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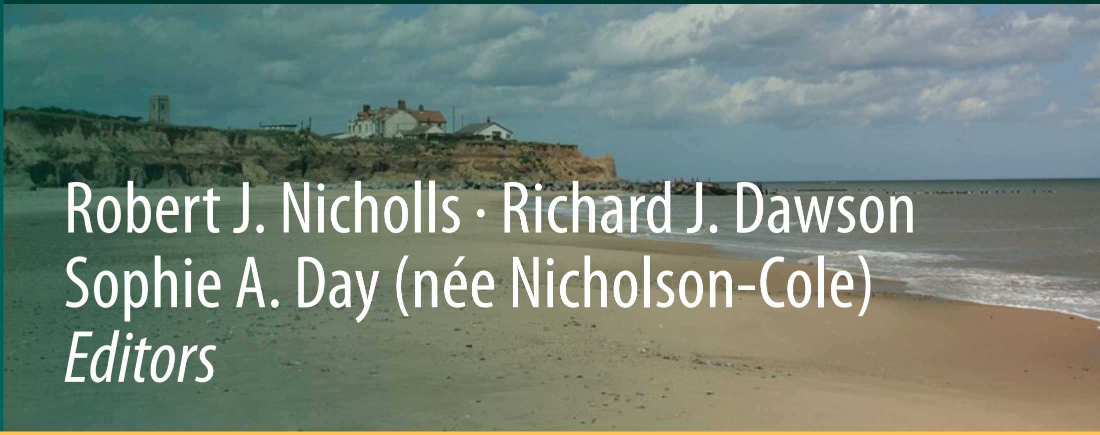

Robert J. Nicholls · Richard J. Dawson
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*Editors*

# Broad Scale Coastal Simulation

## New Techniques to Understand and Manage Shorelines in the Third Millennium

Springer

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## New Techniques to Understand and Manage Shorelines in the Third Millennium

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*Editors*
Robert J. Nicholls
Tyndall Centre for Climate Change Research, Faculty of Engineering and the Environment
University of Southampton
Southampton, UK

Richard J. Dawson
School of Civil Engineering and Geosciences, Tyndall Centre for Climate Change Research
Newcastle University
Newcastle upon Tyne, UK

Sophie A. Day (née Nicholson-Cole)
Tyndall Centre for Climate Change Research, Faculty of Engineering and the Environment
University of Southampton
Southampton, UK

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# Foreword

Global change, including climate change, presents one of the greatest challenges facing the world today. It is affecting food, water and human security as well as biodiversity and ecosystems and their services, with developing countries and poor people being the most vulnerable. Nowhere are the pressures of global change more evident than along our coastlines, where an ever-increasing number of people live. Hundreds of millions of people are threatened by rising sea levels and storm surges, especially those living in deltaic areas, such as Bangladesh; low-lying small island states, such as Kiribati; and cities sinking due to excessive groundwater extraction, such as Bangkok. Even rich cities such as New York are not immune to flooding as witnessed with Hurricane Sandy.

The systems approach that the Tyndall Centre researchers describe in this book has developed an appropriate conceptual framework for integrated coastal assessment at the scales of coastal management. It has enabled them to answer previously intractable questions about how climate change interacts with changing coastal systems. Whilst the work focussed upon North Norfolk in the East of England, the methods and insights are generic and potentially transferable to other coastlines around the UK and the world.

Coasts are complex systems that evolve over a range of time and space scales. Marine climate, beaches, cliffs, farmland, urban areas, erosion and flood protection infrastructure change over timescales of decades, so we need to understand the implications of those changes and start to prepare for them to avoid being burdened with long-term problems. This research recognised that coastlines are embedded within wider socio-economic and environmental systems and sought to understand the implications of climate, socio-economics and coastal management policy as drivers of long-term change. The Tyndall Coastal Simulator simulates the interactions between these processes in order to develop scenarios of change at spatial scales of relevance to coastal decision-makers.

Coastal governance is also a key issue as it is complex and involves multiple actors. By mapping out the process of long-term change, the Tyndall Coastal Simulator can help assess the potential effectiveness of policy instruments and their implications in terms of a range of different issues, including erosion, flooding and biodiversity.

Central to the success of the Tyndall Centre's holistic and policy-relevant approach has been the transdisciplinary nature of the research. This engaged a range of relevant stakeholders, including national and local government, the private sector and members of the public, in co-developing the research programme in order to address the full range of societal issues and concerns. This research showed that integrated modelling, as delivered by the Tyndall Coastal Simulator, can help to bring different stakeholders together in order to develop common understanding of processes and consequences of long-term change. That collective understanding is essential if society is to manage coastal change rather than become its victims.

There is no doubt that this work has broken new ground in terms of transdisciplinary climate change research by demonstrating that individual academic disciplines can advance the state of their art whilst importantly addressing questions of relevance to society that cut across these disciplines. The importance of the work was recognised by industry when an earlier synthesis paper (Dawson et al. 2009, included in Chap. 1 of this book) won the Lloyd's Science of Risk Prize in 2012.

Whilst significant advances have been made, inevitably a host of challenges and scientific uncertainties remain, and so I am pleased to see the Tyndall team reflect on these issues with practitioners and international experts in the final two chapters of this book. Not only does this offer a manifesto for an international research agenda but also a framework/demonstration of how interdisciplinary research should be conducted in international programmes such as the recently launched ICSU/ISSC Future Earth programme. That, however, is for the future. The purpose of this book is to summarise the results from eight years of Tyndall Centre research, which has significantly advanced our understanding of climate change and coastal systems.

Tyndall Centre
University of East Anglia
Norwich, UK
Bob Watson

Monash University
Melbourne, VIC, Australia
Louis Matheson

# Preface

Coastal scientists, engineers and policy makers around the world are increasingly recognising the challenge of sustainable coastal management in the third millennium. Long-term geomorphological, climatic and socio-economic changes are influencing coastal systems at unprecedented spatial scales and over extended timeframes – with profound implications for people, coastal infrastructure and settlements, biodiversity, ecosystem services and governance of the coastal zone.

Coastal researchers and decision-makers are presently ill-equipped to deal with the problems emerging from multiple drivers of change across multiple coastal sectors. This reflects that the coast is a linked system, and any change in one area or sector may influence the impacts for other areas or sectors. An integrated systems-based approach that seeks to represent the interactions between different issues within the coastal zone is fundamental to understanding the impact of global change on coastlines and to assist the sustainable management of our shorelines over the twenty-first century.

In 2000, the Tyndall Centre for Climate Change Research, an interdisciplinary consortium of engineers, scientists and social scientists, was established in the UK. This provided a unique platform to develop a coastal research programme with a major focus on an integrated assessment – this became known as the Tyndall Coastal Simulator – and is now reported in full, for the first time, in this book. An earlier synthesis paper from this research by Dawson et al. (2009) (included within Chap. 1 of this book) won the Lloyd's Science of Risk Research Prize for Climate Change in 2012.

However, there are already a number of books on coastal management, so why might we need another one? Whilst this is certainly a valid question, this book is not a handbook for design, nor is it a compendium of methods that cover every aspect of coastal systems or a compilation of case studies with differing aims. Rather it is a perspective on integrated assessment as applied to coastal problems, which represents a topic where there is an important gap in the literature. This book is structured as follows: Chapter 1 expands upon the challenges of sustainable coastal management and provides an overview of the integrated assessment for the core case study site in

North Norfolk in England. Chapters 2 and 3 describe how global changes in marine climate may alter future sea level, storm surge and offshore wave conditions around the British Isles and especially North Norfolk. Similarly, Chap. 4 quantifies the effects of global and local socio-economic drivers on changes to land use and development in the East of England. The following five chapters consider a range of impacts associated with the climatic and socio-economic changes considered above. Chapter 5 analyses broadscale geomorphic change in the region and Chap. 6 analyses habitat degradation and loss. Chapter 9 brings together the cliff erosion and flood modelling in Chaps. 7 and 8, respectively, to evaluate future erosion and flood risks in terms of expected economic damages under different climatic, socio-economic and management scenarios. Central to the success of this programme was comprehensive engagement with stakeholders. Chapters 10 and 11 describe the visualisation techniques and graphical user interface used to present results in an interactive manner to stakeholders, whilst Chap. 12 considers current decision-making processes and how the management of transitions in the coastal zone could be more adaptive and equitable and effectively implemented. The final two chapters of the book reflect on the key findings of the research, describe a general framework for transferring the Tyndall Coastal Simulator and identify future research priorities for integrated assessment in the coastal zone. This includes reflection on the range of coastal problems across the globe.

Each chapter could be read in isolation, but distinctive to other books on coastal management, each chapter also contributes to the wider integrated assessment. Throughout the book, we reflect on the process of integrating information on the different environmental, social and economic dimensions of coastal management.

Taking a systems perspective of the natural, physical and social environment at a scale that is relevant to livelihoods and the economy has enabled us to analyse how the coastal system as a whole might evolve in a changing physical and socio-economic environment. The application of the Tyndall Coastal Simulator to North Norfolk, UK, demonstrates that it is now feasible to explore long-term integrated projections of coastal processes such as geomorphology, flood risk and land use change, greatly increasing the evidence base available for coastal management decisions. Moreover, the methods and integrated assessment framework are transferable to other coastal areas.

The integrated assessment presented here has highlighted a number of the opportunities, challenges and trade-offs and the need for a long-term perspective on coastal policy in order to allow adaptation to coastal change to occur, for example, the difficulties faced by coastal managers, who in reducing the risk of erosion may actually enhance flood risk (or the cost and viability of mitigating this risk) at sites within the same coastal system. Such results were captured within the Tyndall Coastal Simulator interface allowing the technical results to be accessible to a wide range of stakeholders.

It is now clear that the management of any coastline and the governance structures upon which that management depends need to reflect the connectivity between the various coastal features that comprise the natural and human coastal system and consequential trade-offs in management policy. Furthermore, the Norfolk analysis relates the technical aspects of coastal change to the present, and often emotive, debate around long-term shoreline management – in particular it strengthens the argument for a change in the widespread historic management approach of increasing lengths of "hold the line" towards allowing as much of the coastline as possible to return to a more natural and dynamic configuration, including the associated sediment supply from eroding coasts. Inevitably, this raises a number of fundamental questions from stakeholders, which we have explored through using results from the Tyndall Coastal Simulator, about how to address the concerns of directly and indirectly affected landowners and householders to facilitate this fundamental change in management approach.

More generally, the work presented here shows that there is great potential for coastal stakeholders to develop improved understanding of coastal futures and for decisions to be based on a stronger evidence base. However, our integrated analysis exposed the magnitude of many uncertainties about coastal futures, and so in the context of adaptation, although the broadscale coastal simulation of the type presented here can provide a rich evidence base, it should be regularly reassessed, debated and reviewed as part of an ongoing process to reflect improving knowledge and changing priorities. Thus, we believe the Tyndall Coastal Simulator and tools like it have the potential to provide a platform for the longer-term adaptation process.

Southampton, UK — Robert J. Nicholls
Newcastle upon Tyne, UK — Richard J. Dawson
Southampton, UK — Sophie A. Day (née Nicholson-Cole)

# Acknowledgements

The majority of this work was supported by the Tyndall Centre for Climate Change Research, which was funded by the Natural Environment Research Council (NERC), the Engineering and Physical Sciences Research Council (EPSRC) and the Economic and Social Research Council (ESRC). The methodological development of the risk analysis benefitted from additional support through the Flood Risk Management Research Consortium which was funded by EPSRC in partnership with the DEFRA/EA Joint Research Programme on Flood and Coastal Defence, UK Water Industry Research (UKWIR), Office of Public Works (OPW) (Ireland) and the Rivers Agency (Northern Ireland). In addition, the habitat and stakeholder analysis was supported through the Biodiversity Requires Adaptation in North-West Europe under a changing climate (BRANCH) Project which was funded by EU INTERREG IIIB funds. Richard Dawson's EPSRC fellowship (EP/H003630/1) provided him the flexibility and space to work on this.

For the first phase of work, the Tyndall Centre was led by Professor Mike Hulme (now at King's College London) and Professor John Schellnhuber (currently director of the Potsdam Institute for Climate Impact Research) who both provided practical support and developed an exciting vision for interdisciplinary research. Professor Andrew R. Watkinson (University of East Anglia), who led the coastal research programme during its first phase and latterly the Tyndall Centre, is thanked not just for these roles but for his regular advice and critical review throughout the production of this book.

Stakeholder engagement and collaboration has been central to the Tyndall Centre's philosophy. We are extremely grateful to the many individuals, organisations and coastal communities who contributed their time, data and expertise to provide valuable feedback on the research and insights into the case study location. It is impossible to name them all, but we extend particular thanks to Steve Hayman, Gary Watson and Julian Wright from the Environment Agency; Peter Frew and Robert Young from North Norfolk District Council; Malcolm Kerby, a resident of Happisburgh and founder of the Coastal Concern Action Group; and Clive Stockton, also of Happisburgh and landlord of the Hill House.

The analysis presented here would not have been possible were it not for access to data collected and managed by the Environment Agency, Natural England, North Norfolk District Council, the Met Office, the Ordnance Survey, the British Geological Survey, the British Oceanographic Data Centre (BODC) and the Centre d'Etudes Techniques Maritimes et Fluviales (CETMEF) for their Atlas Numérique d'Etats de Mer Océanique et Côtier.

The aerial photographs that appear in this book were taken by Mike Page and the historical images were provided by Norfolk County Council's Library and Information Service. Others were taken by Sophie Day and Richard Dawson during the course of their research.

The inspiration from this book stemmed from the Dawson et al. (2009) paper that was published in Climatic Change. A number of co-authors of this earlier paper did not contribute directly to this book, but we are grateful for their earlier contribution: Julie Richards (ABPmer), Jianguo Zhou (University of Liverpool), Steve Pearson (British Geological Survey), Jon Rees (NERC and British Geological Survey) and Paul Bates (University of Bristol). However, were it not for Margaret Deignan at Springer inspiring us into action, this book may not have happened, and we also thank Takeesha Moerland-Torpey and the rest of the publishing team at Springer for their guidance and patience.

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# Contents

# Contributors

**Peter Balson** Formerly of British Geological Survey, Kingsley Dunham Centre, Nottingham, UK

**Iain Brown** The James Hutton Institute, Aberdeen, UK

**Jessica Bryson (née Milligan)** Geography and the Lived Environment Research Institute, School of Geosciences, University of Edinburgh, Edinburgh, UK

**Nicolas Chini** Tyndall Centre for Climate Change Research, School of Mechanical, Aerospace and Civil Engineering, University of Manchester, Manchester, UK

**Richard J. Dawson** School of Civil Engineering and Geosciences, Tyndall Centre for Climate Change Research, Newcastle University, Newcastle upon Tyne, UK

**Sophie A. Day (née Nicholson-Cole)** Tyndall Centre for Climate Change Research, Faculty of Engineering and the Environment, University of Southampton, Southampton, UK

**Mark Dickson** School of Environment, The University of Auckland, Auckland, New Zealand

**Corentin M. Fontaine** Namur Centre for Complex Systems and Research Group in Sustainable Development, Department of Geography, University of Namur, Namur, Belgium

**Jon French** Coastal and Estuarine Research Unit, Department of Geography, University College London, London, UK

**Peter Frew** Coastal Strategy for North Norfolk District Council, Coastal Management Consultant, Ely, UK

**Sarah Gardiner** Faculty of Engineering and the Environment, University of Southampton, Southampton, UK

**Jim W. Hall** Environmental Change Institute, Oxford University Centre for the Environment, University of Oxford, Oxford, UK

**Susan Hanson** Faculty of Engineering and the Environment, University of Southampton, Southampton, UK

**Tom Howard** Storm Surges, Hadley Centre, Met office, Exeter, UK

**Simon Jude** Centre for Environmental Risks and Futures, Department of Environmental Science and Technology, School of Applied Sciences, Cranfield University, Bedford, UK

**Sotiris Koukoulas** Department of Geography, University of the Aegean, Mytilene, Greece

**Qiuhua Liang** School of Civil Engineering and Geosciences, University of Newcastle, Newcastle upon Tyne, UK

**Jason Lowe** Department of Meteorology, Met Office, University of Reading, Earley Gate, UK

Department of Meteorology, University of Reading, Reading, UK

**Nobuo Mimura** Institute for Global Change Adaptation Science, Ibaraki University, Mito, Ibaraki Japan

**Mustafa Mokrech** Environmental Institute of Houston, School of Science and Computer Engineering, University of Houston Clear Lake, Houston, TX, USA

**Robert J. Nicholls** Tyndall Centre for Climate Change Research, Faculty of Engineering and the Environment, University of Southampton, Southampton, UK

**Leonard Nurse** Centre for Resource Management and Environmental Studies (CERMES), Faculty of Science and Technology, University of the West Indies (UWI), Barbados

**Melissa Nursey-Bray** Geography, Environment, Population, School of Social Sciences, University of Adelaide, North Terrace, Adelaide, South Australia, Australia

**Tim O'Riordan** School of Environmental Sciences, University of East Anglia, Norwich, Norfolk, UK

**Munsur Rahman** Institute of Water and Flood Management (IWFM) Bangladesh, University of Engineering and Technology (BUET), Dhaka, Bangladesh

**Mark D.A. Rounsevell** Institute of Geography and the Lived Environment, School of Geosciences, University of Edinburgh, Edinburgh, UK

**Tom Spencer** Cambridge Coastal Research Unit, Department of Geography, University of Cambridge, Cambridge, UK

**Peter Stansby** Tyndall Centre for Climate Change Research, School of Mechanical, Aerospace and Civil Engineering, University of Manchester, Manchester, UK

**William J. Sutherland** Conservation Science Group, Department of Zoology, University of Cambridge, Cambridge, UK

**Owen Tarrant** Flooding and Communities, Environment Agency, Bristol, UK

**James Thomas** Experience Prototyping Technician, School of Design, Northumbria University, Newcastle upon Tyne, UK

**Mike Walkden** WSP, Keble House, Southernhay Gardens, Exeter, UK

WSP Group, Exeter, UK

**David Walker** School of Civil, Environmental and Mining Engineering, The University of Adelaide, Adelaide, SA, Australia

**Andrew R. Watkinson** School of Environmental Sciences, University of East Anglia, Norwich, UK

**Kathleen D. White** Global and Climate Change, Institute for Water Resources, US Army Corps of Engineers, Portland, OR, USA

**Judith Wolf** Marine Systems Modelling Group, National Oceanography Centre, Liverpool, UK

**Xing Zheng Wu** Department of Applied Mathematics, School of Applied Science, University of Science and Technology, Beijing, P.R. China

**Robert Young** Coast and Community Partnerships, North Norfolk District Council, Norfolk, UK

**Barbara Zanuttigh** DICAM, University of Bologna, Bologna, Italy

# Acronyms and Abbreviations

| | |
|---|---|
| A1B SRES | A1B Special Report on Emission Scenarios |
| ABM | Agent-Based Model |
| ANEMOC database | Atlas Numérique d'Etats de Mer Océanique et Côtier database |
| AR4 | IPCC Fourth Assessment Report |
| AR5 | IPCC Fifth Assessment Report |
| ASMITA | Model describing inlet-coast morphological interaction described by Stive et al. (1998) |
| CHaMPS | Coastal Habitat Management Plans |
| CS3 | Continental Shelf model grid (~12km resolution) developed for UK tide-surge forecasting |
| DEFRA | Department for Environment, Food and Rural Affairs (England) |
| DELFT3D | Hydro-informatics system developed by Deltares |
| DPSIR | Driver-Pressure-State-Impact-Response is a causal framework for describing the interactions between society and the environment (see, e.g. Maxim et al. 2009) |
| ECMWF | European Centre for Medium-Range Weather Forecasts |
| ERA40 | ECMWF 40-year reanalysis data |
| EU | European Union |
| EurOtop | An assessment manual for Wave Overtopping of Sea Defences and Related Structures |
| FDGIA | Flood Defence Grant in Aid |
| FP7 | 7th Framework Programme of the European Union-funded research |
| GEV distribution | Generalised extreme value distribution |
| GCM | General circulation model |
| GHG | Greenhouse gas |
| GIA | Glacial isostatic adjustment |

| | |
|---|---|
| GIS | Geographic information systems |
| HadCM3 | Hadley Centre Coupled Model, version 3 |
| HadRM3 | Hadley Centre Regional Climate Model, version 3 |
| HAT | Highest astronomical tide |
| IA | Integrated assessment |
| iCOASST | Research project 'Integrating Coastal Sediment Systems' |
| IPCC | Intergovernmental Panel on Climate Change |
| LAT | Lowest astronomical tide |
| LiDAR | Light detection and ranging |
| LISFLOOD-FP | The 2D inundation model originally created by Bates and De Roo (2000) and applied to coastal flood modelling by Bates et al. (2005) |
| LUC | Land use change |
| MCA | Multi-criteria analysis |
| MEECE | Marine Ecosystem Evolution in a Changing Environment |
| Met Office | UK Meteorological Office |
| MHWN | Mean high water neap |
| MHWS | Mean high water spring |
| MHW | Mean high water |
| MIKE | Hydro-informatics system developed by DHI |
| MSL | Mean sea level |
| MUSCL | Monotonic Upstream-Centered Schemes for Conservation Laws |
| NAO | North Atlantic Oscillation |
| NewChan | A finite volume 2D flood model developed by Liang (2008) that employs a Godunov-type scheme to capture different types of shallow-flow hydrodynamics over uneven bed bathymetry |
| NOC | National Oceanography Centre (UK) |
| NNDC | North Norfolk District Council |
| ODN | Ordnance Datum Newlyn |
| OpenMI | Open Modelling Interface (http://www.openmi.org/) |
| POLCOMS | Proudman Oceanographic Laboratory Coastal Ocean Modelling System |
| POLCS3 | POLCOMS on CS3 grid |
| RCM | Regional climate model |
| SAC | Special Areas of Conservation |
| SCAPE | Soft Cliff And Platform Evolution modelling tool (Walkden and Hall 2005) |
| SISYPHE | Near-bed mass sediment conservation solver |
| SLP | Sea-level pressure |
| SLR | Sea-level rise |
| SMP | Shoreline Management Plan |
| SMP6 | Shoreline Management Plan 6 (Weybourne to Lowestoft) |
| SPA | Special Protection Areas |

| | |
|---|---|
| SRES | Special Report on Emissions Scenarios |
| SSSI | Special Sites of Scientific Interest |
| SWAN | Wave action conservation equation solver |
| SWH | Significant wave height |
| TAW | The Technical Advisory Committee for Flood Defence in the Netherlands |
| TE2100 | The Thames Estuary 2100 Project |
| TELEMAC | Hydro-informatics system developed by EDF |
| TELEMAC-2D | Depth-averaged version of TELEMAC |
| TOMAWAC | Wave action conservation equation solver |
| UKCIP02 | UK Climate Impact Projections 2002 |
| UKCP09 | UK Climate Projections 2002 |
| WAM | Wave Model, referring to the first third-generation wave model |
| WAMCS3 | WAM on CS3 grid |

## References

Bates, P. D., & De Roo, A. P. J. (2000). A simple raster-based model for floodplain inundation. *Journal of Hydrology*, *236*, 54–77.

Bates, P. D., Dawson, R. J., Hall, J. W., Horritt, M. S., Nicholls, R. J., Wicks, J., & Hassane, M. A. A. M. (2005). Simplified two-dimensional modelling of coastal flooding for risk assessment and planning. *Coastal Engineering*, *52*(9), 793–810.

Liang, Q. (2008). Simulation of shallow flows in nonuniform open channels. *Journal of Fluids Engineering*, *130*(1), 011205. Doi:10.1115/1.2829593.

Maxim, L., Spangenberg, J., & O'Connor, M. (2009). The DPSIR framework for biodiversity assessment. *Ecological Economics*, *69*(1), 12–23.

Stive, M. J. F. Z. B., Wang, M., Capobianco, P. R., & Buijsman, M. C. (1998). Morphodynamics of a tidal lagoon and the adjacent coast. In J. Dronkers, & M. Scheffers (Eds), *Physics of estuaries and coastal seas* (pp. 397–407). Rotterdam: Balkema.

Walkden, M. J. A., & Hall, J. W. (2005). A predictive mesoscale model of the erosion and profile development of soft rock shores. *Coastal Engineering, 52*, 535–563.

# Chapter 1
# The Challenge for Coastal Management During the Third Millennium

**Richard J. Dawson, Robert J. Nicholls, and Sophie A. Day (née Nicholson-Cole)**

**Abstract** Coastal planners and managers face a wide range of challenges around the world during the twenty-first century. These include geomorphological, climatic, and socio-economic drivers of change, their interaction and the societal and governance issues that they raised. The interplay between these challenges motivated the Tyndall Centre for Climate Research's Coastal Research Programme.

Assessing the impacts of multiple scale drivers and possible responses is problematic, yet failure to do so can limit the utility of the analysis – or lead to undesirable outcomes that are a consequence of thinking too narrowly about a problem. To define and analyse coastal problems in a comprehensive manner, an interdisciplinary team of researchers was assembled. Embracing natural, social and engineering sciences, this team engaged in the development of an integrated assessment, called the Tyndall Coastal Simulator, which was applied and demonstrated in East Anglia in the UK. However, the approach could be applied widely, as discussed at the end of the book.

The Tyndall Coastal Simulator provides a platform to integrate the diverse knowledge and methods developed as part of the integrated assessment process in a meaningful and accessible way. This chapter reviews the need for the Tyndall Coastal Simulator, outlines the main aims of the simulator work and defines its unique contribution to broadscale coastal simulation. It gives an overview of the integrated assessment structure, scenario framework and case study locations adopted in this work, especially North Norfolk. The study site was chosen as an exemplar of the challenges facing coastal stakeholders due to its long history of erosion and flooding and the fact that it is going through a major transition in coastal management strategy. Under this strategy, a number of currently protected clifftop communities will lose their defences causing widespread concern. Hence, this

R.J. Dawson (✉)
School of Civil Engineering and Geosciences, Tyndall Centre for Climate Change Research, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK
e-mail: richard.dawson@newcastle.ac.uk

R.J. Nicholls • S.A. Day (née Nicholson-Cole)
Tyndall Centre for Climate Change Research, Faculty of Engineering and the Environment, University of Southampton, Southampton SO17 1BJ, UK
e-mail: r.j.nicholls@soton.ac.uk; day_soph@yahoo.co.uk



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provides a good study site to develop transferable lessons on the analysis of coastal change and hazards, as well as the issue of managing transitions which will be essential under climate change.

This book builds upon, and significantly extends, work reported in an earlier paper by Dawson et al. (Climatic Change 95:249–288, 2009), included as an Appendix to this chapter, by providing a complete record of methods, results and analysis from the Tyndall Coastal Simulator as well as reflections on broadscale coastal simulation from British and International practitioners and researchers on this 10-year-research effort.

**Keywords** Integrated assessment • Coastal change • Shoreline management • North Norfolk • Tyndall Coastal Simulator

## 1.1 Introduction

### *1.1.1 Background*

This book presents a comprehensive description of an analysis of the coastal zone at a scale suitable to support strategic coastal management. It is distinctive because it looks over broad spatial scales and extended timescales and considers multiple and sometimes competing coastal priorities and drivers. The book demonstrates the first quantification of the relationship between erosion risks and flood risks. The chapters in this book demonstrate the application of a range of relevant methods using real case studies in England and synthesise the lessons learnt from this work at both national and international levels, drawing on the expertise of scientists and policymakers working in the UK and abroad (Box 1.1).

**Box 1.1 What Does This Book Offer?**

- Understanding the implications of global drivers of change for local coastal communities.
- An analysis of the relationships between different dimensions of coastal change, integrating across natural, engineering and social sciences.
- Presentation of a methodology for coastal integrated assessment – each chapter provides an additional contribution to the overall coastal integrated assessment.
- National and international reflection of lessons learnt, transferability and a research agenda for integrated assessment in coastal areas.

Long-term management of the coastal zone is challenging for a number of reasons. Coastal zones attract settlements, are ideal for a range of economic activities and contain important natural habitats that provide a range of ecosystem services. As sea-level rise and possibly intensified storms could increase the incidence of flooding and erosion and degrade coastal ecosystems, all these activities are vulnerable to climatic and other pressures unless appropriate coastal management policies are implemented. Change in the coastal zone is fraught with uncertainty and requires understanding long-term climatic, socio-economic and marine processes. These play out over a range of scales, with global drivers of change interacting with local activities. It is essential to assess this uncertainty in order to improve understanding of impending choices. Hence, it supports informed long-term coastal management policies that can adapt to growing observations and understanding, as well as evolving societal priorities. Moreover, coastal systems are highly interconnected, and any changes in one area or sector may influence impacts elsewhere. In complex situations such as this, an integrated assessment (IA) is required to understand the impacts of change and the implications of different management choices.

The Tyndall Coastal Simulator provides regional impact assessments of climate and socio-economic futures under various management options, with a regional application in the coastal zone of Norfolk, East Anglia, which quantifies for the first time how coastal erosion and coastal flood risk are strongly linked. This has important implications for shoreline management planning both in the UK and more widely. The book covers the development and application of a framework for coastal modelling (including coupling a range of models to describe various processes such as morphodynamics, surge, erosion, flooding and land use change) and visualisation techniques and interface development for the results. It acts as a step-by-step guide through the process of integrated assessment of coastal areas at a broad scale suitable for strategic coastal management and demonstrates the application of these methods using real case studies. It also considers the social science dimension and documents the process of engagement with a range of relevant stakeholders, institutions and the public who are responsible for and affected by coastal management decisions. This stakeholder dimension is an important element of the research and the final methods. The specific research content of this book is set in a broader UK and international context to illustrate the wide-ranging application of the methods used and lessons learned.

This book describes research undertaken by the Tyndall Centre for Climate Change Research on their Coastal Simulator from 2000 to 2012, as part of a major programme of work concerned with sustainable coasts (see Box 1.2). There were two phases of this work: Phase 1 from 2000 to 2006 and Phase 2 after 2006. Whereas Phase 1 necessarily focused on developing an understanding of coastal integrated assessment through the development of interdisciplinary partnerships, Phase 2 was able to extend the depth and breadth of the assessment. Where necessary, these phases are distinguished within the text.

**Box 1.2 Emergence of the Tyndall Centre Coastal Programme**

In 2000, in recognition of the need for more integrated responses to climate change, UK research councils funded an interdisciplinary research consortium, the Tyndall Centre for Climate Change Research, comprising a number of the UK's leading climate research institutions. This centre was funded by UK research councils until 2010 and continues today. When the Tyndall Centre for Climate Change Research was established, the importance of coastal issues in the context of responding to climate change was recognised in a Coastal Research Programme.[1] This research addressed these challenges at a scale that is relevant to coastal management, including considering the interrelated issues of erosion, flood risk management and habitat change, as well as linking this to stakeholder engagement and coastal governance implications.[2] While the starting point was climate change and sea-level rise, it rapidly became apparent that all the relevant drivers of coastal change and risk need to be considered to produce analyses of interest and relevance to coastal managers and policymakers. Further, integration across these different knowledge domains represents a major challenge, and integration has to be built into the process from the beginning if it is to be achieved. This book is based on this research into integrated assessment and its application to coasts.

[1] This continues as the Cities and Coasts theme of the Tyndall Centre (http://www.tyndall.ac.uk/research/cities-and-coasts).

[2] Other important coastal management issues such as water quality are pertinent to the UK and reflected on in a broader context in Chap. 14.

## *1.1.2 Overview of Book Structure*

Figure 1.1 provides an overview of the book structure in the context of the Tyndall Coastal Simulator. This chapter begins by considering the need for developing integrated responses to coastal management in the third millennium. Subsequently, a case study site in North Norfolk on the East of England, which is used throughout the book, is introduced before outlining the conceptual framework for our IA application in North Norfolk – the Tyndall Coastal Simulator. The North Norfolk case study provides a common demonstration site for individual components and crucially acts as a unifying real world case study. The study site was chosen as an exemplar of the challenges facing coastal stakeholders due to its long history of erosion and flooding and the fact that it is going through a major transition in coastal management strategy as part of Shoreline Management Planning (Sect. 1.3).

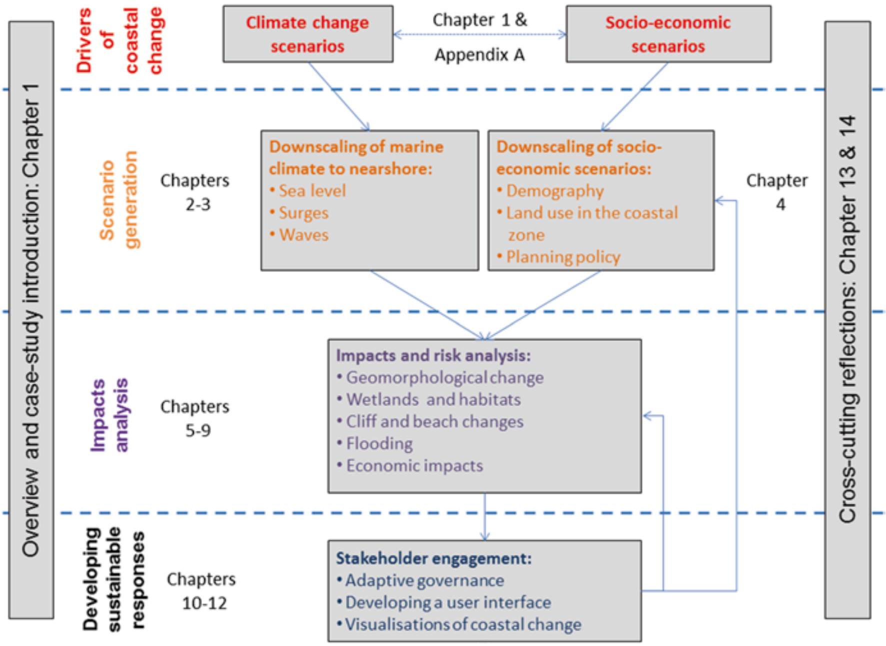


**Fig. 1.1** The structure of this book

Under current proposals, many clifftop communities with coastal defences will not have them replaced as they deteriorate. At Happisburgh, a village in North Norfolk, the defences have already been removed. This is causing an ongoing concern and debate in the region. Hence, North Norfolk provides a good study site to develop transferable lessons on the analysis of coastal change and hazards, as well as the issue of managing transitions which will be essential under climate and other pervasive environmental changes.

Following this introduction, Chap. 2 describes how global changes in marine climate may alter future sea level, storm surge and offshore wave conditions around the British Isles and especially North Norfolk. These changes in offshore conditions are used to drive a wave transformation model, described in Chap. 3, to understand the impact of these changes on storm surges and waves at the shoreline in North Norfolk. In both these chapters, sensitivities to key uncertainties such as climate model parameterization and the potential evolution of offshore sandbanks are explored. While Chaps. 2 and 3 downscale climate drivers to the spatial scale of the North Norfolk case study, Chap. 4 quantifies the effects of global and local socio-economic drivers on changes to residential and nonresidential development in East Anglia, with a focus on the coastal zone.

Chapters 5, 6, 7, 8, and 9 consider a range of impacts and risks associated with the climatic and socio-economic changes considered above. Chapter 5 uses an innovative behavioural systems approach to elicit qualitative insights about geomorphic behaviour of the North Norfolk case study site and neighbouring coastline. Chapter 6 describes a method to assess the likelihood of habitat degradation and loss as a result of coastal change. Long-term changes to the position of cliffs and beach volumes, under different climate scenarios and management regimes, are quantified in Chap. 7 while Chap. 8 describes the inundation modelling used to determine flooded areas under a range of storm surge events and defence breach scenarios. Chapter 9 brings the two preceding chapters together to evaluate future erosion and flood risks, in terms of expected economic damages, under different climatic and socio-economic scenarios. Furthermore, the effects of different management policies on these risks are compared.

Chapters 10, 11, and 12 reflect on a range of issues relevant to stakeholder engagement. Chapter 10 demonstrates, and considers the utility of, a range of visualisation techniques to convey coastal change. The process of developing a bespoke GIS-based graphical user interface, to integrate the results and engage with stakeholders, is described in Chap. 11. Chapter 12 considers current decision-making processes and how the management of transitions in the coastal zone could be more adaptive, equitable and effectively implemented. This chapter also highlights how stakeholders provided a crucial contribution to shaping the research programme and contributing to its impact.

Chapter 13 draws upon input from international authors to reflect on this body of research and consider the potential for broadscale coastal simulation around the world and the transferability of the Tyndall Coastal Simulator. Chapter 14 provides a summary of the key findings of the work, proposes a generic framework for integrated assessment in the coastal zone, including some key issues to consider, and outlines a manifesto for future research and application.

## 1.2 Coastal Management in the Third Millennium: The Need for an Integrated Response

Coastal management in the third millennium is increasingly characterised by large-scale, long-term policy conundrums. These usually involve multiple, often additive, risks and uncertainties and frequently relate to the prioritisation of economic, social, political or environmental objectives that can clash with differing public values. This standoff can paralyse the decision-making process. Analysis of the drivers and processes of change, and their associated uncertainties, requires an integrated approach to understand how risks interact and evolve through time. Furthermore, it is essential to bring different stakeholders together in order to develop a collective understanding of these processes and their consequences of long-term change as well as identify and reach a collective view with regard to suitable options for coastal management.

### 1.2.1 *Drivers of Coastal Change*

Interest and concern about the future of coastal areas is widespread (Valiela 2006). Coastal areas are a major focus for humanity, often with high population densities, growing urban areas and economic importance (Dasgupta et al. 2009; Lichter et al. 2011; Foresight 2011). They also host important coastal habitats and deliver a range of ecosystem services (Agardy et al. 2005; Nicholls et al. 2007). Climate change, and especially sea-level rise through the twenty-first century, is one major source of concern, but other drivers of change such as socio-economic change (e.g. urbanisation) or modifications of sediment budgets by various means are also important (Crossland et al. 2005; Wong et al. 2014). The major issues at the global scale are summarised in Box 1.3.

About 10 % of the total global population live within 10-metre elevation of sea level (Lichter et al. 2011). This is forecast to continue to grow rapidly through the twenty-first century mainly in coastal urban areas – of the world's 19 megacities (with a population of over ten million), 14 are situated in the coastal zone (UN Habitat 2008). Across the 136 large port cities considered by Nicholls et al. (2008a), the collective 2005 population of those cities could grow to 1.2 billion by the 2070s and the number of coastal megacities is estimated to increase from 14 to 31. Urbanisation is also occurring widely in the smaller coastal cities.

Concern about coastal areas is widespread and expressed by the activities of many international organisations. The Intergovernmental Panel on Climate Change (IPCC) has typically included a coastal assessment chapter in its Working Group II reports to date (Nicholls et al. 2007). The United Nations Environment Programme and the United Nations Development Programme are both focusing on coastal adaptation to climate change. The Intergovernmental Oceanographic Commission (IOC)

**Box 1.3 Key Coastal Trends at the Global Scale**

- Population
  - Growing coastal population (double global trends)
  - Urbanising coastal zone (new residents are urban)
  - Increasing tourism, recreation and retirement
- Subsiding, densely populated deltas, especially in urban areas
- Globalisation of trade and international shipping routes
- Degrading coastal habitats and declining ecosystem services' cause
- Increasingly costly coastal disasters
- Climate change and sea-level rise
- A reactive approach to adaptation

is conducting extensive work and guidance on responding to climatic and geologic coastal hazards. The International Geosphere-Biosphere Programme Land-Ocean Interactions in the Coastal Zone (LOICZ) is a dedicated international science project looking at coastal zones. The World Bank and regional development banks are also increasingly considering coastal issues including assessments of the Economics of Adaptation to Climate Change and the future of coastal cities in Asia (e.g. World Bank 2010; Westphal et al. 2013).

### *1.2.2 Adapting to Coastal Change*

Adaptation to environmental change is not a new phenomenon. Throughout history, people and societies have adapted their environments to cope with change and reduce environmental risks (van Koningsveld et al. 2008). Accordingly, when coastal changes have adverse consequences, human beings will adapt to those following a range of possible strategies.

As Klein et al. (2001) note, adaptation may take place in both planned and autonomous contexts. The former is a result of deliberate policy decisions and based on an awareness that coastal conditions have changed or are about to change and that action is required to return to or maintain a desired state, while the latter does not constitute a policy response to coastal stimuli, but is triggered by spontaneous changes in natural and human systems such as market-induced responses. Planned adaptation can be classified in a number of ways (e.g. Adger et al. 2007; Ford et al. 2013). The widely followed approach developed by the Intergovernmental Panel on Climate Change (IPCC) is focused on the adaptation measures themselves (e.g. Wong et al. 2014):

- (*Planned*) *Retreat* – all natural processes are allowed to occur, and human impacts are minimised by pulling back from the coast via land use planning, development controls etc.
- *Accommodation* – all natural system effects are allowed to occur, and human impacts are minimised by adjusting human use of the coastal zone via flood resilience measures, warning systems, insurance (providing the capacity to repair and rebuild) etc.
- *Protection* – natural system effects are controlled by soft or hard engineering (e.g. seawalls, breakwaters, nourished beaches and dunes), reducing human impacts in the zone that would be impacted without protection.

A critical and overarching challenge of climate change is how and when to adapt in the face of scientific evidence: What are the thresholds for action? How are the impacts and consequences valued? And how should adaptation be implemented (Adger et al. 2009)? The adaptation challenge also requires not just incremental but also transformational changes (Moser et al. 2012). Planning for this kind of change