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Review

Communicating complex ecological models to non-scientist end users

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ABSTRACT

Complex computer models are used to predict how ecological systems respond to changing environmental conditions or management actions. Communicating these complex models to non-scientists is challenging, but necessary, because decision-makers and other end users need to understand, accept, and use the models and their predictions. Despite the importance of communicating effectively with end users, there is little guidance available as to how this may be achieved. Here, we review the challenges typically encountered by modellers attempting to communicate complex models and their outputs to managers and other non-scientist end users. We discuss the implications of failing to communicate effectively in each case. We then suggest a general approach for communicating with non-scientist end users. We detail the specific elements to be communicated using the example of individual-based models, which are widely used in ecology. We demonstrate that despite their complexity, individual-based models have characteristics that can facilitate communication with non-scientists. The approach we propose is based on our experiences and methods used in other fields, but which until now have not been synthesised or made broadly available to ecologists. Our aim is to facilitate the process of communicating with end users of complex models and encourage more modellers to engage in it by providing a structured approach to the communication process. We argue that developing measures of the effectiveness of communication with end users will help increase the impact of complex models in ecology.

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1. Complex ecological systems call for complex models

Ecological systems are experiencing a period of pervasive and unprecedented rapid change (Reid et al., 2005). To decide how to manage them appropriately we need the ability to predict how they will respond to different management actions (Evans, 2012). Traditional phenomenological models (i.e. descriptive or correlative models) can be too simplistic to use for prediction because they are limited to the specific local context for which there is already empirical data (Stillman et al., 2015). To capture the complexity and variability of ecological systems, we can use computer simulation models, such as process-based or individual-based models (IBMs; also known as agent-based models; Railsback and Grimm, 2011). Such models simulate a complex system by specifying the processes that characterise interactions between its individual parts. IBMs in particular work on rules that direct the behaviour of individuals in a model population. The population's dynamics emerge during the IBM simulation (Grimm and Railsback, 2005) and these emergent patterns are then compared with empirical data to test the credibility of the model. If the model produces realistic patterns it can be used to predict system dynamics in novel environments, beyond the conditions for which there is already data.

IBMs have been used in ecology for 40 years (DeAngelis and Grimm, 2014) and are increasingly being used as practical tools in contexts such as wildlife conservation (McLane et al., 2011), ecosystem restoration (Darby et al., 2015; Fitz, 2015; Orem et al., 2014), agro-chemical risk assessment (Forbes et al., 2009; Topping et al., 2015), fisheries management (Rose, 2000) and assessing the wildlife impact of renewable energy developments (Nabe-Nielsen et al., 2014 Stillman and Goss-Custard, 2010). They have several advantages over phenomenological models in such contexts (Table 1), including the ability to predict the consequences of different management scenarios, so that decision-makers can visualise the outcomes of alternative courses of action. Despite such advantages however, the complexity of IBMs and other similarly complex models can make it difficult to communicate the underlying drivers, and the precision and credibility of the predictions. These elements are important for achieving end-user acceptance and correct application of the predictions in operational contexts.

Here, we identify the main challenges and suggest an approach to communicating complex ecological models to non-scientist end users. We provide examples for IBMs, although the issues we highlight and the approach we suggest are relevant to most applied ecological models. We draw together the experiences of modellers working in a variety of applied contexts, including ecological risk assessment, multi-species fisheries and conservation.

2. The need to communicate with end users

Communication of complex models is needed to help incorporate scientific evidence into environmental decision making (DeFries et al., 2012; Walsh et al., 2015). Model outputs are used to identify and prioritise management options (e.g. Elmeros et al., 2015 based on Topping et al., 2003; Hyder et al., 2015), to provide an evidence base to inform decision-making, and an audit trail for inspection (Dicks et al., 2014). They must therefore be conveyed to end users so that they are understood and interpreted unambiguously (Fig. 1). Model outputs of key interest normally include predictions of emergent system dynamics for a particular scenario, but also measures of precision and uncertainty that enable the predictions to be understood in context, interrogated, and believed. The end users ('stakeholders') of these outputs can be decision- or policy-makers, risk assessors, regulators and resource managers, who are often non-scientists and/or non-specialists (which in this context are comparable).

There is no broadly accepted procedure for communicating complex ecological models to stakeholders, even though the need for better science communication in general is well-recognised (Fischhoff and Scheufele, 2014) and actively addressed in other fields such as climate science (Kreienkamp et al., 2012; Stephens et al., 2012), fisheries management (e.g. the GAP2, project: http://gap2.eu) and risk assessment (Hunka et al., 2013). This lack of guidance and structure in planning and carrying out communication could limit the effectiveness of complex models in ecological decision-making (Addison et al., 2013), allow a knowledge gap to develop between modellers and practitioners, and reduce the societal impact and relevance of the research (Shanley and López, 2009). To help provide much-needed guidance, we offer a systematic approach to communicating complex models to non-scientist stakeholders based on theory, author experience and examples of good practice.

3. Guidelines exist for communicating with fellow modellers

In recent years, approaches have been suggested that aim to standardise the development and documentation of complex models. This has improved communication amongst modellers, facilitated critical scientific evaluation, and helped to ensure that models can be fully checked and re-implemented if necessary in alternative computer languages or platforms. Pattern-oriented modelling (POM) provides a unifying framework for IBMs (Grimm and Railsback, 2012), the 'ODD' (Overview, Design, concepts and Details) protocol (Grimm et al., 2010, 2006) and 'transparent and comprehensive ecological modelling' (TRACE) documentation (Grimm et al., 2014) help standardise model documentation, 'evaluation' (Augusiak et al., 2014) is a framework for assessing model quality and reliability, and approximate Bayesian computation (ABC) is a method of objectively evaluating and calibrating complex stochastic models (Beaumont, 2010; van der Vaart et al., 2015). These approaches largely focus on the technical details of modelling and by structuring the modelling and reporting ultimately facilitate communication. Generally, however, they present communication of the model outputs to stakeholders as an explicit step in the modelling cycle and provide no specific guidance on how it should be done. We argue that communication should constitute