Tyndall°Centre
for Climate Change Research

Linking sea level rise, coastal biodiversity and economic activity in Caribbean island states: towards the development of a coastal island simulator

Jennifer Gill, Andrew Watkinson, □
and Isabelle Côté□

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Linking sea level rise, coastal biodiversity and economic activity in Caribbean island states: towards the development of a coastal island simulator

Principal Investigator: Professor Andrew Watkinson
Tyndall Centre for Climate Change Research
University of East Anglia
Norwich
NR4 7TJ

Report authors:
Dr Jennifer Gill
Professor Andrew Watkinson
Dr Isabelle Côté

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Section 1 – Overview of Project Work and Outcomes

Non-technical summary

Small island states are amongst the regions most at risk from the impacts of climate change and sea level rise, largely because of their environmental and economic dependence on coastal zones. In the Caribbean, many islands are low-lying and surrounded by coral reefs and mangroves, which provide the majority of coastal protection and fisheries income, in addition to being major tourist attractions.

The potential environmental and economic consequences of climate change for Caribbean coastal zones were explored through four separate areas of research; (1) Sandy beaches and coastal squeeze, (2) Coral reefs and extreme climatic events, (3) Mangroves, fisheries and extreme climatic events and (4) Climate change impacts on tourism. The project developed a number of methodologies for exploring how to quantify the impacts of climate change on biodiversity. It was demonstrated that approximately one third of the beaches on some Caribbean islands could be lost through coastal squeeze, that hurricanes can reduce coral cover by 17%, and that the loss of beaches and coral cover could have a significant impact on tourism within the region.

Key research objectives

- to develop methodologies to address the impact of climate change on the distribution and functioning of key ecosystems that are of economic and conservation significance to small island states;
- to assess how extreme weather events and sea level rise will impact on the ecological characteristics of key coastal habitats in the region (sandy beaches, coral reefs and mangrove forests);
- to explore the links between climate change, biodiversity and the economic activities that are dependent on that biodiversity.

Work undertaken

1. *Sandy beaches and coastal squeeze*: across most of the Caribbean, coastal areas have undergone extensive development as tourist destinations which, in conjunction with sea level rise, is likely to result in significant loss of beaches through coastal squeeze. This study developed Geographical Information System (GIS) databases to model the impacts of sea level rise and coastal development on beach structure. The environmental consequences of these changes were assessed in relation to the impacts on nesting sea turtle populations on these beaches. Information on the distribution of nesting turtles on a wide range of beaches was collated and used to model the physical characteristics of beaches, and how changes in these parameters are likely to influence turtle populations.

2. *Coral reefs and extreme climatic events*: coral reefs are a critical component of coastal protection in tropical areas, in addition to harbouring unparalleled biodiversity and providing significant fisheries and tourism income. Historically, tropical storms and hurricanes have been a major force shaping coral reef structure and function. Coral reefs have existed

through periods of great variation in hurricane frequency and intensity. However, the many current anthropogenic impacts on coral reefs may greatly reduce the capacity of coral reefs to cope with climate change impacts such as extreme storm events, rising sea levels and rising sea surface temperatures. In order to quantify the impact of hurricanes during this period of severe reef degradation, coral studies from across the Caribbean were synthesized in a meta-analysis of temporal changes in coral cover.

3. *Mangroves, fisheries and extreme climatic events*: tropical storms and hurricanes have similarly severe effects on mangrove forests. Studies of mangroves across the Caribbean were again synthesized to allow analyses of the likely impacts of changes in storm frequency and intensity on mangroves, particularly in relation to the importance of mangroves as nursery habitat for important fisheries.

4. *Climate change impacts on tourism*: tourism is the most important source of employment and revenue in many Caribbean states. Key aspects of the popularity of the Caribbean as a tourist destination include wide sandy beaches, clear water, pristine habitats and abundant wildlife. The relative importance of each of these attributes was assessed through questionnaire surveys of tourists on two contrasting islands; Barbados, which is dominated by mass beach-oriented tourism, and Bonaire, which principally attracts diving-based ecotourism.

Results

1. *Sandy beaches and coastal squeeze*: GIS-based elevation models of 13 beaches on the island of Bonaire were constructed and used to assess possible impacts of sea level rise in relation to levels of adjacent coastal development. The impact of these potential changes on the populations of nesting sea turtles was then assessed by modelling the probability of loss of preferred nesting areas under various sea level rise scenarios. Under a predicted sea level rise of 0.5m, up to 32% of the beaches could be lost via coastal squeeze, with significant consequent reductions in the area of nesting habitat available to sea turtles. This work has been provisionally accepted by the journal *Conservation Biology* and is currently under revision.

2. *Coral reefs and extreme climatic events*: a database of 263 separate coral reef surveys from across the Caribbean and spanning three decades was amassed. This database is an extremely powerful resource for quantifying ecosystem change and exploring the relevant drivers. Spatio-temporal analyses of these data revealed that coral cover on reefs right across the Caribbean has declined by 80% in just 30 years, largely as a result of continued pollution, sedimentation and over-fishing. This work was published in *Science* and received a great deal of international publicity. The impact of hurricanes on reefs was analysed within this context of historical decline and showed that the effect of hurricanes on reefs is dramatic in the year following impact but greatly reduced thereafter. There is some evidence of synergy between hurricane impacts and other stressors such as disease and pollution, and declines are greatest in response to high intensity hurricanes. This research suggests that, against this background of severe ecosystem degradation, the capacity of reefs to cope with climate change impacts such as increasing hurricane intensity, rising sea temperatures and sea levels may be irretrievably compromised. The hurricane study will shortly be submitted to the journal *Ecology*.

3. *Mangroves, fisheries and extreme climatic events*: in comparison to coral reefs, far fewer studies of mangrove ecology were available, particularly in relation to hurricane impacts. However, collation of the available data highlighted the importance of the history of hurricane impacts in determining the post-impact response of mangroves, but also the high variance in seedling densities that have been reported following hurricane impacts. Mangrove fish populations show similarly variable responses to hurricane impacts although there was some evidence to suggest that fish communities may differ in response to recent storm history. This study will now be taken forward by a Tyndall-funded PhD student (John McWilliams).

4. *Climate change impacts on tourism*: although the attributes of islands that attract tourists differ greatly from ecotourism through to mass-tourism islands, tourists from both indicated a willingness to pay for the protection of coastal habitats from the effects of climate change. Tourists also indicated a reduced probability of selecting these island destinations if climate change significantly altered features such as beach structure or coral reef health. A manuscript based on this work will soon be submitted to the journal *Environmental Conservation*.

Relevance to Tyndall Centre research strategy and overall Centre objectives

The project contributes to the Research Theme 4 objective of understanding the natural processes and human activities around the coastlines of small island states. The results therefore are a prerequisite for the development of flexible adaptations to changing climate and environmental conditions. Here we provide evidence for the potential impact of climate change on biodiversity and the consequence of those for tourism.

In conjunction with the Tyndall/Joint Nature Conservation Centre (JNCC) studentship the work has been successful in raising the agenda of climate change and biodiversity in the Caribbean British Overseas Territories with the advisory bodies to the UK Government.

Potential for further work

A series of further analyses of the long-term coral reef database are already underway, including analyses of coral-algal phase-shifts in reef habitats and the ability of marine protected areas to adequately protect coral and associated biodiversity in the face of climate change. Predictive models of the impact of the projected IPCC changes in hurricane intensity and frequency on coral reef structure are being developed.

These studies have already led directly to a NERC/ESRC funded PhD study of sea level rise and coastal development in Caribbean islands, and a NERC/Tyndall funded PhD on climate change and biodiversity in the British Overseas Territories. Applications have been submitted for a study of ecotourism impacts on reef biodiversity and a study of environmental change on coral reef fish populations.

Island economies in the Caribbean are strongly dependent on biodiversity. There is a need to explore the adaptive capacity of the islands to potential changes in the stock of biodiversity that have been identified in this study using the databases collected.

Publications

The detailed results of this project have been written up in the following four journal articles, copies of which can be obtained from the respective authors.

- Gardner, T.A., Cote, I.M., Gill, J.A., Grant, A. and Watkinson, A.R. (2003) Long-term region-wide declines in Caribbean corals. *Science*, **301**, 958-960.
  [contact: i.cote@uea.ac.uk]

- Gardner, T.A., Cote, I.M., Gill, J.A., Grant, A. and Watkinson, A.R. (submitted) Hurricanes and Caribbean coral reefs: immediate impacts, recovery trajectories and contribution to long-term coral decline. *Ecology*.
  [contact: i.cote@uea.ac.uk]

- Fish, M.R., Cote, I.M., Gill, J.A., Jones, A.P., Renshoff, S. & Watkinson, A.R. (in revision) Predicting the impact of sea-level rise on Caribbean sea turtle nesting habitat: a GIS approach. *Conservation Biology*.
  [contact: m.fish@uea.ac.uk]

- Uyarra, M.C, Cote, I.M., Gill, J.A., Tinch, R., Viner, D & Watkinson, A.R. (in prep) Preferences of tourists for environmental features: implications for the impact of climate change on Caribbean tourism. *Environmental Conservation*.
  [contact: m.uyarra@uea.ac.uk]

Jenny Gill, Andrew Watkinson and Isabelle Côté
School of Biological Sciences, UEA, and Tyndall Centre
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Tyndall Centre
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The inter-disciplinary Tyndall Centre for Climate Change Research undertakes integrated research into the long-term consequences of climate change for society and into the development of sustainable responses that governments, business-leaders and decision-makers can evaluate and implement. Achieving these objectives brings together UK climate scientists, social scientists, engineers and economists in a unique collaborative research effort.

Research at the Tyndall Centre is organised into four research themes that collectively contribute to all aspects of the climate change issue: Integrating Frameworks; Decarbonising Modern Societies; Adapting to Climate Change; and Sustaining the Coastal Zone. All thematic fields address a clear problem posed to society by climate change, and will generate results to guide the strategic development of climate change mitigation and adaptation policies at local, national and global scales.

The Tyndall Centre is named after the 19th century UK scientist John Tyndall, who was the first to prove the Earth's natural greenhouse effect and suggested that slight changes in atmospheric composition could bring about climate variations. In addition, he was committed to improving the quality of science education and knowledge.

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External Communications Manager
Tyndall Centre for Climate Change Research
University of East Anglia, Norwich NR4 7TJ, UK
Phone: +44 (0) 1603 59 3906; Fax: +44 (0) 1603 59 3901
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