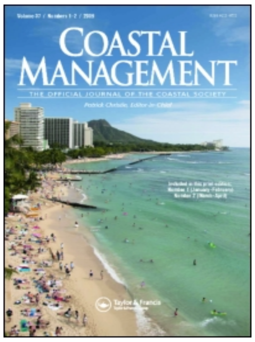

Taylor & Francis
Taylor & Francis Group

Coastal Management

ISSN: 0892-0753 (Print) 1521-0421 (Online) Journal homepage: http://www.tandfonline.com/loi/ucmg20

Vulnerability of Caribbean Island Cemeteries to Sea Level Rise and Storm Surge

Noah J. Mueller & Christopher F. Meindl

To cite this article: Noah J. Mueller & Christopher F. Meindl (2017) Vulnerability of Caribbean Island Cemeteries to Sea Level Rise and Storm Surge, Coastal Management, 45:4, 277-292, DOI: 10.1080/08920753.2017.1327343

To link to this article: https://doi.org/10.1080/08920753.2017.1327343

Published online: 16 Jun 2017.

COASTAL MANAGEMENT
2017, VOL. 45, NO. 4, 277–292
https://doi.org/10.1080/08920753.2017.1327343

Vulnerability of Caribbean Island Cemeteries to Sea Level Rise and Storm Surge

Noah J. Mueller[a] and Christopher F. Meindl[b]

[a]University Writing Program, University of Florida, Gainesville, Florida, USA; [b]Florida Studies Program, University of South Florida St. Petersburg, St Petersburg, Florida, USA

ABSTRACT
The Intergovernmental Panel on Climate Change reports that rising seas by the end of this century will increase the severity of coastal flooding and erosion. The Caribbean region is home to many small islands that are vulnerable to sea level rise and storm surge. Much of the literature examining impacts of sea level rise in the Caribbean focuses on ecosystems, infrastructure, and recreation. Few studies have examined how sea level rise will impact historic and culturally important places. In an effort to address this research gap, geographic information systems and crowd-sourced, georeferenced photographs were used to build a first-of-its-kind database of 542 Caribbean small island cemeteries. Vulnerable cemeteries were then identified based upon elevation, proximity to the ocean, and the coastal profile. Over one-fifth of the cemeteries surveyed are within 100 m of the coast. The highest concentrations of vulnerable cemeteries are on flat islands such as the Cayman Islands. Yet, some mountainous islands such as Saint Martin also have potentially vulnerable cemeteries. These findings suggest that the bereaved, cemetery managers, and managers of coastal areas that have cemeteries may have additional considerations when making long-term decisions about where and how to bury the deceased.

KEYWORDS
Caribbean; cemetery; graveyard; sea level rise; small island developing states (SIDS); storm surge

Introduction

Climate change is the "most significant challenge that cultural heritage will face in the foreseeable future" (Sabbioni, Brimblecombe, and Cassar 2010, p. 100). The Intergovernmental Panel on Climate Change (IPCC) claims that it is all but certain that extreme temperatures over land have increased on a global scale, and there is a 99% probability that global mean sea levels are rising and will continue to rise past the end of the century (IPCC 2013). Clearly, changes in sea level will impact coastal environments. Coastal infrastructure such as highways, airports, and buildings will be negatively affected (Stanton and Ackerman 2007; Bueno et al. 2008), as will coastal ecosystems (Hoegh-Guldberg et al. 2007), and the cost of adapting to sea level rise is expected to be high (Titus et al. 1991).

CONTACT Noah J. Mueller nmueller@ufl.edu University Writing Program, University of Florida, P.O. Box 112020, 302 Tigert Hall, Gainesville, FL 32611, USA.

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ucmg.

While the literature examining impacts and adaptation strategies for infrastructure and ecosystems is comprehensive, research is more limited on climate change impacts and methods of adaptation for historic and culturally important areas. For example, the more than 1500-page, two-part report from the IPCC, the most comprehensive document regarding climate change, has only two small paragraphs addressing built heritage (IPCC 2014a, p.559). The first research to examine cultural heritage and climate change was published less than a decade ago, and it largely focused on atmospheric impacts to European buildings and architecture (Sabbioni, Brimblecombe, and Cassar 2010). This report references sea level only once, and suggests impacts would include "harbor walls, beach huts, and historic lighthouses" (p.70). More recently, research investigating United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Sites found that over 100 global locations are vulnerable to flooding from sea level rise over the next 2000 years (Marzeion and Levermann 2014). The goal of this research is to help fill this gap in climate change impact knowledge by examining the vulnerability of cultural heritage sites in a vulnerable region. Specifically, it will analyze which cemeteries in small islands across the Caribbean are vulnerable to sea level rise, erosion, and storm surges from tropical cyclones.

The Caribbean region is a collection of islands in the west central Atlantic Ocean that help delineate the Caribbean Sea. It is often considered to be the space bounded by the Bahamas to the north, Central America and the Yucatan Peninsula on the west, the northern edge of South America to the south, and inclusively, the Lesser Antilles along the east. This area was selected because of its high concentration of small islands and because the IPCC (2014b) has identified small islands as being some of the most vulnerable locations to sea level rise. Cemeteries and graveyards were investigated because of their importance to most cultures (Francis, Kellaher, and Neophytou 2000) and their common occurrence on small Caribbean islands.

Importance of cemeteries and longevity

Cemeteries are sacred locations. In most ecclesiastical faiths, burial of the deceased and internment of ashes from a cremation are important rituals carried out by surviving family members (Yalom 2008). One particularly important day for many Christians is All Souls' Day, which is typically observed on November 2. In New Orleans during the weeks prior to All Souls' Day, cemeteries and gravesites are cleaned and repaired. Then, on All Souls' Day, cemetery visitation is high with many guests leaving flowers and lighting candles on monuments (Miller and Rivera 2006). Yalom (2008, 141) writes of a woman who had been evacuated from New Orleans in 2005 because of Hurricane Katrina. She was not able to visit her relatives' graves on All Souls' Day, and described it as "like not having Christmas." In addition to being important for religious rituals, cemeteries are heterotopic spaces that simultaneously serve multiple purposes (Foucault and Miskowiec 1986). While serving as places to bury the dead, cemeteries also have political, historical, social, emotional, and geographical importance (Woodthorpe 2011). They often serve as places for grieving, connecting to the past, and family bonding.

Regardless of the purpose, a central theme to cemeteries is longevity. Cemeteries are special places that are meant to last a long time. Memorials of the deceased, from the earliest of times, were rooted in the notion that they are never to be disturbed. The sacred nature of these places dictates that they are elevated, both literally (as they are frequently found atop hills) and symbolically (as the deceased are to have a place to peacefully rest forever). Cemeteries were "the scared and immortal heart of the city" (Foucault and Miskowiec 1986, p. 25). Many early European churchyards would offer burial rights "in perpetuity" to ensure eternal, peaceful resting (Rugg 2000). Sturdy headstones and vaults are built to withstand many decades or even centuries of weathering, and often the architectural shapes symbolize the longevity and sacredness of these locations, such as the obelisk which symbolizes eternity (Francaviglia 1971), or the cross which symbolizes Christian sacredness. More modern users and managers of cemeteries recognize that burial rights in perpetuity are difficult, if not impossible to guarantee. During interviews conducted with cemetery users in the United Kingdom, Francis, Kellaher, and Neophytou (2000) found that most people preferred 75–100-year rights of burial, and that some graves were visited continually for at least four generations. Cemetery users expressed anxiety when burial rights were 50 years or less.

As a result of this expected longevity, cemeteries are susceptible to many forms of weathering and erosion. It is not uncommon to find cemeteries that are 100 or more years in age (Yalom 2008). During these long time periods, many cemeteries have faced extreme rainfall events, hurricanes, and changes in the landscape. For example, many of the cemeteries in New Orleans suffered acute damage and flooding from Hurricane Katrina in 2005, but they are also susceptible to longer term issues, such as sinking into the earth (Yalom 2008). While cemeteries have faced natural processes of weathering and erosion before, perhaps the most recent challenge to this part of our built heritage is sea level rise and coastal erosion. Take for example Crosby Cemetery near Leeville, Louisiana, which is slowly sinking into swamps because of subsidence and coastal erosion (Wilson 2013).

Caribbean sea level change

The IPCC released in 2013 the first chapter of a report on climate change and its likely impacts. The report, drawing in part from Rahmstorf, Perrette, and Vermeer (2012) and Rahmstorf (2012), contends that mean sea level has been rising steadily over the past century, and that advances in understanding the dynamics of oceans, including thermal expansion, land water storage, and glacier meltwater, have led to more refined forecasts of future sea levels. Projections to the end of the century suggest that the global mean sea level is expected to rise between 0.25 and 0.98 m, with a rate of 8–16 mm/yr. Projections to 2300 suggest the sea level could increase by as much as 3 m; however, there are few models that project past 2100. Sea level increases of 7 m are possible by the year 2500 if the Greenland ice sheet were to melt (IPCC 2013).

These projections are made from process-based models. Process-based models make projections only using parts of the environment known to contribute to changes in sea level. For example, IPCC's 4th Assessment Report (2007) using process-based models could only explain 60% of the observed sea level change from 1961 to 2003. An alternative to process-based models are semiempirical models. These models reproduce observed sea level changes over a period of calibration. The IPCC generally disregards semiempirical models because of the lack of consensus in the scientific community about their reliability. Some researchers argue that process-based models underestimate future changes in sea level (Rahmstorf 2007; Jevrejeva, Grinsted, and Moore 2009). Projections from semiempirical models suggest future sea levels by 2100 could be nearly twice as much as the current IPCC report predicts. Jevrejeva, Moore, and Grinsted (2010) predict sea level rise could reach 1.8 m, Vermeer and

Rahmstorf (2009) predict as high as 1.9 m, and Pfeffer, Harper, and O'Neel (2008) suggest possibly as high as 2 m, though they also argue 2 m is the upper limit of what is physically possible for ocean levels by the end of the century. The U.S. Army Corps of Engineers (2011) also claim that a 2-m rise is a reasonable upper bound for sea level rise by 2100, but caution that exceeding the 2 m level is not impossible.

These projections, while important, do little to consider more regionally based changes that could be significantly different than global averages. Sources of regional sea level change such as postglacial rebound, changes in ocean currents, and steric changes are not uniformly distributed across the globe (Church et al. 2004; Church et al. 2011; Tamisiea and Mitrovica 2011; Rahmstorf 2012; Slangen et al. 2012;). There is a dearth of data from the Caribbean of observed sea level changes measured with tide gauges. For many islands, there is limited temporal coverage with gaps and missing data, which makes it difficult to observe changes over long time periods. For other islands, data are completely absent making projections impossible. Many Caribbean island countries are developing nations and have limited resources. Additionally, there are many different nations with multiple languages and dialects within the region, making collaborative work among several islands difficult. Perhaps in part because of these limitations, there are few regional sea level change models for the Caribbean. One exception used available tide gauge data and satellite altimetry data to estimate the rate of change from 1950 to 2009 and found rates of sea level rise to be 2 mm/year (Palanisamy et al. 2012), very similar to the most recent IPCC assessment of global mean sea level rise of 1.7 mm/year between 1901 and 2010 (IPCC 2013). This suggests that sea level rise in the Caribbean by the end of this century will be similar to that of global averages, if not slightly higher.

Sea level rise is a problem not just because of the risk of inundation, but also because increased sea level will also lead to increased rates of erosion (IPCC 2014a). The Bruun rule is a simple model that suggests as sea level rises, higher waves will be able to reach farther inland. It assumes that the profile for a coastline will remain intact and with the conservation of mass, as sea level rises, unconsolidated sediment required to maintain the coastal profile will be transported from land to deeper water (Bruun 1962; Schwartz 1967). While the Bruun rule is not universally accepted (Pilkey and Cooper 2004; Ranasinghe and Stive 2009), there is support for this basic model (Leatherman, Zhang, and Douglas 2000; Zhang, Douglas, and Leatherman 2004) and in some cases, it has successfully estimated the impact of rising seas (Scott, Simpson, and Sim 2012).

It is generally accepted that for every unit increase in sea level, there will be 100 units of inland coastal erosion. However, Bruun's model was based upon the sandy beaches and coastlines of Florida and is preferably applied only to beaches and coasts with gentle profiles and unconsolidated material. Coastlines with varying slopes, toes, notches, and lithology will erode differently from both marine and subaerial processes (e.g. erosion from rain) compared to sandy beaches (Ritter 1979).

For rocky coasts, cliff resistance, rock type, and stratification, hydraulic forces of quarrying, water hammering, and air compression along with wave abrasion are all factors that impact rates of erosion (Kline, Adams, and Limber 2014). Cliff rock composition is an important factor in determining erosion because even soft rocks (e.g. glacial tills, clays, shales, and soft sandstones) (Carpenter et al. 2014) are less erodible than sand and unconsolidated material. Observations of rocky coastline retreat (Moore and Griggs 2002; Robinson 2004) and numerical models such as Soft Cliff And Platform Erosion (SCAPE) (Walkden and Hall 2005; Ashton, Walkden, and Dickson 2011; Appeaning Addo 2014) assess the relative influence of each process on erosion and predict rates of erosion under varying circumstances.

For rocky sea cliffs in particular, notches and/or visors are frequently found at the base of limestone or tuff coasts (Kogure and Matsukura 2010), such as on the islands of Antigua (Day 2007) and Grand Cayman (Jones and Hunter 1992). These notches form from wave action and abrasion, which reduces the stability of the cliff, eventually leading to failure (Sunamura 1992). Forecasting rocky coast sea cliff retreat is difficult. Moore and Griggs (2002) report observations of California cliff retreat averaging between 0.07 and 0.15 m/year, but found erosion "hotspots" that reached as high as 0.63 m/year. Budetta, Galietta, and Santo (2000) observed that cliff retreat rates could be as high as 0.8 m/year, depending upon the rock type. Kline, Adams, and Limber (2014) used a numerical model to predict long-term cliff retreat for cantilevered block coastlines and found erosion rates of 0.23 m/year for an extreme wave climate, but did not consider platform weakening and fatigue or sea level rise.

Despite this volume of literature, Moses (2012, p.221) concluded that sea cliff erosion in the tropics is understudied and that "the fact that published rates are from different sites, often from quite different rock types and measured using methods of highly variable accuracy, together with the lack of studies quantifying erosion rates after the mid-1980s, makes a detailed assessment difficult." Coasts featuring sea cliffs or steep slopes are not as vulnerable to erosion as gentle sloping coastal profiles because their estimated ratios of retreat are less than Bruun's predicted 1:100 ratio. However, for gentle sloping coastlines, using projections of sea level rise and Bruun's 1:100 ratio could indicate which cemeteries are most likely to be impacted by the end of the century. These results can also help direct where finer scale research should be conducted. Higher resolution vulnerability assessments of coastal cemeteries can be achieved by looking at a smaller geographic scale such as the individual island level investigating the vulnerability of an entire island's coastlines (e.g. Schleupner 2005).

Methods

The islands and nations examined are listed in Table 1. These were selected to provide comprehensive coverage of the Caribbean while focusing on the smallest islands. Surveying larger islands such as Cuba was beyond the scope of this research. The methods used for data collection and analysis for this study are similar to those used by Diez, Perillo, and Piccolo (2007), who also considered elevation and coastal profile types in their study of sea level rise vulnerability.

The first step was to identify as many cemeteries as possible for each small Caribbean island. Any location, coastal or interior, that consisted of more than one burial was recorded. Identification tools include Caribbean island government websites and crowd-sourced data from Findagrave.com, Billiongraves.com, and Panoramio.com. We also used the Google Earth search function to inspect current and historical satellite images of the islands and conducted limited fieldwork. Genealogy sources such as Findagrave.com and Billiongraves.com are generally accurate and comprehensive. Billiongraves.com in particular has a large database of user-generated, GPS-tagged tombstone images, which allow for locating and verifying cemeteries. These tools helped identify 542 cemeteries. Since this research represents the first attempt to create such a database, it is difficult to gauge how representative it is for

Table 1. Cemetery distance to the coast.

Nation/territory	Number of cemeteries surveyed	Number of cemeteries (%) ≤100 m of the coast	Excluding steep profiles for cemeteries ≤100 m of the coast	Number of cemeteries (%) ≤200 m of the coast	Excluding steep profiles for cemeteries ≤200 m of the coast
Anguilla[a,b]	5	0 (0.0%)	–	0 (0.0%)	–
Antigua and Barbuda[a,b]	8	1 (12.5%)	–	3 (37.5%)	–
Aruba[a,c,d]	10	0 (0.0%)	–	1 (10.0%)	–
Bahamas[a]	29	16 (55.2%)	–	19 (65.5%)	–
Barbados[a]	26	2 (7.7%)	1 (3.8%)	5 (19.2%)	4 (15.4%)
Bonaire[a,b]	1	0 (0.0%)		0 (0.0%)	–
British Virgin Islands[b]	6	2 (33.3%)	–	2 (33.3%)	–
Cayman Islands[a]	36	32 (88.9%)	–	35 (97.2%)	–
Curacao[a,b]	8	0 (0.0%)	–	0 (0.0%)	–
Dominica[b]	7	2 (28.6%)	1 (14.3%)	5 (71.4%)	3 (42.9%)
Grenada[b]	11	6 (54.6%)	3 (27.3%)	8 (72.7%)	4 (36.4%)
Guadeloupe[a,b]	14	6 (42.9%)	5 (35.7%)	8 (57.1%)	7 (50.0%)
Jamaica[a,b,c,d]	118	10 (8.5%)	8 (6.8%)	12 (10.2%)	10 (8.5%)
Martinique[a,b]	47	11 (23.4%)	4 (8.5%)	19 (40.4%)	11 (23.4%)
Montserrat[b]	2	0 (0.0%)	–	0 (0.0%)	–
Puerto Rico[a,b,c]	86	5 (5.8%)	4 (4.7%)	8 (9.3%)	7 (8.1%)
Saint Martin[a,b]	10	5 (50.0%)	–	6 (60.0%)	–
Sint Eustatius[b]	3	1 (33.3%)	0 (0.0%)	2 (66.7%)	1 (33.3%)
St. Barthelemy[a,b]	4	3 (75.0%)	–	4 (100%)	–
St. Kitts and Nevis[b]	12	1 (8.3%)	–	2 (16.7%)	1 (8.3%)
St. Lucia[b]	13	7 (53.9%)	6 (46.1%)	9 (69.2%)	7 (53.8%)
St. Vincent[a,b]	8	2 (25.0%)	1 (12.5%)	3 (37.5%)	2 (25.0%)
Trinidad and Tobago[a,c,d]	56	3 (5.4%)	2 (3.6%)	5 (8.9%)	4 (7.1%)
Turks and Caicos[a]	8	3 (37.5%)	–	4 (50.0%)	–
U.S. Virgin Islands[a,b]	14	2 (14.3%)	–	3 (21.4%)	–
Total	542	120 (22.1%)	100 (18.5%)	163 (30.0%)	138 (25.5%)

Notes. [a]sedimentary rocks such as limestone and marine strata [b]volcanic rocks including tuffs, [c]intrusive rocks, and [d]metamorphic rocks. Geology data from Case and Holcombe (1980).

the study area, but fieldwork on Grand Cayman completed after using remote access cemetery identification tools only produced three additional cemeteries out of 31.

Latitude and longitude, as provided by Google Earth, were recorded for the estimated center of each cemetery. The cemetery center, as opposed to an edge, was selected to provide a reference point for digital mapping of each cemetery. Large cemeteries may have multiple elevations; however, the center provides a good location to evaluate the elevation of the entire cemetery. This elevation was collected as provided by Google Earth. El-Ashmawy (2016) investigating a method for creating a low-cost Digital Elevation Model (DEM) from Google Earth contends that Google Earth elevation data can be used for preliminary studies. Furthermore, Google Earth elevations have been found to correlate strongly with Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Shuttle Radar Topography Mission (SRTM) elevation data (Rusli, Majin, and Din 2014), and elevation estimates for small areas have been found to be more accurate in Google Earth than in SRTM data, on which Google Earth's elevation estimate models are based (Sharma and Gupta 2014). This is particularly important because many cemeteries were much smaller than the pixel resolution of the SRTM DEM data.

Using Google Earth's measurement tool, the distance between the coast and the closest discernible grave was measured. Although determining the center of each cemetery is important for basic mapping purposes (i.e. showing where cemeteries are relative to each other), it is important to determine the edge of each cemetery that is closest to the coast because the purpose of this research is to determine if any part of a cemetery may be impacted by coastal hazards such as storm surge and sea level rise. Indeed, there are many ways to define coastlines, but visual interpretation in the field or from photography is the most common (Boak and Turner 2005). This research determined the coastline as where water visibly contacted the land by analyzing Google Earth satellite images ranging in date from 2004 to 2015.

Sometimes Google Earth software claims the elevation of the coastline to be greater than zero. This can be observed by looking at the software-provided elevation when the location queried is visibly ocean water on the satellite image. This probably occurs because of the method of interpolation used by Google Earth. The algorithms that Google Earth software uses to estimate the elevation of any given location are proprietary information and to the best of our knowledge are unknowable to researchers. SRTM DEM data are raster data, and finer scaled estimates on coastal cells will frequently give elevations higher than zero.

Since this research is interested in the relative position of the ocean to the land, it was assumed that the actual elevation of the coastline is zero for all cases. For any cemetery within 2000 m of the coastline, if the elevation of the coastline provided by Google Earth was greater than zero, the elevation of the cemetery was reduced by an amount equal to the coastal elevation provided. This process renders the coastline to have a true elevation of zero. This process also reduced the elevation of several cemeteries, but maintains the relative relationship between the coastline and graveyard. For example, if the elevation of a cemetery as provided by Google Earth was 5 m, and the elevation of the coastline was 1 m, the corrected elevation of the cemetery was calculated as 4 m, thus rendering the observed coastline to be 0 m in elevation. This process of standardization was only completed on cemeteries within 2000 m of the coastline because after this distance, the terrain of the islands is varied enough that the relationship between the two locations is less clear. Furthermore, the effects of sea level rise or storm surge are expected to be minimal or absent for more interior locations.

In this study, cemeteries <200 m from the sea were also analyzed using satellite imagery in combination with contour maps and elevations provided by Google Earth to determine if the coastal profile was a steep grade or sea cliff. Sea cliffs were identified as having vertical or near-vertical coastal profiles. Coasts judged to have slopes $\geq 45^\circ$ were treated as having a steep slope. Those cemeteries considered to be on a steep slope or at the top of a cliff were excluded from analysis. This is because of the high degree of uncertainty in predicting rates of cliff recession and because the Bruun rule was developed for gentle sloping shorelines that comprise unconsolidated material. Cemeteries >200 m from the sea did not have their profiles analyzed because a 2 m rise in sea level using the 1:100 ratio of erosion predicted by the Bruun rule ipso facto means that any cemetery more than 200 m from the coast will likely not be impacted by the maximum expected sea level rise in 2100.

Results

Cemeteries were sorted and grouped into categories based upon elevation and distance to the coast. One hundred twenty cemeteries are within 100 m of the coastline, and an additional 43 graveyards are between 100 and 200 m of the coastline. Cemeteries this far from the coast are likely to be impacted by 1 and 2 m increases in sea level using the 1:100 ratio of the Bruun rule. This first suggests that 30% of Caribbean small island cemeteries are vulnerable to inundation or coastal erosion by the end of the century. However, some of these cemeteries are situated along steep sloping coastlines or sea cliffs. Removing these graveyards reduces the number of cemeteries <100 m from the coast to 100, and an additional 38 are between 100 and 200 m from the ocean (see Table 1). This more accurate estimation suggests that about a quarter of all Caribbean small island cemeteries are vulnerable to inundation and erosion by the end of this century.

When considering vulnerability to storm surge flooding by evaluating cemetery elevation, the number of vulnerable burial sites decreased slightly. All coastal profiles were included in this analysis because a sufficiently high storm surge will wash over low-elevation sea cliffs. Storm surge heights can vary widely, but it is not uncommon for intense Category 4 or Category 5 hurricanes to have 5 m high storm surges (Elsner and Kara 1999). How far inland a storm surge will penetrate also varies considerably depending upon the topography of the coastline, tide, and storm surge height. One hundred thirty cemeteries have elevations <5 m (see Table 2). All of these were within 2 km of the ocean, and 96.9% (126) were within 1 km of the coastline, both of which are not unreasonable distances of inland penetration from storm surge and storm induced waves. For example, when Hurricane Rita made landfall in low-lying Louisiana in 2005, it had a storm surge that reached as far as 80 km inland (Berenbrock, Mason, and Blanchard 2009).

One theme that emerges from the data is that islands with the largest number of low-elevation coastal cemeteries are flat islands composed mostly of sedimentary rock. Over a third

Table 2. Cemetery elevation.

Nation/territory	Number of cemeteries surveyed	Number of cemeteries (%) ≤1 m elevation	Number of cemeteries (%) ≤2 m elevation	Number of cemeteries (%) ≤5 m elevation
Anguilla[a,b]	5	0 (0.0%)	0 (0.0%)	0 (0.0%)
Antigua and Barbuda[a,b]	8	0 (0.0%)	0 (0.0%)	2 (25%)
Aruba[a,c,b]	10	0 (0.0%)	3 (30.0%)	3 (30.0%)
Bahamas[a]	29	5 (17.2%)	10 (34.5%)	18 (62.1%)
Barbados[a]	26	0 (0.0%)	0 (0.0%)	4 (15.4%)
Bonaire[a,b]	1	0 (0.0%)	0 (0.0%)	0 (0.0%)
British Virgin Islands[b]	6	0 (0.0%)	0 (0.0%)	2 (33.3%)
Cayman Islands[a]	36	3 (8.3%)	9 (25.0%)	33 (91.7%)
Curacao[a,b]	8	0 (0.0%)	1 (12.5%)	1 (12.5%)
Dominica[b]	7	0 (0.0%)	0 (0.0%)	0 (0.0%)
Grenada[b]	11	0 (0.0%)	1 (9.1%)	2 (18.2%)
Guadeloupe[a,b]	14	1 (7.1%)	1 (7.1%)	4 (28.6%)
Jamaica[a,b,c,d]	118	2 (1.7%)	6 (5.1%)	17 (14.4%)
Martinique[a,b]	47	0 (0.0%)	2 (4.3%)	6 (12.8%)
Montserrat[b]	2	0 (0.0%)	0 (0.0%)	0 (0.0%)
Puerto Rico[a,b,c]	86	2 (2.3%)	5 (5.8%)	7 (8.1%)
Saint Martin[a,b]	10	3 (30.0%)	5 (50.0%)	6 (60.0%)
Sint Eustatius[b]	3	0 (0.0%)	0 (0.0%)	0 (0.0%)
St. Barthelemy[a,b]	4	0 (0.0%)	0 (0.0%)	2 (50.0%)
St. Kitts and Nevis[b]	12	0 (0.0%)	0 (0.0%)	0 (0.0%)
St. Lucia[b]	13	1 (7.7%)	5 (38.5%)	7 (53.8%)
St. Vincent[a,b]	8	0 (0.0%)	0 (0.0%)	1 (12.5%)
Trinidad and Tobago[a,c,d]	56	1 (1.8%)	1 (1.8%)	3 (5.4%)
Turks and Caicos[a]	8	1 (12.5%)	3 (37.5%)	6 (75.0%)
U.S. Virgin Islands[a,b]	14	0 (0.0%)	1 (7.1%)	6 (42.9%)
Total	542	19 (3.5%)	53 (9.8%)	130 (23.9%)

Notes. [a]sedimentary rocks such as limestone and marine strata, [b]volcanic rocks including tuffs, [c]intrusive rocks, and [d]metamorphic rocks. Geology data from Case and Holcombe (1980).

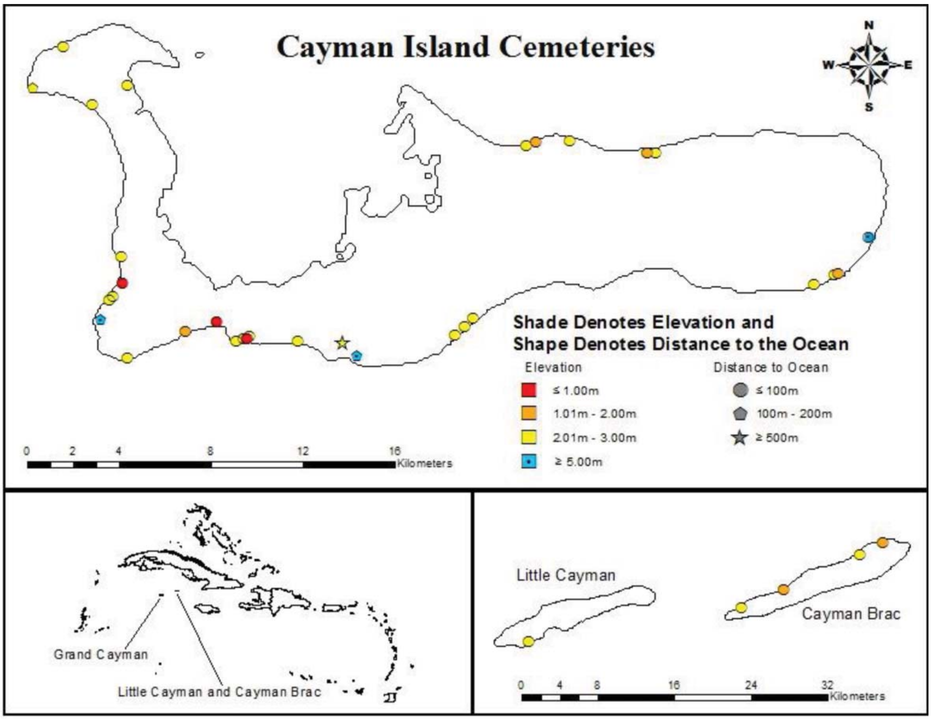

Figure 1. Location and elevation of cemeteries, categorized by the distance to the ocean, of the Cayman Islands.

of the cemeteries surveyed in the Turks and Caicos, over half in the Bahamas, and over 88% in the Cayman Islands were within 100 m of the coast, and none of these islands have cemeteries on steep coastal profiles. Half of the cemeteries in the Turks and Caicos, over half in the Bahamas, and all but one cemetery in the Cayman Islands were within 200 m of the coast (see Figure 1). Furthermore, the Bahamas (10) and the Cayman Islands (9) have the highest total number of cemeteries below 2 m in elevation. Anguilla is also a relatively flat island (the highest point is 65 m above sea level) with extensive limestone and karst topography (Christman 1963), but none of its cemeteries are vulnerable because they are all located more than 200 m from the coast. Likewise, Aruba, Bonaire, and Curacao have extensive marine strata (Alexander 1961), but only Aruba has one cemetery less than 200 m from the coast and only three with elevations below 2 m.

Mountainous islands, such as Martinique, contained the most cemeteries situated on steep coastal profiles. Of the 19 cemeteries that were within 200 m of the coast on Martinique, eight of them were situated near the top of steep grades adjacent to the ocean. The other nations and territories with sea cliff cemeteries were Jamaica, Puerto Rico, Trinidad, Guadeloupe, Sint Eustatius, Dominica, St. Lucia, St. Vincent, Grenada, and St. Kitts and Nevis. Not surprisingly, the mountainous islands have fewer low-elevation cemeteries than flatter islands. Anguilla, Bonaire, Dominica, Montserrat, Puerto Rico, Sint Eustatius, St. Kitts and Nevis, and Trinidad and Tobago each had less than 10% of their cemeteries below 5 m in elevation. Although Jamaica has nearly the same number of graveyards <5 m in elevation as the Bahamas, this accounts for less than 15% of the cemeteries surveyed in Jamaica,

Table 3. Cemetery elevation and distance to the coast.

		Cemeteries (%) ≤100 m of the coast		Cemeteries (%) ≤200 m of the coast	
Nation/territory	Number of cemeteries surveyed	Cemeteries with elevations ≤5 m	Cemeteries with elevations ≤2 m	Cemeteries with elevations ≤5 m	Cemeteries with elevations ≤2 m
Cayman Islands	36	31 (86.11%)	9 (25.0%)	32 (88.9%)	–
Saint Martin	10	5 (50.0%)	4 (40.0%)	–	–
Bahamas	29	14 (48.3%)	8 (27.6%)	–	–
St. Lucia	13	5 (38.5%)	3 (23.1%)	6 (46.2%)	4 (30.8%)
Turks and Caicos	8	3 (37.5%)	1 (12.5%)	–	–
St. Barthelemy	4	1 (25.0%)	0 (0.0%)	2 (50.0%)	–
Guadeloupe	14	3 (21.4%)	1 (7.1%)	–	–
Grenada	11	2 (18.2%)	1 (9.1%)	–	–
British Virgin Islands	6	1 (16.7%)	0 (0.0%)	–	–
US Virgin Islands	14	2 (14.3%)	1 (7.1%)	3 (21.4%)	–
Antigua and Barbuda	8	1 (12.5%)	0 (0.0%)	2 (25%)	–
St. Vincent	8	1 (12.5%)	0 (0.0%)	–	–
Jamaica	118	8 (6.8%)	3 (2.5%)	9 (7.6%)	–
Martinique	47	3 (6.4%)	1 (2.1%)	4 (8.5%)	–
Barbados	26	1 (3.8%)	0 (0.0%)	–	–
Trinidad and Tobago	56	2 (3.6%)	0 (0.0%)	–	–
Puerto Rico*	86	3 (3.5%)	2 (2.3%)	–	3 (3.5%)
Aruba	10	0 (0.0%)	0 (0.0%)	1 (10.0%)	1 (10.0%)
Total	542	86 (15.9%)	34 (6.3%)	94 (17.3%)	37 (6.8%)

Note. Anguilla, Bonaire, Curacao, Dominica, Montserrat, Sint Eustatius, and St. Kitts and Nevis had no cemeteries that were both ≤200 m from the coastline and ≤5 m in elevation.
*One cemetery has a steep coastal profile.

compared to over half of Bahamian graveyards. St. Lucia and St. Martin each have more than half of their cemeteries below 5 m, and each has five cemeteries below 2 m in elevation. Furthermore, four of St. Martin's low elevation cemeteries are also <200 m from the coast. While flat islands generally have more vulnerable cemeteries, this does not preclude mountainous islands from having vulnerable cemeteries too.

Another approach to determining cemetery vulnerability to coastal erosion and storm surge is to consider both elevation and distance to the coastline simultaneously (see Table 3). Coastal contours of all types were included in this analysis because only one cemetery that was both within 200 m of the coast and had an elevation <5 m was situated atop a steep coastal profile. One theme that emerges from this table is that the majority of vulnerable cemeteries are ≤100 m from the coast. The more liberal application of the Bruun rule including cemeteries within 200 m only adds a few more graveyards regardless of the elevation considered. This is largely attributed to the nature of most coastlines: elevation increases quickly as one heads inland from the coast. This table also highlights the vulnerability of flatter Caribbean islands. When considering the most conservative analysis of cemeteries that are both <100 m of the coast and <2 m in elevation, the Cayman Islands (9) and the Bahamas (8) have the two highest counts of vulnerable cemeteries.

Finally, identifying places with an elevation of <5 and <200 m from the coastline serves as a good tool for estimating the vulnerability of not just cemeteries but any coastal infrastructure. As one would expect, these restrictions captured the most vulnerable Caribbean cemetery, Tibeau cemetery on Carriacou, Grenada, which is currently being washed into the sea (Fitzpatrick, Kappers, and Kaye 2006). But these thresholds also eliminate circumstances where the Bruun rule is inappropriate. Applying both the elevation and distance to sea restrictions eliminated all but one cemetery, which sits atop a steeply contoured coast. Therefore, this research is a practical application of the Bruun rule, and used in conjunction with an elevation restriction, is a useful guide for assessing coastal vulnerability.

Discussion

This research elicits four main implications. First, how does the lifespan of a cemetery impact family decisions such as selecting plots for family members? The burial of a loved one is an emotional time and part of the grieving process (Rugg 1998). Some of the comfort that can be afforded to the bereaved is contingent upon the safety and security of the burial plot, at least for an extended period of time. This is why cemeteries often have fences, which are used to prevent such sites from disturbance (Rugg 2000) and grave re-use, when it occurs at all, is permitted only after several decades have passed. Families need to decide if they are comfortable being buried in a location that is vulnerable to coastal hazards, which may affect their chosen resting place.

Additionally, family members frequently plan to be buried near one another, sometimes buying multiple plots in close proximity (Francis, Kellaher, and Neophytou 2000). If one family member is already buried in a vulnerable location, this complicates the decision of interring more family members there, raising several questions. First, should they try to relocate the remains of the deceased to a safer location? If not, should they subject more family to the risks of disturbance? It is not uncommon to purchase burial plots prior to needing them (Llewellyn 1998). In this case, should families make a second purchase in a safer location, or try to renegotiate their rights of interment to a safer part of the cemetery? All of these decisions carry a burden, not just because of obvious emotional reasons but also because of financial considerations. Within a cemetery, not all burial locations cost the same (Llewellyn 1998). When trying to renegotiate the right of burial to a safer area of the cemetery, if the new location is more expensive, who should pay the difference? If trying to have previously interred remains relocated, who should pay for those expenses? Because the family is initiating the disinterment process, it is likely they will be asked to cover any additional expenses.

The second major issue exposed by this research is how sea level rise may impact the long-term management of graveyards. Llewellyn (1998) argues that good cemetery managers think on long time scales and manage their businesses in ways that are designed to provide long-term care and maintenance to the property. This often includes resetting head stones and taking care not to chip away at monuments with lawn care equipment (Strangstad 2013). But these problems are likely to be just a subset of concerns facing coastal cemetery caretakers over the next century. How to approach sea level rise is likely a new concern for many cemetery staff and they may not know how to best handle this emerging situation. Even the most prudent managers who have built an endowment trust in anticipation of damage from hurricanes which frequent the Caribbean may not have budgeted for encroaching oceans and higher magnitude storm surges resulting from sea level rise. As a result, who will be responsible for additional future expenses? Long-term fiscal strategies for cemeteries still making sales may include increasing the cost of new burial plots to offset the potential cost of future repairs from flooding, erosion, or tropical cyclone damage. Yet for older cemeteries that are no longer accepting new burials, there are no new sources of money to cope with these problems (Woodthorpe 2011).

In addition to the financial decisions, the cemetery managers will need to develop other strategies to prevent damage from coastal hazards. Cemetery regulations and policies vary by nation, and many of the cemeteries on small islands are managed by the respective governments. Even privately owned cemeteries are subject to burial laws and codes.

Investigations into the cemetery management policies for the Bahamas, the Cayman Islands, Puerto Rico, and the United States Virgin Islands did not reveal any substantial codified rules. Furthermore, while conducting fieldwork, the acting director of the Grand Cayman Recreation, Parks and Cemetery Unit, said in an interview that the procedure for preparing cemeteries for coastal hazards such as hurricanes involved removing loose items such as garbage cans. Even individual flowers left by cemetery visitors were not touched by cemetery staff. This suggests that there are few, if any, strategic decisions being made about government-managed cemeteries on small islands in the Caribbean. Even simple practices such as imposing a setback limit for new burials or strategically placing new cemeteries away from the coasts could help prevent damage to headstones. However, this is not necessarily easy to accomplish because population growth, foreigners seeking new homes, and limited space on small islands can dramatically increase the cost of real estate. In the overall planning of an island, new cemetery locations that are moved away from the coast may end up being placed in areas that are vulnerable to other natural hazards.

Third, sea level rise and coastal hazards are of particular concern for historic cemeteries, not just because they often are no longer accepting new burials and have limited revenue available, but also because of their historic value. All cemeteries should be preserved because of their importance to surviving family members, but maintaining the integrity of older cemeteries is also important because they are outdoor museums (Miller 2015) displaying artwork and craftsmanship from stone cutters and sculptors. Historic cemeteries provide in single locations different styles of artwork representing different architectural styles over time (Francaviglia 1971). It is not uncommon for details of each person to be inscribed on tombstones, and because death is a universal aspect of life, historic cemeteries often have information from a multitude of races, ethnicities, and socioeconomic statuses (Yalom 2008). Historic cemeteries may have the only recorded information for some individuals. This makes them sources of information for historians, particularly if they are interested in a comprehensive sample of society, or studying past epidemics and plagues.

Beyond the practical value of historic cemeteries for research purposes, the significance of these places has likely changed over time, and which cemeteries are important will vary from community to community or even from person to person. Funding for cemetery restoration is not expected to be plentiful for these developing nations, and this means tough decisions will need to be made regarding which graveyards should be protected and how. Questions for the community may include what cemetery information will be recorded, whether the selected cemeteries will be protected in whole or in part and how, and would it be wise to relocate them? These are difficult questions to answer, at least in part, because of the different costs associated with each method of preservation and the different or absent cemetery policies and oversight for each island.

The final issue is how these findings support Integrated Coastal Management (ICM). Tobey et al. (2010) argues that ICM will not be dramatically altered because of climate change. They suggest that potential sea level rise generates four additional considerations for coastal managers. This investigation into the vulnerability of coastal cemeteries underscores three of these considerations.

First, as Tobey et al. (2010) argue, coastal managers need to ensure that coastal ecosystems remain intact to help buffer perturbations to the coastal systems. They specifically argue that natural resource extraction should not compromise coastal ecosystems. For example, sand and gravel mining can not only destroy beaches but can be detrimental to coastal heritage. One example of this is the Tibeau cemetery on Carriacou, where sand mining is a leading cause of damage to the cemetery (Fitzpatrick, Kappers, and Kaye 2006). This is not to suggest a halt to all coastal sand mining operations. Sand for beach nourishment is an important tool in coastal management (Davidson, Nicholls, and Leatherman 1992; Valverde, Trembanis and Pilkey 1999), but care should be given when deciding where to harvest sand.

Second, uncertainty must be considered in coastal management. Tobey et al. (2010) contend that the complexity and uncertainty of climate change and its projected impact on coastal systems can become barriers to action. There is uncertainty in sea level rise projections and predicted rates of coastal erosion. Using the precautionary principle, Tobey et al. (2010) argue that actions can be taken based upon emerging trends even when managers lack all the information they prefer to have before making decisions. Despite uncertainty, coastal managers who make decisions regarding vulnerable cemeteries should begin thinking about how sea level change may impact their heritage resources.

Finally, coastal managers should start thinking on longer time scales. Tobey et al. (2010) suggest that longer planning horizons be considered in the decision-making process. Sea level change and coastal erosion are gradual processes and management should look far into the future to plan for them accordingly. In particular, coastal areas with cemeteries should incorporate longer planning horizons because graveyards should be designed to last for a century or more with minimal or no disturbance. Coastal managers with burial locations essentially become cemetery managers and should consider planning at the centurial time scale or longer.

Conclusion

This research used readily available information technologies and tools to build a database of more than 542 cemeteries in small island Caribbean states. Using widely cited estimates of sea level rise by the year 2100 as well as the Brunn rule, we determined that 138 cemeteries are vulnerable to sea level rise or storm surge from powerful tropical storms (or both) by the end of this century. Not surprisingly, most vulnerable graveyards are on relatively flat islands with sandy coastlines.

Effective coastal management involves consideration of those spaces that have special meaning to local communities. While cemeteries are the focus of this research, coastal areas frequently have other cultural resources such as historical lighthouses, settlements, and military fortifications—and many of these significant resources in the Caribbean are equally threatened. Many of the tools employed in this research for finding and evaluating cemeteries can be applied to other cultural resources in the Caribbean, as well as to cultural and historical resources in other regions. As the twenty-first century progresses, coastal managers everywhere will increasingly be tasked with solving complex problems such as maintaining the integrity of cultural and historical resources in the face of increased sea level rise.

References

Alexander, C. S. 1961. The Marine terraces of Aruba, Bonaire, and Curacao, Netherlands Antilles. *Annals of the Association of American Geographers* 51:102–23.

Appeaning Addo, K. 2014. Managing shoreline change under increasing sea-level rise in Ghana. *Coastal Management* 42:555–67.

Ashton, A. D., J. Walkden, and M. E. Dickson. 2011. Equilibrium responses of cliffed coasts to changes in the rate of sea level rise. *Marine Geology* 284:217–29.

Berenbrock, C., R. R. Mason, and S. F. Blanchard. 2009. Mapping Hurricane Rita inland storm tide. *Journal of Flood Risk Management* 2:76–82.

Boak, E. H., and I. L. Turner. 2005. Shoreline definition and detection: A review. *Journal of Coastal Research* 21:688–703.

Bruun, P. 1962. Sea-level rise as a cause of Shore Erosion. *Journal of the Waterways and Harbors Division* 88:117–30.

Budetta, P., G. Galietta, and A. Santo. 2000. A methodology for the study of the relation between coastal cliff erosion and the mechanical strength of soils and rock masses. *Engineering Geology* 56:243–56.

Bueno, R., C. Herzfeld, E. A. Stanton, and F. Ackerman. 2008. The Caribbean and climate change: The costs of Inaction. Stockholm Environment Institute—US Center and the Global Development and Environment Institute, Tufts University, Medford, MA.

Carpenter, N. E., M. E. Dickson, M. J. A. Walkden, R. J. Nicholls, and W. Powrie. 2014. Effects of varied lithology on soft-cliff recession rates. *Marine Geology* 354:40–52.

Case, J. E., and T. L. Holcombe. 1980. *Geologic-Tectonic map of the Caribbean region*. Department of the Interior: United States Geological Survey.

Christman, R. A. 1963. Geology of St. Bartholomew, St. Martin, and Anguilla, lesser Antilles. *Bulletin of the Geological Society of America* 64:65–96.

Church, J. A., J. M. Gregory, N. J. White, S. M. Platten, and J. X. Mitrovica. 2011. Understanding and projecting sea level change. *Oceanography* 24:130–43.

Church, J. A., N. J. White, R. Coleman, K. Lambeck, and J. X. Mitrovica. 2004. Estimates of the regional distribution of sea level rise over the 1950–2000 period. *Journal of Climate* 17:2609–25.

Davidson, A. T., R. J. Nicholls, and S. P. Leatherman. 1992. Beach nourishment as a Coastal management tool: An annotated bibliography on developments associated with the artificial nourishment of beaches. *Journal of Coastal Research* 8:984–1022.

Day, M. 2007. The Karstlands of Antigua, their land use and conservation. *The Geographical Journal* 173:170–85.

Diez, P. G., G. M. E. Perillo, and M. C. Piccolo. 2007. Vulnerability to sea-level rise on the coast of the Buenos aires province. *Journal of Coastal Research* 23:119–26.

El-Ashmawy, K. L. A. 2016. Investigation of the accuracy of google earth elevation data. *Artificial Satellites* 51:89–97. https://doi.org/10.1515/arsa-2016-0008

Elsner, J. B. and A. B. Kara. 1999. *Hurricanes of the North Atlantic*. Oxford: Oxford University Press.

Fitzpatrick, S. M., M. Kappers, and Q. Kaye. 2006. Coastal erosion and site destruction on Carriacou, West Indies. *Journal of Field Archaeology* 31:251–62.

Foucault, M. and J. Miskowiec. 1986. Of other spaces. *Diacritics* 16:22–27.

Francaviglia, R. V. 1971. The cemetery as an evolving cultural landscape. *Annals of the Association of American Geographers* 61:501–09.

Francis, D., L. Kellaher, and G. Neophytou. 2000. Sustaining cemeteries: the user perspective. *Mortality* 5:34–52.

Hoegh-Guldberg, O., P. J. Mumby, A. J. Hooten, R. S. Steneck, P. Greenfield, E. Gomez, C. D. Harvell, P. F. Sale, A. J. Edwards, K. Caldeira, N. Knowlton, C. M. Eakin, R. Iglasias-Prieto, N. Muthiga, R. H. Bradbury, A. Dubi and M. E. Hatziolos. 2007. Coral reefs under rapid climate change and ocean acidification. *Science* 318:1737–42.

IPCC. 2007. Climate change 2007: The physical science basis. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

IPCC. 2013. Climate change 2013: The physical science basis. *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

IPCC. 2014a. Climate change 2014: Impacts, adaptation, and vulnerability. *Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

IPCC. 2014b. Climate change 2014: Impacts, adaptation, and vulnerability. *Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

Jevrejeva, S., A. Grinsted, and J. C. Moore. 2009. Anthropogenic forcing dominates sea level rise since 1850. *Geophysical Research Letters* 36:L20706. doi:10.1029/2009GL040216

Jevrejeva, S., J. C. Moore, and A. Grinsted. 2010. How will sea level respond to changes in natural and anthropogenic forcings by 2100? *Geophysical Research Letters* 37:L07703, doi:10.1029/2010GL042947

Jones, B. and I. G. Hunter. 1992. Very large boulders on the coast of grand cayman: The effects of Giant Waves on rocky coastlines. *Journal of Coastal Research* 8:763–74.

Kline, S. W., P. N. Adams, and P. W. Limber. 2014. The unsteady nature of sea cliff retreat due to mechanical abrasion, failure and comminution feedbacks. *Geomorphology* 219:53–67.

Kogure, T. and Y. Matsukura. 2010. Critical notch depths for failure of coastal limestone cliffs: case study at Kuro-shima Islands, Okinawa, Japan. *Earth Surface Processes and Landforms* 35:1044–56.

Leatherman, S. P., K. Zhang, and B. C. Douglas. 2000. Sea level rise shown to drive Coastal Erosion. *Eos* 81:55–57.

Llewellyn, J. F. 1998. *A cemetery should be forever: The challenge to managers and directors*. Glendale, CA: Tropico Press.

Marzeion, B. and A. Levermann. 2014. Loss of cultural world heritage and currently inhabited places to sea-level rise. *Environmental Research Letters* 9:1–7.

Miller, S. E. 2015. Cemeteries as participatory museums. *Advances in Archaeological Practice* 3:275–90.

Miller, D. S., and J. D. Rivera. 2006. Hallowed ground, place, and culture: The cemetery and the creation of place. *Space and Culture* 9:334–50.

Moore, L. J. and G. B. Griggs. 2002. Long-term cliff retreat and erosion hotspots along the central shores of the Monterey Bay National Marine Sanctuary. *Marine Geology* 181:265–83.

Moses, C. A. 2012. Tropical rock coasts: Cliff, notch and platform erosion dynamics. *Progress in Physical Geography* 37:206–26.

Palanisamy, H., M. Becker, B. Meyssignac, O. Henry, and A. Cazenave. 2012. Regional sea level change and variability in the Caribbean sea since 1950. *Journal of Geodetic Science* 2:125–33, doi:10.2478/v10156-011-0029-4

Pfeffer, W. T., J. T. Harper, and S. O'Neel. 2008. Kinematic constraints on glacier contributions to 21st-century sea-level rise. *Science* 321:1340–43.

Pilkey, O. H. and J. A. G. Cooper. 2004. Society and sea level rise. *Science* 303:1781–82.

Rahmstorf, S. 2007. A semi-empirical approach to projecting future sea-level rise. *Science* 315:368–70.

Rahmstorf, S. 2012. Sea-level rise: towards understanding local vulnerability. *Environmental Research Letters* 7:021001. doi:10.1088/1748-9326/7/2/021001

Rahmstorf, S., M. Perrette, and M. Vermeer. 2012. Testing the robustness of semi-empirical sea level projections. *Climate Dynamics* 39:861–75.

Ranasinghe, R. and J. Stive. 2009. Rising seas and retreating coastlines. *Climate Change* 97:465–68.

Ritter, D. F. 1979. *Process geomorphology*. Dubuque, Iowa: Wm. C. Brown Company.

Robinson, E. 2004. Coastal changes along the coast of Vere, Jamaica over the past two hundred years: data from maps and air photographs. *Quaternary International* 120:153–61.

Rugg, J. 1998. 'A few remarks on modern sepulture': current trends and new directions in cemetery research. *Mortality* 3:111–28.

Rugg, J. 2000. Defining the place of burial: what makes a cemetery a cemetery? *Mortality* 5:259–75.

Rusli, N., M. R. Majid, and A. H. M. Din. 2014. Google Earth's derived digital elevation model: A comparative assessment with Aster and SRTM data. *IOP Conference Series: Earth and Environmental Science* 18:012065. doi:10.1088/1755-1315/18/1/012065

Sabbioni, C., P. Brimblecombe, and M. Cassar eds., 2010. *The atlas of climate change impacts on European cultural heritage: Scientific analysis and management strategies*. New York: Anthem.

Schleupner, C. 2005. Spatial analysis as tool for sensitivity assessment of sea level rise impacts on Martinique. FNU-71.

Schwartz, M. L. 1967. The Bruun theory of sea-level rise as a cause of shore erosion. *The Journal of Geology* 75:76–92.

Scott, D., M. C. Simpson, and R. Sim. 2012. The vulnerability of Caribbean coastal tourism to scenarios of climate change related to sea level rise. *Journal of Sustainable Tourism* 20:883–98.

Sharma, A. and D. Gupta. 2014. Derivation of topographic map from elevation data available in google earth. *Civil Engineering and Urban Planning: An International Journal* 1:14–21.

Slangen, A. B. A., C. A. Katsman, R. S. W. van de Wal, L. L. A. Vermeersen, and R. E. M. Riva. 2012. Towards regional projections of twenty-first century sea-level change based on IPCC SRES scenarios. *Climate Dynamics* 38:1191–209.

Stanton, E. A. and F. Ackerman. 2007. *Florida and climate change: The costs of inaction*. Global Development and Environment Institute, Tufts University, Medford, MA.

Strangstad, L. 2013. *A graveyard preservation primer*. Plymouth, UK: AltaMira.

Sunamura, T. 1992. *Geomorphology of rocky coasts*. West Sussex, UK: Wiley & Sons.

Tamisiea, M. E. and J. X. Mitrovica. 2011. The moving boundaries of sea level change: Understanding the origins of geographic variability. *Oceanography* 24:24–39.

Titus, J. G., R. A. Park, S. P. Leatherman, J. R. Weggel, M. S. Greene, P. W. Mausel, S. Brown, C. Gaunt, M. Trehan, and G. Yohe. 1991. Greenhouse effect and sea level rise: The cost of holding back the sea. *Coastal Management* 19:171–204.

Tobey, J., P. Rubinoff, D. Robadue Jr., G. Ricci, R. Volk, J. Furlow, and G. Anderson. 2010. Practicing coastal adaptation to climate change: Lessons from integrated coastal management. *Coastal Management* 38:317–35.

U.S. Army Corps of Engineers. 2011. Sea-level change considerations in civil work programs. Department of the Army Engineering Circular No. 1165-2-212, Washington, D.C.

Valverde, H. R., A. C. Trembanis and O. H. Pilkey. 1999. Summary of beach nourishment episodes on the U.S. East Coast barrier islands. *Journal of Coastal Research* 15:1100–18.

Vermeer, M. and S. Rahmstorf. 2009. Global sea level linked to global temperature. *Proceedings of the National Academy of Sciences* 106:21527–32.

Walkden, M. and J. Hall. 2005. A predictive Mesoscale model of the erosion and profile development of soft rock shores. *Coastal Engineering* 52:535–63.

Wilson, X. Focus turns from saving to documenting sinking cemeteries. *Houma Courier*, January 12, 2013. Accessed July 30, 2015. http://www.houmatoday.com/article/20130112/ARTICLES/130119878

Woodthorpe, K. 2011. Sustaining the contemporary cemetery: Implementing policy alongside conflicting perspectives and purpose. *Mortality* 16:259–76.

Yalom, M. 2008. *The American resting place: Four hundred years of history through our cemeteries and burial grounds*. New York: Houghton Mifflin.

Zhang, K., B. C. Douglas, and S. P. Leatherman. 2004. Global warming and coastal erosion. *Climate Change* 64:41–58.