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The Implications of Climate Change on Coastal Visitor Numbers: A Regional Analysis

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ABSTRACT

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It is anticipated that climate change will have a significant impact on participation in outdoor recreation via changes to weather conditions and modifications to the environments that visitors use. Coastal tourism may be particularly affected by these impacts, as beach visitors are strongly influenced by weather conditions, and sea level rise could have a significant effect on the appearance of coastlines. Despite the importance of coastal tourism to the global economy, the magnitudes of the likely impacts of climate change on beach visits are currently poorly understood. Using a case study of the coastline at East Anglia, U.K., this work models these potential impacts under four future climate change scenarios. Using a Geographical Information System, the output of a model linking visits with beach characteristics and weather conditions is combined with data on likely changes in beach width, temperature, and precipitation to predict future visitor demand. The results suggest that climate change will result in a net increase in visitors on this section of coast, with the positive effects of warmer and drier weather outweighing the negative influences of reductions in beach width due to sea level rise. The findings are discussed in the context of beach management strategies.

ADDITIONAL INDEX WORDS: *Coastal tourism, coastal management, sea level rise.*

INTRODUCTION

Future changes to the climate are likely to have a considerable effect on outdoor recreation because environmental conditions are strongly associated with decisions to make recreational visits (de Freitas, 2001). Predicted changes in weather conditions and associated modifications to landscapes at tourist destinations are expected to alter tourist demand and travel patterns. For example, regions where the climate is predicted to become warmer and drier might experience an increase in levels of outdoor recreation, whereas localities which experience a change to cooler or wetter conditions may see fewer visitors (Lise and Tol, 2002).

Research into the impacts of climate change on tourism has focused on three key areas. Firstly, several studies have examined the effects of changes in weather patterns on global flows of tourists (*e.g.,* Gossling and Hall, 2006; Hamilton, Maddison, and Tol, 2005; Lise and Tol, 2002; Maddison, 2001). These studies have suggested that increased temperatures will lead to a greater number of tourists travelling to northern latitudes at the expense of visits to southern areas. In particular, currently popular destinations in the Mediterranean are predicted to receive fewer visitors as summers are expected to become uncomfortably hot in this region (Amelung and Viner, 2006; Nicholls, 2006). Secondly, there has been research into the impacts of climate change on the winter sports industry, particularly skiing. This has focused on the Alps (*e.g.,* Elsasser and Burki, 2002), Canada (*e.g.,* Scott, McBoyle, and Mills, 2003), and Scotland (*e.g.,* Harrison, Winterbottom, and Sheppard, 1999). These studies have demonstrated that a reduction in the depth and extent of winter snow cover, along with fewer snow lying days, will reduce the number of days that are suitable for skiing and may lead to loss of revenue from winter sports. Finally, a number of studies have examined the implications of climate change for coastal recreation. Of all types of outdoor leisure, coastal tourism is likely to be particularly affected by climate change because intertidal areas will undergo additional environmental changes due to sea level rise (Braun *et al.,* 1999). Previous research has particularly focused on small islands which are economically dependent on coastal tourism, such as those in the Caribbean (*e.g.,* Belle and Bramwell, 2005; Uyarra *et al.,* 2005), and also on low-lying areas where sea level rise could result in considerable disruption to infrastructure and services, such as in Fiji (*e.g.,* Becken, 2005).

Visiting the coast is one of the most popular outdoor recreational activities in the United Kingdom, as demonstrated by attendance figures; this trend is common to many countries. Indeed, a study of preferences amongst householders

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undertaken by Tunstall *et al.* (1997) found that beach visits were rated as more enjoyable than those to a national park, lake, river, wood, museum, leisure centre, or theme park. Given the importance of coastal recreation to the wider tourist industry, knowledge of the effects that climate change may have on the recreational uses of beaches is economically valuable, as well as being essential from an environmental management perspective (de Freitas, 2001). For example, increased levels of visitation may result in benefits such as income generation and employment opportunities (Klein, Osleeb, and Viola, 2004), yet greater visitor numbers may also adversely impact biodiversity (Priskin, 2003). Insight into how visitor numbers might be affected by climate change will allow appropriate visitor management strategies to be developed, minimising the negative impacts on coastal habitats (Bishop and Gimblett, 2000).

Beach recreation is heavily dependent on favourable weather conditions, particularly during the summer when the primary activities that many visitors undertake are sunbathing and swimming (de Freitas, 1990). Hence anticipated changes to more favourable conditions resulting from rises in mean monthly temperatures and fewer precipitation events during the summer may increase levels of visitation. For example, Loomis and Crespi (1999) estimate that a 2.5°C increase in temperature could increase the number of visits made to beaches in the United States by 14%. Nevertheless, visitors are also influenced by the physical appearance of the coast, often preferring wide and sandy beaches (Jędrzejczak, 2004; Tudor and Williams, 2006), and predicted sea level rise is expected to decrease beach width, whilst an increase in the frequency and intensity of storms may increase erosion and result in habitat loss (Brown and McLachlan, 2002; Pethick, 2001). These changes could adversely affect the aesthetic appearance of beaches and cause a decrease in their attractiveness as locations to visit (Braun *et al.,* 1999; Gossling and Hall, 2006).

It is likely that relationships between recreation, weather conditions, and the physical appearance of beaches are complex, and the net effect that climate change may have is unclear. To our knowledge, no previous work has been undertaken in the U.K. which has attempted to evaluate them over space and time for a section of coastline. Focusing on the beach environment, this study applies a model of the way visitors respond to beach characteristics and weather conditions to assess the implications of sea level rise, increases in air temperatures, and changes in precipitation patterns on future coastal recreation in East Anglia, U.K., an example of a low-lying and geologically soft coastline. Annual visitor numbers at beaches are estimated for the 2020s, 2050s, and 2080s using four climate change scenarios. Predicted changes in levels of visitation are discussed in the context of beach management strategies.

METHODOLOGY

Case Study Site

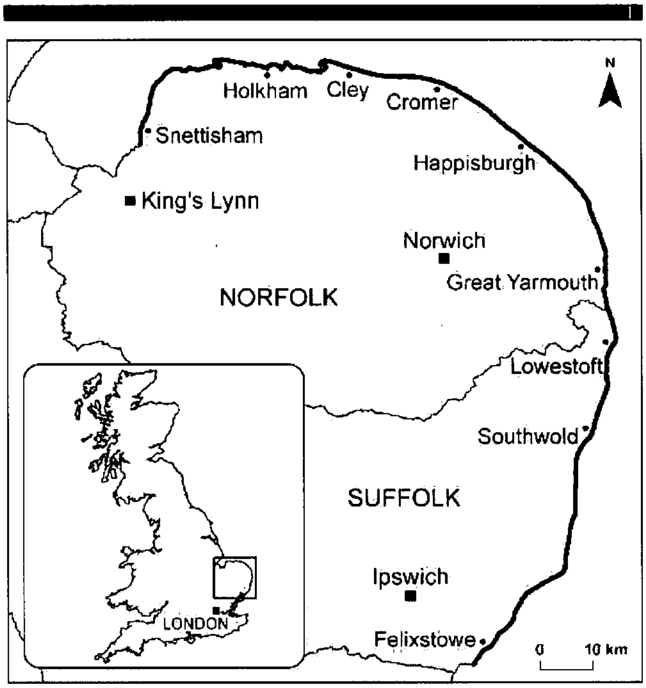

Figure 1. Map of the East Anglian coastline, which shows the study area (indicated by a black line) and the location of this area within the U.K. (inset).

The East Anglian coastline (Figure 1), within the counties of Norfolk and Suffolk, supports a high diversity of coastal habitats. Extensive salt marshes, particularly in North Norfolk, are recognised as internationally important Special Areas of Conservation, Special Protection Areas, and Ramsar sites (Environment Agency *et al.,* 2006). Much of the coastline of Norfolk and Suffolk is a designated Area of Outstanding Natural Beauty. Further national designations are found throughout the region, including over 500 Sites of Special Scientific Interest (SSSI) and 15,000 ha of National Nature Reserves (NNR). The region also has the Norfolk Broads Wetlands, equivalent in terms of their statutory designation to a national park. As such, they attract a large number of visitors; in North Norfolk alone, tourist expenditure contributes an estimated £357 million to the economy, underpinning over 7000 full-time jobs. Eighty-four percent of these jobs are provided as a direct result of visitor spending activity, with the remainder being supported indirectly through tourism business linkages and through the resultant expenditure of employees on local goods and services (Scott Wilson Consultants, 2005). Most recent estimates suggest that 900,000 day visits are made to the Norfolk coast alone each year and that coastal tourism is important to the local economies of both Norfolk and Suffolk (North Norfolk District Council, 2003). It is anticipated that climate change may have a considerable impact on the East Anglian coastline because it is low lying, so a relatively small increase in sea level could significantly reduce beach width and alter coastal morphology. It is also geologically soft and consequently very susceptible to erosion (Pethick, 2001).

To determine the effect that climate change may have on coastal recreation within East Anglia, research was conducted in a number of stages, focusing on the coastline between

Snettisham in Norfolk and Felixstowe in Suffolk. Firstly, a methodology was developed which applied a model regarding the way visitors respond to spatial and temporal changes along the coast to estimate visitor numbers for a range of beach types in relation to weather conditions. Secondly, the effects of climate change and associated sea level rise on the coast were identified for four different scenarios. Thirdly, the methodology presented in the first stage was applied to predict future levels of visitation, taking into account likely changes identified from the scenarios. Finally, the implications of predicted changes in visitor numbers were evaluated and possible management strategies outlined.

Spatial and Temporal Factors Affecting Visitor Numbers

Several investigations have considered how visitor numbers vary between locations in relation to beach characteristics (*e.g.*, Jędrzejczak, 2004; Tudor and Williams, 2006; Tzatzanis and Wrbka, 2002) and how numbers change at locations over time with weather conditions (*e.g.*, de Freitas, 1990; Dwyer, 1988). However, no studies have examined how visitor numbers may respond to modifications to both beach characteristics and weather conditions.

Two regression models were developed to predict visitor numbers at coastal sites. The first model described geographical variations in levels of visitation by predicting visitor numbers within 200-m-long sections of the East Anglian coastline from beach characteristics. Information regarding levels of visitation along the East Anglian coastline was obtained from aerial video footage. These data were available from a study recently undertaken at the Tyndall Centre for Climate Change Research, University of East Anglia, U.K., which examined the effect of tourists on the distribution of ringed plover (*Charadrius hiaticula*) and oystercatcher (*Haematopus ostralegus*) territories and the impacts of climate change on this interaction (Tratalos *et al.*, 2005). The coastline from Snettisham in Norfolk to Felixstowe in Suffolk was filmed from an aircraft on Saturday, 12 April; Saturday, 21 June; and Sunday, 24 August 2003. The dates were chosen to allow levels of visitation to be compared between peak and off-peak seasons. Filming was undertaken during the middle of the day. Successively longer stretches of coastline were filmed during each of the flights so that they covered 150 km, 205 km, and 215 km, respectively for the three flight dates. The locations of all individuals visible on the beach in the videos were digitised into a geographical information system (GIS), ArcGIS 9.1 (ESRI, Redlands, California), to a precision of 1 m.

In order to associate levels of visitation with beach characteristics, the coastline was divided into 200-m sections within the GIS. Although coastlines seldom exhibit abrupt boundaries between environmental features, examining the coastline at this resolution allowed the total number of visitors recorded within each section to be compared to the section's predominant environmental characteristics. Visitor numbers were assessed in relation to distance to beach entrances, beach characteristics (sand, shingle, boulders, presence of strandline debris, presence of vegetation), beach awards (blue flag, good beach guide), environmental designations (SSSI, NNR), environmental features behind the beach (dunes, cliffs), availability of facilities (a pier; an urban area behind the beach; distance to the nearest car park, toilet, campsite, hotel, and public house), and a distance-weighted measure of the population living around the beach entrance. These variables were measured during field surveys and using the GIS. Those variables that were derived from visual field surveys were estimated by visual observation by a researcher on foot at 200-m intervals along the coastline. All other variables were identified from U.K. Ordnance Survey (OS) MasterMap data, 1:50,000 OS maps, and aerial photographs within the GIS. Dummy variables identifying data derived from each of the three flights were included within the model to account for the additional visitors observed during June and August, compared to the baseline case of April. The results from the analysis of flight data demonstrated that visitor numbers increased as the proportion of sand, beach width, and availability of facilities increased, and they provided a means of using the presence of these attributes to predict visitor numbers in each section of coastline.

The second model described temporal variations in visitation by relating mean hourly visitor numbers observed at two sites to day of the week, school holidays, and weather conditions. This model was constructed based on visitor numbers and weather conditions recorded during biweekly surveys at Holkham and Cley beaches in Norfolk between January 2004 and July 2005. The two beaches were selected because they differ considerably in their physical appearance and the number of visitors they receive. Holkham is a wide sandy beach with a shallow gradient and receives approximately 500,000 visitors annually (English Nature, 2003). In contrast, Cley is a narrow shingle beach with a steep gradient and receives approximately 100,000 visitors annually (Klein and Bateman, 1998). Monitoring visitor numbers at the two sites provided an insight into how visitors respond to weather conditions at physically contrasting beaches.

To allow variation in levels of visitation over a year to be examined, surveys were undertaken approximately biweekly between January 2004 and July 2005. They were conducted at the main beach entrance between 0800 and 1700 hours or until 2100 hours during the summer. The number of people entering the beach (arrivals) was recorded for 10 minutes within each hour. Additional note was taken when organised groups of visitors, such as bird-watching groups or school groups, entered the beach whilst counts were being taken. The conditions noted for each survey included the season and whether the day was a weekend or school holiday. Weather conditions and the level of the tide were measured hourly on each survey day. Regression models were fitted to relate visitor arrivals to these conditions, and they allowed a quantification to be made of the manner by which visitor numbers increased during weekends, school holidays, and warm and dry weather conditions. A more detailed description of these methods can be found in Coombes (2007) or acquired from the authors.

Taken individually, the spatial model predicts visitor numbers for a range of beach characteristics but for fixed weather conditions (the baseline conditions are those observed on 12

April 2003), whilst the temporal model predicts visitor numbers for a variety of weather conditions but for fixed beach characteristics (those observed at Holkham and Cley). Assuming that visitors respond to weather conditions in a similar manner at different locations, as suggested by the findings at Holkham and Cley, predictions made using the spatial model may be adjusted using the coefficients from the temporal model; in this way visitor numbers can be predicted for a range of beach characteristics in relation to a variety of weather conditions. Here, the spatial model was used to make an initial estimate of visitor numbers for each 200-m beach section according to beach characteristics. Then the differences between the weather conditions on 12 April 2003 and those predicted for each scenario were determined. Based on these differences, the slope coefficients from the temporal model were used to adjust the spatial estimates for different weather conditions.

To test whether this methodology accurately predicted visitor numbers for a range of beach types and weather conditions, it was applied to predict visitors for eight East Anglian beaches (Thornham, Brancaster, Wells, Salthouse, Sheringham, West Runton, Trimingham, and Winterton), and the results were compared to observed visitor numbers recorded in field surveys. These beaches were selected because they differ considerably in their physical appearance and the number of visitors they receive. Visitor numbers were observed on five occasions at each beach (once each season and twice during the summer) to encompass a range of weather and holiday conditions. The method was used to predict visitor numbers at the beaches for the same weather and holiday conditions as observed during field surveys. The level of association between the predicted visitor numbers and those observed was high ($r_s = 0.673$, $n = 40$, $p < 0.001$), suggesting the method worked well. This method was therefore used to predict future visitor numbers to the East Anglian coastline for a range of climate change scenarios, as described in the following sections.

Climate Change Scenarios and Implications for the East Anglian Coastline

The likely implications of climate change for the East Anglian coastline were assessed for three time periods (2020s, 2050s, and 2080s) and for four greenhouse gas emissions scenarios (low, medium-low, medium-high, and high), according to the U.K. Climate Impacts Programme (UKCIP) framework (Hulme *et al.,* 2002). The UKCIP scenarios were developed from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (IPCC, 2000) and represent alternative pathways for future economic, social, and technical developments. As there is uncertainty regarding the degree of climate change which will take place, such scenarios provide a means of exploring a range of possible futures. Likely changes in beach width, mean monthly air temperatures, and the number of rain days each month were calculated for every 200-m section along the study area coastline for each scenario.

The effect of sea level rise on beach width was calculated based on IPCC predictions (Hulme *et al.,* 2002; IPCC, 2001), taking into account regional subsidence rates of −0.08 cm/y (UKCIP, 2005). Together, these represent a rise in sea level of 10–11 cm, 20–24 cm, and 31–44 cm by the 2020s, 2050s, and 2080s, respectively, depending on the level of greenhouse gases emitted. Beach width was represented as the distance between mean low-water level and mean high-water level as marked on OS MasterMap 1 : 2500 digital map data. Relative changes in these water levels were estimated in the ArcGIS GIS (ESRI) using beach profile data supplied by the U.K. Environment Agency.

Information regarding current monthly temperatures (°C), monthly precipitation (mm), and the number of rain days per month were obtained from the U.K. Meteorological Office 5 km–by–5 km gridded data sets (Meteorological Office, 2007), whilst future estimates of monthly temperatures and monthly precipitation for the 2020s, 2050s, and 2080s were obtained from UKCIP02 5 km–by–5 km gridded data sets (UKCIP, 2007). So that changes in temperature and precipitation, relative to present conditions, could be calculated across the study area, the ArcGIS software was used to assign each 200-m-long section of coastline to a 5-km grid cell within the Meteorological Office and UKCIP02 data sets. In the temporal model described above, the relationship between visitor numbers and temperature was modelled using a series of dummy variables representing 5°C temperature bands. This allowed the relationship with temperature to be nonlinear. The UKCIP scenarios predict temperature changes of 1°C or 2°C over the next 80 years. To incorporate the effect of relatively small changes in temperature on visitor numbers within the analysis, slope coefficients were estimated at 1°C intervals by linear interpolation between each of the modelled 5°C bands. Similarly, precipitation was modelled using a dummy variable to represent the presence or absence of rain on any given day. The UKCIP data for future monthly rainfall were converted to monthly rain days, based on the ratio between current monthly rainfall and current monthly rain days, so that it was compatible with the model. Insufficient data were available to take into account changes in the intensity of precipitation events. A summary of the predicted changes in beach width, temperatures, and rain days for East Anglia is provided in Table 1.

Predicting Future Visitor Numbers

Annual visitor numbers to the East Anglian coastline were predicted for the 2020s, 2050s, and 2080s for each of the four emissions scenarios using the models described above. Firstly, a prediction of visitor numbers was made for each 200-m section of coastline according to its characteristics and incorporating the estimates for beach width following sea level rise. These values were then adjusted according to the expected holiday dates and weather conditions for each day of the year for the 2020s, 2050s, and 2080s, taking into account weekends, school holidays, mean monthly temperatures, and the number of rain days each month. This process was repeated for each emissions scenario. Daily predictions of visitor numbers were then summed to predict total annual visitor numbers.

Table 1. *Summary of beach width, temperatures, and rain days for each emissions scenario. The values presented represent the mean results for the entire study area.*

		2020s				2050s				2080s			
	Present (2007)	Low	Medium-Low	Medium-High	High	Low	Medium-Low	Medium-High	High	Low	Medium-Low	Medium-High	High
Mean beach width (m)	142	137	137	137	137	133	133	133	132	129	129	128	126
Mean annual temperature (°C)	9.7	10.4	10.5	10.5	10.6	11.1	11.3	11.5	11.9	11.6	12.0	12.9	13.5
Total annual rain days	116	116	116	116	116	116	115	115	115	115	115	115	115

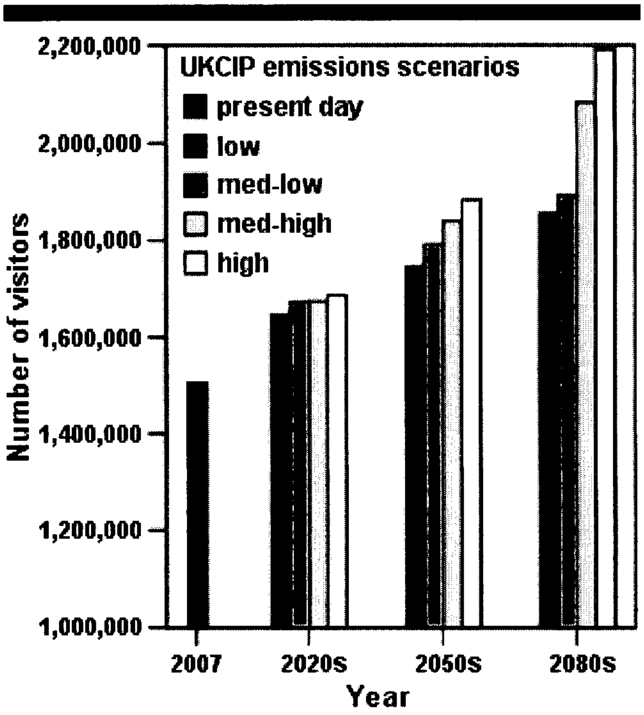

Figure 2. Predicted annual visitors to the East Anglian coastline for the 2020s, 2050s, and 2080s based on predicted sea level rise and changes in weather conditions. The y-axis starts at 1,000,000 visitors per year.

RESULTS

Predicted Changes to the Coastline

Table 1 illustrates that sea level rise may reduce mean beach width along the East Anglian coastline by 13–16 m by 2080, and mean annual temperature may increase by 1.9–3.8°C, depending on the level of greenhouse gases emitted. While there is expected to be little change in the annual number of rain days, it is anticipated that the distribution of rainfall across the year will alter, with summers becoming drier and winters becoming wetter. At present there are an average of 25 rain days during the summer (June to August) and 32 rain days during the winter (December to February), as calculated from the Meteorological Office data. Under the high emissions scenario for 2080, this is predicted to decrease to 16 rain days during the summer and increase to 41 rain days during the winter.

Effect of Climate Change on Visitor Numbers

Figure 2 shows predicted annual visitor numbers for the 2020s, 2050s, and 2080s based on anticipated sea level rise and changes in weather conditions. The results demonstrate that climate change is predicted to result in a net increase in coastal visitor numbers within East Anglia, with a rise of 9–12% by the 2020s, 16–25% by the 2050s, and 23–46% by the 2080s depending on the degree of climate change that occurs. These ranges of values illustrate the importance of socioeconomic pathways in determining the extent to which climate change may affect coastal recreation, particularly over longer

Table 2. *Predicted effects of sea level rise and changes in weather conditions on percent change in visitor numbers to the East Anglian coastline for the 2020s, 2050s, and 2080s. The ranges of numbers presented represent the low and high emissions scenarios.*

	Sea Level Rise			Changes in Weather Conditions		
	2020s	2050s	2080s	2020s	2050s	2080s
% change in visitor numbers	−0.3 to −0.3%	−0.3 to −0.3%	−0.4 to −0.5%	10 to 12%	16 to 26%	24 to 46%

timescales. Notably, the predicted increase in visitors by 2080 for the high emissions scenario is double that predicted for the low emissions scenario compared to 2007 values.

Although it is predicted that climate change may result in a net increase in visitor numbers, taken individually, sea level rise and changes in weather conditions are likely to have contrasting implications. Table 2 summarises the predicted effects of these changes. It is apparent that increases in temperatures and changes to precipitation patterns are likely to have a greater effect on levels of visitation than changes in beach characteristics due to sea level rise, and these changes in weather patterns account for approximately 98% of the overall predicted changes in annual visitor numbers resulting from climate change.

Changes in the Distribution of Visitors across the Year

Climate change is unlikely to result in a uniform increase in temperature for each month, and so visitor numbers may be affected in different ways depending on the time of the year. Figure 3 shows predicted monthly visitor numbers for the 2020s, 2050s, and 2080s. Whilst visitor numbers are predicted to increase across the year, a greater increase is predicted during the summer and early autumn when weather conditions are expected to become warmer and drier than they are at present. In contrast, the rate of increase in visitor numbers is predicted to be lower during the winter and spring due to an increase in the number of rain days during these seasons, reflecting the fact that changes in precipitation patterns may have a small effect on the distribution of visitor numbers across the year. Visitor numbers during summer (June to August) currently account for 40% of total annual visits, whilst numbers during winter (December to February) currently account for 15%. Under the high emissions scenario, this disparity is predicted to increase slightly to 42% during summer and decrease to 13% during winter by 2080.

Implications of Changes in Visitor Numbers for Coastal Management

Whilst an overall rise in visitor numbers may bring economic benefits, greater visitor numbers may increase degradation of vegetation and soils (Boorman and Fuller, 1977), increase disturbance of birds (Burger, Gochfeld, and Niles, 1995), and decrease the aesthetic value of beaches due to increased litter (Bellan and Bellan-Santini, 2001). Changes in recreation patterns may therefore require targeted management strategies, both at individual beaches and across the region more generally, to minimise disturbance of coastal habitats. Table 3 presents a summary of the predicted effects of climate change on visitor numbers, and it outlines the environmental implications of changes in visitation levels and possible management strategies at beaches. Increased temperatures, leading to a net rise in visitor numbers, could increase disturbance of flora and fauna. At environmentally sensitive sites, visitor management strategies that aim to limit the spatial extent of visitor impacts, such as restricting access to parts of the beach that provide habitats for breeding birds, may reduce habitat disturbance. In contrast, sea level rise is predicted to decrease beach width at low-lying locations, which may limit growth of visitor numbers. Coastal defence strategies that aim to maintain beach width, such as managed realignment of sea defences, may help preserve the

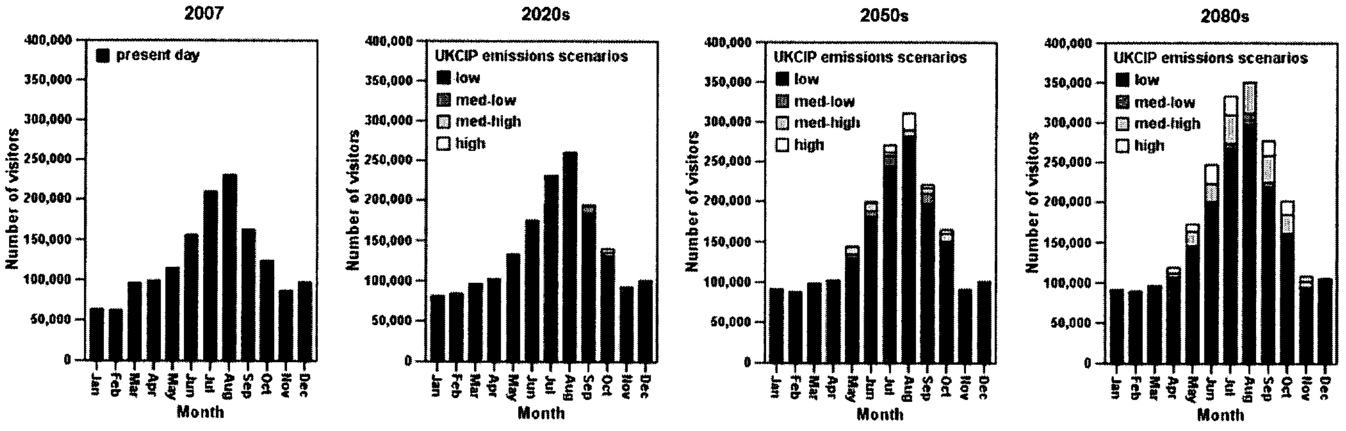

Figure 3. Monthly visitors to the East Anglian coastline predicted for 2007 and the 2020s, 2050s, and 2080s based on predicted sea level rise and changes in weather conditions.

Table 3. *Summary of predicted effects of climate change on visitor numbers, potential environmental implications, and possible management strategies.*

	Predicted Impact of Climate Change by the 2080s		Effect of Climate Change Components on Annual Visitor Numbers by the 2080s		Potential Environmental Implications of Changes in Visitor Numbers	Possible Management Strategies
	Low Emissions	High Emissions	Low Emissions	High Emissions		
Mean beach width	−13 m	−16 m	−0.40%	−0.50%	Sea level rise may have a minor impact on the distribution of visitor numbers across coastal regions by limiting growth of visitor numbers at beaches which are low lying and where sea defences have been constructed.	Beach width may be maintained by realigning existing sea walls further inland (King and Lester, 1995; Turner *et al.*, 1998).
Mean annual temperature	1.9°C	3.8°C	24%	46%	Greater visitor numbers may increase degradation of vegetation and soils (Boorman and Fuller, 1977), increase disturbance of birds (Burger, Gochfeld, and Niles, 1995), and decrease the aesthetic value of beaches due to increased litter (Bellan and Bellan-Santini, 2001). Greater visitor numbers would increase pressure on existing facilities and infrastructure.	Measures to control the spatial extent of visitor impacts, such as providing boardwalks between car parks and the beach, would limit pressure on biodiversity (Brown and McLachlan, 2002). Provision of additional facilities such as car parks would alleviate pressure on existing facilities (Turner *et al.*, 1998).
Total summer rain days	−5 d	−9 d	0.1%	0.3%	Changes in precipitation patterns may have a minor impact on the distribution of visitor numbers across the year by increasing visitor numbers during the summer. This may increase impacts on biodiversity, particularly since coastal birds are more susceptible to disturbance during the spring and summer as this is the main breeding period (Sekercioğlu, 2002).	Measures to control visitor impacts during the summer, such as temporarily fencing off sections of dunes to provide areas where birds can nest undisturbed, would limit pressure on biodiversity (Ikuta and Blumstein, 2003).
Total winter rain days	5 d	9 d	−0.1%	−0.3%		

presence of intertidal habitats and alleviate negative impacts of sea level rise on coastal recreation.

DISCUSSION AND CONCLUSIONS

This study has quantified the effects of changes in temperature, precipitation, and sea level rise on visitor numbers at beaches for four climate change scenarios, using the case study of the East Anglian coastline. It demonstrates that the implications of climate change for coastal recreation are complex; modifications to weather conditions are expected to increase visitor numbers, whilst reductions in beach width may limit this growth at low-lying beaches. Climate change may therefore affect the distribution of visitors along the coastline and across the year. Notably, warmer and drier conditions during the summer and early autumn could extend the length of the peak tourist season.

The most influential component of climate change on coastal recreation is expected to be increased temperatures, having a greater impact on visitor numbers at beaches than modifications to precipitation and sea level rise. Under each of the scenarios, higher mean temperatures are predicted to result in a net increase in visitors, although the effects are not likely to be severe until the 2080s. The increase in temperatures will be particularly marked in the high emissions scenario, which by 2080 is predicted to result in considerably more beach visitors compared to the other lower emissions scenarios. This illustrates the importance of socioeconomic pathways in determining the degree of climate change that occurs and, in turn, the extent to which coastal recreation will be affected, especially over longer timescales. Consequently, climate policies which affect the amount of greenhouse gases emitted may have important implications for the future growth of coastal tourism. Although the number of visitors was always predicted to increase with rises in temperature in this study, a highly nonlinear relationship may be present in some locations whereby visits increase to a point and then begin to decline as conditions become too hot (see Hamilton, Maddison, and Tol, 2005; Maddison, 2001). The predictive methodology we have adopted would permit this phenomenon to occur, but the temperature threshold was not reached in East Anglia over the time period of the study.

Although it is predicted that sea level rise may have a minor impact on visitor numbers in comparison to the effects of changes in weather conditions, reductions in beach width could limit growth of tourism at some locations. Beaches which are low lying and which contain sea defences are most likely to be affected by reduced beach width. Sea defences are generally constructed to protect property from flooding, and therefore coastal squeeze (where beaches reduce in width because they are unable to migrate inland due to the presence of hard sea defences at their landward margin [Klein *et al.*, 2001]) is most likely to occur where towns are located. Consequently, growth of recreation in urban areas may be limited by a reduction in beach area associated with this coastal squeeze, whereas rural beaches, which often possess high biodiversity value, are more likely to maintain beach width and therefore experience increased visitor numbers. This has important implications for biodiversity as rural locations supporting a greater diversity of flora and fauna may be particularly sensitive to visitor impacts.

Increased visitor impacts due to higher levels of visitation and changes in the distribution of visitors along coastlines may be further compounded by two factors. Firstly, given anticipated reductions in beach width, there would effectively be greater visitor numbers located within a reduced coastal area. Secondly, coastal flora is likely to experience additional stress from increased temperatures and reduced precipitation and may therefore be more susceptible to damage by trampling (Gallet and Roze, 2001). Targeted management strategies, such as restricting visitor access to environmentally sensitive areas, may help to minimise habitat disturbance.

The findings of this research are presented with a number of caveats. Firstly, the methodology developed assumes that visitors respond to conditions in a similar manner at different locations. Although the predictive accuracy of the methodology was evaluated at eight East Anglian beaches and was found to be good, testing it over a greater range of locations and weather conditions would further validate this assumption. The coastlines of Norfolk and Suffolk are distinctive in that they are relatively distant from large urban areas that are visited by significant numbers of tourists, and hence day tourists are likely to form a greater proportion of total visitor numbers than at some localities (U.K. National Statistics, 2006). This is potentially important; it could be that sensitivity to weather conditions, for example, differs between day and overnight visitors, with those staying for longer periods possibly being less sensitive to the conditions on any day. The areas also attract a smaller proportion of international visitors compared to some locations in the U.K., and overseas tourists have important implications for climate change (Gossling, 2002). The sensitivity of the methodology developed here to these factors should be addressed by applying it in new locations.

A second caveat is that better information regarding secondary environmental changes resulting from climate change may help improve the predictions. For example, it was not possible within this study to consider how sea level rise may impact beach accretion and erosion patterns. The model we adopted assumes that coastal inundation will occur, whilst in reality a variety of processes, including erosion, are likely to be important. However, there are considerable uncertainties regarding which processes may predominate and what their implications may be on different sections of the coast. The coastline of our study area is varied, spanning sediment cells and having low-energy and high-energy sections. Although the application of the Bruun effect (Bruun, 1962)—where, though the initial effect is assumed to be inundation, eventually enough material will be deposited offshore to re-establish the beach profile at a higher elevation—is commonly advocated, Stive (2004) argues that it may not predominate in many situations. Unfortunately, a more dynamic modelling exercise was beyond the scope of this research, as the data were not available to undertake it in a way that would provide a suitable level of confidence in our results. However, a worthy extension to the work presented here will be to incorporate a more dynamic model of coastal response than we are able to do.

Finally, a better understanding of the way visitors perceive and respond to environmental changes could help inform outputs (Lise and Tol, 2002). For example, previous research has suggested that climate change could lead to changes in the global flows of tourists (Gossling and Hall, 2006) and increase the number of domestic holidays (Hamilton, Maddison, and Tol, 2005), if weather conditions became similar to those currently experienced in the Mediterranean (Amelung and Viner, 2006). Nevertheless, numbers may not increase by the amount predicted here if visitors' response to good weather is less marked in a future with warmer and sunnier summers.

This study has focused on the immediate beach environment. However, the implications of the predicted changes in visitor numbers are likely to be much broader. For example, it may be that new tourism infrastructure, such as upgraded transportation networks and the expanded provision of accommodation, is required to provide capacity for an increase of visitors in the region. Furthermore, there may need to be changes in the types of tourism products developed and marketed, particularly if increased tourism demand is to be accommodated in such as way as to reduce adverse impacts on sensitive beach environments and their associated hinterlands. Although our climate change scenarios incorporate a consideration of socioeconomic pathways, trends such as overall tourism displacement within the U.K. and between the U.K. and other countries, plus modifications in levels of government regulation via carbon taxation on travel, were not explicitly quantified. These factors may all be important and, whilst their quantification was beyond the scope of this work, they should be addressed in future research.

Although this study has focused on the implications of climate change for coastal recreation within East Anglia, the issues identified are relevant to other coastal regions. Given the importance of temperature in determining levels of visitation, it appears likely that coastlines which experience a rise in mean temperatures will see a corresponding increase in visitors. Since reductions in beach width appear to have little influence on visitor numbers, geologically soft and low-lying coastlines which are vulnerable to sea level rise may experience similar levels of growth in tourism to hard coastlines. Low-lying areas will, in particular, require targeted management strategies to minimise associated increases in habitat disturbance, as intertidal habitats will be under increased stress as they adapt to changes in sea level.

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