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An integrated multi-criteria scenario evaluation web tool for participatory land-use planning in urbanized areas: The Ecosystem Portfolio Model

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ABSTRACT

Land-use land-cover change is one of the most important and direct drivers of changes in ecosystem functions and services. Given the complexity of the decision-making, there is a need for Internet-based decision support systems with scenario evaluation capabilities to help planners, resource managers and communities visualize, compare and consider trade-offs among the many values at stake in land use planning. This article presents details on an Ecosystem Portfolio Model (EPM) prototype that integrates ecological, socio-economic information and associated values of relevance to decision-makers and stakeholders. The EPM uses a multi-criteria scenario evaluation framework, Geographic Information Systems (GIS) analysis and spatially-explicit land-use/land-cover change-sensitive models to characterize changes in important land-cover related ecosystem values related to ecosystem services and functions, land parcel prices, and community quality-of-life (QoL) metrics. Parameters in the underlying models can be modified through the interface, allowing users in a facilitated group setting to explore simultaneously issues of scientific uncertainty and divergence in the preferences of stakeholders. One application of the South Florida EPM prototype reported in this article shows the modeled changes (which are significant) in aggregate ecological value, landscape patterns and fragmentation, biodiversity potential and ecological restoration potential for current land uses compared to the 2050 land-use scenario. Ongoing refinements to EPM, and future work especially in regard to modifiable sea level rise scenarios are also discussed.

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1. Introduction

For terrestrial and coastal ecosystems, land-use/land-cover change is one of the most important direct drivers of changes in ecosystem functions and services (Agardy et al., 2005; Hassan et al., 2005; Chhabra and Geist, 2006; Metzger et al., 2006). More specifically, the fragmentation of habitat from expanding development across landscapes appears to be a major driver of terrestrial species decline and the impairment of terrestrial and coastal ecosystem integrity; in some cases causing irreversible impairment from a land-use planning perspective (Peck, 1998; McKinney, 2002; Folke et al., 2004; Agardy et al., 2005; Alberti, 2005; Brody, 2008). In low lying coastal regions, changes in flood control measures in response to future land-use change and sea level rise-related impacts (e.g., ground water pumping to lower water tables for flood control to protect new developments from more intense storm surges and rising ground water tables due to sea level rise) are expected to be additional drivers of land-cover and other ecological change (Renken et al., 2005). The United States National Research Council (NRC, 2008) states that population growth and development will also put strain on water resources and its availability for human consumption, alter regional water budget, and influence exposure of people and assets to storm-related risks.

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Evaluation of variable and scalar impacts of land-use/land cover change on a case-by-case basis is common (SFRPC, 2003) but not ideal. Resource managers and land-use planners have come to realize that evaluating proposed land-use conversions on a piecemeal, parcel-by-parcel basis leads to a myopic view of the regional cumulative ecological and environmental effects of the conversion of natural land-cover and agricultural parcels to developed parcels (Marsh and Lallas, 1995; Boyd and Wainger, 2003; DeFries et al., 2004; Alberti, 2005). In addition to the unintended ecological effects of land-use change, the nexus of low elevations, low gradients, an extremely porous aquifer, high surface-water/groundwater connectivity, large environmentally-sensitive coastal wetlands, and rapidly growing urban areas makes some regions (such as South Florida in the United States) especially vulnerable to sea level rise impacts, including increased storm risks. Land-use planning is an inherently complex process given such complex and diverse issues, the multitude of stakeholders (for example, resource management agencies, city and regional planners, developers, local residents, environmental groups, and agricultural interest groups), and conflicting goals. Considering the potentially large capital investments in ecosystem restoration, the prioritization and careful consideration of how to allocate those funds for particular efforts is paramount to the effective management of urbanizing regions (NRC, 2008).

Considering the complexity and inherent uncertainty of the problem, there is the need for modeling and scenario evaluation frameworks and tools to support and facilitate planning and resource management efforts. For example, there are relatively few case studies that demonstrate the use of spatially-explicit modeling and evaluation frameworks supporting integrated land-use/climate change adaptation planning (Chan et al., 2006; Labiosa et al., 2009; Nelson et al., 2009; Norman et al., 2010). Other scholars acknowledge related challenges such as the need to synthesize complicated and diverse information, dealing with the many uncertainties in the face of conflicting goals and sets of interests, and accounting for a broad range of stakeholders who use such tools (Solecki et al., 1999; Brody, 2008; Mulkey, 2009; Noss, 2011). This article focuses on the informational aspects of this problem, describing the Ecosystem Portfolio Model (EPM), a web-delivered decision support system with scenario building and evaluation tool sets designed for use in participatory planning processes. The term "portfolio" is used here to represent the disparate set of value metrics and endpoints of interest that decision-makers and stakeholders can use to compare land-use change scenarios at a regional scale.

With the EPM, we take a place-based view of integrated model development and decision support and tailor the modeled planning endpoints, the models used, and the methods of placing values on those endpoints to the decision problem at hand. Several applications of the EPM have been supported by the U.S. Department of the Interior, including applications in Puget Sound (Washington State, USA; Byrd et al., 2011), the Santa Cruz Watershed (Arizona, USA and Sonora, MX; Norman et al., 2010), and in Miami Dade County (South Florida, USA; Labiosa et al., 2009; Hogan et al., 2012). Each EPM application is organized around the particular management issues and linkages between management actions and ecosystem outcomes. While each application uses the same multicriteria, model-based web-delivered framework, the management problems and modeled endpoints differ according to user needs. The EPM framework is transferrable, but to date we have taken the approach of starting with user analysis workshops and designing the particular application based on user needs. Our approach places fundamental importance on stakeholder participation in land-use decision-making, but makes no attempt to determine normative socially "optimal" land-use plans. Given the various inherent programmatic, funding, and monitoring difficulties, projects of suitable scope and scale for feasible implementation and long-term assessment with comprehensive indicators are essential to address, as well incorporating a "collaborative process for stakeholder participation and learning" (NRC, 2008). The goal is for the EPM to be used within a public, participatory decision-making process that allows the preferences and goals (e.g., balancing of expected tradeoffs, dealing with issues of accessibility to amenities, dealing with uncertainty and risk) of the decision participants to be reflected within their choices for decision criteria, models and information used, weights applied, and statements of preferences over possible outcomes.

2. The EPM as a decision support system

Land-use/land cover change has long been seen and researched as a predominantly environmental problem stemming from habitat loss, stream impairment, land degradation and diminishing quality of ecosystem services due to the pressures of urban growth and development. More recently, researchers have focused their attention on identifying proper ways of integrating metrics of land-use/land cover change with collaborative and participatory ecological planning (Luz, 2000), formation of community identity (Stewart et al., 2004), residents' perception and preferences with regard to landscape change (Palmer, 2004; Wagner and Gobster, 2007), and human perspectives on landscape dynamics and "ecological aesthetics" (Gobster and Westphal, 2004; Gobster et al., 2007). A rich body of literature emerged from the conceptual foundations of the long-term socio-ecological research (Redman et al., 2004; Haberl et al., 2006). Although these studies do not address the linkages between metrics of land-use/land cover change and quality of life, they provide a useful paradigm for the exploration of these relationships. Wagner and Gobster (2007), for instance, use quantitative and semi-quantitative methods to assess landscape change and impact on natural areas and streams while at the same time conduct semi-structured interviews to elicit perceptions and preferences from residents of the community with regard to these changes.

The EPM is a multi-criteria decision support system (Fig. 1) that evaluates proposed land-use changes and land-use plans in terms of relevant first-order ecological and community quality-of-life criteria scores and predicted changes in market land price (Labiosa et al., 2009, 2010; Hogan et al., 2012). By definition, a DSS is an interactive, computer-based tool—or collection of tools—intended to enable decision makers to better interpret information from data, analysis, and models to identify and solve problems. There are multiple possible objectives for using a DSS, including improving the decision making process or improving probable outcomes from decisions to be made (D'Erchia et al., 2002). In these two examples, different evaluation criteria would support different decision support approaches. An ideal, integrated suite of tools should have the following characteristics: interdisciplinary and integrated focus, comprehensiveness in time, useful visualization, multiple spatial scales, policy-relevance to the local and regional decision context, ability to interactively modify inputs through the interface, compatibility with other desired tools, accessibility to a wide range of users, and affordability of acquisition and use (Condon et al., 2009; NSF, 2009). In the case of the EPM, the integration of models provides a coupled natural system—human system view from a broader, regional planning perspective. The dynamic complexity of coupled systems is not well understood, and scholars have generally focused their work on theoretical research efforts (Liu et al., 2007). The use of a GIS model-based multi-criteria framework allows users to consider spatially-explicit tradeoffs between important criteria and to explore the implications of different assumptions about the relative importance of the different criteria (Labiosa et al., 2009). Decision rules