 To 3.7 [1.8] 10	(-)0.8 To 0.0 [-0.6] (-)5	to 2030 to 2030 best estimate to 2100
Church et al. (1991)		70 (Combined)		to 2050
Wigley & Raper (1993)		31 (Combined)		to 2100
Titus & Narayanan (1995)	9	5	(-)1	to 2100
Warrick et al. (1996)	16	6	(-)1	to 2100
Raper et al. (1996)	2.59 To 14.67 7.13 To 24.94	0.44 To 4.63 10.33 To 13.76	(-)3.77 To 3.86 (-)8.51 To 7.74	to 2050 to 2100
Gregory and Oerlemans (1998)	13.2 To 18.2	7.6 To 9.3	(-)7.9 To (-)9.7	to 2030
Harvey (2000)		25 To 70 (Combined)		to 2100
Total Studies' Rows & Columns: Mean Estimates (by year as noted) (read by rows)	12.22cm 23.79cm 49.82cm			to 2030 to 2050 to 2100
Total All Studies' Rows & Columns: Mean Estimates	38.67cm			all studies through 2100

Source: Adapted and modified from Gable et al., (1991).

Table 4

Contribution of Thermal Expansion To Future
Global Eustatic Sea-Level Rise

Author(s)	Estimates (cm)	Notes and Comments
Gornitz et al. (1982)	20	to 2050
Revelle (1983)	30	to 2080
Hoffman et al. (1983)	28 To 115	to 2100
Hoffman et al. (1986)	28 To 83	to 2100
Robin (1986)	30 To 50	to 2100
Wigley & Raper (1987)	4 To 8	to 2025
Raper et al. (1988)	4 To 12	to 2030
Van Der Veen (1988)	8 To 16	to 2080
Oerlemans (1989)	6.5	to 2025
Meier (1990)	10 To 30	to 2050
Mikolajewicz et al. (1990)	19	to 2040
Warrick & Farmer (1990)	8.4 To 14	to 2030
Warrick & Oerlemans (1990)	10.1 [6.8 To 14.9] 43	to 2030 to 2100
Church et al. (1991)	25	to 2050
Wigley & Raper (1993)	25	to 2100
Woodworth (1993)	13 $\pm$ 4 31	to 2025 to 2080
Titus & Narayanan (1995)	21	to 2100
Raper et al. (1996)	8.14 To 15.44 19.8 To 40.42	to 2050 to 2100
Warrick et al. (1996)	28	to 2100
Gregory and Oerlemans (1998)	22.5 To 29.9	to 2100 (see: Harvey 2000)
Harvey (2000)	5 To 30	to 2100

Table 4 (continued)

Total Studies' Rows & Columns:		
Mean Estimates (by year as noted)	9.13	to 2030
	19.16	to 2050
	33.14	to 2100
Total All Studies' Rows & Columns:		
Mean Estimates	26.02	all studies through 2100

Source: Adapted and modified from Gable et al., (1991).

Table 5

Estimates of Future Global Eustatic Sea-Level Rise (cm)

Author(s)	Best Estimate (Range)	Notes and Comments
Gornitz et al. (1982)	40	to 2050
Revelle (1983)	71	to 2080
Hoffman et al. (1983)	56 To 345	to 2100
PRB (1985)	10 To 160	to 2100
Hoffman et al. (1986)	58 To 367	to 2100
Robin (1986)	25 To 165	over the next century $\pm$ 2086
Yaeger (Villach Conf. 1987)	(-)4 To 140	to 2050
Wigley & Raper (1987)	4 To 8	to 2025
Raper et al. (1988)	8 To 28	to 2030
Van Der Veen (1988)	28 To 66	to 2085 ~100 years
Oerlemans (1989)	20.5 $\pm$ 21.1 33.0 $\pm$ 56.5 65.6 $\pm$ 32.0	to 2030 to 2050 to 2100
Pirazzoli (1989)	Indeterminable	
Meier (1990)	30	to 2050
Mikolajewicz et al. (1990)	19	to 2040
Warrick & Farmer (1990)	17 To 26	to 2025/2030
Warrick & Oerlemans (1990)	18 (8 To 29) 44 (21 To 71) 66 (31 To 110)	to 2030 to 2070 to 2100
Wyrski (1990)	10	to 2040
Church et al. (1991)	35 (15 To 70)	to 2050
Wigley & Raper (1992)	48 To 66 (10.5 To 80.5)	to 2100
Wigley & Raper (1993)	3 To 124 (46 Middle)	to 2100
Woodworth (1993)	13 $\pm$ 4 61 $\pm$	to 2027 to 2087

Table 5 (continued)

Haq (1994)	45 To 60 ± 30 To 100	to 2100
Gornitz (1995)	48 (10 < 100)	to 2100
Jelgersma & Tooley (1995)	20 To 72 60 best estimate (28 To 100) 36 To 176 48 To 297	to 2030 to 2100 (2100 range) to 2050 to 2100
Moerner (1995)	10 To 20 ± 5	to 2100
Titus & Narayanan (1995)	5 To 77	to 2100
Nicholls & Leatherman (1996)	70 To 115	to 2100 in eastern U.S. & Gulf coast
Raper et al. (1996)	49 (20 To 86)	to 2100
Warrick et al. (1996)	38 To 55 49 (20 To 86)	to 2100 to 2100 (best estimate) to 2100 (from no. above)
Gregory and Oerlemans (1998)	35 To 48	to 2100 (see also: Harvey 2000)
Harvey (2000)	25 To 70	to 2100
Total Studies' Rows & Columns: Mean Estimates (by year as noted)	16.43 41.33 74.85	to 2030 to 2050 to 2100
Total All Studies' Rows & Columns: Mean Estimates	61.53	all studies through 2100

Source: Adapted and modified from Gable et al., (1991).

Table 6

Recent Relative Land-Level/Sea-Level Changes for Selected Wider Caribbean Locations

Locality	Emergence (+) Submergence (-)		
	mm/yr	cm century	
Port-Au-Prince, Haiti	-9.3	-93.0	(higher relative sea levels)
Puerto Cortes, Honduras	-8.9	-89.0	
Progreso, Mexico	-5.2	-52.0	
Puerto Plata, Dominican Republic	-4.4	-44.0	
Cartagena, Colombia	-3.6	-36.0	
Puerto Castilla, Honduras	-3.2	-32.0	
Key West, Florida	-2.2	-22.0	
Riohacha, Colombia	-2.0	-20.0	
Magueyes Island, Puerto Rico	-1.9	-19.0	
Guantanamo Bay, Cuba	-1.8	-18.0	
Puerto Limon, Costa Rica	-1.6	-16.0	
Cristobal, Panama	-1.1	-11.0	
Veracruz, Mexico	-0.8	-8.0	
Port Royal, Jamaica	-0.5	-5.0	
Barahona, Dominican Republic	(+2.3)	(+23.0)	(lower relative sea levels)
Carmen, Mexico	(+2.6)	(+26.0)	
Alvarado, Mexico	(+5.3)	(+53.0)	

Source: Adapted and Modified from Aubrey et al., (1988); Gable et al., (1990);
& the Permanent Service for Mean Sea Level (Bridston, U.K.).

Table 7 Management of Relative Sea-Level Rise after Newman and Fairbridge, (1986)

- * Evacuation and retreat from littoral areas
- * Legislated withdrawal from coastal investments and habitations
- * Shoreline defense by a variety of engineering works
- * Manipulation of the hydrologic cycle - through reservoirs storage and irrigation projects providing hydroelectric power potential in interior drainage basins and/or "inland seas" such as the Aral-Caspian depression. "Ecological consequences... of manipulation of the hydrologic cycle interruptions are largely unknown." (p. 320)
- * "Since 1932... reservoir and irrigation storage have caused relative sea-level rise to lag about 26 years behind its projected uncontrolled rate of rise." (p. 320)
- * "For the 25 year period from 1937-1983, continental storage might account for a reduction of as much as 0.75 mm/yr^{-1} in eustatic sea-level rise." (p. 320)
- * "Sea-level rise joins 'death and taxes' as the inexorable fate of mankind." (p. 320)

Table 9 Carbon Dioxide Emissions (1996) for Selected Countries

Rank	Country/Entity	1996 (million metric tons)
1	USA	5,301.0
2	China	3,363.5
3	Russia	1,579.5
4	Japan	1,167.7
5	India	997.4
6	Germany	861.2
7	U.K.	557.0
8	Canada	409.4
9	South Korea	408.1
10	Italy	403.2
12	France	361.8
14	Mexico	348.1
26	Netherlands	155.2
62	Cuba	31.2
70	Trinidad and Tobago	22.2
75	Puerto Rico	15.8
81	Dominican Republic	12.9
85	Jamaica	10.1
123	Haiti	1.1

Source: Adapted and Modified from Kurian, (2001).

Table 10 Worldwide Greenhouse Gas Air-Sea Interaction									
Gas	Concentration (ppbv)*	Sources		Rate of Increase (% per annum)	Relative Contribution (% Total = 100%)	Residence Time (Year for decay)	Relative Radiation (Absorption per molecule)		
		Natural	Anthropogenic						
Carbon Dioxide	356,000	150,000	7,100	0.4	60	<120		1	
Methane	1,714,000	110 to 210	300 to 450	0.6	15	10		25	
Nitrous oxide	311	6 to 12	4 to 8	0.25	5	150		200	
Tropospheric Ozone	10 to 50			0.5	8	0.1		2,000	
CFC-11	0.28			(+4)**	4	65		12,000	
CFC-12	0.48			(+4)**	8	120		15,000	
*ppbv = parts per billion by volume (not by weight)									
**rate of increase numbers are ~ a decade old. Due to Montreal Protocol on chlorofluorocarbons the rate of increase of CFC's, if in compliance, should be zero by 2000, though residence time in the atmosphere assures the survival of these anthropogenic chemicals.									
Source: Modified and adapted from US EIA, (1999); Thurman, (1996); and Rodhe, (1990).									

**Table 11 Lesser Antilles Tourist Arrivals by Principle Purpose of Visit: Holiday/Vacation
(Percentage Distribution; Selected Years)**

	1989	1993	1999
Anguilla	89	96	97
Antigua and Barbuda	n.a.	n.a.	94
Barbados	88	92	85
British Virgin Islands	96	98	97
Dominica	79	83	81
Grenada	68	82	57^
Guadeloupe	n.a.	82	78
Martinique	85	82	82
Montserrat	91	79	61*
St. Christopher and Nevis	95	94	93
St. Lucia	92	90	93
St. Vincent and the Grenadines	85	76	59**
U.S. Virgin Islands	68	71	71***

^~32% of arrivals were listed as "other" and were not on business.

*~37% of arrivals were business related likely due to volcanic and geological studies (1998).

**~33% of arrivals were listed as "other" and were not on business.

***~20% of arrivals were listed as "other" and were not on business.

Source: Adapted and modified from Caribbean Tourism Statistical Report(s)

Table 12 Caribbean Tourism Organization Lesser Antilles Visitor Survey(s) with Purpose of Visit: Anguilla & Barbados

Purpose of Visit: (%)	Barbados											
	Anguilla						Barbados					
	(Winter '94)						(Summer '93)					
Length of Stay (Days) -->	1-3	4-7	8-14	15-21	>21		1-3	4-7	8-14	15-21	>21	
	[% Visitors]						[% Visitors]					
	↓						↓					
<i>Vacation</i>	8.3	55.8	31.7	2.9	1.3	[89.8]	6.8	36.3	45.8	9.4	1.7	[81.7]
<i>Business</i>	65.4	34.6	0.0	0.0	0.0	[3.7]	37.8	40.1	11.3	5.4	5.4	[6.3]
<i>Business & Vacation</i>	10.2	53.1	32.6	4.1	0.0	[3.6]	38.9	43.9	12.9	2.9	1.4	[2.1]
<i>Visit Friends & Relatives</i>	38.5	26.9	26.9	7.7	0.0	[1.9]	13.4	25.7	36.5	17.9	6.5	[4.9]
<i>Other</i>	7.7	30.8	0.0	61.5	0.0	[1.0]	23.5	29.5	35.6	9.2	2.2	[5.0]
Category Total* (%)	10.9	55.2	29.5	3.3	1.1		10.4	35.9	42.2	9.4	2.1	

*Does not include "Honeymooners" for Anguilla

Source: Adapted and modified from Ott (1995; 1994)

Table 13

Caribbean Tourism Organization Lesser Antilles Visitor Survey: Anguilla

Length of Stay (Days) -->	Anguilla (Winter '94)					[% Visitors] ↓
	1-3	4-7	8-14	15-21	>21	
<i>Purpose of Visit: (%)</i>						
<i>Vacation</i>	8.3	55.8	31.7	2.9	1.3	[89.8]
<i>Business</i>	65.4	34.6	0.0	0.0	0.0	[3.7]
<i>Business & Vacation</i>	10.2	53.1	32.6	4.1	0.0	[3.6]
<i>Visit Friends & Relatives</i>	38.5	26.9	26.9	7.7	0.0	[1.9]
<i>Other</i>	7.7	30.8	0.0	61.5	0.0	[1.0]
Category Total* (%)	10.9	55.2	29.5	3.3	1.1	

*Does not include "Honeymooners" for Anguilla

Source: Adapted and modified from Ott (1995)

Table 14 Caribbean Tourism Organization Lesser Antilles Visitor Survey: Barbados

Length of Stay (Days) →	Barbados					[% Visitors ↓]	(Winter '94)					[% Visitors ↓]
	(Summer '93)											
	1-3	4-7	8-14	15-21	>21		1-3	4-7	8-14	15-21	>21	
Purpose of Visit: (%)												
Vacation	6.8	36.3	45.8	9.4	1.7	[81.7]	4.8	38.7	46.1	7.6	2.8	[80.4]
Business	37.8	40.1	11.3	5.4	5.4	[6.3]	48.0	33.4	14.9	1.6	2.1	[7.0]
Business & Vacation	38.9	43.9	12.9	2.9	1.4	[2.1]	19.4	53.2	17.2	6.8	3.4	[6.1]
Visit Friends & Relatives	13.4	25.7	36.5	17.9	6.5	[4.9]	9.6	28.7	31.8	10.2	19.7	[3.0]
Other	23.5	29.5	35.6	9.2	2.2	[5.0]	27.9	23.4	35.5	8.1	5.1	[3.5]
Category Total (%)	10.4	35.9	42.2	9.4	2.1		8.3	38.6	42.5	7.4	3.2	

Sources: Adapted and modified from Ott (1994)

Table 15

Caribbean Tourism Organization Lesser Antilles Visitor Survey(s)

<i>Purpose of Visit: (%)</i>	Anguilla	Barbados	
	(Winter '94)	(Summer '93)	(Winter '94)
<u>Vacation</u>	89.8*	81.7	80.4
<i>Business</i>	3.7	6.3	7.0
<i>Business & <u>Vacation</u></i>	3.6	2.1	6.1
<i>Visit Friends & Relatives</i>	1.9	4.9	3.0
<i>Day Trip</i>	n.a.	n.a.	n.a.
<i>Other</i>	1.0	5.0	3.5
Total All <u>Vacation</u> Categories	93.4	83.8	86.5

*includes 4% on "Honeymoon"

Source: Adapted and modified from Ott (1995; 1994)

Table 16 All Vacationers' Decision-making Factors: Anguilla & Barbados with Coded Average Ranking

	Anguilla		Barbados	
	<i>Stayover Visitor</i>	<i>Day Excursionist</i> (Winter '94)	<i>Stayover Visitor</i> (Summer '93)	<i>Stayover Visitor</i> (Winter '94)
Beaches/Climate	3.92	3.84	3.50	3.66
Natural Attractions - Nature	2.72	3.11	1.97	2.12
Culture/Heritage	2.15	n.a.	2.04	2.22
Accessibility	2.73	n.a.	2.17	2.44
Watersports	n.a.	1.71	n.a.	n.a.
Proximity to St. Maarten	n.a.	3.80	n.a.	n.a.

Coded Avg. Ranking:
 Very Important = 4.0
 Important = 3.0
 Somewhat Important = 2.0
 Not so Important = 1.0
 Not Important = 0.0

Source: Adapted and modified from Ott (1995; 1994)

Table 17 North American and European Vacationers' Decision-making Factors

	Anquilla (Winter '94)				Barbados (Summer '93)				Barbados (Winter '94)							
	Slayover Visitor		Day Excursionist		Slayover Visitors											
	Canada	Continental Europe	U.K.	U.S.A.	Canada	Continental Europe	U.K.	U.S.A.	Canada	Continental Europe	U.K.	U.S.A.				
Beaches/Climale	3.79	4.00	3.94	3.94	3.86	3.86	3.86	3.83	3.57	3.66	3.67	3.57	3.84	3.40	3.83	3.77
Natural Attractions - Nature	2.92	3.33	2.47	2.70	2.66	2.86	2.86	3.25	2.11	2.50	1.78	2.12	2.25	2.16	1.88	2.22
Culture/Heritage	2.83	2.10	1.93	2.14	n.a.	n.a.	n.a.	n.a.	1.96	1.99	1.91	2.32	2.37	2.18	2.17	2.23
Accessibility	2.61	2.78	2.21	2.76	n.a.	n.a.	n.a.	n.a.	2.38	1.73	2.08	2.22	2.77	2.08	2.33	2.57
Watersports	n.a.	n.a.	n.a.	n.a.	n.a.	1.50	1.50	1.99	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Proximity to St. Maarten	n.a.	n.a.	n.a.	n.a.	3.95	3.60	3.60	3.82	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Coded Avg. Ranking:
 Very Important = 4.0
 Important = 3.0
 Somewhat Important = 2.0
 Not so Important = 1.0
 Not Important = 0.0

Source: Adapted and modified from Olt (1995, 1994)

Table 18

North American and European Vacationers' Decision-making Factors: Anguilla

Anguilla (Winter '94)

	<i>Stayover Visitor</i>				—	<i>Day Excursionist</i>			
	<u>Canada</u>	<u>Continental</u>	<u>U.K.</u>	<u>U.S.A.</u>		<u>Canada</u>	<u>Continental</u>	<u>U.K.</u>	<u>U.S.A.</u>
	<u>Europe</u>					<u>Europe</u>			
Beaches/Climate	3.79	4.00	3.94	3.94		3.86	3.86	3.86	3.83
Natural Attractions - Nature	2.92	3.33	2.47	2.70		2.66	2.86	2.86	3.25
Culture/Heritage	2.83	2.10	1.93	2.14		n.a.	n.a.	n.a.	n.a.
Accessibility	2.61	2.78	2.21	2.76		n.a.	n.a.	n.a.	n.a.
Watersports	n.a.	n.a.	n.a.	n.a.		1.07	1.50	1.50	1.99
Proximity to St. Maarten	n.a.	n.a.	n.a.	n.a.		3.95	3.60	3.60	3.82

Coded Avg. Ranking:

Very Important = 4.0

Important = 3.0

Somewhat Important = 2.0

Not so Important = 1.0

Not Important = 0.0

Source: Adapted and modified from Ott (1995)

Table 19

North American and European Vacationers' Decision-making Factors: Barbados

	Barbados (Summer '93)				—	Barbados (Winter '94)			
	Stayover Visitors								
	<u>Canada</u>	<u>Continental Europe</u>	<u>U.K.</u>	<u>U.S.A.</u>		<u>Canada</u>	<u>Continental Europe</u>	<u>U.K.</u>	<u>U.S.A.</u>
Beaches/Climate	3.57	3.66	3.67	3.57		3.84	3.40	3.83	3.77
Natural Attractions - Nature	2.11	2.50	1.78	2.12		2.25	2.16	1.88	2.22
Culture/Heritage	1.96	1.99	1.91	2.32		2.37	2.18	2.17	2.23
Accessibility	2.38	1.73	2.08	2.22		2.77	2.08	2.33	2.57

Coded Avg. Ranking:

Very Important = 4.0

Important = 3.0

Somewhat Important = 2.0

Not so Important = 1.0

Not Important = 0.0

Source: Adapted and modified from Ott (1994)

Table 20
Slayover Tourist (Visitor) Arrivals in (Thousands) in the Lesser Antilles, Selected Years 1970 - 1999

	1970	1980	1981	1982	1983	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Anguilla	1.0	5.7	6.2	6.7	7.8	15.4	16.7	21.0	25.7	28.4	31.2	29.7	30.4	36.7	43.7	38.5	37.5	43.2	43.9	40.8
Antigua and Barbuda	63.4	86.8	84.7	87.0	101.1	156.0	163.2	177.0	195.0	198.0	205.7	204.7	217.9	249.4	262.9	220.0	228.2	240.4	234.3	239.6
Barbados	156.4	369.9	352.6	303.8	328.3	359.1	369.8	421.9	451.5	481.3	432.1	394.2	385.5	398.0	425.6	442.1	447.1	472.3	512.4	517.9
British Virgin Islands	33.5	87.0	109.6	113.7	116.9	129.9	145.7	172.7	176.0	175.6	180.0	136.4	n.a.	200.2	238.7	219.5	243.7	244.3	279.1	285.9
Dominica	13.5	14.4	15.9	19.0	19.6	21.5	24.4	28.7	31.8	35.2	45.1	46.3	47.0	51.9	58.5	60.5	63.9	65.4	65.5	73.5
Grenada	30.4	29.4	25.1	23.2	35.0	52.0	57.3	57.4	81.8	88.6	82.0	85.0	87.8	93.9	108.0	108.0	108.2	110.7	115.8	125.3
Guadeloupe	47.2	156.5	132.8	189.4	194.0	216.4	248.3	292.6	328.7	284.0	288.4	370.5	340.5	452.7	555.6	640.0	625.0	690.0	893.0	711.0
Martinique	33.4	158.5	157.0	178.2	176.0	183.5	183.3	233.9	280.0	311.7	281.5	315.1	320.7	388.4	416.0	457.2	477.9	513.2	548.8	504.3
Montserrat	9.5	15.5	15.6	14.6	15.0	16.5	15.6	17.0	17.9	17.0	18.7	19.2	17.3	21.0	21.3	17.7	8.7	5.1	7.5	9.9
St. Christopher and Nevis	13.5	32.8	35.5	34.5	34.3	46.1	55.1	64.6	69.6	72.1	75.7	83.9	86.3	88.6	94.2	78.9	84.2	88.3	93.2	84.0
St. Eustatius	n.a.	n.a.	n.a.	n.a.	n.a.	4.8	6.0	6.4	6.3	6.4	6.8	9.2	12.9	9.5	10.7	6.6	6.2	8.5	8.6	9.2
St. Lucia	29.5	79.7	88.6	70.2	77.4	94.5	111.7	111.6	125.3	132.8	138.4	159.0	177.5	184.1	218.8	232.3	235.7	248.4	252.2	260.0
St. Maarten	100.0	221.5	228.0	256.2	307.5	356.5	396.2	451.5	478.7	503.7	564.7	548.0	588.7	520.2	585.7	479.7	384.7	439.2	458.5	444.8
St. Vincent and the Grenadines	16.4	50.4	44.7	37.1	37.7	42.1	42.1	48.0	47.0	48.9	53.9	51.8	53.1	56.7	55.0	60.2	57.9	65.1	67.2	68.3
U.S. Virgin Islands	372.4	380.0	343.7	340.0	350.0	411.5	489.8	555.0	543.0	450.0	482.5	470.3	467.3	581.2	540.5	454.0	372.8	392.9	418.2	483.8

Source: Adapted and modified from Caribbean Tourism Organization Statistical Reports(s)

Table 21 Stayover Tourist (Visitor) Arrivals in (Thousands) in the Wider Caribbean Islands, Selected Years 1970 - 1999

	1970	1980	1981	1982	1983	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Anguilla	1.0	5.7	0.2	6.7	7.8	15.4	16.7	21.0	25.7	28.4	31.2	29.7	30.4	36.7	43.7	38.5	37.5	43.2	43.9	46.8
Antigua and Barbuda	83.4	86.0	84.7	87.0	101.1	156.0	168.2	177.0	195.0	198.0	205.7	204.7	217.9	249.4	282.9	220.0	228.2	240.4	234.3	238.6
Barbados	158.4	369.9	352.6	303.6	328.3	359.1	388.6	421.9	451.5	481.3	432.1	384.2	385.5	396.0	425.6	442.1	447.1	472.3	512.4	517.9
British Virgin Islands	33.5	97.0	109.6	113.7	118.9	120.9	145.7	172.7	176.0	175.6	180.0	138.4	n.a.	200.2	238.7	219.5	243.7	244.3	279.1	285.9
Dominica	13.5	14.4	15.9	19.0	19.6	21.5	24.4	26.7	31.8	35.2	45.1	48.3	47.0	51.8	58.5	60.5	63.3	65.4	65.5	73.5
Grenada	30.4	29.4	25.1	23.2	35.0	52.0	57.3	57.4	61.8	68.6	82.0	85.0	87.6	93.9	100.0	108.0	108.2	110.7	115.8	125.3
Guadeloupe	47.2	156.5	132.8	189.4	194.0	218.4	246.3	202.8	328.7	284.0	268.4	370.5	340.5	452.7	555.6	640.0	625.0	660.0	693.0	711.0
Martinique	33.4	158.5	157.0	179.2	176.0	193.5	193.3	233.9	289.0	311.7	281.5	315.1	320.7	368.4	419.0	457.2	477.0	513.2	548.8	564.3
Montserrat	9.5	15.5	15.0	14.8	15.0	16.5	15.0	17.0	17.9	17.0	18.7	19.2	17.3	21.0	21.3	17.7	8.7	5.1	7.5	9.9
St. Christopher and Nevis	13.5	32.8	35.5	34.5	34.3	48.1	55.1	64.8	66.6	72.1	75.7	83.9	89.3	86.8	94.2	76.8	64.2	89.3	93.2	84.0
St. Eustatius	n.a.	n.a.	n.a.	n.a.	n.a.	4.0	6.0	8.4	6.3	6.4	6.6	9.2	12.8	9.5	10.7	8.8	8.2	8.5	8.0	9.2
St. Lucia	28.5	79.7	68.6	70.2	77.4	94.5	111.7	111.8	125.3	132.8	138.4	150.0	177.5	184.1	218.8	232.3	235.7	248.4	252.2	280.6
St. Maarten	100.0	221.5	228.0	258.2	307.5	356.5	398.2	451.5	479.7	503.7	564.7	548.0	588.7	520.2	585.7	479.7	364.7	439.2	458.5	444.8
St. Vincent and the Grenadines	18.4	50.4	44.7	37.1	37.7	42.1	42.1	48.0	47.0	49.9	53.9	51.8	53.1	56.7	55.0	60.2	57.9	65.1	87.2	88.3
U.S. Virgin Islands	372.4	380.0	343.7	340.0	350.0	411.5	468.8	555.0	543.0	450.0	482.5	470.3	487.3	561.2	540.5	454.0	372.8	382.9	418.2	483.8

Wider Caribbean Locales

Aruba	75.0	188.9	221.2	220.2	191.2	206.7	181.2	231.8	278.0	344.3	432.8	501.3	541.7	562.0	582.1	818.9	640.6	648.0	647.4	683.3
Bahamas	801.5	1181.3	1030.6	1101.1	1200.0	1388.3	1375.2	1479.9	1475.0	1575.1	1561.8	1427.0	1388.9	1488.7	1516.0	1598.1	1833.1	1617.6	1540.0	1577.1
Cuba	n.a.	100.9	84.2	100.3	n.a.	240.5	281.9	293.4	309.2	328.3	340.3	424.0	480.8	544.1	819.2	741.9	1044.3	1170.1	1415.6	1602.8
Jamaica	309.1	395.3	408.4	487.8	588.2	571.7	683.8	738.9	648.9	714.8	640.8	644.6	698.0	978.7	1088.2	1147.0	1182.4	1192.2	1225.3	1248.4
Turks and Caicos Is.	2.0	11.9	12.3	13.3	13.0	29.2	35.4	36.6	47.1	47.3	41.9	54.8	52.0	66.8	70.9	77.8	86.5	92.1	105.9	117.6

Source: Adapted and modified from Caribbean Tourism Organization Statistical Reports(s)

Table 22

Stayover Tourist (Visitor) Arrivals in (Thousands) in the Lesser Antilles, Selected Years with Percent Change Yr. 1970 - Yr. 1999

	1970	1980	1981	1982	1983	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	% Increase Yr. 1970-Yr. 1999
Anguilla	1.0	5.7	6.2	6.7	7.8	15.4	16.7	21.0	25.7	28.4	31.2	28.7	30.4	36.7	43.7	38.5	37.5	43.2	43.9	46.8	721.0*
Antigua and Barbuda	63.4	86.6	84.7	87.0	101.1	156.0	166.2	177.0	195.0	198.0	205.7	204.7	217.9	249.4	262.9	220.0	228.2	240.4	234.3	239.6	278.0
Barbados	156.4	369.9	352.6	303.8	328.3	359.1	369.8	421.9	451.5	461.3	432.1	394.2	385.5	396.0	425.6	442.1	447.1	472.3	512.4	517.9	231.0
British Virgin Islands	33.5	97.0	109.6	113.7	118.9	129.9	145.7	172.7	176.0	175.8	160.0	136.4	n.a.	200.2	238.7	219.5	243.7	244.3	279.1	285.9	753.5
Dominica	13.5	14.4	15.9	19.0	19.6	21.5	24.4	26.7	31.8	35.2	45.1	46.3	47.0	51.9	56.5	60.5	63.3	65.4	65.5	73.5	444.5
Grenada	30.4	29.4	25.1	23.2	35.0	52.0	57.3	57.4	61.8	68.6	82.0	85.0	87.6	93.9	109.0	108.0	108.2	110.7	115.8	125.3	312.0
Guadeloupe	47.2	156.5	132.8	189.4	194.0	216.4	246.3	292.5	328.7	284.0	288.4	370.5	340.5	452.7	555.6	640.0	625.0	660.0	693.0	711.0	1406.5
Marinique	33.4	158.5	157.0	176.2	176.0	193.5	183.3	233.9	280.0	311.7	281.5	315.1	320.7	366.4	419.0	457.2	477.0	513.2	548.8	564.3	1589.5
Montserrat	9.5	15.5	15.6	14.6	15.0	16.5	15.6	17.0	17.9	17.0	18.7	19.2	17.3	21.0	21.3	17.7	8.7	5.1	7.5	9.9	4.0
St. Christopher and Nevis	13.5	32.8	35.5	34.5	34.3	46.1	55.1	64.6	69.6	72.1	75.7	83.9	88.3	88.6	94.2	78.9	84.2	88.3	93.2	84.0	522.0
St. Eustellus	n.a.	n.a.	n.a.	n.a.	n.a.	4.6	6.0	6.4	6.3	6.4	6.6	9.2	12.9	9.5	10.7	8.8	8.2	8.5	8.6	9.2	100**
St. Lucia	29.5	79.7	68.6	70.2	77.4	94.5	111.7	111.6	125.3	132.8	138.4	159.0	177.5	194.1	218.6	232.3	235.7	248.4	252.2	280.6	783.0
St. Maarten	100.0	221.5	228.0	258.2	307.5	356.5	396.2	451.5	479.7	503.7	564.7	548.0	568.7	520.2	585.7	479.7	364.7	439.2	458.5	444.8	345.0
St. Vincent and the Grenadines	16.4	50.4	44.7	37.1	37.7	42.1	42.1	46.0	47.0	49.9	53.9	51.6	53.1	56.7	55.0	60.2	57.9	65.1	67.2	68.3	316.0
U.S. Virgin Islands	372.4	380.0	343.7	340.0	350.0	411.5	469.8	555.0	543.0	450.0	462.5	470.3	487.3	561.2	540.5	454.0	372.6	392.9	418.2	483.8	30.0

*From 1980

**From 1985

Source: Adapted and modified from Caribbean Tourism Organization Statistical Report(s)

Table 23

Lesser Antilles Selected Tourism Activity Data (with Percent Change(s))

	Visitor Stayover Arrivals (thousands)						Percent Change	
	1970	1980	1985	1990	1995	2000	Yr.1970-Yr.2000	
Anguilla	1.0	5.7	15.4	31.2	38.5	43.8	428.0	
Antigua and Barbuda	63.4	86.6	156.0	205.7	220.0	206.9	228.3	
Barbados	156.4	369.9	359.1	432.1	442.1	544.7	248.0	
British Virgin Islands	33.5	97.0	129.9	160.0	219.5	285.9*	753.5	
Dominica	13.5	14.4	21.5	45.1	60.5	68.9	410.0	
Grenada	30.4	29.4	52.0	82.0	108.0	128.9	324.0	
Guadeloupe	47.2	156.5	216.4	288.4	640.0	711.0*	1406.5	
French St. Martin	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		
St. Barthelmy	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		
Martinique	33.4	158.5	193.5	281.5	457.2	526.3	1476.0	
Montserrat	9.5	15.5	16.5	18.7	17.7	10.3	8.5	
St. Christopher and Nevis	13.5	32.8	46.1	75.7	78.9	84.0*	522.0	
St. Eustatius	n.a.	n.a.	4.6	6.6	8.8	19.2	317.4**	
St. Lucia	29.5	79.7	94.5	138.4	232.3	259.0	778.0	
St. Maarten	100.0	221.5	356.5	564.7	479.7	512.2	412.2	
St. Vincent and the Grenadines	16.4	50.4	42.1	53.9	60.2	68.3*	315.5	
U.S. Virgin Islands	372.4	380.0	411.5	462.5	454.0	629.8	69.1	

* Data for 1999

** 1985 to 2000

Source: Adapted and modified from Caribbean Tourism Organization Statistical Report(s)
The Tourism Monitor Vol. 6 No. 3, May, 2001.

Table 24 Lesser Antilles Selected Tourism Activity: Estimated Visitor Expenditures in U.S. \$ (millions)

	1980	1985	1990	1994	1998	1999
Anguilla	2.6	11.3	34.6	51.0	58.1	56.5
Antigua and Barbuda	42.0	132.5	298.2	293.4	255.6	290.0
Barbados	253.7	309.0	493.5	597.6	703.0	666.2
British Virgin Islands	42.3	67.8	132.1	197.7	232.0	299.9
Dominica	2.1	8.7	25.0	31.4	38.2	48.8
Grenada	14.8	32.4	37.5	59.3	61.1	66.6
Guadeloupe	110.9	95.0	197.1	330.2	390.1	400.2
Martinique	74.6	92.8	240.0	378.9	415.0	404.0
Montserrat	4.5	7.7	7.2	23.6	8.0	10.7
St. Christopher and Nevis	8.7	31.0	57.7	76.9	75.7	70.4
St. Lucia	33.6	90.0	153.8	224.1	291.3	311.1
St. Maarten	108.8	128.5	315.5	419.8	412.9	449.4
St. Vincent and the Grenadines	13.7	23.0	56.0	44.0	74.0	78.9
U.S. Virgin Islands	304.3	507.4	697.0	919.6	940.6	954.9

Source: Adapted and modified from Caribbean Tourism Organization Statistical Report(s)

Table 25
Wider Caribbean Islands Estimated Visitor Expenditures in U.S. \$ (millions)
with Percent Change Yr. 1985 - Yr. 1999

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	% Increase Yr. 1985-Yr. 1999
Anguilla	11.3	15.1	19.7	24.4	28.1	34.6	30.8	35.2	43.3	51.0	48.5	48.0	57.2	58.1	56.5	400.0
Antigua and Barbuda	132.5	156.2	191.0	542.3	267.1	298.2	314.0	242.9	276.8	293.4	246.7	257.9	269.4	255.6	290.0	118.9
Aruba	126.5	158.1	203.6	273.3	309.8	353.4	396.3	442.4	464.1	450.7	521.2	613.5	688.3	732.3	777.7	514.8
Bahamas	995.0	1105.0	1145.8	1149.5	1310.0	1332.9	1192.7	1243.5	1304.0	1332.6	1346.2	1450.0	1415.9	1354.1	1582.9	59.1
Barbados	309.0	326.9	378.7	460.0	527.8	493.5	459.7	462.5	528.0	597.8	611.8	632.9	657.2	703.0	666.2	115.5
British Virgin Islands	67.8	88.8	110.8	120.8	124.7	132.1	109.4	98.9	196.4	197.7	205.4	287.6	210.2	232.0	299.9	342.3
Cuba	116.4	150.0	145.0	189.0	204.0	243.4	387.4	567.0	720.0	850.0	1100.0	1380.0	1353.0	1571.0	1714.0	1372.5
Dominica	8.7	11.2	12.8	14.0	18.5	25.0	28.1	26.4	28.9	31.4	34.1	36.6	39.5	38.2	48.8	461.0
Grenada	32.4	39.6	42.1	28.2	30.8	37.5	41.7	42.3	48.1	59.3	58.3	59.5	59.4	61.1	66.6	105.5
Guadeloupe	95.0	163.0	188.0	223.2	203.3	197.1	233.6	270.7	369.6	330.2	380.4	353.9	371.5	390.1	400.2	321.3
Jamaica	406.8	516.0	595.0	525.0	593.0	740.0	764.0	858.0	942.0	973.0	1068.5	1100.0	1131.0	1197.0	1279.5	214.5
Martinique	92.8	107.8	210.0	230.0	272.3	240.0	254.6	281.6	331.5	378.9	414.8	410.6	397.0	415.0	404.0	335.3
Montserrat	7.7	7.5	9.8	9.1	9.1	7.2	9.9	13.7	17.0	23.6	19.9	9.7	5.5	8.0	10.7	39.0
St. Christopher and Nevis	31.0	38.0	47.4	48.7	52.5	57.7	67.5	67.4	69.8	78.9	65.1	66.6	67.3	75.7	70.4	127.1
St. Lucia	90.0	118.0	126.2	134.2	144.6	153.8	173.4	207.9	221.0	224.1	267.8	268.5	283.7	291.3	311.1	245.6
St. Maarten	128.5	162.7	173.9	226.5	260.3	315.5	309.9	340.1	389.6	419.8	348.8	321.9	378.6	412.9	449.4	249.7
St. Vincent and the Grenadines	23.0	29.3	35.2	52.0	50.5	56.0	53.0	41.1	44.0	44.0	41.1	63.7	70.6	74.0	78.9	243.0
Turks and Caicos Is.	12.2	21.7	24.0	37.5	39.3	36.5	50.1	47.7	52.8	70.0	52.6	99.3	112.9	157.0	238.0	1850.8
U.S. Virgin Islands	507.4	509.8	639.4	659.6	621.4	697.0	777.9	816.1	901.6	919.6	822.3	781.0	894.1	940.6	954.9	88.0

Source: Adapted and modified from Caribbean Tourism Organization Statistical Report(s)

Table 26

Lesser Antilles Selected Tourism Activity Data Various Years 1980 - 1999

	Visitor Stayover Arrivals (thousands)					Estimated Visitor Expenditures in U.S. \$ (millions)				
	1980	1985	1990	1995	1999	1980	1985	1990	1995	1999
Anguilla	5.7	15.4	31.2	38.5	46.8	2.6	11.3	34.6	48.5	56.5
Antigua and Barbuda	86.6	156.0	205.7	220.0	239.6	42.0	132.5	298.2	246.7	290.0
Barbados	369.9	359.1	432.1	442.1	517.9	253.7	309.0	493.5	611.8	666.2
British Virgin Islands	97.0	129.9	160.0	219.5	285.9	42.3	67.8	132.1	205.4	299.9
Dominica	14.4	21.5	45.1	60.5	73.5	2.1	8.7	25.0	34.1	48.8
Grenada	29.4	52.0	82.0	108.0	125.3	14.8	32.4	37.5	58.3	66.6
Guadeloupe	156.5	216.4	288.4	640.0	711.0	110.9	95.0	197.1	380.4	402.0
Martinique	158.5	193.5	281.5	457.2	564.3	74.6	92.8	240.0	414.8	404.0
Montserrat	15.5	16.5	18.7	17.7	9.9	4.5	7.7	7.2	19.9	10.7
St. Christopher and Nevis	32.8	46.1	75.7	78.9	84.0	8.7	31.0	57.7	65.1	70.4
St. Eustatius	n.a.	4.6	6.6	8.8	9.2	n.a.	n.a.	n.a.	n.a.	n.a.
St. Lucia	79.7	94.5	138.4	232.3	260.6	33.6	90.0	153.8	267.8	311.1
St. Maarten	221.5	356.5	564.7	479.7	444.8	108.8	128.5	315.5	348.8	449.4
St. Vincent and the Grenadines	50.4	42.1	53.9	60.2	68.3	13.7	23.0	56.0	41.1	78.9
U.S. Virgin Islands	380.0	411.5	462.5	454.0	483.8	304.3	507.4	697.0	822.3	954.9

Source: Adapted and modified from Caribbean Tourism Organization Statistical Report(s)

Table 27

Lesser Antilles Selected Tourism Activity: Visitor Accommodations (Rooms)

	1980	1985	1990	1995	1999
Anguilla	150	461	741	951	1120
Antigua and Barbuda	1350	1949	2752	3317	3185
Barbados	6680	6852	6709	5084	5643
British Virgin Islands	651	848	1138	1515	1626
Dominica	157	405	531	607	857
Grenada	570	600	1105	1652	1928
Guadeloupe	2461	2605	2732	4235	4459
French St. Martin	367	1130	1791	2903	2979
St. Barthelemy	209	491	549	612	571
Martinique	2235	2914	5802	7210	7341
Montserrat	131	236	710	710	243
St. Christopher and Nevis	584	780	1402	1563	1754
St. Eustatius	90	n.a.	93*	139	62
St. Lucia	1245	1735	2370	3974	4125
St. Maarten	1670	2300	3400	3707	4274**
St. Vincent and the Grenadines	500	987	1058	1176	1540
U.S. Virgin Islands	4834	4784	4520	5154	4849

*Data for 1989

**Data for 1998

Source: Adapted and modified from Caribbean Tourism Organization Statistical Report(s)

Table 28

Lesser Antilles Selected Tourism Activity: Visitor Accommodations (Rooms)
with Percent Change Yr.1980 - Yr.1998

	1980	1985	1990	1994	1998	% Change Yr.1980-Yr.1998
Anguilla	150	461	741	913	1045	597
Antigua and Barbuda	1350	1949	2752	3317	3185	136
Barbados	6680	6852	6709	5685	5752	-16
British Virgin Islands	651	848	1138	1485	1594	145
Dominica	157	405	531	757	623	297
Grenada	570	600	1105	1428	1602	216
Guadeloupe	2461	2605	2732	4402	4772	94
French St. Martin	367	1130	1791	2903	2973	710
St. Barthelemy	209	491	549	612	626	200
Martinique	2235	2914	5802	7220	7400	231
Montserrat	131	236	710	710	221	442 through 1994
St. Christopher and Nevis	584	780	1402	1593	1762	202
St. Eustatius	90	n.a.	93*	139	73	-23
St. Lucia	1245	1735	2370	2954	3769	203
St. Maarten	1670	2300	3400	3707	4274	156
St. Vincent and the Grenadines	500	987	1058	1215	1550	210
U.S. Virgin Islands	4834	4784	4520	5461	4929	2

*Data for 1989

Source: Adapted and modified from Caribbean Tourism Organization Statistical Report(s)

Table 29

*Wider Caribbean Islands Estimated Contribution of
Hotels and Restaurants to GDP by Percentage*

	1989	1994	1999
Anguilla	35.3	36.5	26.2
Antigua and Barbuda	14.8	15.6	12.0
Aruba	27.0	n.a.	42.0*
Bahamas	11.9	8.6	10.0**
Barbados	11.9	14.0	11.2
British Virgin Islands	21.1	24.4	25.3**
Dominica	1.5	2.7	2.7
Grenada	5.2	9.7	9.0
Jamaica	2.0	2.0	2.5
Martinique	5.0	n.a.	n.a.
Montserrat	2.7	2.9	0.0
St. Christopher and Nevis	7.5	11.4	9.3*
St. Lucia	9.4	11.8	13.0
St. Vincent and the Grenadines	2.1	2.5	2.2

*1998

**1995

Source: Adapted and modified from Caribbean Tourism Organization Statistical Report(s).

Table 30 Tourism Related Hotel Room Taxes by Percent (%) for 2000

Destination	Hotel Room Tax (%)
Anguilla	8.0
Antigua & Barbuda	8.5
Barbados	7.5
British V.I.	7.0
Dominica	5.0
Grenada	8.0
St. Kitts & Nevis	7.0
St. Lucia	8.0
St. Maarten	8.0
St. Martin	5.0
St. Vincent	7.0
U.S.V.I.	15.0

Note: British V.I. Room tax is per person.

Source: Adapted and Modified from Caribbean Tourism Organization Statistical Report (2000).

Table 31 Tourist Trade: Receipts from Foreign Nationals (1995) in U.S. \$ (millions)

"For many small islands tourism provides more revenue than taxes or foreign aid. Foreign tourism is the major provider of hard currencies for most nations of the world. Generally, tourism statistics do not distinguish between business travel and travel for pleasure."
(Kurian, 2001 p.259)

Rank	Country/Entity	\$ (millions)
1	USA	61,137
2	France	27,527
3	Italy	27,451
4	Spain	25,701
5	U.K.	19,073
17	Netherlands	5,762
42	Puerto Rico	1,826
46	Dominican Republic	1,604
49	Bahamas	1,346
53	Cuba	1,100
55	Jamaica	1,069
59	U.S. Virgin Islands	821
62	Barbados	680
66	Netherlands Antilles	639
72	Aruba	521
76	Guadeloupe	458
79	Martinique	384
81	Antigua and Barbuda	329
87	St. Lucia	268
115	Haiti	81
120	Trinidad and Tobago	73
122	St. Kitts and Nevis	65
125	Grenada	58
128	St. Vincent and the Grenadines	57
143	Dominica	33

Source: Adapted and Modified from Kurian, (2001).

Table 32 Tourist Trade: Receipts from Foreign Nationals (1995) in U.S. \$ (millions)
With Selected Island Locales

"For many small islands tourism provides more revenue than taxes or foreign aid. Foreign tourism is the major provider of hard currencies for most nations of the world. Generally, tourism statistics do not distinguish between business travel and travel for pleasure." (Kurian, 2001 p.259)

Rank

Caribbean	Other	Country/Entity	\$ (millions)
	1	USA	61,137
	2	France	27,527
	3	Italy	27,451
	4	Spain	25,701
	5	U.K.	19,073
	17	Netherlands	5,762
	26	Malaysia	3,910
	37	The Philippines	2,450
	40	New Zealand	2,163
42		Puerto Rico	1,826
46		Dominican Republic	1,604
49		Bahamas	1,346
53		Cuba	1,100
55		Jamaica	1,069
	57	Guam	950
59		U.S. Virgin Islands	821
62		Barbados	680
	65	Northern Mariana Islands	655
66		Netherlands Antilles	639
72		Aruba	521
76		Guadeloupe	458
79		Martinique	384
81		Antigua and Barbuda	329
	82	Fiji	312
87		St. Lucia	268
	89	French Polynesia	260
	93	Sri Lanka (Ceylon)	224
	95	The Maldives	210
	109	New Caledonia	107
	111	The Seychelles	100
115		Haiti	81
120		Trinidad and Tobago	73
122		St. Kitts and Nevis	65
	124	Papua New Guinea	60
125		Grenada	58
	126	Vanuatu	58
128		St. Vincent and the Grenadines	57

Table 32 (continued)

143	<i>Dominica</i>	33
158	<i>Tonga</i>	11
159	<i>American Samoa</i>	10
169	<i>Solomon Islands</i>	6
175	<i>Marshall Islands</i>	2
180	<i>Kiribati</i>	1
182	<i>Tuvalu</i>	0.3

Source: Adapted and Modified from Kurian, (2001).

Table 33

Lesser Antilles Selected Shoreline Change Assessments

Coastal Erosion Average Trends (unless otherwise noted)

Antigua and Barbuda	Fort James area (1942 to 1968) was 0.3 m/yr (1 foot/yr) Oakwood area (1942 to 1968) was 1 m/yr (3 feet/yr) Whole Island (1992 to 1994) was 0.85 m/yr "mean change in beach width"
British Virgin Islands	Whole Archipelago (1989 to 1992) was 0.36 m/yr "mean change in beach width"
Dominica	Whole Island (1987 to 1992) was 1.06 m/yr "mean change in beach width"
Grenada	Grand Anse area (1951 to 1970) was 0.4 m/yr Grand Anse area (1970 to 1984) was 0.7 m/yr Sauteurs area (1970 to 1984) was 1.8 m/yr Grand Mai area (bayhead beach) (1970 to 1984) was 2.9 m/yr Whole Island (1985 to 1991) was 0.31 m/yr "mean change in beach width"
Montserrat	Whole Island (1990 to 1994) was +1.07 m/yr "mean change in beach accretion"
St. Christopher and Nevis	Old Road Town to Sandy Point Town (1968 to 1983) was 0.7 m/yr Nevis: Whole Island (1988 to 1993) was 0.85 m/yr "mean change in beach width" St. Kitts: Whole Island (1992 to 1994) was 0.27 m/yr "mean change in beach width"
St. Lucia	Vigie and Choc Beaches (bayhead beaches) (1941 to 1970) was 0.6 m/yr

Source: Principally after UNESCO Regional Office for Science and Technology for Latin America and the Caribbean, Montevideo Uruguay (1987) and Cambers (1997)

Table 34 Lesser Antilles Selected Average Shoreline Change (General Timeframe 1985 - 1994);
With Percent Locales Facing Erosion

Island	Number of Sites Measured	Number of Sites Eroding	Number of Sites Accreting	Mean Change in Beach Width (m/yr)	Percent Locales Facing Erosion
Antigua	30	24	6	-0.85	80
British V.I.	44	32	12	-0.36	73
Dominica	23	21	2	-1.06	91
Grenada	40	26	14	-0.31	65
Montserrat	10	2	8	1.07	20
Nevis	17	13	4	-0.85	76.5
St. Kitts	35	22	13	-0.27	63

Source: Adapted and modified from Cambers (1997)

Table 35 Lesser Antilles Beach and Dune Changes Resulting Primarily from 1995 Hurricane Luis.

Island:	General Distance to Center of "Luis" (km)	Average Retreat of Land/Dune Edge (m)	Average Change in Profile width (m)
Barbuda	5	17.5	-1.1
Anguilla	28	8.9	-8.7
Antigua	40	4.9	-4.9
St. Kitts	70	4.0	-3.2
Nevis	90	5.2	-5.7
Montserrat	90	3.5	-10.9
Dominica	180	2.5	-6.7

Source: Adapted and modified from Cambers, (1997).

Table 36 Lesser Antilles Beach and Dune Changes Resulting Primarily from Episodic Hurricanes

Locale:		
Nevis	Mean Change in Profile Width (m) 1989 - 1990	Average Change in Dune/Land Edge Position (m) 1989 - 1990
	-5.2	-3.9 out of 16 beaches surveyed
	Mean Change in Profile Width (m) 1995 - 1996	Average Change in Dune/Land Edge Position (m) 1995 - 1996
	-5.7	-5.2 out of 17 beaches surveyed

Table 36b. Changes in Beach Width at Selected *St. Kitts* Locales (1992 - 1995)

	Conaree Beach	South Frigate Bay Beach
1992	30.07m	25.39m
1995	11.68m	5.06m

Source: Adapted and modified from Barrett and Huggins, (1997); and Farrell and Lloyd, (1997).

Table 37 Pertinent Factors Contributing to Coastal Erosion (non site-specific)

"Erosion is a 'problem' in the sense that increasing numbers of people live (or recreate) within the coastal zone, and find themselves in the path of what is otherwise a natural process" (Komar, 2000 p. 3). "The ... coast does not need protection from the effects of erosion and sea-level rise, human activity in the coastal zone needs the protection" (Boothroyd, et al., 1998, p. A5-1). "The effect of any amount of future (relative) sea-level rise will be an increased rate of coastal erosion as waves will break higher on bluffs and dunes... for any given storm intensity." "...Hotels and other buildings now protected by coastal engineering structures will be subject to increased wave attack as the protection structures are overtopped by smaller and smaller storms" (Boothroyd, et al., 1998 p. A5-9). "There is no reason to believe that storm frequency and severity will change significantly in the next 100 years, thus sea-level rise is the variable factor affecting projected shoreline positions" (Boothroyd, et al., 1998 p. A5-18). Selected natural and human factors, or a combination of both, include:

- * Wave energy and intensity... due to El Nino events (Komar, 2000 p. 12);
- * Episodic major storm-surge overwash of the beach;
- * Enhanced longshore sediment transport due to patterns of littoral wave refraction;
- * Rising (relative) sea-level... partly as a result of greenhouse warming;
- * Aeolian sand transport in the beach system;
- * Sediment budget starvation (debit) by the formation of inlet deposits;
- * Tides and tidal current flow;
- * Placement of dams on rivers;
- * Construction of seawalls, groyne systems and jetties;
- * Sediment budget starvation (debit) in the down-drift leeside of a groyne/seawall system;
- * Sediment budget starvation (debit) by dredging at inlets and removal of sand out of the littoral beach cell;
- * Beach sand mining for aggregate in the Lesser Antilles
- * Regional sand budget in island settings;
- * Coral reef die-back; corals are a primary source of white calcareous beach sand in the Lesser Antilles;
- * Littoral sand permanently lost offshore down submarine canyons (e.g. California coast);

Source: Adapted and modified from Boothroyd et al., 1998; Komar, 2000; Pilkey et al., 2000 from Forum "Sea-Level Rise Shown to Drive Coastal Erosion" EOS, *Transactions, American Geophysical Union* Vol. 81 (38), pp. 436 to 441.

Table 38 Lesser Antilles Selected Effect of Storm-Events on Estimated Visitor Expenditures in U.S. \$ (millions)
The Storm-Events of 1995, Hurricanes Luis and Marilyn

	1994	1996	1998	1999
Anguilla	51.0	48.0	58.1	56.5
Antigua and Barbuda	293.4	257.9	255.6	290.0
St. Maarten	419.8	321.9	412.9	449.4
U.S. Virgin Islands	919.6	781.0	940.6	954.9

Source: Adapted and modified from Caribbean Tourism Organization Statistical Report(s)

Table 39 Lesser Antilles Selected Effect of Storm-Events on Visitor Accommodations (Rooms)
The Storm-Events of 1995, Hurricanes Luis and Marilyn and in 1998, Georges

	1995	1996	1998	1999
Anguilla	951	866	1045	1120
Antigua and Barbuda	3317	3185	3185	3185
St. Barthelemy	612	623	626	571
St. Eustatius	139	77	73	62
St. Maarten	3707	4043	4274	3065
U.S. Virgin Islands	5154	4087	4929	4849

Source: Adapted and modified from Caribbean Tourism Organization Statistical Report(s)

Table 40 U.S. Virgin Islands Selected Effect of Storm-Events on Visitor Accommodations (Rooms)
Recent Hurricane Storm-Events

	1989	1990	1995	1996	1998	1999
U.S. Virgin Islands	5231	4520	5154	4087	4929	4849

Source: Adapted and modified from Caribbean Tourism Organization Statistical Report(s)

Table 41 Lesser Antilles Selected Meteorological Natural Disasters 1995-2000

Loss Event	
<i>Antigua and Barbuda</i>	
Hurricane Luis Sept. 1995	High wind speeds, gusts up to 270 km/h, heavy rain, storm surge, high waves up to 3 metres. 65% of buildings in Antigua destroyed. Many hotels destroyed, tourist industry affected. Injured: 158. Fatalities: 15. Economic losses: US\$ 300.00m
Hurricane Georges Sept. 1998	Gusts up to 210 km/h, high waves, heavy rain. Hundreds of houses, businesses damaged. Losses to marinas. Power failures. Fatalities: 2. Economic losses: > US\$ 60.0m. Insured losses: US\$ 50.0m.
<i>Dominica</i>	
Hurricane Luis Sept. 1995	Major losses to banana plantations, crops destroyed.
Hurricane Marilyn Sept. 1995	High wind speeds. Buildings damaged. Losses to banana plantations. Economic losses: US\$ 175.00m.
<i>Guadeloupe</i>	
Hurricane Luis Sept. 1995	High wind speeds, gusts up to 270 km/h. Roads flooded, trees downed. Injured: 8. Fatalities: 1.
Hurricane Georges Sept. 1998	Gusts up to 210 km/h, high waves, heavy rain. Houses damaged. Power failures. Economic losses: US\$ 6,000.00m. Insured losses: US\$ 2,000.00m. For Guadeloupe, Antigua, Montserrat, Dominica, St. Kitts & Nevis, St. Croix, Saint-Barthelemy, Saint-Martin
<i>Martinique, Dominica and U.S. Virgin Isles</i>	
Hurricane Marilyn Sept. 1995	High wind speeds, torrential rain, floods. Houses, road flooded/damaged. Economic losses: US\$ 160.0m.

Table 41 (continued)

Montserrat

Hurricane Luis
Sept. 1995

High wind speeds, gusts up to 220 km/h. Hundreds of houses damaged/destroyed. Power and water supply failure, telephone lines cut.

St. Kitts and Nevis

Hurricane Georges
Sept. 1998

Gusts up to 210 km/h, high waves, heavy rain. 85% of houses damaged, 3 hospitals, numerous health centers, sports facilities, super markets, schools damaged. 45% of businesses, 55% of industrial buildings damaged. Airport, control tower, power plant, ports of Basseterre and Zante damaged. Losses to tourist industry. Power lines, poles downed, generators damaged. Power failures. Losses to agriculture: 50% of sugar crops damaged, farms destroyed. Food stock destroyed. Homeless: 3,000 (50% of shelters damaged). Fatalities: 4. Economic losses: US\$ 400.00m

*Virgin Islands
(U.S. & British);
(Dominica & Martinique
St. Martin)*

Hurricane Luis
Sept. 1995

High wind speeds, gusts up to 270 km/h, heavy rain.

Hurricane Marilyn
Sept. 1995

Gusts up to 160 km/h, heavy rain, storm surge. St. Thomas 20-25% of buildings destroyed, St. Croix >6,000 buildings damaged/destroyed. St. John 25% of buildings destroyed, 40-5-% damaged 1,700 yachts damaged/destroyed (economic losses = U.S. \$136.00m). Homeless: 10,000. Fatalities: 7. Economic losses: U.S. \$136.00m.

Hurricane Bertha
July-96

Wind speeds 100 km/h, heavy rain. 2,500 houses damaged, trees uprooted. Damage to refineries. Fatalities: 2 (St. Martin).

Table 41 (continued)

Virgin Islands
(U.S. & British);
(Guadeloupe, Antigua,
Montserrat, Dominica,
St. Kitts & Nevis,
Saint Barthelemy,
Saint Martin et al.)

Hurricane Georges
Sept. 1998

Gusts up to 210 km/h, high waves, tornadoes, large hail (5 cm in diameter), torrential rain, flood, landslides, mudslides. Tourist resorts affected. Infrastructure disrupted: airports, ports closed, roads, highways, bridges damaged/destroyed. Fatalities: >4,000 (all countries). Economic losses: US\$ 100.00m
Insured losses: US\$ 50.0m.

Source: Munich Re Insurance Company, Germany (February, 2001).

Table 15

Caribbean Tourism Organization Lesser Antilles Visitor Survey(s)

	Anguilla	Barbados	
	(Winter '94)	(Summer '93)	(Winter '94)
<i>Purpose of Visit: (%)</i>			
<i><u>Vacation</u></i>	89.8*	81.7	80.4
<i>Business</i>	3.7	6.3	7.0
<i>Business & <u>Vacation</u></i>	3.6	2.1	6.1
<i>Visit Friends & Relatives</i>	1.9	4.9	3.0
<i>Day Trip</i>	n.a.	n.a.	n.a.
<i>Other</i>	1.0	5.0	3.5
Total All <u>Vacation</u> Categories	93.4	83.8	86.5

*Includes 4% on "Honeymoon"

Source: Adapted and modified from Ott (1995; 1994)

Table 43 Wider Caribbean Islands Natural Disaster Profiles: Tropical Storms, Hurricanes and Floods (with El Niño Years)

Year	El Niño La Niña	Tropical Storms and Hurricanes				Floods				Combined Total			
		No. of Events	People Affected	Deaths	No. of Events	People Affected	Deaths	No. of Events	Deaths	People Affected	No. of Events	Deaths	Deaths
1999	✓✓	3	2,079,600	20	0	0	0	3	0	2,079,600	3	20	20
1998	-	5	4,686,292	491	0	0	0	5	0	4,686,292	5	491	491
1997	✓	0	0	0	1	7,000	0	1	0	7,000	1	0	0
1996	✓	6	360,458	87	6	54,046	6	12	6	414,504	12	93	93
1995	✓	11	223,996	26	1	33,800	0	12	0	257,796	12	26	26
1994	✓	4	1,698,308	1,124	2	43,600	25	6	25	1,741,908	6	1,149	1,149
1993	✓	3	152,785	7	6	607,066	89	9	89	759,851	9	96	96
1992	✓	1	1,700	4	3	9,861	21	4	21	11,561	4	25	25
1991	✓	0	0	0	2	234,340	10	2	10	234,340	2	10	10
1990	✓	10	3,500	6	2	11,000	4	12	4	14,500	12	10	10
1989	✓	12	79,944	61	2	24,930	0	14	0	104,874	14	61	61
1988	✓	6	1,681,506	149	10	1,316,051	49	16	49	2,997,557	16	198	198
1987	✓	4	438	3	7	35,910	42	11	42	36,348	11	45	45
1986	✓	2	2,000	12	5	191,318	249	7	249	193,318	7	261	261
1985	✓	3	499,961	11	3	3,000	550	6	550	502,961	6	561	561
1984	✓	3	10,000	2	1	100	0	4	0	10,100	4	2	2
1983	✓	2	3,000	0	2	39	15	4	15	3,039	4	15	15
1982	✓	1	180,000	24	0	0	0	1	0	180,000	1	24	24
1981	✓	0	0	0	1	150,000	20	1	20	150,000	1	20	20
1980	✓	10	665,516	322	0	0	0	10	0	665,516	10	322	322
1979	✓	7	1,651,713	1,451	4	251,000	117	11	117	1,902,713	11	1,568	1,568
1978	✓	1	270	6	0	0	0	1	0	270	1	6	6
1977	✓	0	0	0	2	18,000	7	2	7	18,000	2	7	7
1976	✓	0	0	0	0	0	0	0	0	0	0	0	0
1975	✓	1	0	26	1	0	0	2	0	0	2	26	26
1974	✓	1	50,000	2	0	0	0	1	0	50,000	1	2	2
1973	✓	1	2,510	6	0	0	0	1	0	2,510	1	6	6
1972	✓	0	0	0	1	40,000	78	1	78	40,000	1	78	78
1971	✓	0	0	0	0	0	0	0	0	0	0	0	0
1970	✓	4	5,000	65	2	210	63	6	63	5,210	6	128	128
1969	✓	0	0	0	0	0	0	0	0	0	0	0	0
1968	✓	1	0	0	0	0	0	1	0	0	1	0	0
1967	✓	4	1,000	54	0	0	0	4	0	1,000	4	54	54
1966	✓	10	264,856	778	0	0	0	10	0	264,856	10	778	778
1965	✓	1	1,200	0	0	0	0	1	0	1,200	1	0	0
1964	✓	4	90,100	121	0	0	0	4	0	90,100	4	121	121
1900-1963	✓	56	390,370	24,463	10	2,000	1,138	66	1,138	392,370	66	25,601	25,601

* At least one of the following criteria must be fulfilled in order for a disaster (natural hazard) to be included in this database
 A declaration of a state of emergency
 A call for international assistance
 A report of not <100 people affected
 A report of not <10 deaths

* = Transitional Year

Source: Adapted and modified from CRED International Disaster Database (2001)
 Catholic University of Louvain, Brussels, Belgium. Data for 1999 interpolated from NOAA, National Hurricane Center Records.
 Information on El Niño and La Niña interpolated from NOAA Climate Prediction Center Databases.

Table 44 Caribbean (Islands) Natural Disaster Profiles: Earthquakes and Volcanoes

Year	<i>Earthquakes</i>			<i>Volcanoes</i>		
	No. of Events	People Affected	Deaths	No. of Events	People Affected	Deaths
1998	0	0	0	2	0	0
1997	0	0	0	1	4,200	32
1996	0	0	0	1	4,000	0
1995	0	0	0	0	6,000	0
1994	0	0	0	0	0	0
1993	0	0	0	0	0	0
1992	1	12,879	0	0	0	0
1991	0	0	0	0	0	0
1990	0	0	0	0	0	0
1989	0	0	0	0	0	0
1988	2	3	0	0	0	0
1987	0	0	0	0	0	0
1986	0	0	0	0	0	0
1985	0	0	0	0	0	0
1984	0	0	0	0	0	0
1983	0	0	0	0	0	0
1982	0	0	0	0	0	0
1981	0	0	0	0	0	0
1980	0	0	0	0	0	0
1979	0	0	0	1	20,000	2
1978	0	0	0	0	0	0
1977	0	0	0	0	0	0
1976	1	8	1	1	75,003	0
1975	0	0	0	0	0	0
1974	0	0	0	0	0	0
1973	0	0	0	0	0	0
1972	0	0	0	0	0	0
1971	0	0	0	1	2,000	0
1970	0	0	0	0	0	0
1969	0	0	0	0	0	0
1968	0	0	0	0	0	0
1967	0	0	0	0	0	0
1966	0	0	0	0	0	0
1965	0	0	0	0	0	0
1964	0	0	0	0	0	0
1900-1963	5	90,000	1,398	3	0	43,565*

* Most of these were in Martinique in 1902

Source: Adapted and modified from CRED International Disaster Database (2001)
Catholic University of Louvain, Brussels, Belgium.

Table 45 Major and Minor Atlantic Basin Hurricanes 1944 - 2000

	Minor	Major		Total
1944	4	3	1944	7
1945	3	2	1945	5
1946	2	1	1946	3
1947	3	2	1947	5
1948	2	4	1948	6
1949	4	3	1949	7
1950	4	7	1950	11
1951	6	2	1951	8
1952	3	3	1952	6
1953	3	3	1953	6
1954	6	2	1954	8
1955	4	5	1955	9
1956	2	2	1956	4
1957	1	2	1957	3
1958	3	4	1958	7
1959	5	2	1959	7
1960	2	2	1960	4
1961	2	6	1961	8
1962	3	0	1962	3
1963	5	2	1963	7
1964	1	5	1964	6
1965	3	1	1965	4
1966	4	3	1966	7
1967	5	1	1967	6
1968	4	0	1968	4
1969	9	3	1969	12
1970	3	2	1970	5
1971	5	1	1971	6
1972	3	0	1972	3
1973	3	1	1973	4
1974	2	2	1974	4
1975	3	3	1975	6
1976	4	2	1976	6
1977	4	1	1977	5
1978	3	2	1978	5
1979	3	2	1979	5
1980	7	2	1980	9
1981	4	3	1981	7
1982	1	1	1982	2
1983	2	1	1983	3
1984	4	1	1984	5
1985	4	3	1985	7
1986	4	0	1986	4
1987	2	1	1987	3
1988	2	3	1988	5
1989	5	2	1989	7
1990	7	1	1990	8
1991	2	2	1991	4

Table 45 (continued)

	Minor	Major	Total	
1992	3	1	1992	4
1993	3	1	1993	4
1994	3	0	1994	3
1995	6	5	1995	11
1996	3	6	1996	9
1997	2	1	1997	3
1998	7	3	1998	10
1999	3	5	1999	8
2000	5	3	2000	8
Total(s):	3.6	2.3	5.9 Central Tendency: Avg. Total per/year 1944-2000	

Source: Adapted and modified from Goldenberg, et al., (2001)

Table 46 Elements of Ecosystem Management and Fundamental Scientific Precepts and Steps to Implementing Ecosystem Management

What is an Ecosystem?

It is defined as "a spatially explicit unit of the Earth that includes all the organisms, along with all components of the abiotic environment within its boundaries."

What is Adaptive Management?

It is a "process that combines democratic principles, scientific analysis, education, and institutional learning to manage resources sustainably in an environment of uncertainty."

Elements of Ecosystem Management:

Fundamental Scientific Precepts:

1	Sustainability	<i>Spatial and Temporal Scale are Critical</i>
2	Goals	<i>Ecosystem Function Depends on its Structure, Diversity and Integrity</i>
3	Sound Ecological Model and Understanding	<i>Ecosystems are Dynamic in Space and Time</i>
4	Complexity and Connectedness	<i>Uncertainty, Surprise and Limits to Knowledge</i>
5	The Dynamic Character of Ecosystems	
6	Context and Scale	<u>Steps to Implementing Ecosystem Management:</u>
7	Humans as Ecosystem Components	· Defining Sustainable goals and objectives
8	Adaptability and Accountability	· Reconciling Spatial Scales
		· Reconciling Temporal Scales
		· Making the System Adaptable and Accountable

Source: Adapted and modified from Christensen et al. (1996)

Table 47 Selected Ecosystem Goods and Services and Science Applications for Ecosystem Management

Goods:	Services:
Tourism and Recreation	Regulating Climate
Wild Genes for Domestic Plants and Animals	Provide beauty, inspiration, and research
Medicinal Plants	Absorbing and detoxifying pollutants
Construction Materials (e.g. Sand Aggregate)	Storing and cycling essential elements
Food	Cleansing water and air

*Science Applications for
Ecosystem Management:*

Goals and expectations

Models

Monitoring

Data Management and Feedback

Research

Education

Source: After Christensen et al. (1996)

Table 48 Ecosystem Management: A Selected Overview of Central Themes

<u>Central Themes:</u>	
Hierarchical context	
Ecological Boundaries:	<i>"It is clear that the definition and boundaries of ecosystems vary considerably, for example, from large marine ecosystems to watersheds to bioregions to ecoregions to estuaries." Or, for example, corridors, patches, oases, and stepping stones.</i>
Ecological Integrity	
Data collection	
Monitoring	
Adaptive Management	
Interagency Cooperation	
Organizational Change	
Humans embedded in nature	
Values	

Source: Adapted and modified from Hennessey (1998)

Table 49 Ecosystem Management: A Selected Overview of Central Themes and Barriers to Ecosystem Management

<u>Central Themes:</u>	
Hierarchical context	
Ecological Boundaries	
Ecological Integrity	
Data collection	
Monitoring	
Adaptive Management:	<i>is "learning by doing, that is treating programs as experiments."</i> <i>is an approach to natural resource policy that encompasses the theme that "policies are experiments."</i>
Interagency Cooperation	
Organizational Change	
Humans embedded in nature	
Values	

Table 49 (continued)

Barriers:

The goals of ecosystem management are not clearly specified:

A minimum level of ecosystem integrity and functioning needs to be defined.

Ecosystem boundaries need to be delineated.

The ecosystems approach will require coordination of activities among federal agencies managing resources in the same ecosystem.

Procedural requirements for long-range planning create barriers to interagency cooperation.

Collaboration and consensus building with federal, local and indigenous governments and the public will be difficult because of incentives, authorities, and interests that are beyond the scope or authority of the federal government.

There is still much uncertainty about how ecosystems function, which contributes to differences in the interpretation of scientific evidence.

The need to expand pilot projects to other areas.

Source: Adapted and modified from Hennessey (1998)

Table 50 A Tool for Development of Organizational Policy while Utilizing the Best Practicable Means to Achieve the Precautionary Principle: Environmental Auditing

"Environmental Auditing is defined as a management tool comprising systematic, documented, periodic and objective evaluation of the performance of the organization, management system and processes designed to protect the environment..." (Goodall, 1995 p. 30)

Pre-Audit	Environmental Audit	Post-Audit
Define an environmental policy consistent with regulatory requirements written in understandable vernacular	Consultations	Consideration by Management
Scoping Exercise, environmental review to establish baseline performance objectives	Measurement & Identification	Decision to Modify and/or Adopt Recommended Practices
Review of Policy, measurable targets and management programs while considering any legal, operational, and business requirements technological options and financial resources available	Interpretation & Evaluation of Data	Preparation of Plan
Decision making, including establishment of an implementation program	Full Audit: Site e.g., Analysis of the Degradation of Tourist Beaches	Implementation of Program Plan With procedures for periodic review and revision wherever necessary Establish a flexible environmental management program as a performance guide with identification of point people in the organization like a Marine Safety Officer aboard a vessel
The policy should specifically address requirements and standards needed to achieve ISO14001 certification	Partial Audit: Exposure of Environmental Risks and Issues such as CFC-free aerosols	
The policy must accurately reflect company expectations, provide an effective framework for resolution of relevant issues and where policy must be reviewed, approved and accepted by upper level management	Production of Audit Report	
The policy framework should define appropriate program objectives and targets		
The policy must be compatible with the results that can be obtained		
Adequate resources need to be allocated to the process		
The policy should improve dialog with interested parties and stakeholders		
The idea is to promote general environmental awareness among all employees		

Organizational refers to public and private interests, e.g. service companies, non-governmental organizations, government agencies, etc.

Source: Adapted and modified from Wu and Hunt, (2000); and Goodall, (1995).

Table 51

The International Organization for Standardization (ISO): An Opportunity for Adaptive Science Based Policy and Management

- * "ISO develops voluntary technical standards which add value to all types of business operations..."
- "ISO standards also serve to safeguard consumers and ISO standards represent an international consensus on the 'state-of-the-art'."
- * "The ISO 14000 family of International Standards on environmental management...offers a wide-ranging portfolio of standardized methods...that provide scientifically valid data on the environmental effects of economic activity."
- * "The ISO 14000 family of International Standards support the objective of 'sustainable development'."
- * The ISO 14000 series, with their first publications printed in September of 1996... "meets the needs... and concerns of those interested in the environmental management of organizations."
- * "The ISO 14000 family of standards is made up of, a systematic approach of documents related to EMS - environmental management systems - (i.e., ISO 14001 & 14004)...and environmental management tools (i.e., the audit) and the EPE (the environmental performance evaluation)."
- * "Establishment and implementation of an organization's EMS is of central importance in determining the organization's environmental policy, objectives, and targets...providing a framework for continuous improvement of environmental performance."
- * "Environmental management tools exist to assist the organization in realizing its environmental policy, objectives, and targets."
- * "The ISO 14000 family is made up of documents which are generally applied at the organizational level (documents for environmental management systems, environmental auditing and environmental performance evaluation)."
- * "The ISO 14000 standards are practical tools for the manager who is not satisfied with mere compliance with legislation...they're for the proactive manager...providing a strategic approach to"...conducting, implementing and evaluating environment-related measures that can "bring return on investment in environment-related measures."

Organizations with ISO 14001 certification in the Lesser Antilles as of December 2000

Barbados	3	
Saint Lucia	2	
Trinidad & Tobago	1	
& in other wider Caribbean Islands --		Dominican Republic & Puerto Rico = 2

Source: Kerr, M., and A. Hussein, (1998). ISO 14000 - Meet the whole family! (www.iso.ch) and Oluooh - Wauna, L. O., (2001).

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