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Discussion

Projecting biodiversity and wood production in future forest landscapes: 15 key modeling considerations

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ABSTRACT

A variety of modeling approaches can be used to project the future development of forest systems, and help to assess the implications of different management alternatives for biodiversity and ecosystem services. This diversity of approaches does however present both an opportunity and an obstacle for those trying to decide which modeling technique to apply, and interpreting the management implications of model output. Furthermore, the breadth of issues relevant to addressing key questions related to forest ecology, conservation biology, silviculture, economics, requires insights stemming from a number of distinct scientific disciplines. As forest planners, conservation ecologists, ecological economists and silviculturalists, experienced with modeling trade-offs and synergies between biodiversity and wood biomass production, we identified fifteen key considerations relevant to assessing the pros and cons of alternative modeling approaches. Specifically we identified key considerations linked to study question formulation, modeling forest dynamics, forest processes, study landscapes, spatial and temporal aspects, and the key response metrics – biodiversity and wood biomass production, as well as dealing with trade-offs and uncertainties. We also provide illustrative examples from the modeling literature stemming from the key considerations assessed. We use our findings to reiterate the need for explicitly addressing and conveying the limitations and uncertainties of any modeling approach taken, and the need for interdisciplinary research efforts when addressing the conservation of biodiversity and sustainable use of environmental resources.

1. Introduction

Efforts to safeguard biodiversity in production forests are motivated by growing societal concerns regarding biodiversity losses (CBD, 2010), and increasing recognition of the role biodiversity plays in sustaining the ecological processes from which many ecosystem services derive (Cardinale et al., 2012; Hooper et al., 2012; Schröter et al., 2014; Thompson et al., 2011). To evaluate measures to maintain forest biodiversity while sustaining wood production and other services is however complicated. This is at least partially due to the long-term time perspective applied in forestry, the large spatial and temporal scales at which species populations respond, global environmental change, and the

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diversity of interactions, including trade-offs, among ecosystem services (Bennett et al., 2009; MEA, 2005; Raudsepp-Hearne et al., 2010; Van der Plas et al., 2016). Despite this complexity, the consequences of alternative policies and management scenarios still need to be predicted and evaluated (Schmolke et al., 2010). It is for this reason that predictive models, which can simulate a system's response, behavior, and interactions to a specified set of conditions (Korzukhin et al., 1996), are increasingly needed to guide the effective management of biodiversity and the commodities derived from production forests (Pretzsch et al., 2008; Seidl et al., 2013).

In response to this need, an ever growing variety of modeling approaches are being produced which have the capacity to project the future development of forest systems through time, and assess the implications of different management approaches for biodiversity and the provision of goods and services (e.g. Hynynen et al., 2005; Messier et al., 2003; Pretzsch et al., 2002; Seidl et al., 2012; Teck et al., 1996; Wikström et al., 2011). The rapid nature by which these modeling approaches are developing has however created both opportunities and obstacles. Whereas modeling approaches can provide valued insights, the diversity of approaches available, the respective answers they provide, and the associated caveats required for their interpretation presents an obstacle to researchers and end users trying to decide upon which modeling approach to apply and how to interpret the implications and uncertainties of model outcomes. Furthermore, the informed evaluation of these choices requires guidance from a number of scientific disciplines due to the breadth of relevant considerations that are necessary.

As forest planners, conservation ecologists, ecological economists, and silviculturalists experienced with modeling trade-offs and synergies between biodiversity, wood biomass production and economic returns, we identified fifteen key considerations relevant to assessing the pros and cons of pursuing alternative modeling directions. We clarify some of the types of options available for addressing each consideration, and describe the respective advantages and disadvantages of different modeling approaches. We also provide a table of illustrative studies providing further in-depth guidance regarding the key considerations raised (Table 1). Whereas our research setting biases us towards the Fennoscandian context and perspective, we also provide examples and references where potentially beneficial to the reader from other regional settings. Although the primary focus of this paper is the effective modeling of forest biodiversity, wood production and their economic evaluation, many of the considerations we address are directly relevant to the modeling of other ecosystem services from production forest landscapes.

2. Key considerations

We identified 15 key considerations linked to study question formulation, modeling forest dynamics, forest processes, study landscapes, spatial and temporal aspects, and the key response metrics – biodiversity and wood biomass production, as well as dealing with trade-offs and uncertainties. We use section and subsection headings for ease of reference, and not to imply a specific hierarchy or lack of interaction among the key considerations assessed.

2.1. Study questions

2.1.1. 'What if' versus 'How to' questions

When evaluating trade-offs or synergies for biodiversity and wood production outcomes from forest management decisions, the modeling approach used may vary depending on whether so called 'What if' versus 'How to' questions are being addressed (Nobre et al., 2016). By 'What if' questions, we refer to modeling attempts to understand the implications of different scenarios. Specifically, these involve evaluating the implications for a response indicator, if a given management intervention or environmental change takes place. These approaches are often ideal for systems with a high degree of complexity or stochasticity, and when clear policy relevant management scenarios can be defined (e.g. Eggers et al., 2015). The advantage of such approaches often lies in the relative ease of formulating the problem, and the resultant conceptual clarity with respect to question formulation and output interpretation. The cost of this simplicity is that they are useful only for predicting the consequences of a limited set of predefined scenarios, but not for finding the most cost-effective solutions among a continuous scale of possible scenarios (Eggers et al., 2015).

In contrast to 'What if', 'How to' questions focus on identifying a single or limited set of management alternatives from a larger set, which meet a desired set of objectives and specific constraints. Often this approach implies an optimization, i.e. it provides a mean of determining the optimal values for a set of variables, given specified objectives and constraints. For example, if a specific minimum spatial extent of species' habitat is necessary to sustain their populations, 'How to' approaches may be employed to determine how to achieve this goal while minimizing the costs (for example in terms of decreased revenues from wood fiber production) for a range of different forest management alternatives (Öhman et al., 2011).

Whereas linear programing has commonly been employed in addressing 'How to' questions that involve optimization models, the occurrence of integer variables and non-linear relationships stemming from the inclusion of biodiversity aspects often requires other techniques, such as integer programming or mixed-integer programming, which enlist branch and bound algorithms (Snyder and ReVelle, 1996; Öhman and Wikström, 2008). Unfortunately the advantages of integer or mixed-integer programming are counterbalanced by the computational time required for solving the formulated problem. An alternative could be to use heuristic methods, which are search techniques designed for solving complex problems and nonlinear relationships, aiming to find a good solution at a reasonable computational cost (Reeves, 1993). However, a disadvantage is that these methods do not ensure that the optimized solution has actually been identified.

2.2. Modeling forest dynamics

The dynamics of forest systems are driven primarily by ecological feedbacks and external drivers, such as climate, land-use, soils, and other disturbance events. The modeling approach chosen to capture such forest dynamics will necessarily depend on the specific purpose of the end-user. The three primary alternatives for modeling forest dynamics are to apply process-based, empirical, or forest successional models (Larocque et al., 2016). In all three cases, tree regeneration, stand and tree growth, and mortality are typically modelled, which requires parameter estimates. Process-based models (e.g. FOREST-BGC (Running and Coughlan, 1988; Running and Gower, 1991) and 3-PG (Landsberg and Waring, 1997)) obtain such estimates by simulating and calibrating physiological and biogeochemical processes. As these types of models are well suited to describing cause and effect relationships (Mäkelä et al., 2000), they are often preferable when environmental conditions vary to such an extent that forest dynamics are altered (e.g. due to climatic change). However, this capacity comes at the cost of a need for detailed parameterization, and the high-resolution input often makes practical implementation cumbersome.

In contrast, empirical growth models forecast forest development based on the statistical analysis of dendrometric data from