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Transparent and feasible uncertainty assessment adds value to applied ecosystem services modeling

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ABSTRACT

We introduce a special issue that aims to simultaneously motivate interest in uncertainty assessment (UA) and reduce the barriers practitioners face in conducting it. The issue, "Demonstrating transparent, feasible, and useful uncertainty assessment in ecosystem services modeling," responds to findings from a 2016 workshop of academics and practitioners that identified challenges and potential solutions to enhance the practice of uncertainty assessment in the ES community. Participants identified that one important gap was the lack of a compelling set of cases showing that UA can be feasibly conducted at varying levels of sophistication, and that such assessment can usefully inform decision-relevant modeling conclusions. This article orients the reader to the 11 other articles that comprise the special issue, and which span multiple methods and application domains, all with an explicit consideration of uncertainty. We highlight the value of UA demonstrated in the articles, including changing decisions, facilitating transparency, and clarifying the nature of evidence. We conclude by suggesting ways to promote further adoption of uncertainty analysis in ecosystem service assessments. These include: Easing the analytic workflows involved in UA while guarding against rote analyses, applying multiple models to the same problem, and learning about the conduct *and value* of UA from other disciplines.

1. Introduction: Why promote "transparent, feasible, and useful" uncertainty assessment?

1.1. Background and motivation

Over the last decade, as the ecosystem services (ES) framework has proliferated, multiple researchers have expressed the need for ES analysts to improve consideration of the uncertainties that are embedded in applied modeling efforts (Seppelt et al., 2011; Hou et al., 2013; Hamel and Bryant, 2017). There are signs trends may be moving in the right direction, reflected by recent articles giving significant attention to major uncertainty, sensitivity, and validation issues in the ES realm (e.g. Santos de Lima et al., 2017; Bagstad et al., 2018; Ochoa and Urbina-Cardona, 2017). However, we do not yet have evidence that context-appropriate uncertainty assessment[1] is becoming a routine part of ES modeling practice.

Hamel and Bryant (2017) argue that, while there are a few legitimate challenges specific to conducting uncertainty assessment (UA) in the ES realm,[2] for the most part relevant methods exist and are more commonly applied within other disciplines (e.g., hydrology and policy analysis, and the broader realm of integrated environmental modeling, cf Refsgaard et al., 2007; Bennett et al., 2013; Uusitalo et al., 2015). Though the use of comprehensive and consciously-framed UA may not be routine in these other disciplines (see, e.g., Guillaume et al., 2017 in the water resources realm), it does feature more prominently, and modelers are able to draw on at least some default UA techniques within their respective discipline. This raises two questions: Why are these methods not more widely adopted within the ES realm, and what

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[1] As in Hamel and Bryant (2017, p. 2) we "use 'uncertainty assessment' as an umbrella term including problem scoping, qualitative treatments of uncertainty, and formal quantitative analysis techniques" – including sensitivity analysis, and also verification and validation efforts.

[2] Namely, that typical ecosystem services assessments are fundamentally spatial, biophysical and social all at the same time.

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can be done to promote adoption of context-appropriate uncertainty assessment?

These questions were explored as part of a three-day workshop held in November 2016 at the National Center for Socio-Environmental Synthesis (SESYNC), in the United States. Bringing together 18 academics and practitioners (including most authors of this article), this three-day workshop systematically identified many challenges limiting widespread adoption of UA by ES practitioners, as well as ways in which those challenges could be addressed (Bryant and Hamel, 2017). While the group determined a host of interacting causes and potential solutions, most causes could be categorized under two broad justifications: that UA was perceived as "too hard" to conduct (i.e., too time consuming relative to available resources, or requiring sophisticated methodological skills), or relatedly, not worth doing (i.e., even when done, UA is not likely to change conclusions or affect decisions). Among other recommended solutions, participants determined that a set of clear and compelling case studies showing the feasibility and value of UA could help address this problem. To do so, such a set would include cases demonstrating that UA can be feasibly conducted at varying levels of sophistication, and that such assessment can usefully inform decisions or research conclusions, rather than just put ranges on the predicted outcomes or valuations – in other words, that UA can provide useful information and build confidence, rather than just complicate or obfuscate. As indicated by its straightforward name "*Demonstrating transparent, feasible, and useful uncertainty assessment in ecosystem services modeling,*" this special issue aims to serve as such a collection.

We recognize that the issue of promoting uncertainty assessment is a many-faceted one – in terms of what success looks like, and in the pressures, incentives and constraints facing analysts and the stakeholders with whom they interact and communicate (see Merritt et al., 2017 for a useful collection of examples). Many of these complications are illustrated by articles in this special issue and also detailed in Section 2.5 of the workshop report (Bryant and Hamel, 2017). What is appropriate is also context- and resource dependent, with different techniques and levels of effort appropriate at different times for different decisions. But overall, some assessment of model adequacy for the purposes to which the model may be put is critical – not just for the quality of scientific findings, but also for communication and legitimacy in the eyes of stakeholders (Willcock et al., 2016). Formal or not, sophisticated or not, consideration of uncertainty plays an important role in such assessment.

1.2. Purposes of this article and special issue

Given the above, we created this special issue under an open call, to serve as a resource with two related but distinct purposes:

- Provide exemplar cases of the many ways that uncertainty analysis can be conducted ("transparent and feasible").
- Provide a succinct body of articles that demonstrate why it is useful to conduct uncertainty analysis in the ES realm ("useful").

The contributions of some articles lean more heavily to the first bullet and some more to the second. Different readers will find different value in the assembled articles, depending on their background and the way in which they interact with the modeling process (e.g., as analyst, project manager, scientist, stakeholder, or decision-maker). Some may be exposed to new methods, and some will be inspired to try methods with which they only had loose familiarity, but which they had not considered worth understanding deeply enough to implement. Above all, we hope that many readers will find convincing demonstration of the value that uncertainty assessment can bring to a modeling effort. For those already convinced, we hope they will find helpful material with which to engage others on this topic.

This article itself aims to (1) orient the reader to the content of the special issue while drawing out key messages on the practice and utility of uncertainty assessment, and (2) provide critical reflections in the form of lessons and recommendations on remaining challenges and how to overcome them. These are based on the included articles as well as our own experiences as applied ES modelers and participants in the SESYNC workshop noted above.

2. Overview: Diverse applications, modeling methods, and approaches to uncertainty assessment

2.1. Orientation to articles

This special issue presents papers spanning a broad array of methods and application areas, with domains including forests, fisheries, cultural landscapes, urban green infrastructure, and others. On the methods front, it includes examples ranging from simple variation of input data, to Monte Carlo methods combined with stochastic dominance tests, to scenario considerations treated probabilistically, to those treated with participatory assessment. The work described includes ES modeling approaches that encompass process-based, proxy-based,[3] and qualitative considerations, and covers applications on four continents. Table 1 provides an overview of the key dimensions of each article, and in the text below we draw out key lessons for the ES community, focusing in particular on the "useful" aspect of the uncertainty analysis.

The issue begins with a review article (Baustert et al., 2018, this issue) that many readers unfamiliar with formal conceptions of uncertainty may find useful for assessing the special issue papers and considering uncertainty in their own work. Baustert et al. describe and cross-walk the steps, frameworks and elements of uncertainty assessment that have already been brought forth in the literature, orienting the reader to common concepts and terminology and where they differ (e.g., those of Walker et al., 2003; Refsgaard et al., 2007; Warmink et al., 2010). They review sources of uncertainty, help interpret the underlying frameworks, and their overview can assist an analyst in judging whether the nuances of the different frameworks are important for their work. Their paper will also help readers of other articles in this special issue consider uncertainty more systematically.

The remainder of the papers all demonstrate a complete or partial ecosystem services assessment that includes an examination of one or more key uncertainties, and how those uncertainties can be treated using available methods. As Table 1 provides a concise overview of topics and methods, we do not explicate these further, but instead use the rest of this section to highlight how the articles demonstrate the value of uncertainty assessment.

2.2. Demonstrating how uncertainty assessment can matter

To realize the goals of the special issue, this section highlights the ways in which the uncertainty-oriented analysis in the papers provides benefits to modelers and potential stakeholders. Note that these are not necessarily the primary contributions of the papers mentioned, but rather, our view of key points related to UA. We of course encourage readers to review Table 1 and examine abstracts of the relevant papers to read them for their own substantive contributions as well.

2.2.1. More complete uncertainty assessment can change the recommended course of action

Changing the recommended decision is perhaps the most obvious and compelling way that UA could make a difference in a modeling

[3] Adopting the language of Lavorel et al. (2017, p. 243) we "define proxy models as models that relate ES indicators to land or marine cover, abiotic and possibly biotic variables by way of calibrated empirical relationships or expert knowledge." A classic example would be assuming particular levels of provisioning or carbon sequestration are associated with each category in a land-use/land-cover map.