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Isavela N. Monioudi
University of the Aegean

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Research Article

Beach Carrying Capacity at Touristic 3S Destinations: Its Significance, Projected Decreases and Adaptation Options under Climate Change

Isavela N. Monioudi*, **Adonis F. Velegrakis**

Department of Marine Sciences, University of The Aegean, Mytilene, Greece

ABSTRACT

The objective of this short contribution is to discuss a most significant emerging challenge for the 3S tourism: The reduction of the beach carrying capacity for recreation due to the erosion brought by climate change. Projections on the potential carrying capacity reductions of two major touristic island 3S destinations in the Mediterranean (Santorini, Greece) and the Caribbean (Saint Lucia) are presented. The results show severe impacts on the carrying capacity of all beaches in these islands. By 2050 and under the moderate RCP 4.5 scenario, up to 50% of the Santorini beaches will permanently retreat by 50% of their current recorded maximum width due to the relative sea level rise, whereas under the 100-year extreme storm conditions at least 67% of all beaches will be completely (at least temporarily) inundated, exposing backshore assets to flooding. Under the same scenario and date, up to 34% of all St Lucian beaches may permanently retreat by more than 50% of their present maximum width, whereas under the extreme (1-100 year) storm event more than 50% of the beaches will suffer total erosion, at least temporarily. It appears that costly adaptation measures will be required to maintain the beach carrying capacity in 3S tourism destinations, particularly beach nourishment schemes. Management of the beach carrying capacity problem requires mainstreaming of the assessment of, and the response to beach erosion within the tourism development and management strategies and plans; both require considerable human, technological and financial resources which should be (at least) assessed as a matter of urgency.

Keywords: Carrying capacity; 3S Tourism; Beach erosion; Beach nourishment; Climate change

INTRODUCTION

Sandy coasts (beaches) are critical components of the natural and human coastal system. They constitute a substantial fraction of the global coastline, are by themselves important habitats, and buffer the backshore coastal ecosystems, infrastructure and assets against marine flooding [1-3]. Beaches also have a high hedonic value and economic potential; they are pillars of tourism which has been increasingly associated with vacationing wholly, or partially, at coastal locations and beach recreational activities according to the 'Sun, Sea and Sand-3S' tourism model [4,5].

Touristic coastal areas/beaches are also recognized as most climate-sensitive regions. Climate is both a key facilitator and a limiting factor for tourism. Modified patterns of atmospheric and oceanographic variables, such as mean and extreme temperatures, relative humidity, rainfall, sunshine hours, wind speeds and waves, will likely affect the suitability of the coastal destinations for beach recreational activities [6].

At the same time, global beaches are under increasing erosion [7], which can be differentiated into (a) irreversible retreat of the shoreline, due to Mean Sea Level Rise (MSLR) and/or negative coastal sedimentary budgets that force either beach landward migration or drowning [8] and (b) short-term erosion, caused by storm waves/surges, which although might not result in permanent beach erosion, they can be, nevertheless, very damaging for backshore infrastructure and assets [9,10]. In both cases, there are negative implications for the carrying capacity of beaches for leisure activities, their aesthetics and the associated tourist infrastructure [11].

Beach erosion is projected to increase under climate change. The projected Relative Sea Level Rise (RSLR), combined with potential increases in the intensity/frequency of energetic events will exacerbate beach erosion [12]. As beach dimensions determine the available surface area for recreational users and services, beach

Correspondence to: Isavela N. Monioudi, Department of Marine Sciences, University of The Aegean, Mytilene, Greece, E-mail: imonioudi@marine.aegean.gr

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erosion will have severe impacts on the coastal human environment and the beach hedonic value and carrying capacity for recreation and tourism [13-15].

The objective of this short contribution is to discuss a most significant emerging challenge for the 3S tourism: The reduction of the beach carrying capacity for recreation due to the erosion brought by climate change. There is a focus on island locations, as many island beaches are both vulnerable and major touristic destinations, with tourism, in many cases, forming a very significant fraction of islands' GDP [16,17]. Towards this objective, a short overview of the issue is presented together with projections on the potential carrying capacity reductions for the beaches of two touristic island destinations in the Mediterranean (Santorini, Greece) and the Caribbean (Saint Lucia).

MATERIALS AND METHODS

Beach carrying capacity

An essential component of 3S tourism: Tourism has been one of the fastest-growing sectors of global economy, with its economic contribution assessed as about 10% of global GDP [18]. In 2019 (before the COVID-19 pandemic), international tourist flows and exports reached 1.4 billion and 1.7trillion USD respectively, being the world's third largest export industry after chemical and fuels, and ahead of automotive products and food [5]. For many regions, tourism has become a key factor for their development, facilitating growth of enterprises and increasing prosperity [19]. This is particularly true in the case of coastal regions and particularly islands, which in recent decades have emerged as major tourist destinations [20].

Beach tourism is one of the earliest modern forms of tourism and a staple of the tourism industry [21]. Many Mediterranean coastal areas and islands are dependent on 3S tourism [22]. In Catalonia (Spain), tourism contributes approximately 11% of the GDP, with most visits associated with beach recreational tourism [23]. 3.2 million international tourists visited the Republic of Cyprus in 2016 contributing about 21.4% of the GDP with forecasts suggesting this contribution to increase by more than 20% by 2027 [24]. Here, tourism activities and infrastructure are concentrated at the coast: 91% of the 2016 international tourists stated that they had a coastal vacation [24], whereas 94% of the Cyprus hotel beds are located at the coast [25]. Similarly, the majority of the Greek tourist arrivals have island destinations [26], whereas about 17% of the Spanish arrivals have had a Balearic island destination [27]. In the Caribbean, 3S (beach) tourism accounts for more than 23% of the Gross Domestic Product (GDP) in many Small Island Developing States (SIDS) [16,28]. In Seychelles, tourism accounted for about 57% of GDP in 2014 [29], whereas the tourism sector contributed approximately 40% of the Fiji GDP in 2016 [30].

Tourism growth has introduced significant challenges to beaches, such as habitat destruction, littering, water pollution and overcrowding [11]. Surveys on tourists perspectives have shown that in addition to beach cleanliness, safety, information availability and habitat management, overcrowding is considered as a very significant criterion by potential tourists, with the beach carrying capacity preference being about 22 m^2 of beach space for each tourist [31].

Recent studies have demonstrated the socio-economic significance of the beach carrying capacity and its dynamics. [32] have found using a Willingness To Pay (WTP) approach that (a) the non-market value of the sustainable carrying capacity in selected Italian beaches varied from more than € 50 million per season at a popular urban beach to € 1 million at a remote natural beach; and (b) the huge non-market value of these beaches should provide incentives for decision-makers to pursue beach protection and restoration measures. In Catalonia, by 2050 the tourist carrying capacity of beaches will decrease down to 83% of the current values, even in the absence of climate change due to the dominant erosive behavior of the Catalan coast; when sea-level rise is also considered, the beach carrying capacity will decrease further to 74% to 53% of the current value under the RCP 4.5 and RCP 8.5 respectively [33]. It should be mentioned that the optimal number of tourists for long-term sustainable growth may be smaller than the carrying capacity of the tourism destination [34]. Finally, wide beaches apart from their recreation potential provide also storm/erosion protection to backshore assets, the value of which has been found to increase with beach width [35].

Climate change impacts on the beach carrying capacity: Sea level rise-induced erosion will contribute significantly to the reduction of the areal surface of beaches worldwide in the absence of effective adaptation measures [12]. Consequently, there will be decreases in the recreational carrying capacity of beaches which, in turn, could impact on the economies of regions associated with the 3S tourism model. Beaches will face increasing erosion (and flood) risks/losses in the future, due mostly to the Relative Sea Level Rise (RSLR) and extreme hydro-meteorological events; the contribution of the anthropogenic drivers of losses such as increasing coastal urbanization and asset values would possibly decline with time through market processes and international/national regulation restricting the development and exposure of the coastal zone, for instance, the 2008 ICZM Protocol to the Barcelona Convention 'set-backs' future Mediterranean coastal development [36].

Beaches have been projected to be 'hotspots' of coastal erosion (and of decreasing ecosystem services) in many regions, according to global and regional models [12,37,38]. In the Mediterranean 3S touristic hotspot such as the Italian North Adriatic beaches (which are already under erosional stress) have been projected to face severe erosion challenges by the end of the century [39]; similarly, sea level rise has been projected to likely cause increasing beach erosion along the central Italian Adriatic coast (Molise), potentially exposing economic activities and assets to serious damages [40]. In Israel, [41] have estimated beach losses under sea level rises of 0.2 to 1.0 m and found that most beaches will be affected; Dado beach (Haifa) will be severely damaged by a sea level rise as low as 0.4 m, whereas the Tel Aviv Promenade beach will face severe challenges under 1 m sea level rise. Along the Mediterranean Egyptian coast, several 'hotspots' of beach erosion have been identified (particularly in the Alexandria coast), both in terms of the current trends and future projections [42,43]. In Catalonia (Spain) [23] have found that withstanding spatial variations in the induced climate change impacts along the coast, Catalonia's key coastal tourism brands, Costa Brava and Costa Daurada, will be the most affected economically, with an expected GDP loss by 2100 of approximately € 2200 million and € 1820 million (2019 values), respectively under the RCP 8.5 scenario.

In Greece, the RSLR will force by 2050 irreversible beach retreats of 3.5-15 m, depending on the beach characteristics and the sea level and wave forcing. Due to the mostly small widths of the Greek beaches, at least 10% of all beaches will permanently retreat by 50% of their currently recorded Beach Maximum Widths (BMWs) according to conservative projections (RCP 4.5); by 2100 (RCP 8.5), projections suggest that 40-89% of all beaches will permanently retreat by distances equal to or greater than their BMWs. Beach erosion/flooding will be also exacerbated by the changes in the frequency/intensity of extreme sea level events (ESLs) [44]; in these cases, even if the beaches might eventually recover, there might be severe flood damages/losses for their backshore ecosystems, and touristic infrastructure and assets [45]. For the Greek Aegean archipelago, in particular, under a storm-induced sea level rise of 0.6 m superimposed on a mean sea level rise of 0.5 m, complete erosion/inundation of 31- 88% of all beaches (29-87% of beaches currently fronting coastal infrastructure/assets) has been projected, at least temporarily [17].

Elsewhere, ‘hotspots’ of erosion have been identified along the Kuwaiti coast, requiring innovative coastal protection solutions [46], at the Iranian coast [47] and Cape Town (S. Africa), where at least 80% of the city's 2019/2020 ‘Blue Flag’ beaches are threatened from rising sea levels and coastal erosion [48]. For the Basque urban sandy beaches of Northern Spain, shoreline mean erosion in the range of 10-45 m under the RCP 4.5 scenario and 14-66 m under RCP 8.5 by the year 2100 has been projected [49]. In the Caribbean, a major 3S tourism destination, beaches are already under a severe beach erosion stress [50]. This has been projected to increase under climate change [51]. In the Bahamas, a recent assessment of the vulnerability of the coastal tourism infrastructure to beach erosion/flooding has shown that, as 28% and 60% of the total hotels/resorts are situated within 50 m and 100 m from the current coastline respectively, there is a high risk of significant damages/losses under climate change; Although a RSLR of 1 m threatens a small number of properties by itself, when combined with weak, moderate and strong tropical storms, coastal flooding has been projected to impact 34%, 69%, and 83% of the touristic infrastructure/assets (hotels and resorts) respectively [52]. Similarly, changes in the hydro-meteorological forcing have been projected to induce greater beach erosion and flooding along previously (more) stable shorelines at many Pacific islands, where local communities conceive beach erosion as the critical coastal hazard [53,54].

Carrying capacity projections for two touristic islands in the Mediterranean and Caribbean

In order to get some more insights of the challenge, two test cases in Aegean and Caribbean archipelagos are presented now in more detail. These involve two very significant touristic island destinations: the islands of Santorini (Greece) and St Lucia (Caribbean), respectively.

Study areas: Santorini in Figure 1 is located in the Aegean archipelago and has an area of 90.7 km^2 and a permanent population of 15,550, its population density is 171/km^2. The island is a famous touristic destination and its economic development is first and foremost related to tourism. The continuous increase in touristic activities has created challenges related to the infrastructure required to meet this development as well as the island’s carrying capacity, in 2017 there were 221 tourists/km^2 per day. In 2018, there were ~525,000 international tourist arrivals at Santorini airport and almost 750,000 cruise passenger arrivals (Athinios Ferry Port) [55]. Santorini beaches are micro tidal, with a tidal range of less than 0.1 m recorded on springs [56] and have a bathing water quality assessed as ‘excellent’ according to the European ‘Bathing Waters’ Directive 2006/7/EC.

St Lucia is a Small Island Developing State (SIDS), located at southern Lesser Antilles volcanic arc in the eastern Caribbean (Figure 1), with an area of 616 km^2 and a population of about 180,000 (population density of 300/km^2), and a GDP of 1.71 billion USD (2017). It has a vibrant tourism industry based on the 3S model that contributes up to 41.5% of GDP (direct and indirect contributions, 2015). In 2016, there were more than 840,000 international tourist arrivals at the St Lucia’s international (Hewanorra and George Charles) airports, whereas St Lucia is also a major cruise ship destination (677,400 arrivals in 2016). Beaches are the primary natural resources supporting tourism in Saint Lucia, with coastal resorts designed so as to offer ocean views and immediate access to the beaches.

At the same time, Saint Lucia faces significant climatic risks: it has been ranked as 49th out of 180 countries for the period 1996-2015 [57]. Sea levels show a rising trend since 1976, which since 2005-2016 has exceeded the average trend of the Caribbean basin [58]. Since 1850, Saint Lucia has been hit by 63 storms/hurricanes that have caused human losses and substantial economic damages [59]. It should be noted that all tourist transportation assets (seaports and airports) of Saint Lucia have been assessed as particularly vulnerable to marine flooding under climate change; this might present additional problems to its tourism industry [60].

Beach erosion assessment approaches: The geo-spatial characteristics of all ‘dry’ beaches of Santorini and St Lucia, such as length, Beach Maximum Width (BMW) and area were recorded from images and other related optical information available in the Google Earth Pro application according to [17]. ‘Dry’ beaches were defined as the low-lying sedimentary bodies, bounded on their landward side by natural boundaries (vegetated dunes or cliffs) and artificial structures (embankments/seawalls, roads and buildings) and on their seaward side by the shoreline. Additional information was also recorded, including the presence of coastal works and the density of the backshore assets as a percentage of the beach length.

The most recent available and clear images were selected for digitization. The examined images span the period 2019-2020 for Santorini and 2006-2015 for St Lucia. As the time periods of the examined information differs by location, the findings related to erosion/accretion and the backshore urbanization are not temporally coherent along the coast. Constraints in the approach also stem from the accuracy/resolution of the (not properly georectified) images and the varying hydrodynamic conditions during the image collection that can affect shoreline delimitation. These may introduce uncertainties which, however, cannot be avoided in studies at these scales [17, 45]. Finally, the geospatial characteristics of 30 and 91 beaches in Santorini and St Lucia respectively were recorded.

Beach erosion is driven by the slow-onset RSLR, as well by extreme sea levels (ESLs, the compound effect of mean sea levels, tides, storm surges and coastal wave set ups) and extreme waves. Projections of the RSLR, tide and ESL along the coasts of Santorini and St Lucia were abstracted from the JRC (Joint Research Centre) database [61]. To assess beach erosion/inundation, the above projections were utilized to drive two cross-shore (1-D) morphodynamic model ensembles: A 'long-term' ensemble comprising the analytical models Bruun, Dean and Edelman and a 'short-term' ensemble consisting of the numerical SBEACH, Leont'yev, XBEACH and Boussinesq models (for model details and validation see [17]). The former was used to assess beach erosion under RSLR and the latter to assess beach erosion/inundation due to episodic extreme storm condition and specifically under the 1-100 year Extreme Sea Level (ESL 100). For both cases, projections for the year 2050 under the IPCC RCP 4.5 and high end estimates, i.e. 95th percentile [62] were examined. The projections were converted using as baseline the year 2020 for Santorini and the year 2010 for Saint Lucia, in accordance with the time periods of the digitized beach polygons.

Given the spatio-temporal scales of the application, the input data of the models could not be based on in situ measurements. Therefore, the models were set up using a plausible range of environmental conditions (i.e. combinations of different beach slopes, wave conditions and sediment size); a total of 101 combinations. As initial bathymetry linear profiles were considered with various slopes (1/10-1/30). Simulations were carried out using varying wave conditions, i.e. wave heights (H) of 1-4 m and periods (T) 4-8 s and different median sediment sizes (0.2-5 mm). Due to the different conditions used in the model set ups, the models produced ranges of beach erosion projections. For the examined RSLR scenario, there were 303 retreat projections from the 3 long-term ensemble models' simulations; then, the 50th and 90th percentiles of these projections (the median and the value that 90% of beach erosion projections are less severe, respectively) were estimated. Similarly, for the extreme episodic event examined (ESL 100), the 50th and 90th percentiles were estimated from the 404 retreat/inundation results given by the 4 models of the short-term ensemble.

RESULTS

Beach erosion assessment

Santorini has 30 beaches (Figure 1) with a total area of about 577,100 m^2, indicating a total carrying capacity (i.e., the number of visitors that can be simultaneously hosted) of about 26,230 visitors (22 m^2

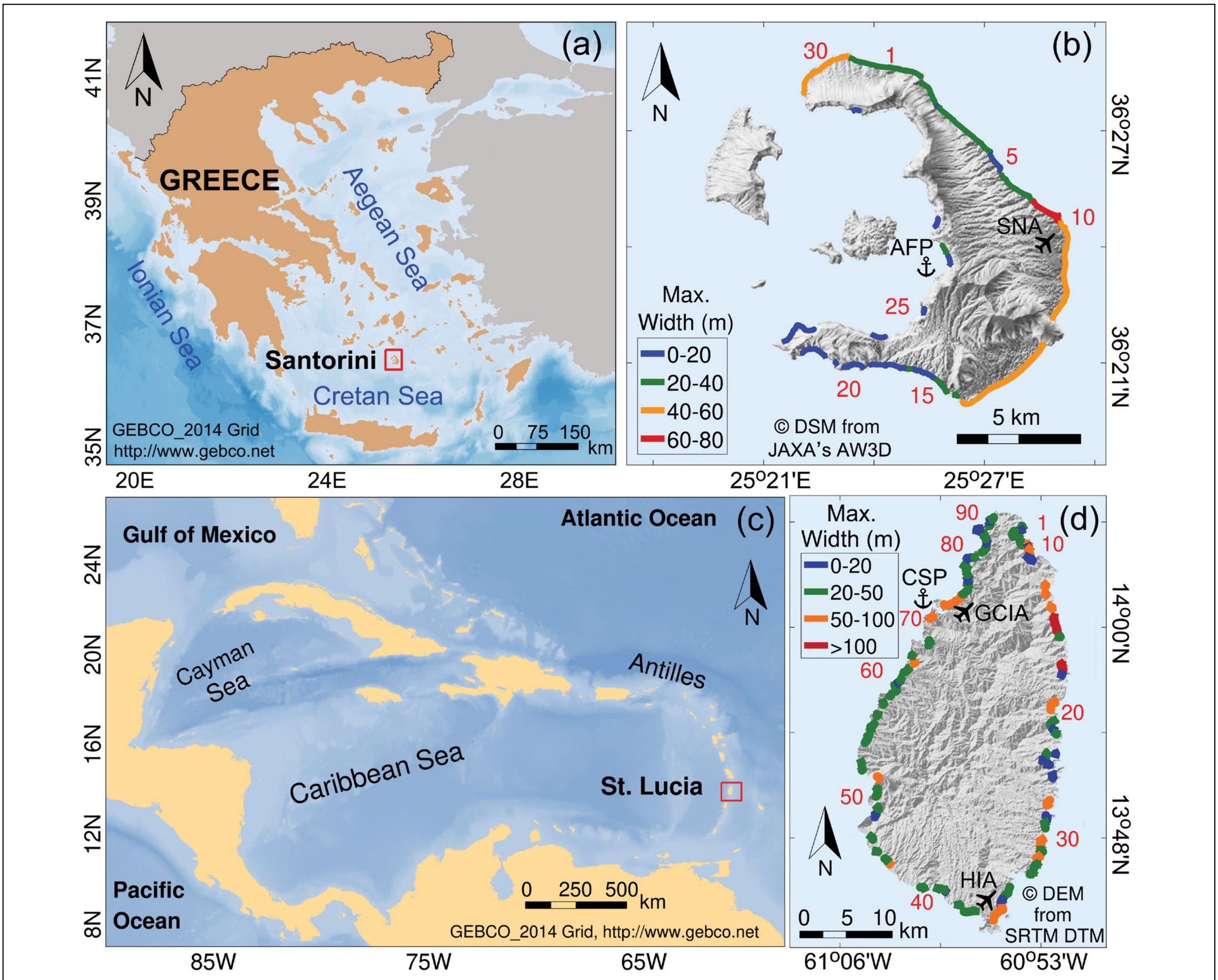

Figure 1: Location map and beaches (clockwise beach numbering starting from the north) of Santorini and St Lucia. SNA, Santorini National Airport; AFP, Athinios Ferry Port; HIA, Hewanorra International Airport; GCIA, George Charles International Airport; CSP, Port Castries.

per visitor, [31]). Most beaches are narrow; 46% of the recorded maximum 'dry' beach widths were found to be less than 20 m and 82% less than 50 m. Regarding the sediment type, mixed texture sediments (sandy gravels) have been associated with 67% of the beaches, whereas about 30% of the beaches were classified as sandy beaches. 73% of the beaches were found to directly front coastal infrastructure/assets (without any 'set-back' of the construction line) (Figure 1).

Model results show that by the year 2050, according to the high end projections, i.e. 95th percentile [62] under the moderate RCP 4.5 scenario, a RSLR of 0.26 m will force irreversible beach retreats between 5.3 and 9.7 m, based on the 50th and 90th percentile of the morphodynamic modeling estimates respectively. However, due to the mostly small maximum width of the Santorini beaches, up to 50% of them will permanently retreat by 50% of their recorded BMWs; since many of these beaches also lack the accommodation space to retreat landwards, will probably suffer coastal squeeze in Figure 2. As a consequence, the carrying capacity of these beaches will be reduced to more than half, as the conservative indicator of the maximum width is used in the assessment. The 100-year ESL (ESL 100) in 2050 (1.21 m) will result in storm beach inundation of up to about 24.5 and 36.5 m, under the RCP 4.5 (high end projection) scenario based on the medium (50th percentile) and high (90th percentile) model estimates respectively. The impacts could be devastating since 67-80% of all beaches will be completely (at least temporarily) inundated under the medium and high projections, respectively in Figure 2. In terms of asset exposure, 55-73% of the beaches presently fronting assets are projected to be overwhelmed during the event. These frontline backshore assets will sustain damages, even if there will be a post-storm beach recovery as they are located within the envelop of beach erosion-recovery (Figure 2).

A total of 91 beaches were recorded in St Lucia (Figure 1), with a total area of about 718,170 m^2 and a carrying capacity of about 32,640 visitors. Most of these beaches have lengths <1.8 km, are bounded by rock promontories, with the majority showing small maximum widths: 26% of the recorded maximum 'dry' beach widths were found to be less than 20 m and 81% less than 50 m, with only 2% having maximum widths exceeding 100 m. Regarding the sediment texture, the majority (84%) of the beaches have been classified as sandy beaches. 34% of the beaches were found to

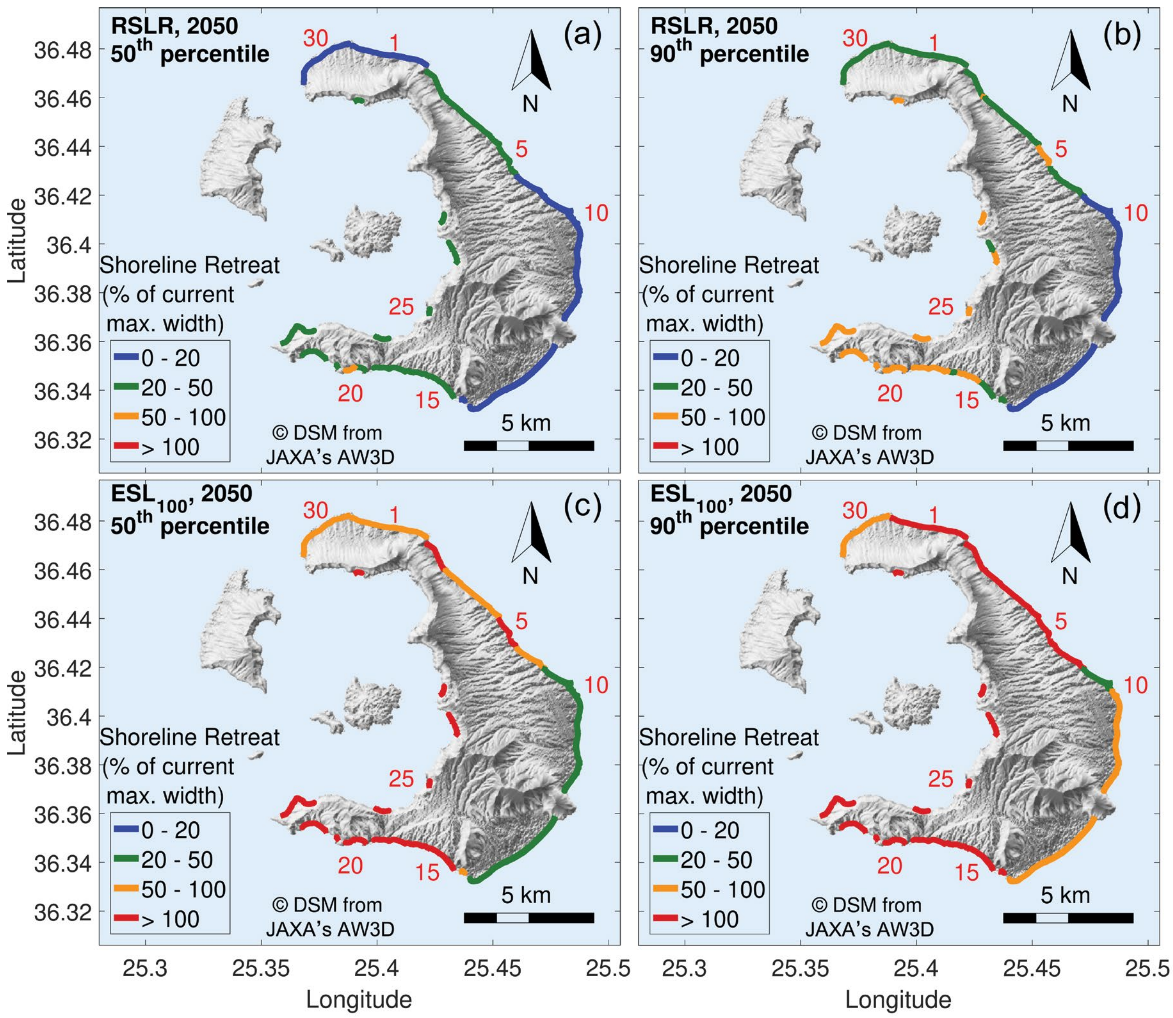

Figure 2: The 50th and 90th percentiles of beach retreat/inundation projections of the 30 beaches (clockwise beach numbering starting from the north) of Santorini under RSLR and ESL 100 for the year 2050 based on the RCP 4.5 and high end projection, expressed as percentages of their current maximum width.

directly front coastal infrastructure/assets (without any 'set-back' of the construction line) and only 19% of the beaches were observed to host coastal technical works, with groynes/jetties appearing as the most dominant technical measure.

Under a RSLR scenario of 0.3 m, projected for the year 2050 based on the RCP 4.5 and high end projection [62], up to 34% (most impacting estimations, 90th percentile) of all St Lucian beaches will retreat by distance equal to or greater than half of their present BMWs (Figure 3). With regard to extreme storm events, the model projections indicate that the ESL 100 (2.26 m) in 2050 will result in storm-induced shoreline retreats/inundations of between 45.1 and 68.7 m, based on the 50th and 90th percentile of range estimates, respectively, and under the RCP 4.5 (high end projection) scenario. Even under the medium model estimates, the ESL 100 will induce (temporarily) total erosion/flooding of 50% of all beaches of Saint Lucia (77% of beaches fronting assets) (Figure 3). Based on the high model estimates, impacts are projected to be very severe, as 75% of beaches (94% of beaches fronting assets) will be overwhelmed (Figure 3).

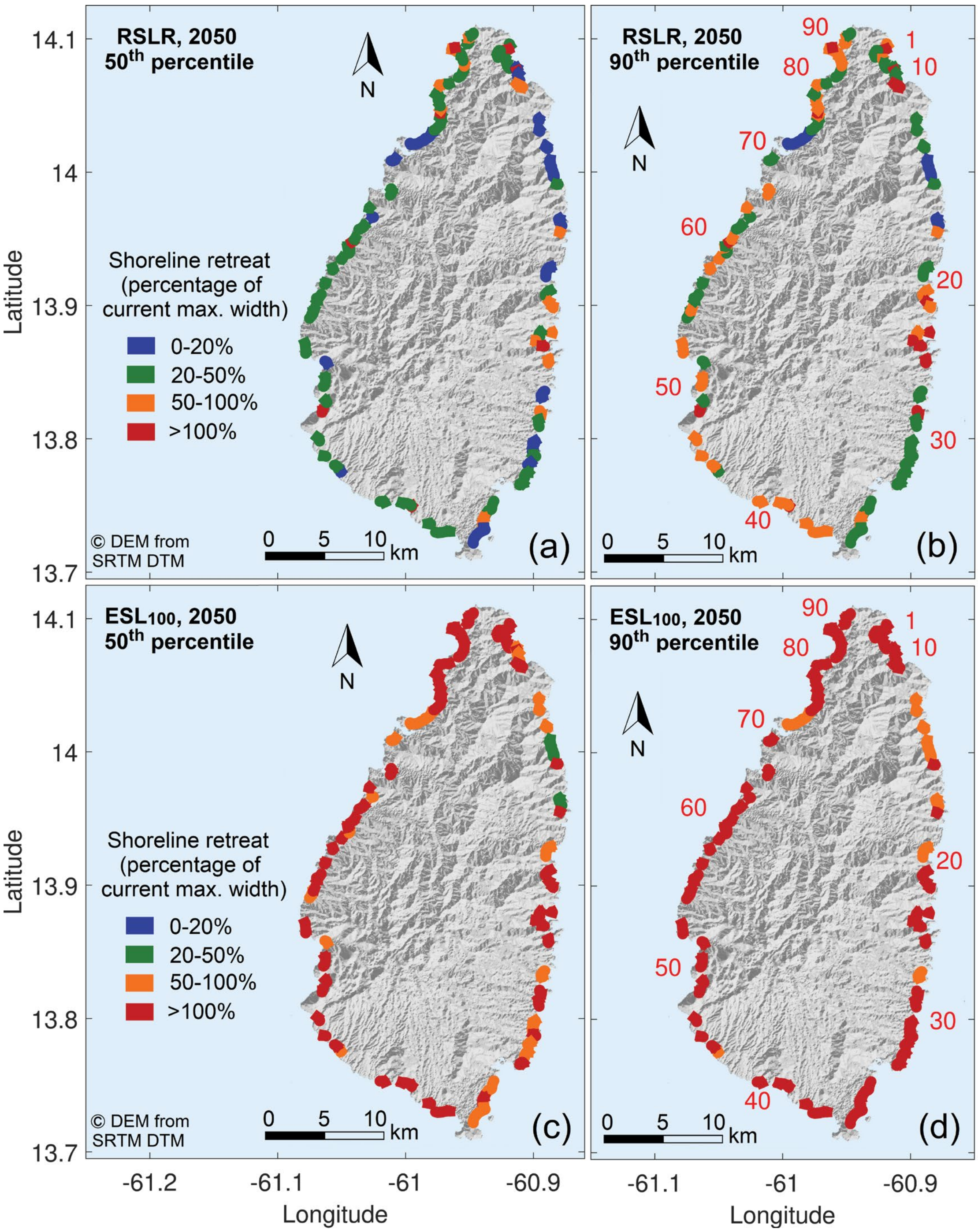

Figure 3: The 50th and 90th percentiles of beach retreat/inundation projections of the 91 Saint Lucian beaches (clockwise beach numbering starting from the north) under RSLR and ESL 100 for the year 2050 based on the RCP 4.5 and high end projection, expressed as percentages of their current maximum width.

DISCUSSION

This short overview and the above projections for the two touristic islands Santorini and St Lucia suggest that there will be significant erosion of touristic beaches under climate change. Substantial decreases are expected in both the beach carrying capacity for recreation and the beach ability to buffer backshore touristic infrastructure/assets with potentially negative impacts on visitor numbers and expenditures which could have far-reaching social-economic impacts for 3S touristic destinations. It appears that there is an urgent need for integrated coastal zone management in these areas which incorporates tourism management strategies and climate change adaptation measures to deal with these effects. Both require: (a) beach erosion assessments at different spatial and temporal scales; (b) planning/implementation of effective adaptation options.

Beach erosion assessments under the present and future climatic regimes should, ideally, involve simulations under different scenarios of Relative Sea Level Rise (RSLR) and extreme sea levels and waves. Different approaches/models can be used depending on the scale, resolution and objectives of the application, the availability of geo-spatial and hydrodynamic information, as well as the type of erosion, slow-onset due to RSLR or rapid episodic erosion due to extreme events [45]. It is noted, however, that in order to assess beach erosion in the high spatio-temporal detail that may be required for local applications, detailed information should be collated/analyzed such as high-resolution satellite imagery, repeated (LiDAR) surveys, Unmanned Aerial Vehicle (UAV) optical photogrammetric surveys and ground video monitoring of the 'dry' beach dynamics [56, 63].

Management of beach erosion requires well-planned beach maintenance and restoration, with beach protection schemes being essential to mitigate erosion. These schemes can be based on either 'hard' or 'soft' (more eco-friendly) measures [64]. The former are mainly associated with the construction of hard structures (groynes, seawalls and breakwaters), whereas the latter mostly with beach nourishment schemes; both have advantages and disadvantages.

Hard technical measures can be effective in the protection of waterfront infrastructure and assets or beaches from storm wave conditions but they are costly [54]; they can also have undesirable consequences, such as migration of beach erosion downstream of the groyne systems, accelerated erosion of the beaches fronting seawalls, and changes in the nearshore flows behind breakwaters that can create health/safety issues, near shore pollution and degradation of beach aesthetics [65-68]. Their major disadvantage, however, is that they could be inefficient to mitigate on their own beach erosion/drowning under the RSLR and, thus, permanent reductions in the beach carrying capacity [69].

In comparison, 'soft' beach nourishment can be used to mitigate beach erosion, including that induced by RSLR [70,71]; beach nourishment can raise and extend the beach seawards and, thus, assisting in the maintenance of the beach carrying and wave buffering capacities under RSLR. Since it appears vital for the two tested island economies to maintain the carrying capacity of their beaches under sea level rise (and future storms), beach nourishment should be considered. Therefore, the sediment volumes (and costs) required to nourish sustainably the beaches of both Santorini and Saint Lucia, under sea level rise have been estimated according to the widely used approach proposed by [72].

Nourishment was assessed under the premise that the present carrying capacity of the beaches should be maintained. Therefore, the nourishment sediment volumes required to raise the beaches by as much as the predicted RSLR (the wave run up height was also taken in to consideration) and extend them seaward by as much as the predicted retreat by the 'long-term' model ensemble simulations. A beach morphodynamic parameter of crucial importance for the design of beach nourishment (and hard coastal protection) schemes is the beach closure depth, i.e. the maximum offshore water depth that limits the offshore extent of the beach sediment 'reservoir'. In the present study, the closure depth has been estimated according to [73]. The 50^{th} and 90^{th} percentile (and the corresponding forcing environmental conditions), of the model results under the RCP 4.5 (high end projection) scenario and the beach lengths (application to the entire beach was considered) were used to drive the estimations.

Significant quantities of replenishment material would be needed to preserve the current dimensions and carrying capacity of the 30 Santorini beaches. By 2050 the projected retreat under RSLR alone would require between 1.4 and 2.6 million m^3 of suitable replenishment material that is sufficiently similar in terms of composition and size to the existing beach sediments. If a value of 15 €/m^3 is considered, the potential cost of these adaptation measures would be between 20.8 and 38.5 million €. In the case of Saint Lucia, the necessary volume of nourishing (filling) sediments to preserve the beaches by 2050 under the projected RSLR for RCP 4.5 (high end projection) has been estimated between 2.8 and 4.4 million m^3 with the potential costs estimated as 42.5 and 66.7 million € (assumed unit cost of 15 €/m^3).

It appears that beach nourishment could be the required adaptation measure to preserve the carrying capacity, although some additional hard coastal protection works might also be required [45]. However, beach nourishment can be also costly, particularly as repeated nourishment may be required to maintain the beach [72]. Another major challenge for beach nourishment schemes concerns the availability of the requisite replenishment material, which is not as plentiful as one thinks, particularly the sandy material [74]. As land-based sources in many areas have been depleted, suitable resources for replenishment material have been sought offshore (marine aggregates) [75]. However, prospecting for and exploitation of these resources in an environmentally sustainable manner is not an easy exercise, as they require considerable human, technological and financial resources which may not always be available [76-78].

In touristic island settings (such as Santorini and Saint Lucia), the high overseas transportation costs, practical difficulties in the discharging of the nourishment material on the island beaches and environmental and aesthetic considerations indicate that marine aggregate should be first sought locally [79]. Thus, the availability of, and accessibility to, appropriate local marine aggregate resources for beach nourishment should be given particular attention and considered in marine spatial plans (e.g., the EU Marine Spatial Planning Directive 2014/89/EU) as a matter of priority.

Finally, it should be noted that maintenance of the width and carrying capacity of touristic beaches is essential not only for the sustainability under climate change of the tourism and hospitality industry in 3S destinations, but also for the hedonic value of the backshore touristic (and other) assets. [80] have argued that beach width could be endogenous to hedonic price equations due to the role that property values play in benefit-cost analysis of beach replenishment operations, there is evidence to suggest that adaptation measures against beach erosion can have a significant positive impacts on waterfront asset values [81].

CONCLUSION

This short study has shown that climate change will exacerbate beach erosion with significant (in many cases critical) impacts on the carrying capacity of beaches for recreation, as well as their ability to protect backshore infrastructure and assets from beach erosion and flooding. This can have far-reaching consequences for the tourism and hospitality industry in 3S tourism destinations.

In order to maintain beach services, adaptation measures will be required. Due to the necessity of maintaining the beach carrying capacity (to at least the present values) under the projected RSLR (and exacerbated storm sea levels and waves), beach nourishment should be (at least part of) the solution. It should be noted though that this solution can be constrained by the availability (and costs) of suitable replenishment material, particularly in the case of touristic island destinations.

Finally, management of the situation requires mainstreaming of the assessment of and the response to beach erosion within the tourism development and management strategies and plans. However, the assessment and management of beach erosion and reducing carrying capacity are not easy exercises, as they require considerable human, technological and financial resources. It is submitted that due to the projected large-scale of the problem, any such resource requirements/gaps should be (at least) assessed as a matter of urgency.

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