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A comparative assessment of decision-support tools for ecosystem services quantification and valuation

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ABSTRACT

To enter widespread use, ecosystem service assessments need to be quantifiable, replicable, credible, flexible, and affordable. With recent growth in the field of ecosystem services, a variety of decision-support tools has emerged to support more systematic ecosystem services assessment. Despite the growing complexity of the tool landscape, thorough reviews of tools for identifying, assessing, modeling and in some cases monetarily valuing ecosystem services have generally been lacking. In this study, we describe 17 ecosystem services tools and rate their performance against eight evaluative criteria that gauge their readiness for widespread application in public- and private-sector decision making. We describe each of the tools' intended uses, services modeled, analytical approaches, data requirements, and outputs, as well time requirements to run seven tools in a first comparative concurrent application of multiple tools to a common location – the San Pedro River watershed in southeast Arizona, USA, and northern Sonora, Mexico. Based on this work, we offer conclusions about these tools' current 'readiness' for widespread application within both public- and private-sector decision making processes. Finally, we describe potential pathways forward to reduce the resource requirements for running ecosystem services models, which are essential to facilitate their more widespread use in environmental decision making.

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1. Introduction

A large and rapidly growing body of research seeks to identify, characterize, and value ecosystem goods and services – the benefits that ecosystems provide to people (Millennium Ecosystem Assessment (MA), 2005). However, the development of decision-support tools (hereafter tools) that integrate ecology, economics, and geography to support decision making is a more recent phenomenon (Ruhl et al., 2007; Daily et al., 2009). Current tools range from simple spreadsheet models to complex software packages. Unlike *ad hoc* methods for quantifying ecosystem services (e.g., Egoh et al., 2012; Martinez-Harms and Balvanera, 2012), this new generation of analytical tools is intended to enable replicable and quantifiable ecosystem services analyses. Assuming that tools are well-documented and tested, they can add credibility and trust to the decision process, increasing stakeholder confidence in their use. If they are flexible enough for use in diverse decision contexts and can be affordably applied, they could reasonably be incorporated into public- and private-sector environmental decision making on a routine basis.

Numerous groups of tool developers are now developing new approaches for integrating ecosystem services into both public- and private-sector decision-making processes. While aspirations to aid decision makers are cross-cutting, the tools vary greatly. Some are designed to be generalizable to any location in the world while others are place-specific. The tools differ in their approaches to economic valuation, spatial and temporal representation of services, and incorporation of existing biophysical models.

Despite the proliferation of tools, there has been little systematic review and evaluation of ecosystem services tools, in order to determine tool strengths, weaknesses, and applicability to various settings and concurrently apply multiple tools to a common study area. The scope of most other reviews has been limited, providing detailed descriptions of 2–3 tools and references to another 2–4 tools (Nelson and Daily, 2010; Vigerstol and Aukema, 2011). Aside from the rapid evolution of ecosystem service tools, a major reason why thorough reviews have been difficult to complete has been the challenge in circumscribing what constitutes an ecosystem service tool amidst the variety of emerging tools for conservation, land-use planning, and hydrologic and ecological modeling. Additional reviews have addressed some of these other types of tools, as well as one-off modeling approaches not intended to for broader applicability (Institute for European Environmental Policy (IEEP) et al., 2009; Ambrose-Oji and Pagella, 2012; Egoh et al., 2012; Martinez-Harms and Balvanera, 2012; Smart et al., 2012).

Indeed, a broad tradeoff exists between using new ecosystem service tools, many of which are intended to be transferrable to new geographic and decision contexts, versus using existing mapping or modeling approaches that are locally known and trusted by decision makers but require the addition of an ecosystem services component. Emerging ecosystem service tools offer the potential for "standardizing" assessments to facilitate testing and comparison across broad geographic contexts, and provided that models are clearly documented, user-friendly, and easily parameterized, they may facilitate widespread adoption of ecosystem services for decision making. However, these models are often less well known to decision makers, so they face the critical step of achieving stakeholder trust and buy-in. Other well-accepted models may already have such buy-in, but lack an ecosystem services component. Such tools, then, must seek to add components that accurately quantify ecosystem services. The lack of comparability between such locally adapted models may have the added disadvantage of limiting the comparability of their results and their use within common decision frameworks. This tradeoff is also partly related to scale: while some generalized models may be highly effective at the national to regional level, they may be ineffective at the local level if they cannot incorporate accurate, high-resolution data while accounting for local influences on ecosystem service supply, demand, and value. In such cases locally developed models may better account for fine-scale analysis (Smart et al., 2012). However, an improved understanding of generalized models was generally preferred by the U.S.-based public-sector resource management agencies and multinational corporations involved in this review. These entities, which are making decisions across a broad range of geographies, agreed that uniform processes and protocols would be easier to use; however, for localized decision making, adaptation and use of local models might be a preferred strategy (Smart et al., 2012).

While the relative value of these two approaches is a worthwhile debate in the field of ecosystem service modeling, the intent of this review is to qualitatively catalog and evaluate methods that are already generalizable or are intended by their developers to become so. In exploring this part of the tool landscape, it is beyond the scope of the paper to address the adaptability of other biophysical models to ecosystem services and whether that approach or the use of generalizable ecosystem service models is a more appropriate course of action.

This paper is based on a study that was undertaken in 2010 through 2011, which was spurred by the growing demand for more comprehensive analyses of the ecological and socioeconomic consequences of land-management decisions, particularly within the U.S. government's policy direction for environmental and natural resource management (President's Council of Advisors on Science and Technology (PCAST), 2011; Council on Environmental Quality (CEQ), 2013). In response, the U.S. Department of Interior-Bureau of Land Management (BLM) launched a pilot project with the U.S. Geological Survey (USGS) to assess the usefulness and feasibility of ecosystem services valuation as an input into decision-making. The BLM manages nearly 100 million hectares of land across the western U.S. from Alaska's North Slope to the Mexican border. Under its multiple-use mission, BLM's responsibilities range from facilitating the development of oil, gas, coal, solar energy, and other commodities to providing many forms of recreation, restoring habitat, and preserving scenic values, archeological heritage, and environmental quality (Bureau of Land Management (BLM), 2005).

BLM's goals for the comparative tools assessment were to (1) determine which, if any, methods for valuing ecosystem services are ripe for operational use across the agency, and (2) evaluate the utility of ecosystem service valuation for its resource management decision processes. The first phase of this effort used a study area – the San Pedro River watershed in southeast Arizona and northern Sonora, Mexico (hereafter San Pedro) – that had a legacy of biophysical research to draw upon and a variety of ecological stressors relevant to federal resource management.

The BLM-USGS initiative was coupled with comparative application of additional ecosystem service tools and analysis of their relevance to the private sector – through engaging the same technical specialist to conduct the assessment, which was concurrently coordinated by Business for Social Responsibility (BSR), an independent nongovernment organization (NGO) focused on sustainability issues and their application to the private sector. The BSR initiative asked of all tools where a hypothetical residential development within the San Pedro should be sited to minimize impacts on the provision and flows of ecosystem services (Waage et al., 2011). Based on this comparative application, we summarize the findings from these two linked studies in this article through a review of ecosystem services software and modeling tools.

To our knowledge this is the first effort to evaluate multiple ecosystem service tools and their applicability to environmental decision making across both public- and private-sector contexts. Our analysis includes both (1) place-specific tools – customized for