Introduction

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This book began life as a review of environmental scenario modelling undertaken by the Swedish University of Agricultural Science (SLU) on behalf of the Swedish Environmental Protection Agency (Naturvårdsverket) and the Swedish Agency for Marine and Water Management (Havs och vattenmyndigheten) (Sang & Ode-Sang, 2015). That report focused on several categories of problems which together represent coupled systems with impact on the 16 Environmental Goals set out by the Swedish Government (Prop. 2009/10:155) as its legislative response to domestic and international environmental obligations such as the UN Sustainable Development Goals (United Nations, 2015a). The book extends that core to provide global context, via a set of case studies drawn from around the world and to look beyond simply modelling the problem to how such models can help identify solutions, particularly where these rely on natural processes, i.e. nature-based solutions (NBS).

WORKING MODELS FOR WICKED PROBLEMS

The recent special report from the Intergovernmental Panel on Climate Change (IPCC, 2018) represented a notable shortening of the time frame by which climate change is expected to have serious impacts. Models which had to date tended to focus on a 100-year horizon or longer now predict significant effects by as early as 2050, well within a typical strategic planning remit. The IPCC report also gathered together research on the potential impact of climate change for human and natural systems touching on every aspect of the ecosystem services which sustain quality of life for people, such as: the marine environment and fishing resources; freshwater ecology and water resources for drinking and irrigation; impacts on biodiversity, agricultural systems and food security; as well as direct threats to human life from extreme weather – as further emphasised by the Fourth National Climate Assessment from the USA (USGCRP, 2018).

Sea-level rise (SLR) clearly has huge significance for the population it will displace, with many major cities already facing difficult decisions as to what can (or should) be protected and what must be given up to the sea. However, its role as the central message for the impact of climate change has perhaps served to obscure from public discourse the complexity and intractability of the many other issues related to climate change but also other drivers. It is in the combination of pressures, some with contradictory mitigation options, that the real difficulty lies. For example, if the only issue were SLR, then a planned 'retreat' to higher ground over the course of a century might seem like a reasonable solution. However, if the land which this would urbanise is prime agricultural land and food security is also a major concern, then the decision becomes rather harder. To compound this, in addition to climate change, there are other trends to contend with over the same timescale such as population growth (United Nations, 2015b) and urbanisation (CCFLA, 2015). In the past, urban expansion while protecting other land resources might have been met by land reclamation from the sea, yet SLR makes that more expensive and contentious (Nicholls, 1995) and further impacts biodiversity and related ecosystem services (Yu et al., 2017) already under pressure from climate change (Bakker et al., 2016), as does conversion of existing land to agriculture (OECD, 2008; Kanianska, 2016). 'Caught between urban sprawl and the deep blue sea' densification of cities might seem an obvious strategy to accommodate more people. However, the higher risk of extreme temperatures (Mora et al., 2017) means this must be achieved without exacerbating the urban heat island effect (Musco, 2016).

It is to deal with this kind of 'wicked' problem, where the complexity is impossible to intuitively grasp and the trade-offs significant, that planners are increasingly turning to computer models to help. That alone would suggest this book to be apposite reading, but there is actually a far harder planning problem to be found in the gaps between these intersecting scenarios: uncertainty. The scenarios of global drivers contain considerable uncertainty even within the scientific consensus. Furthermore, even if the chances of a particular scenario are in general quite well modelled, the risk of a 10-year, 100-year or 1000-year event are still probabilities; when they may happen is uncertain. So planners are faced with highly contentious problems around how much resources to commit today in order to create resilience to future events. For some of these issues, such as storm damage, a balance can be struck between protective measures such as sea walls and short-term emergency response measures. Other issues, such as planning for migration, are different in that they may present as non-linear but gradual changes in typical annual migration rates or a sudden event such as refugees fleeing a war or natural disaster. Both require a wide variety of facilities such as accommodation, health care, schools and so on, facilities which are likely to need long-term investment. Spatial planning of our landscape and cities takes time, yet it is increasingly clear that the scenarios to plan for are changing more rapidly and have greater uncertainty than in the past, while solutions must operate within a narrowing envelope of options.

Decisions such as what to protect from SLR and what to abandon are highly contentious politically, particularly if it involves asking people already lacking in resources to commit these for (maybe someone else's) possible benefit some years into the future. NBS can help to overcome such issues by offering rapidly realised benefits such as food or income, while also mitigating environmental problems for the future. However, 'win–win' solutions are not always obvious. So if the 'best-laid plans' are not to be simply overtaken by more immediate interests, it is important that models which help decision-makers understand the challenges also help them achieve consensus around a course of action. That is why it was considered so important that this book includes the societal dimension, in terms of how to communicate models, how to model societal responses and how to integrate models into a participatory process through methods such as geodesign

(Steinitz, 2012) to find consensus around plans with sufficient detail to be workable and sustained over time.

The book opens with a chapter sharing the extensive experience of Miller et al. as to how stakeholders ranging from government organisations to ordinary citizens can become part of understanding problems and planning solutions with the help of modelling and visualisation techniques. Chapter 2 (Ge and Polhill) then considers how human behaviour can be included within models of the systems to learn how the whole system can be directed towards some desired outcome. Chapters 3, 4 and 5 review in detail available models for three key biophysical systems – soil (Aitkenhead), freshwater (Dunn) and marine (Akoumianaki and Capet). Chapter 6 picks up several of the same themes as these, but takes a more specifically planning-focused view, looking at issues relating to both fresh- and sea water flooding (Sang). Deak Sjöman and Johansson (Chapter 7) look at similar NBS to Chapter 6 (i.e. green infrastructure), but show how it can be utilised in relation to urban climate management and thus apply a quite different set of models to the same NBS.

By this point, a potentially bewildering range of models has been set before the reader (see Appendix for a list), Chapter 8 (Sang and Aitkenhead) looks at how the overall process may be supported by a spatial data infrastructure as well as the use of data mining as an alternative (potentially more generic) approach to modelling a range of issues.

Chapter 9 (Gottwald, Janssen and Raymond) looks to the future of planning, considering how this knowledge might be brought together to include both modelling and public participation within a geodesign process to solve 'wicked' problems in spatial planning and environmental management. In particular, this chapter exemplifies the value which may be obtained from using simpler models within a participatory setting.

In addressing models relevant to this broad range of subjects, many mainstream modelling methodologies are discussed. However, the reviewers were asked to focus on models which would be likely to be of particular relevance to an applied policy setting across a range of scales. The review should be read in this light; it is not intended to form a comprehensive collation of all models on a given subject, and the emphasis is on practical, rather than experimental, options. Where reviewers have provided recommendations or other evaluations of particular models this is their professional opinion given within this context.

THE SCALE OF THE PROBLEM: UNCERTAINTY, COMPLEXITY AND CONFLICT IN ECOSYSTEM SERVICES

For at least 20 years there has been a growing political recognition of the interdependence between different ecosystems and humanity's dependence on Ecosystem Services (ES), as encoded within the Convention on Biological Diversity (CBD, 1994), Arhus Convention (UNECE, 1998) and the European Landscape Convention (Council of Europe, 2000). This has focused interest on understanding systems at the landscape scale, that being the entire system over an 'area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors' (Council of Europe, 2000). The Millennium Ecosystem Assessment sought to provide a picture of the current state of ES around the world as to the existing degree of environmental degradation, but also its likely resilience to future scenarios (Peterson et al., 2003; Hassan et al., 2005). In parallel to this 'policy'-level interest, increasing knowledge of the environmental processes in combination with rapidly increasing computer power has allowed systems to be modelled in much greater detail and over much larger scales than was possible only a decade ago. These models may explore large data sets ('data mining') to find subtle relationships or may simulate biophysical processes such as flooding, soil nutrient flow or crop growth to provide information on a detailed scale or to assess the strategic impact of future scenarios (Aitkenhead et al., 2011; Demir & Krajewski, 2013; Negm et al., 2014). It has also been increasingly recognised that people are part of these systems, are important drivers of change, and that solving complex environmental problems may be more effectively achieved by understanding people's motivations and attitudes and influencing public opinion (Peterson et al., 2003).

Figure I.1 provides an illustration of how different components of a system may be addressed by different types of models, with the output of some providing inputs in terms of scenarios on which other models may run. However, even this simple situation shows how complexity quickly accrues at the landscape scale. For example, climate change may be taken as an externality, with current trends providing some basic scenarios, or alternative climate scenarios may be developed based on statistical trends plus expert knowledge encoded into simulations. This choice influences the freshwater and marine systems and both options carry their own potential sources of error. Historical data may not hold true in the future, while expertise may be incorrect; in both cases the levels of rainfall or SLR will also reflect some imprecision. These errors thus propagate to the flood models and the predicted impact of flooding on a range of other risks from food security and electricity supply to soil loss and biodiversity. Thus, models need to be selected which provide effective knowledge about individual systems, but an alternative might be selected in order to minimise error propagation at an integrated landscape scale.

Attention must therefore be paid to the purpose of the model. For example, will anthropogenic effects be encoded and incorporated within the model, where one may face issues of quantifying vague data, or will the model be used to inform stakeholder opinion, where the risk is that those with less expertise may see precision as validity.

Figure I.2 shows a 'meta-model' of the system illustrated in Figure I.1, with a focus on the role of the modelling stages as illustrated by the colour of the links between landscape issues. For example, CO_2 emissions may be a driver of climate change; which emission scenarios to use could be established via participatory methods; the climate model output then acts as one driver of models as to future land use and thus production of food, which acts as a limiter to how large an

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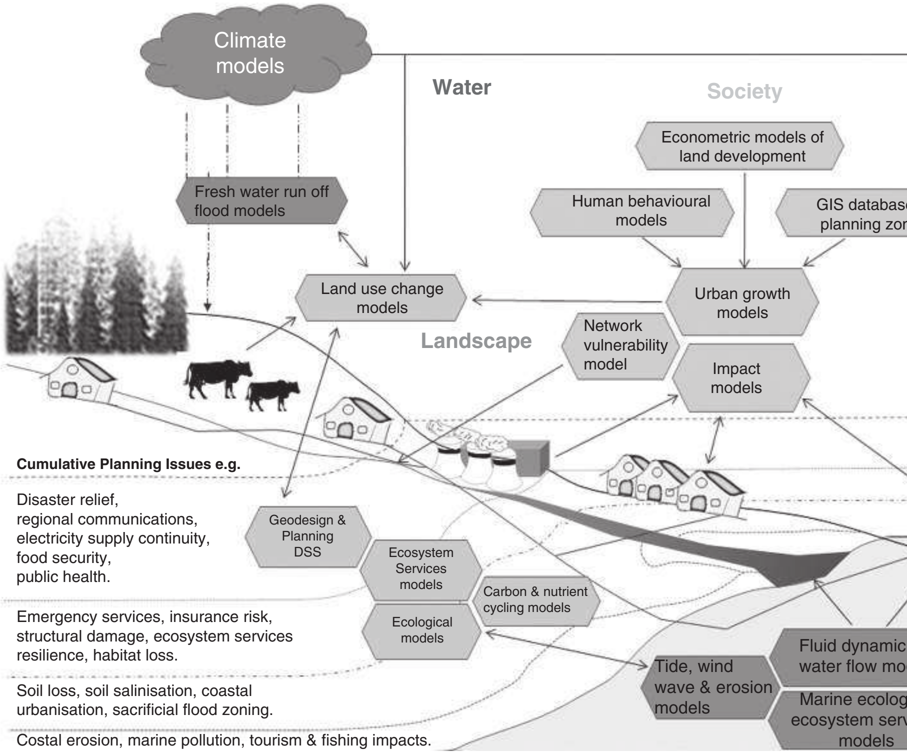

FIGURE I.1 A coupled socio-environmental system. (A black and white version of th colour version, please refer to the plate section.)

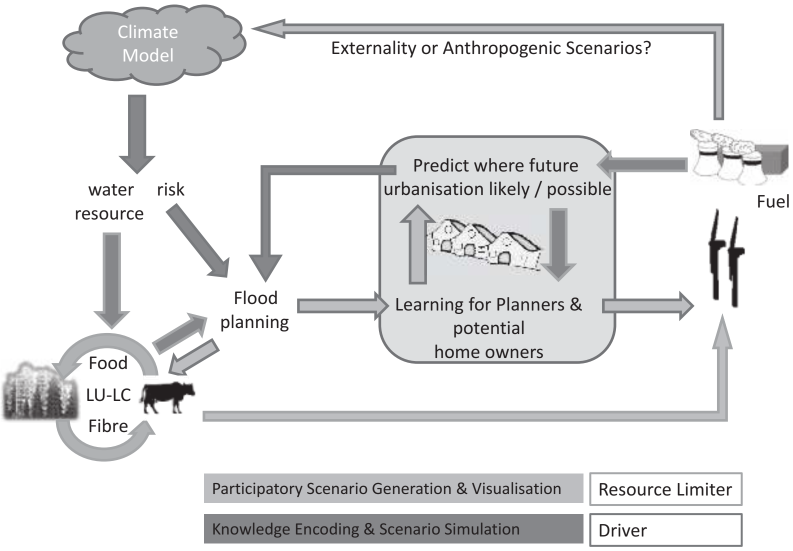

FIGURE I.2 A meta-model of a coupled socio-environmental system. (A black and white version of this figure will appear in some formats. For the colour version, please refer to the plate section.)

urban population can be sustained affecting future energy needs and thus emissions, and so on.

Both of these figures are forms of conceptual model, sitting at different levels of complexity, emphasising different aspects of the same system and serving different ends. The first might serve as a schematic for how proposed models will be integrated and the questions, uncertainties and feedback links they will address. The second may support discussion with policy makers as to what ecosystem services are at stake and how they might be protected. The same conceptual model is unlikely to serve both purposes well. Computer models, while necessarily more complex (in order to be specific in their predictions), nonetheless must also reflect a particular higher-level conceptualisation in order to serve a particular audience or purpose, and so exclude some aspects in order to emphasise others. From an NBS point of view that might, for example, mean focusing on those natural elements of direct relevance to people, but in a complex natural web of functions defining what is especially relevant is difficult. Sometimes that might be achieved by encoding expert knowledge into the model about how a system works, or finding statistical thresholds beyond which a system changes, or by simply asking people what they consider to be most important. Whichever method is used, different and potentially conflicting priorities arise. Modelling can help to make such considerations unambiguous and to understand the implications a given decision may have for the system as a whole.

PRECISION, PARTICIPATION AND PRAGMATISM

The book is parenthesised by chapters focusing on public participation and planning. Chapter 1 explores in depth the various methods by which public participation has been included within the modelling process itself and how modern visualisation technology is making the subject matter more intuitive and engaging. The aim is to generate a scenario are based on discussions between experts and other stakeholders as to what factors should be considered and what outputs shown (for example, the worst or best case).

Knowledge encoding is where information is first gathered, e.g. from statistical databases or via stakeholder consultation, and then its implications distilled and encoded into a modelling method. The method may be simple (e.g. GIS overlay) or complex (e.g. cellular automata), but the underlying principle is to generate an explicit and repeatable model leading to a scenario which is as representative of our knowledge as possible. That is not necessarily the same as objectivity – models may take one or indeed many perspectives on a problem – but it does mean that the evidence base is explicit and open to question. Social Science and increasingly the humanities have become integral parts of the modelling process, be that in providing methods to understand different sectors of public opinion (Peterson et al., 2003; Sang & Birnie, 2008), or building expert knowledge into models (Pricea et al., 2012), or even simulating human and wildlife decision-making through cellular automata or agent-based models (ABMs) (McLanea et al., 2011). Chapter 2 specifically addresses how ABMs represent decision-making, what ABMs show and how they are being used to address environmental management. It is notable that all chapters emphasise the important role stakeholders have to play in improving the accuracy or relevance of the models they review. Combining socio-economic and biophysical models has also become an important potential tool in policy and planning by allowing examples of future scenarios to be developed based on robust evidence, and communicated through intuitive visualisations (Miller & Morrice, 2006). In this way, stakeholders can be shown the potential impact of developments, or potential future problems if we (collectively) fail to adapt our behaviour to use common pool resources sustainably (Ostrom et al., 1994).

The emphasis on the human dimension throughout this book is not at the expense of attention to detail on the modelling of natural phenomena. Chapter 3 is a highly detailed review of soil modelling. One of the most prolific fields of modelling, soil models range from pragmatic 'rules of thumb' about likely typical soil categories to highly sophisticated models for the interaction between specific soil characteristics and physical and biotic forces. This chapter provides key examples of the principal methods plus the likely requirements to implement each and considers the implications of this for their relevance to application in determining real intervention with NBS. Chapter 4 provides a deep analysis of modelling NBS for managing freshwater resources covering the principal advantages and issues for different modelling approaches across a range of different scales for several NBS including provision of safe drinking water, integrated river basin management, stream chemistry and pollution management. Chapter 5 explores marine models and ecosystem services assessment frameworks for enhancing coastal adaptation and ensuring ocean sustainability. Modelling marine ecosystem change and processes faces particular difficulties. In addition, there is a scarcity of comparisons between