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Research Paper

Increasing user awareness in environmental decision models through interactive steering

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ABSTRACT

The ability to anticipate global environmental changes will significantly reduce the biophysical, social and economic costs associated with eventual adaptation. An abstract modelling process often supports evidence-based decision making. Nonetheless, there are inherent difficulties for stakeholders in understanding complex scenario modelling. It is important to develop communication systems that support understanding of complex spatial decision models. This research used a Land Use Allocation (LUA) process, in the context of future agricultural land use under climate change scenarios, as a study in complex environmental modelling. The primary objective was to identify interactive options that can reduce the difficulty stakeholders have in understanding such an environmental model. A Spatial Model Steering (SMS) exploratory framework enabled users to explore the effects of climate change on land suitability, as a key aspect of LUA, and thus increase their perception of the influence of key factors. Within this framework, a user can visually steer the key climate, and climate response, related factors (rainfall, market price, and carbon price) of the LUA model, explore and compare "what if" future land use opportunities by adjusting these factors and visualize the spatial distribution of land suitability outcomes. The research compared the SMS approach with traditional methods of model output presentation and established that, with this approach, users develop both increased understanding of the key factors governing the underlying models and greater awareness of the uncertainty in the outcomes. This result provides a basis for the future use of complex spatial decision models within public debate.

1. Introduction

In the context of landscape and environmental planning, decision makers and stakeholders (people who have a vested interest in the outcome of such decisions) should be aware of the risks and consequences of their choices. This should hold true even when faced with the highly complex decisions that arise when planning for the future under complicated and uncertain environmental challenges (Reed et al., 2009). Complex, interrelated global environmental issues include population growth, water shortages and climate change. To aid decision-making, complex models are often created in an attempt to simulate the influence of factors provoking environmental change and hence to anticipate the effects of a range of decisions. However for many potential users, including fellow developers, such models, and their inherent uncertainty, are poorly understood and hence not fully trusted (Dunford, Harrison, & Rounsevell, 2015). Moving towards greater trust in, and use of, such models depends upon giving users a greater awareness of the role of different factors in the model outputs, and in the levels of uncertainty associated with those outcomes.

Communicating the interactions of factors underlying environmental models is not an easy task, and should be done in an integrated, holistic manner (Pahl-Wostl, 2007). Even if large data models can be more easily understood by the "divide and conquer" approach (Moody, 2002), presently there is no satisfactory way to completely describe what a user of a certain model knows about it (Law, Roto, Hassenzahl, Vermeeren, & Kort, 2009). Humans have two, sometimes conflicting, approaches to processing information, one is experiential processing, and the other is analytical processing (Epstein, 1994). Experiential processing involves direct, vivid experience by the learner, which can have a strong emotional impact and more easily results in action and behaviour change (Fagerlin, Wang, & Ubel, 2005). On the other hand, analytical processing involves abstraction, cognition, and analysis of data sets (Epstein, 1994). While analytical processing is the basis for understanding of most complex models, it is increasingly evident that most people, especially those not scientifically sophisticated or fully conversant with a particular discipline, rely extensively on experiential processing for a better understanding of complex issues like factor contributions and risk in climate forecasts (Marx et al., 2007). It is

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overly simplistic to see the farmer as reliant on experiential processing while the views of the scientist, and the planner, are supported by analytical processing, but this distinction may help in understanding the need for systems which can support both points of view. It is evidently important to develop communication systems that support these two modes of processing to engender a complementary understanding of complex models (Godek and Murray, 2008; Marx et al., 2007; Miller, 2011; Reed et al., 2013). This dual approach may be even more relevant when it comes to communication of uncertainty, or lack of confidence, in the informationrevealed by a given modelling system (Jakeman, Chen, Rizzoli, & Voinov, 2008; Pahl-Wostl, 2007).

For example, one of the most difficult challenges that the scientific community faces when addressing and communicating climate change research lies in the inherent uncertainty present in all future projections. We, therefore, use climate change and its potential influence on land use decision making as the central example for this paper. Uncertainty arises not only from the intrinsic complexity of climate models but also because of the compound nature of future climate predictions and associated outcomes. These outcomes must be based on earlier predictions, which at the same time are based on current forecasts. As a result, the uncertainty of future projections increases substantially as the time frame increases (Allen & Ingram, 2002; Tebaldi, Smith, Nychka, & Mearns, 2005). Accordingly, there is a need for a comprehensive approach to communication of climate change models and uncertainty assessment (Mann, 2009). It is important to note that the concept of uncertainty is used in different ways across different fields, reflecting the underlying way of thinking that is typical of a certain discipline (refer to Walker (2003) for a review on this subject). This research will use the definition, quoted in the next paragraph, relevant to the environmental modelling and scenario forecasting field of knowledge (Klauer & Brown, 2004; Refsgaard, van der Sluijs, Højberg, & Vanrolleghem, 2007).

There are inherent limitations in our capability to predict future environmental conditions. When scientists use current knowledge to project certain conditions into the future, this current knowledge cannot describe a future outcome completely. Therefore, "a stakeholder is uncertain if s/he lacks confidence about the specific outcomes of an event. Reasons for this lack of confidence might include a judgment of the information as incomplete, blurred, inaccurate, unreliable, inconclusive, or potentially false" (Refsgaard et al., 2007). This uncertainty assessment should be present not only at the beginning, in the proper identification of all uncertainty sources, but also in all stages of the developing cycle (Refsgaard et al., 2007). A useful taxonomy for analysing uncertainty is:

- Bounded uncertainty: an uncertain event is composed of individual outcomes that are 'known' to the extent that the range of possible outcomes can be assessed quantitatively.
- Unbounded uncertainty: while components of these uncertain events cannot be quantified in any undisputed way, their plausibility or the convincingness of the evidence can still be assessed (Refsgaard et al., 2007).

This research focuses on two subsets of uncertainty, one within each of these broader categories:

- When taking decisions under an Environmental Integrated Modelling Framework EIMF (Kassahun et al., 2010; Rizzoli et al., 2008) or through a Spatial Decision Support System (SDSS), users may have low confidence in their perception of key factors and the way in which these influence outcomes of the modelling. This is a kind of unbounded uncertainty with a focus on understanding model inputs.
- In relation to model outputs, users may have difficulty synthesizing multiple outputs, based on different input parameters, and interpreting the degree of output variation and how this is distributed across the landscape (e.g. in this experiment stakeholders were asked which areas showed the most variation in land suitability). Although bounded, this "non-traditional" uncertainty assessment is often left out or not properly taken into account when assessing the overall performance of complex modelling frameworks (Pahl-Wostl, 2007; Refsgaard et al., 2007).

To better understand how people's awareness of, and hence confidence in, complex models can be enhanced, this research tested two different approaches to user interaction with an environmental assessment process. The first approach was the traditional linear model paradigm (setup → run in a "black box machine" → analyse results → repeat process). In the second approach, spatial model steering (SMS) allowed dynamic steering of a model's outcomes (see Ninõ-Ruiz, Bishop & Pettit (2013) for technical details). These approaches were tested in the specific context of land use allocation (LUA), based on land suitability analysis (LSA) under different climate change scenarios.

We believe that the SMS approach brings many advantages − to landscape planning and environmental management more broadly. Instead of analysing results in a separate post-processing step, stakeholders can modify and react quickly to unexpected deviations of the model, or a change in the environment, thus providing a deeper understanding of the system behaviour (Huang, 2003; Kresimir, 2008; Varela et al., 2012), as well as fitting better adaptive decision-making processes and dynamic management frameworks (Cary & Roberts, 2011). Even more important, steering through an interactive visualisation interface allows real (or near real) time iteration towards the specific knowledge that the stakeholders want to obtain, in the process finding out which parameters are the most suitable for a particular purpose (Riedel, 2008; Yang et al., 2011). In the same manner, it allows testing of plausible ranges of coefficients or finding outcomes which meet the LUA objectives (Dutta, Morshed, Aryal, D'este, & Das, 2014) and can support participatory land use planning (Pettit, 2005; Pettit et al., 2013). If environmental-process-model outputs are visualised in this cohesive manner, complex data layers can be perceived or analysed simultaneously, especially in the field of climate change scenarios (Pettit, Raymond, Bryan, & Lewis, 2011; Pettit, Cartwright & Berry, 2006; Wang, Chen, Ju, & Li, 2010; Warrick, 1999).

This research utilises the previously reported SMS approach (Ninõ-Ruiz et al., 2013) to explore how stakeholders understand environmental models and the uncertainty associated with the assessments of possible futures produced in response to different climate change scenarios. Our principal objective was to review interactive options which can reduce the difficulty stakeholders have in understanding a complex spatial decision model and gain a better sense of its inherent uncertainty.

2. Land use allocation

It is essential to understand land use issues to assess fully the effects of global environmental change. Land use decisions may have a profound impact on biodiversity, land productivity due to soil degradation, and availability of land and water (Searchinger et al., 2008). To assess these issues, and associated land use option, coupled with the complexity of climate change effects, a scenario-based Land Use Allocation (LUA) may be used (Bryan, Crossman, King, & Meyer, 2011; Fiorese & Guariso, 2010; Griffon, Auclair, & Nespoulous, 2010; McNeill, 2006; Verburg, 2008; Wang et al., 2010). LUA may be considered as the medium to long term (10–90 years) strategic planning process by which land managers (whether farmers, corporations or planners) consider diverse environmental, social and economic factors, before choosing to produce one or more commodities in a given region. In this manner an assessment is made to identify the most appropriate multidimensional pattern to achieve a desirable goal (these dimensions include the spatial, biophysical, economic and political) (Malczewski, 2004). Typically, a LUA process is preceded by a Land Suitability Analysis (LSA),