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The vulnerability of Caribbean coastal tourism to scenarios of climate change related sea level rise

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Sea level rise (SLR) is considered a growing, certain and prominent consequence of anthropogenic climate change. Despite the high value of tourism properties and economic activity in the coastal zone, the tourism sector is largely absent from the SLR literature. This study created a geo-referenced database of 906 major coastal resort properties in 19 Caribbean Community (CARICOM) countries to assess their potential risk to a scenario of one-metre SLR. An estimated 266 (29%) resort properties would be partially or fully inundated by one-metre SLR; between 440 (49%) and 546 (60%) of resort properties would be at risk of beach erosion damage associated with the same SLR scenario. In addition, many resorts would experience significant losses of beach area prior to resort property loss. The vulnerability and the adaptive capacity of individual coastal tourism properties and destination communities is argued to differ substantially. Losses of over 50% of coastal properties are likely in five countries, three of which are highly dependent on tourism. These differentials would transform the competitive position and sustainability of coastal tourism destinations in the region, with important implications for property values, potential tourism revenues, insurance costs, destination marketing, as well as local and national economies.

Keywords: climate change; sea level rise; coastal tourism; Caribbean; adaptation; geographic information system

Introduction

From the ancient Roman Empire, to medical tourism in the middle ages, to the emergence of all-inclusive coastal resorts in the twentieth century, the seaside holds a special place in the development of tourism. Today, coastal tourism is considered by many to be the largest segment of the global tourism industry (Hall, 2001; Honey & Krantz, 2007). The socioeconomic impacts of mass coastal tourism are varied and typically highly uneven within coastal communities. This is often more pronounced in developing countries where coastal tourism may dominate the local economy, and therefore can be far more culturally invasive (Honey & Krantz, 2007; Jennings, 2004; Stonich, 2000). The environmental impacts of unplanned coastal tourism development have been well documented and include the destruction of coastal habitat (mangroves, seagrass beds, wetlands) and diminished biodiversity, over consumption and draw down of freshwater aquifers, water pollution and subsequent impacts on marine species and coral reefs, increased erosion and over-fishing

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(Duval, 2004; Hall, 2001; Jennings, 2004). Nonetheless, after 60 years of mass sun, sand and sea (3S) tourism development, growth in coastal tourism remains strong in many regional markets, with emerging economy markets and trends to “residential tourism”, which integrates beach resorts with vacation homes and condos, important contemporary drivers of growth (Honey & Krantz, 2007).

Coastal environments are among the most physically dynamic on Earth, yet there exists a tremendous stability bias with respect to coastal development. Coasts are influenced by short-term extreme storm events that can alter shore areas in the matter of hours as well as long-term gradual processes, such as changes in sea level. Importantly, both of these processes are projected to accelerate in the twenty-first century as a result of anthropogenic climate change. The Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2012; Solomon et al., 2007) concluded that there has been a discernible human influence on several aspects of climate, including air and ocean surface temperatures, precipitation patterns (distribution and intensity), wind patterns and the intensity of some extreme storm events (such as extra-tropical storm tracks in both hemispheres). Because of limited observing capabilities in the past, the IPCC (2012) has low confidence in any observed long-term increases in tropical cyclone activity (i.e. intensity, frequency, duration). However, it projects that average tropical cyclone maximum wind speed is likely to increase in the decades ahead, while the global frequency of tropical cyclones is likely to remain essentially unchanged (IPCC, 2012). Increased mean sea level rise (SLR) coupled with the likely increase in tropical cyclone maximum wind speed, would be a particularly salient issue for tropical small island states.

The IPCC Fourth Assessment Report (AR4) reported that the mean global sea surface rose by 1.8 mm/year over the period 1961–1993 and by 3.1 mm/year between 1993 and 2003 (Solomon et al., 2007) and that anthropogenic climate change contributed to this acceleration (Nicholls et al., 2007). More recent measurements indicate the rate of SLR has reached 3.4 mm/year between 1995 and 2010, far higher than the average rate of 0.1–0.2 mm/year increase recorded by geological data over the last 3000 years (Rahmstorf, 2010).

The IPCC projected a global SLR of 0.18–0.59 m from 1990 to 2100 (Soloman et al., 2007). These projections of future SLR assumed a near-zero net contribution from the Greenland and Antarctic ice sheets because of uncertainty about future ice mass changes in these regions. SLR projections have been vigorously discussed since the IPCC AR4 in 2007. Accumulating evidence suggests that both the Greenland and Antarctic ice sheets have been losing mass at an accelerating rate over the past two decades (Rignot, Koppes, & Velicogna, 2010), leading a number of experts to criticize the IPCC’s SLR projections as highly conservative (Hansen, 2007; Oppenheimer, O’Neill, Webster, & Agrawala, 2007; Pfeffer, Harper, & O’Neel, 2008).

Table 1 provides a summary of the most recent projections of global SLR over the twenty-first century and compares these newer studies to the IPCC AR4 projections and the continuation of current trends. Recent studies project the rate of global SLR will continue to accelerate in the decades ahead and that the total SLR by the end of the century could be as much as 1.5–2 m above levels of the late twentieth century (Grinstead, Moore, & Jevrejeva, 2009; Horton et al., 2008; Jevrejeva, Moore, Grinsted, & Woodworth, 2008; Vermeer & Rahmstorf, 2009). That these upper estimates would occur is highly unlikely, as are the lower estimated range, however the central estimates of four of the five most recent studies exceed 1 m SLR by the end of the twenty-first century.

Importantly, due to gravitational and geological factors, the rate of SLR is not expected to be uniform globally: in the Caribbean it is projected to exceed the worldwide average SLR by a factor of 1.2–1.4 (Tamisiae & Mitrovica, 2011).

Table 1. Scenarios of global sea level rise in the twenty-first century.

		2100		
	2050*	Low range	Central estimate	High range
Continuation of current trend (3.4 mm/year)	13.6 cm	—	30.6 cm	—
IPCC (Solomon et al., 2007)	8.9–23.8 cm	18 cm	—	59 cm
Rahmstorf (2007)	17–32 cm	50 cm	90 cm	140 cm
Horton et al. (2008)	∼30 cm	—	100 cm	—
Vermeer and Rahmstorf (2009)	∼40 cm	75 cm	124 cm	180 cm
Grinstead et al. (2009)	—	40 cm	125 cm	215 cm
Jevrejeva et al. (2008)	—	60 cm	120 cm	175 cm

*Where not specified, interpreted from original sources.

Although the exact magnitude of future global SLR remains uncertain, it is considered to be one of the most certain and most prominent consequences of anthropogenic climate change (Solomon et al., 2007). Consequently, a considerable literature has developed over the last 20 years that examines the potential impacts of SLR on ecosystems and society, including the number of vulnerable people, economic implications and even the physical existence of some sovereign nations (Nicholls et al., 2007; Nicholls et al., 2011). Importantly, none of the regional and global scale studies of the impacts of SLR have specifically examined potential damage to the tourism sector or compared the relative vulnerability of coastal tourism to other economic sectors. The absence of tourism studies, despite the high value of tourism properties and economic activity in the coastal zone, may be explained by the lack of readily available geospatial data sets of coastal tourism assets (e.g. resorts, beaches, transport infrastructure) at the regional or global scale.

With coastal tourism identified as the largest tourism segment globally and massive continuing investment in coastal tourism properties, a number of scholars have observed that remarkably little analysis of the implications of SLR for the tourism sector has been undertaken (Anning, Dominey-Howes, & Withycombe, 2009; Buckley, 2008; Gössling & Hall, 2006; Honey & Krantz, 2007; Moreno & Becken, 2009; Phillips & Jones, 2006; Scott et al., 2008; Weaver, 2011). Buckley (2008, pp. 72–73) noted, "Most coastal tourism destinations . . . seem to have remained remarkably blasé about rising sea levels, even though these are one of the best-documented aspects of global change".

This paper contributes to addressing this important knowledge gap in the rapidly developing literature on climate change and sustainable tourism by assessing the potential impact of projected SLR on the coastal tourism infrastructure of 19 countries within the Caribbean Community (CARICOM). The Caribbean was identified as a priority for analysis of the vulnerability of coastal tourism to SLR for several reasons. The Caribbean has the most tourism-intensive economy (i.e. tourism represents the greatest proportion of the regional economy) among the 12 regions ranked by the WTTC (2011), where tourism represents 14% of GDP, 13% of employment (2.2 million jobs), 12% of investment and 17% of exports. The Caribbean has also been repeatedly ranked as one of the major tourism regions most vulnerable to climate change (Deutsche Bank Research, 2008; Hall, 2008; Scott et al., 2008), in part due to the continued dominance of coastal tourism in the region (Cameron & Gatewood, 2008; Duval, 2004). More broadly, many of the Caribbean countries also exemplify the characteristics that are thought to make Small Island Developing States (SIDS) particularly vulnerable to the effects of climate change, including: relative isolation, small land masses, concentrations of population and infrastructure in coastal areas, a limited economic base and dependency on natural resources, combined with limited financial, technical and institutional capacity for adaptation (IPCC, 2007). Finally, a lack of detailed SLR impact analyses in the region had been noted in the literature (Dasgupta, Laplante, Meisner, Wheeler, & Yan, 2008).

The paper begins with an overview of SLR scenarios for the twenty-first century and a review of the extant literature on SLR and tourism. The subsequent section sets out the procedures used to develop a regional inventory of major coastal tourism resort infrastructure and integrate it into a Geographic Information System (GIS) with a satellite-based Digital Elevation Model. The sea level scenarios and methods for estimating the inundation and erosion impacts of SLR are also outlined. The regional- and country-specific flooding and erosion impacts associated with various levels of SLR are then described. The paper concludes with discussion of adaptation strategies, including the special challenges for coastal tourism, and associated policy and planning implications.

Sea level rise and tourism

The impacts of SLR on coastal areas are many, but those most pertinent to tourism include: inundation of coastal lands, erosion and loss of coastal habitat and beach area through the process of "coastal squeeze" (where the coastal margin is prevented from landward migration by a fixed boundary such as a sea wall or road), impeded drainage and increased risk of riverine flooding, salinity intrusion into freshwater supplies and higher water tables which can adversely affect the stability of foundations of coastal infrastructure.

While infrastructure damage is the paramount SLR risk to coastal tourism, the loss of beach resources represents a second significant impact that has already begun. Widespread beach erosion, with 70% of the world's monitored beaches observed to be receding (Bird, 1985), has been attributed to the process of beaches repositioning themselves further inland in response to ongoing SLR. SLR trends in the Caribbean have roughly paralleled global trends over the last 30 years (Nicholls & Cazenave, 2010) and Cambers (2009) argues that this was undoubtedly a causative factor contributing the observed erosion at a large majority of 113 monitored beaches in eight Caribbean countries (an average of 0.5 m/year between 1985 and 2000).

The implications of SLR for the future of coastal tourism development were first discussed more than 20 years ago by Gable (1987, 1990) and Leatherman (1989). More recent publications have further examined the potential policy and planning responses to SLR and linkages to coastal zone management (Hamilton, 2007; Moreno & Becken, 2009; Phillips & Jones, 2006; Scott et al., 2008), while others have focused on estimating the potential impacts of SLR on tourism infrastructure and coastal resources, the potential demand side response of tourists to SLR impacts as well as adaptation responses. These two main focal themes are briefly reviewed.

The potential impacts of SLR on tourism infrastructure and coastal resources (mainly beaches) have been examined in a number of locations. In the World Heritage Site of Venice, Italy, a fivefold increase in flooding events in San Marco square occurred between 1900 and 1990 (from 7 to 40 times per year) and it was estimated that with a further 0.3 m SLR, flooding events would increase to 360 days of the year (Francia & Juhasz, 1993). Similarly, large areas of the historical city of Alexandria, Egypt were found to be at risk to a 0.5 m SLR, including a series of high-value cultural tourism sites and beach areas (El-Raey, Dewindar, & El-Hattab, 1999). On the Island of Martinique, Schleupner (2008) found that a large majority of tourist beaches (83%) would be affected by coastal flooding and up to 62% of coastal infrastructure (tourism and nontourism) would be at risk to damage by SLR induced erosion. In Prince Edward Island, Canada, flooding and erosion associated with sea levels projected by the IPCC for the later decades of the twenty-first century were estimated to put over 300 designated heritage properties (key tourism attractions and, in some cases, accommodation) and nearly 50% of other coastal tourism properties at risk (Environment Canada, 2002).

A series of studies in the United States have found substantial potential economic impacts associated with SLR on coastal tourism and related recreation properties. Stanton and Ackerman (2007) estimated that with a 0.68 m SLR, impacts to the tourism sector in Florida would include half of existing beaches, 74 airports, 1362 hotels–motels and over 19,000 historic structures. Resultant losses in tourism properties and visitation were estimated to be in the tens of billions of dollars by 2050. A study of SLR impacts on tourism and coastal property at five major tourism beach areas in California estimated that a 1.4 m SLR could cause over US $2 billion in damage by 2100 (King, McGregor, & Whittett, 2011). In North Carolina, a 46 cm rise in sea level would put US $1.2 billion worth of residential property (mostly vacation home properties) at risk in four counties alone and cause substantial losses in recreation benefits from reduced opportunities for beach trips (US $3.5 billion discounted at a 2% rate) and fishing trips (US $430 million using a 2% discount rate) (Bin, Dumas, Poulter, & Whitehead, 2007).

Relatively few studies have examined the potential impact of beach loss on coastal tourism demand. In Europe, an early study by Braun et al. (1999) used the combined scenarios of temperature and precipitation changes with SLR and beach loss to examine the impact on the likelihood of traveling to the Baltic and North Sea coasts of Germany. With increased temperatures the likelihood of choosing the North German coast for a holiday was only slightly higher than the scenario where climate change impacts on the Mediterranean were very limited. In scenarios where some potential negative impacts on the German coasts occurred (e.g. beach erosion, increased frequency of rain), the likelihood of visiting was substantially lower, even when possible adaptations were included (e.g. greater setbacks of tourism infrastructure, more diversified indoor activities). Similar scenarios of climatic and environmental change on the East Anglian coast of the United Kingdom by Coombes and Jones (2010) resulted in minor reductions in visitation (less than 1%) from beach loss (though beach loss was presented as 13–16 m to beaches with widths of over 250 m), but large gains through warmer temperatures (24–26%).

In the Caribbean, a survey of tourists on the islands of Barbados and Bonaire found that under a severe scenario where "beaches largely disappeared", 77% would be unwilling to return to the 3S destination of Barbados for the same price, while 43% would be unwilling to return to Bonaire, which is known as a dive tourism destination and where beaches are not the primary tourism asset (Uyarra et al., 2005). Buzinde, Manuel-Navarrete, Kerstetter, and Redclift (2010a) and Buzinde, Manuel-Navarrete, Yoo, and Morais (2010b) used qualitative approaches (tourist interviews and online tourist comments about destinations and trip experiences) to examine tourist perceptions of beach erosion and attempts to restore the beach in the Playacar, Mexico area. Tourists were classified into three response categories: positive, negative and reconciliatory. Those with a positive view of the situation largely focused on the additional recreational opportunities provided by the erosion control structures in the water (i.e. large sand filled geotextile bags). Those with negative reactions were often unaware of the severely eroded beaches and had expected pristine, extensive beaches portrayed in tourism marketing images. This discrepancy between promoted images and reality left them feeling deceived. The reconciliatory group also viewed the beach erosion control measures as aesthetically unpleasant but understood they were part of ongoing work to restore the beach through beach nourishment. Some of these tourists appeared aware of the degraded condition of the beach before arrival and therefore did not have a sense of misrepresentation by tourism operators. It is unclear what proportion each group represented or how the perceptions varied among specific market segments, which is important in order to understand the potential impact on destination reputation and future demand. It is also unclear as to the role prior knowledge of the degraded state of the beaches or price discounts played in the varied interpretations of these three groups or their respective intentions to return to this destination at the same price or at discounted prices.

Studies of adaptive responses to SLR in tourism destinations are even more limited. An early study by Leatherman (1989) examined the costs of beach nourishment to stabilize major recreational beaches in 21 coastal states in the United States. The costs through to 2060 were estimated as between US $6.5 billion (1990 dollars) under a 0.32 m SLR scenario and $20.4 billion (1990 dollars) under a 0.95 m scenario. The estimated costs of beach nourishment were far less than the damage associated with lost tourism and recreation benefits and it was concluded that beach nourishment would be a primary adaptive by communities and state tourism organizations.

Hamilton (2007) examined the implications of two adaptation approaches – levies and beach nourishment – on the revenue of tourism accommodations in the coastal districts of Schleswig-Holstein, Germany. An increase in the length of levies would diminish the aesthetics of the coastline, resulting in a reduction in the average price of accommodation and loss of revenue of over €1.2 million per year, while beach nourishment would not diminish accommodation revenues. The capital and maintenance costs of each adaptation strategy were not compared.

Buckley's (2008, p. 1) analysis of SLR adaptation by local government in Byron Bay, Australia provides important insight into how misunderstandings or misrepresentations of the likely effects of SLR were used by local government to "plac[e] severe and irrational restrictions on development of residential and holiday accommodation" and "prevent beachfront landowners from protecting their own properties against erosion". In this situation it is argued that climate change science was misused for political reasons and needlessly damaged the destination's tourism industry by driving investment to nearby communities that did not adopt such restrictions on coastal properties. This case demonstrates the dangers of speculation and lack of information on the magnitude and anticipated timelines of potential impacts under varied SLR scenarios. This information is a prerequisite for coastal management agencies, local governments, citizens and the tourism industry, to engage in an informed dialogue on future coastal development and effective and equitable SLR adaptation options. Providing the 19 CARICOM countries some insight into these important questions was the primary objective of the scenarios created in this study.

Methodology

Inventory of Caribbean coastal tourism infrastructure

The first step in this analysis was to develop an inventory of coastal tourism properties in the 19 CARICOM countries included in the study (see Table 2). Although Smith Travel Research Inc. (WTTC, 2011) maintains a database of hotels/resorts in the Caribbean (n = 2282 in 2011), the geospatial coordinates (latitude and longitude) and elevation of each hotel/resort are not available in this comprehensive data set. Consequently, a number of information sources were used to develop a geospatial data set of coastal resort and hotel properties. Accommodation lists from national tourism websites in all 19 countries were

Table 2. Country level SLR inundation and erosion impacts.

CARICOM member country	Tourism contribution to GDP (2011)[b]	Number of coastal resort properties	Resort properties partially or fully inundated by 1 m SLR	Resort properties damaged by erosion (50 m scenario)	Resort properties damaged by erosion (100 m scenario)
Anguilla[a]	64%	60	38	35	42
Antigua & Barbuda	74%	99	10	34	44
Barbados	47%	75	6	42	50
Belize	No data	44	32	42	44
British Virgin Island[a]	58%	14	8	5	6
Cayman Island [a]	24%	63	11	15	25
Dominica	25%	17	0	5	6
Grenada	24%	45	5	14	19
Guyana	No data	10	0	0	0
Haiti	6%	28	13	14	17
Jamaica	24%	105	8	34	52
Montserrat	No data	1	0	0	0
St. Kitts & Nevis	28%	22	14	15	18
St. Lucia	46%	30	2	5	9
St. Vincent & the Grenadines	26%	21	2	8	16
Suriname	No data	19	1	2	2
The Bahamas	18%	133	48	77	93
Trinidad & Tobago	7%	24	8	15	16
Turks & Caicos Island[a]	No data	96	60	78	87
Total		906	266 (29%)	440 (49%)	546 (60%)

[a]Are associate members of CARICOM; [b]Source: WTTC (2011).

used to develop an initial inventory of potential resorts/hotels on the coast. The geographic location and elevation of each coastal resort/hotel was then verified using Google Earth Pro© before including it in the data set.

Only resorts/hotels within 100 m of the coast and that had a minimum of 50 rooms/100 beds were included in the sample. Major inland resorts along with small coastal villas/guesthouses were not included. A total of 906 coastal properties digitized by the research team were included in the analysis. Table 2 identifies the number of properties included from each country.

Construction of geographic information system and digital terrain model

A GIS was constructed in ArcGIS© using the best available geospatial data. CARICOM country boundaries were derived from the National Geospatial Intelligence Agency's World Vector Shoreline data set (NOAA, 2010). All inland lakes and depressions not connected to the sea by rivers or artificial channels, and thus not affected by SLR, were masked out using geospatial data obtained from version 2 of the Global Self-consistent, Hierarchical, High-resolution Shoreline Database (GHHS) (NOAA, 2010). Due to the small area of many of the CARICOM nations, careful inspection for data completeness was performed. Approximately 5000 unnamed country boundary polygons (mainly small islands) were inspected and subsequently updated with corrected country identifications. After inspection, all of the geospatial data was projected using the World Equal Area projection. The horizontal datum used for the study was the World Geodetic System 1984. Latitude and longitude geographic coordinates of the 906 tourism properties were presented in decimal degrees.

A continuous sink-filled digital terrain model (DTM) was created for the study area using data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM), which was recently made available to the research community by the United States National Aeronautics and Space Administration (NASA) and the Japanese Ministry of Economy, Trade and Industry (METI). The horizontal resolution of the GDEM is 30 m per pixel and the vertical resolution 1 m. As a research grade data set, the GDEM data was examined for quality and anomalies. Some anomalies in the data were observed along the coasts of Guyana and Suriname due to cloud cover during collection and other anomalies (METI, NASA & USGS, 2009). Consequently, we have lower confidence in the findings for these two nations (their 29 resorts/hotels represent 3% of the sample size).

Coastal flooding and erosion impact scenarios

Table 1 summarizes the most recent global SLR projections over the twenty-first century. With the central estimates of four of five of studies exceeding 1 m and the rate of SLR in the Caribbean region projected to exceed the global average by a factor of 1.2–1.4 (Tamisiae & Mitrovica, 2011), the SLR scenario selected for this study was +1 m. While this scenario does not represent the worse-case scenario in the literature (and other recent government SLR vulnerability assessments in the United States and the Netherlands [e.g. Delta Commission, 2008; Herberger, Cooley, Herrera, Gleick, & Moore, 2009] have explored scenarios greater than 1 m), it is closer to the central estimates of most of the studies in Table 1 and provides greater comparability with the larger number of regional and global SLR impact assessments that use arbitrary 1 m incremental scenarios (e.g. Dasgupta et al., 2008).

The potential inundation impacts associated with a 1 m SLR scenario were calculated by overlaying the flooded contiguous coastal pixels in the DTM with the location of the 906 coastal resorts/hotels. A 100 m property buffer was applied to the central point of each resort/hotel, and properties that contained a minimum of 10% of flooded pixels were recorded as impacted by 1 m SLR.

Large areas of the Caribbean coast are highly susceptible to erosion, and beaches have experienced accelerated erosion in recent decades (Cambers, 2009). Higher sea level is expected to accelerate coastal erosion in these areas. The amount of coastal retreat due to SLR can be estimated by several methods. In the absence of information necessary to apply more advanced three-dimensional shoreline recession modeling techniques, which was found to be almost universally the case throughout the Caribbean, two-dimensional conceptual models like the Bruun Rule (Bruun, 1962) provide a means to complete a first-order assessment of the implications of erosion related to SLR. Because of its simplicity, the Bruun Rule has been widely applied in the study of erosion impacts resulting from SLR (Aboudha & Woodroffe, 2006). It is based on the concept that an existing beach profile will remain largely constant and as sea level increases, sediment required to maintain this profile in deeper water is derived from erosion of the shore material. The readjustment of the beach profile to an equilibrium state produces inland retreat of approximately 50–100 times the vertical increase in sea level (i.e. for a 1 m SLR, 50–100 m of erosion is predicted). It does not account for long-shore interactions. The Bruun Rule has been the subject of some debate and criticism, but is still generally supported (Stive, 2004; Zhang, Douglas, & Leatherman, 2004). This analysis examined the impacts of both the low and high range of erosion response scenarios for the 906 coastal tourism properties.

Results

Of the 906 major coastal resort properties inventoried for this analysis, 266 (29%) were found to be at risk of partial or full inundation by a 1 m rise in sea level (Table 2). The analysis revealed that the potential inundation impacts of 1 m SLR would not be uniform among the CARICOM countries, with inundation losses of more than 50% of coastal properties in five countries (Anguilla, Belize, British Virgin Islands, St. Kitts and Nevis and Turks and Caicos Islands). The greatest vulnerability is in Anguilla, British Virgin Islands and Turks and Caicos Islands, where the relative economic importance of tourism to the national economy is also very high.

A far higher number of coastal resort properties were found to be vulnerable to coastal erosion associated with a 1 m SLR (Table 2). A conservative interpretation of the Bruun Rule – a 50 m erosion scenario in coastlines with unconsolidated beach materials – projected 440 (49%) coastal resort properties would be damaged. Using the Bruun Rule as typically applied in the literature – a 100 m erosion scenario associated with 1 m SLR – a total of 546 (60%) coastal resort properties were projected to be damaged. The countries with coastal resort properties at greatest risk to SLR-induced erosion damage were Belize and Turks and Caicos Islands, with over 80% of resort properties at risk in the 50 m erosion scenario. A further eight countries have over 50% of resort properties at risk in the 100 m erosion scenario (Anguilla, Barbados, Haiti, St. Kitts and Nevis, The Bahamas and Trinidad and Tobago).

Beaches are critical assets for tourism in the Caribbean and a primary design goal of coastal resorts is to maintain an aesthetic of undisrupted ocean views and unhindered access to beach areas. A critical observation from this analysis is that a much greater proportion of resort front beach assets would be degraded or lost to inundation and accelerated erosion,

Figure 1. “Coastal squeeze” of resort front beach asset.

as beaches would essentially have disappeared prior to damages to resort properties and infrastructure. This process of lost beach area is identical to the “coastal squeeze” leading to lost coastal wetlands and other habitats, where the coastal margin is squeezed between some fixed natural or human-made landward boundary (e.g. a sea wall protecting a resort property or resort buildings – see Figures 1 and 2) and the rising sea level. This process squeezes the beach area until it is eventually lost. While significant loss of beach assets will have occurred in all of the coastal resorts projected to be at risk to inundation and erosion associated with a 1 m SLR scenario, the beach assets will have also been degraded at the coastal resort properties not reported to be at risk in this analysis. Beach quality plays an important role in the selection of Caribbean destinations and the price guests are willing to pay (Anning et al., 2009; Ghermandi & Nunes, 2011). There is a chance that beach decline results in a slippery slope toward destination decline. As beach resources degrade, price structures for coastal accommodations begin to decline, affecting profitability and eventually resulting in closures, unemployment and further decline in overall destination image. This analysis does not account for the complex physical and socioeconomic interactions of the coastal tourism system, and therefore underestimates the impact of SLR to coastal tourism properties throughout the study area. Further scenario-based research is required to examine these market complexities and interpret the implications for specific destination communities.

The differential vulnerability to SLR inundation and erosion among the 19 CARICOM countries can be largely explained by three factors: the geophysical characteristics of the islands and their different coastal topographic settings (e.g. extensive low coastal plains below, low lying islands largely composed of unconsolidated materials, volcanic islands), the proximity of resort properties to the coastline and the level of coastal structural protection in place to prevent erosion impacts. While all countries currently have coastal set back requirements for new resort construction, this was not always the case and the earlier the

Figure 2. Structural protection to preserve artificial beach area.

tourism development occurred in the country, the greater likelihood tourism infrastructure will be in very close proximity to the shoreline. Similarly, the level of enforcement and flexibility of exemptions of coastal set back and structural protection has also varied by country and era of construction.

Discussion

A valid critique of many engineering and geomatics-based SLR studies is that they represent only the potential impacts of future SLR and have not adequately accounted for adaptation strategies. History demonstrates that societies will not idly watch high value land, infrastructure and cultural assets be lost to the sea. There are three response approaches to SLR: retreat – in which coastal properties are abandoned and the shoreline and coastal ecosystems allowed to shift landward; accommodation – where existing land uses continue, but the risks to people and infrastructure are managed through elevated structures and risk sharing strategies (e.g. flood insurance programs) and protection – where hard structures (e.g. sea walls and dikes) or other "soft" engineered approaches (e.g. vegetation, beach nourishment, dune construction) are used to protect the land from the sea and allow existing land uses to continue with little modification. All have important environmental, economic and social implications and the particular combination of these responses will vary substantially by region and type of land use.

Nicholls et al. (2011) conclude that while the potential land loss and infrastructure damage impacts of a 1–2 m SLR over the twenty-first century would be severe, these will be partially avoided through widespread implementation and upgrade of coastal protection. Although structural and "soft" engineering (particularly beach nourishment) protection strategies have widespread application in coastal tourism destinations, their use for SLR adaptation in the tourism sector presents some special challenges. Typical structural coastal protection is not well suited to the business objectives of coastal resorts: providing unobstructed views of the sea and maintaining unhindered access to the beach and sea. While structural protection can be easily designed to protect resort buildings, coastal squeeze will mean that resorts will lose their critical beach asset (Figures 1 and 2) unless it is accompanied by substantial investment in beach nourishment. The impact of contemporary beach erosion illustrates the negative economic impact of beach loss on resort attractiveness, room rates and property value (Buzinde et al., 2010a, 2010b; Cowell, Thom, Jones, Everts, & Simanovic, 2006; Hamilton, 2007; Houston 2002) and serves as a useful analogue for the impacts of SLR without beach nourishment. The available evidence suggests strongly that when 3S tourism becomes 2S, price structures, profitability and destination image are put at risk. The economics of structural protection and beach nourishment required to adapt to 1 m SLR have not been adequately assessed. So while structural protection will be a prudent course of action for certain tourism sector assets, such as airports, cruise ship terminals and cities that function as important tourism destinations, it is uncertain whether it would similarly represent an effective and economical response by coastal resorts that must maintain beach area and aesthetics sufficient to attract international tourism clientele. Engineered solutions, such as the artificial beach area preserved by a sea wall in Figure 2, may be more suited to low-yield budget all-inclusive 3S tourism, where expansive natural beach areas are not marketed and other factors (e.g. entertainment, shopping, price) are the more salient decision criteria.

The adaptive capacity of coastal destinations to cope with SLR will be determined by a number of key factors: policy and planning frameworks that enable or actively assist coordinated structural protection and cost-sharing of beach nourishment; resort property ownership and local taxation structures; insurability and insurance costs; the ability to afford the major costs associated with structural protection and recurrent beach nourishment, which typically must be redone every decade or sometimes after major storm events, and the availability of affordable and environmentally sustainable sources of sand. For example, major destinations with a cluster of large resorts owned by multinational corporations with greater access to capital to afford coastal protection would have greater adaptive capacity than small communities with less dense or only isolated resort development. This differential adaptive capacity will alter the sustainability and competitive relationships among coastal destinations over time, with the likely effect of further concentrating higher-yield coastal tourism in destinations with capacity to maintain natural beach area.

Coastal retreat is a largely untested strategy for coastal tourism destinations. The planning required for coordinated retreat would be highly complex, severely challenging local governments and planning authorities and would very likely result in major legal disputes, substantial impacts on property values, a reduced taxation base and a decline in tourism activity during this transitional phase. Nonetheless, this may become the only option for destinations unable to afford structural protection and beach nourishment. Notably, retreat may also be unavailable as an adaptation response where natural barriers or existing land uses (e.g. residential areas, transportation corridors) physically or economically prevent landward relocation of coastal tourism properties.

Conclusions

Using a geo-referenced database of over 906 major coastal resort properties in 19 CARICOM countries, it is estimated that 266 (29%) would be partially or fully inundated by a 1 m rise in sea level. Between 440 (49%) and 546 (60%) of these resort properties would be at risk to erosion damage associated with the same 1 m SLR, while a much larger number would experience significant loses of beach assets. The adaptive capacity of individual coastal tourism properties and destinations is argued to differ substantially, with salient implications for destination competitiveness and the sustainability of coastal tourism in some destinations.

With the inextricable link between coastal tourism and local and national economies in the Caribbean, there remains an important need to improve SLR risk mapping by obtaining high-resolution topographical and bathymetrical data sets (e.g. light detection and ranging data) and assessing the adaptation options (policy, planning, design) available to tourism properties and communities (e.g. where beach nourishment is feasible or natural landward migration of beaches is possible). Such information is a prerequisite for coastal management agencies, local governments, citizens and the tourism industry, to engage in an informed dialogue on future coastal tourism development and begin the process of mainstreaming SLR into existing scenarios, tourism master plans, institutions and regulatory frameworks. This improved information base is also essential to avoid maladaptation (which is an action or process that increases vulnerability to climate change-related hazards [Lim & Spanger-Siegfried, 2005]), such as continued tourism investment in high-risk zones or the unjustified near-term restrictions on tourism development that could needlessly and adversely affect property values and job creation. The tourism research community has an important role in this endeavor to avoid asymmetric access to information on property risk that could favor certain property owners and help foster participatory, community-based adaptation processes.

A number of studies have found that tourism stakeholders indicate a clear need for government leadership on climate change adaptation (see Scott, Hall, & Gössling, 2012 for a review) and communications with coastal tourism stakeholders in the Caribbean also reveal this to be particularly the case with respect to adaptation to SLR. The very long timeframes of SLR impacts are considered largely incompatible with coastal tourism investment and business planning, restricting SLR adaptation to a very low priority status. Real estate speculation is a reality of coastal tourism development, with many investors planning to divest from coastal resort projects within a few years and well before the typical 25–30 year life cycle of a coastal resort. Foreign ownership that increasingly dominates coastal regions and often involves multiple layers of investors and managers (Honey & Krantz, 2007) exacerbates these barriers to SLR adaptation planning.

In conclusion, this analysis represents but a first step in understanding the vulnerability of tourism to SLR. Much more is needed to assess physical and socioeconomic adaptation potential through the complex interaction of physical processes, tourism marketing, tourist perceptions, coastal property markets, insurance, coastal management regulations and protection cost structures and community planning responses.

While this study focused on the Caribbean region, it is clear that SLR will similarly represent the preeminent long-term threat to the sustainability of coastal tourism in SIDS and indeed coastal tourism destinations worldwide. It is, therefore, imperative that the coastal tourism research community together with coastal management professionals initiate the process of adapting to SLR, not because there is an impending catastrophe, but because there will be important opportunities to avoid adverse impacts in the near-term, and because the complex planning required for coastal management and protection (environmental assessments, financing, land acquisition and construction) often takes decades to complete.

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