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Dilemmas of modelling and decision-making in environmental research

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ABSTRACT

Multiple dilemmas confound social-ecological modelling. This review paper focuses on two: a modeller's dilemma associated with determining appropriate levels of model simplification, and a dilemma of decision-making relating to the use of models that were never designed to predict. We analyse approaches for addressing these dilemmas as they relate to shallow coastal systems and conclude that wicked problems cannot be adequately addressed using traditional disciplinary or systems engineering modelling. Simplified inter- and trans-disciplinary models have the potential to identify directions of system change, challenge thinking in disciplinary silos, and ultimately confront the dilemmas of social-ecological modelling.

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1. Introduction

This paper examines two dilemmas prevalent in environmental research: a modeller's dilemma and a dilemma of decision-making. Modellers' face many dilemmas, but a central issue relates to tradeoffs between simplifications that are necessary to represent certain characteristics of a system, and the need also to represent intricacies within the system in sufficient detail in order to produce outputs that are useful in some way. This dilemma is particularly challenging in the case of social-ecological systems, which have interacting physical, ecological, and social components. How should these components be treated within models? A related

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dilemma confounds environmental management: models not intended for decision-support have nevertheless become a crutch on which decision-making often relies, with insufficient critical consideration of model limitations in the planning process, and application of models in ways that modellers may not have intended (Groeneveld et al., 2017; Kelly et al., 2013). Improved environmental planning requires progress in resolving these related dilemmas.

This paper reviews literature with an aim of identifying approaches of addressing and minimising these two dilemmas confronting modellers and decision makers. The dilemmas are recognisable across much environmental research, but we focus on shallow coastal systems, particularly estuaries, which are highly valued for providing essential ecosystem services and contributing to wider marine ecosystem function, but are also vulnerable due to their physical properties (e.g. shallow water depths) and processes such as increasing population, urbanisation, and changes in climate and land use (McNamara and Werner, 2008a; IPCC, 2014).

Box 1 sets out some of the key concepts used in this review paper. The approach has involved critiquing literature from diverse fields pertaining to social-ecological modelling, wicked problems, trans- and interdisciplinary research, ABM, estuarine modelling and estuarine management. The review is concerned with determining appropriate methods for approaching uncertainty in complex social-ecological systems and selecting suitable techniques for modelling feedbacks between, and interactions within these systems, as set out in Schlüter et al. (2012), but with a specific focus on how the two dilemmas impact upon model form, function and use.

Systems engineering models differ from the other definitions in Box 1 as they represent a single-discipline way of approaching a problem. This type of model represents a traditional approach to environmental management, as opposed to a holistic post-normal science approach. Schlüter et al. (2012) set out the main differences between traditional and social-ecological systems approaches to the management of human-environment systems, chief among which is that traditional methods utilise a ‘command and control’ technique whereas social-ecological systems management aim to enhance system resilience. The three other concepts are fundamentally intertwined; the post-normal science approach is a methodology that often incorporates transdisciplinarity when attempting to address wicked problems in complex social-ecological systems. This review was undertaken using a post-normal science approach, reviewing literature from the fields of social-ecological modelling, wicked problems, trans- and interdisciplinary research, agent-based modelling (ABM), estuarine modelling and estuarine management. Our review is concerned with determining appropriate methods for approaching uncertainty in complex social-ecological systems and selecting suitable techniques for modelling feedbacks between and interactions within these systems, as set out in Schlüter et al. (2012), but with a specific focus on how the two dilemmas impact upon model form, function and use.

The review paper focuses on shallow coastal areas that occur at the downstream end of terrestrial drainage systems and are highly exposed to anthropogenically-derived pollution (Davies, 2015; Millennium Ecosystem Assessment, 2005a). Worldwide, shallow coastal ecosystems are undergoing rapid changes creating a research imperative to understand the complex interrelationships between ecological, physical and social processes that drive environmental change (e.g. McGranahan et al., 2007; Moser et al., 2012; Nicholls et al., 2011; Small and Nicholls, 2003). Rapid urbanisation and increasing population in coastal areas can stress the existing social-ecological systems while climate change is making these areas increasingly less suitable to sustain human populations (Crossett et al., 2004; Moser et al., 2012). The consequences of sea-level rise are already being felt in some of the least developed countries such as Bangladesh where some 46% of the population lived within 10 m of mean sea level in 2007 (McGranahan et al., 2007). However, sea-level rise is a global problem with 10% of world population concentrated in only 2% of the land area (McGranahan et al., 2007) and 2.4% of global population at risk of displacement by sea-level rise by the end of the 21st century (Nicholls et al., 2011). Anthropogenic alteration of natural systems makes natural processes (e.g. rainfall, flooding, storm surge) more complex by introducing runoff channelisation, water treatment and discharge, interfering with natural flow regulation. In particular, urbanised systems experience exacerbated impacts of relatively common events due to a combination of expanded impervious surfaces and channelised drainage networks (Baird, 2009; Schiff and Benoit, 2007).

Computational models can help understand these complexities and should therefore be an important resource for decision-makers in avoiding or mitigating impacts that reduce environmental, ecological, social and economic resilience. However, progress has been limited by the two dilemmas. Modellers are confronted with the challenge of how to adequately represent the physical, ecological and social dimensions of shallow coastal systems, and decision-makers are challenged by how to utilise models that are designed for social learning or developing system understanding, when a predictive model is desired for decision-making purposes.

Our aim in this paper is to reconcile the two dilemmas by identifying optimum modelling approach(es) for fully integrated consideration of social, ecological and geophysical systems in a single model. To accomplish this, we review literature so as to explore the potential for post-normal science, transdisciplinarity and particularly ABM to understand complex environmental problems and suggest a way forward. The review paper is structured as follows: first, the nature of the two dilemmas are elaborated and environmental problems are categorised as tame, complicated, and wicked (see Box 2); second; literature relevant to modelling shallow

Box 1
Terminology.

Post-normal science approach – A “systematic, synthetic and humanist” (Funtowicz and Ravetz, 1993: 739) approach to science in which human-environmental systems are viewed and treated holistically. The approach explicitly recognises human agency in an environmental system, and stakeholder values and opinions are taken into account. This is considered an appropriate approach for tackling wicked problems (Konig et al., 2017).

Social-ecological system - We use the term ‘social-ecological’ system to recognise that there is a fundamental connection between ‘the human’ and ‘the natural’, but that each functions as an independent system.

Systems engineering models – a ‘socio-technical’ approach to modelling requires as many facets of system form as possible to be included in a highly complicated model so as to streamline a system for human benefit (Baxter and Sommerville, 2011).

Transdisciplinarity - pertains to a research methodology where stakeholders and researchers from multiple disciplines come together during a research project in order to facilitate highly integrated research (Klein, 2014)

Wicked problem - an issue beset by uncertainty, plurality, and interdependence and that are unable to be convincingly defined (Rittel and Webber, 1973).