Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/envsci

Maps, laws and planning policy: Working with biophysical and spatial uncertainty in the case of sea level rise

Justine Bell [a], *Megan I. Saunders* [b], *Javier X. Leon* [c], *Morena Mills* [c], *Andrew Kythreotis* [d], *Stuart Phinn* [c], *Peter J. Mumby* [f], *Catherine E. Lovelock* [g], *Ove Hoegh-Guldberg* [h], *T.H. Morrison* [e,*]

[a] *TC Beirne School of Law, University of Queensland, Australia*
[b] *The Global Change Institute and the Marine Spatial Ecology Lab, School of Biological Sciences, The University of Queensland, Australia*
[c] *The Global Change Institute and the School of Geography, Planning and Environmental Management, The University of Queensland, Australia*
[d] *Cardiff School of Planning and Geography and Sustainable Places Research Institute, Cardiff University, United Kingdom*
[e] *School of Geography, Planning and Environmental Management, The University of Queensland, Australia*
[f] *Marine Spatial Ecology Lab, School of Biological Sciences, The University of Queensland, Australia*
[g] *School of Biological Sciences, The University of Queensland, Australia*
[h] *The Global Change Institute, The University of Queensland, Australia*

ARTICLE INFO

Available online 18 September 2014

Keywords:
Sea-level rise
Uncertainty
Mapping
Law
Policy
Planning

ABSTRACT

Rapid sea level rise over the 21st century threatens coastal settlements and populations worldwide. Significant land-use policy reform will be needed to mitigate exposure to hazards in the coastal zone. Sea-level rise maps that indicate areas that are potentially prone to future inundation are a valuable tool for policymakers and decision makers. However, errors, assumptions, and uncertainties inherent in spatial data are not often explicitly recognised or communicated. In 2011, the state of Queensland, Australia, published a series of 'state of the art' sea-level rise maps as part of its coastal planning regime. This article uses the Queensland coastal planning regime as a case study to explore how errors, uncertainties and variability in physical, geographical and biological processes in the coastal zone pose challenges for policy makers. Analysis of the case study shows that the use of spatial data in sea-level rise policy formulation is complicated by the need to: (1) acknowledge and communicate uncertainties in existing and projected rates of rise; (2) engage in site-specific mapping based upon best available scientific information; (3) incorporate probabilities of extreme weather events; (4) resolve whether coastal engineering solutions should be included in mapping; (5) ensure that mapping includes areas required for future ecosystem migration; (6) manage discretion in planning and policy decision-making processes; (7) create flexible policies which can be updated in line with scientific developments; and (8) balance the need for consistency with the ability to apply developments in science and technology. Scientists working with spatial data and governments

* *Corresponding author*. Tel.: +61 (7) 3365 6083.
E-mail address: t.morrison@uq.edu.au (T.H. Morrison).

http://dx.doi.org/10.1016/j.envsci.2014.07.018

developing and implementing coastal planning policies can recognise, communicate, and seek to overcome uncertainty by addressing these factors.

1. Introduction

Maps today are central to the world of government and public policy. New Geographical Information Systems ('GIS') and digital mapping technologies allow a previously unimaginable amount of social and environmental information to be linked to a geographic location with unprecedented clarity. New computer developments also advance the ability to analyse relationships among different kinds of data. This ''legibility'' is one of the central distinctions between the premodern and modern state: ''The premodern state was, in many crucial respects, partially blind; it knew precious little about its subjects, their wealth, their landholdings and yields, their location, their very identity. It lacked anything like a detailed ''map'' of its terrain and its people. It lacked, for the most part, a measure, a metric, that would allow it to ''translate'' what it knew into a common standard necessary for a synoptic view'' (Scott, 1998, p. 2).

Modern policymakers, communities and media commentators by contrast find the simple graphic portrayal of complex information extremely powerful in understanding and making decisions. Yet, while the scope of mapping capabilities is expanding, problems remain. These problems include: operational effectiveness of satellite imagery, privacy issues, evidential use in courts and by regulatory bodies, data transfer issues, use for broader public communication, competing local knowledges, use by environment and land use advocates, and issues with scientific uncertainty (Purdy, 1999; Robbins, 2003; McCusker and Weiner, 2003). One of the most difficult aspects of all of these is *scientific uncertainty*. Whereas scientists are used to working with uncertainty and complexity, the general public, environment and land use advocates and policy makers are often more inclined to seek certainty and often deterministic solutions (Bradshaw and Borchers, 2000; Waite et al., 2009; Bebbington, 2012). The problem of uncertainty is nowhere more challenging than in the case of sea level rise (SLR).

Global sea-levels rose by approximately 20 cm over the 20th century, and the rate of rise is likely to accelerate throughout the 21st century due to global warming (Nicholls and Cazenave, 2010). Human settlements have traditionally favoured the most hazardous areas within the coastal zone, with at least 600 million people living less than 10 m above current sea-level (McGranahan et al., 2007). Consequently, calls for changes to land-use policies to incorporate SLR impacts are increasingly common (e.g. IPCC, 2007; Revell et al., 2011), and data to inform these policies are increasingly needed (e.g. Tribbia and Moser, 2008; Hunt and Watkiss, 2011).

This article discusses and analyses the challenges of using spatial data projecting SLR in land-use planning for new developments. To illustrate the planning and policy challenges associated with SLR we draw on a case study from Queensland, Australia. The paper proceeds as follows. First, we provide an overview of the biophysical and spatial uncertainties in SLR policy. This includes uncertainties in sea-level observations and forecasts, SLR modelling techniques and the potential impacts of SLR on coastal systems. We then analyse how a real-world planning case has sought to respond to these uncertainties. The State Government of Queensland, Australia, was one of the first jurisdictions to incorporate mapping methods into their coastal plan and therefore provided an ideal case study. Analysis reveals that while the Queensland Coastal Plan provided certainty for stakeholders by integrating mapping into land-use planning, the high degree of uncertainty associated with the factors outlined below continues to influence how sea-level rise is understood to impact the population and infrastructure of coastal areas, and warrants further consideration by scientists and policymakers. From this analysis we distill 8 general principles and recommendations for scientists and policymakers working with biophysical and spatial uncertainty in the case of SLR.

2. Biophysical and spatial uncertainties in SLR policy

There is general agreement that the massive global impact of SLR on coastal populations can be mitigated and/or adapted to through effective land-use planning. Maps of 'at-risk' areas can be identified from analysis of spatial data and used as a tool for stakeholders to better understand potential impacts, create better planning policies, and undertake other associated decision-making processes.

Maps of SLR can vary from simple 'bathtub' models which indicate locations of inundation based on present topography, through to more realistic inundation scenarios incorporating responses of vegetation and the shoreline to rising seas. Furthermore, SLR mapping can be integrated with more general coastal hazard models, which may indicate locations prone to storm surge or river flooding. SLR maps can also reduce uncertainty by delivering science to policy-makers in an accessible format. Evidence-based spatial data can also minimise poor decisions by providing a consistent basis for decision-making (Tribbia and Moser, 2008).

This is dependent, however, on appropriate supporting information on the methods of production and accuracy, and how effectively uncertainties have been dealt with. In the case of SLR, there are a number of uncertainties critical to policy and plan development. These include uncertainties in sea-level observations and forecasts, uncertainties in SLR modelling techniques, and uncertainties relating to the potential impacts of SLR on coastal systems. These are outlined in detail below.