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Research paper

Simulating urbanization scenarios reveals tradeoffs between conservation planning strategies

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HIGHLIGHTS

- We explored urbanization scenarios based on hypothetical land use policies.
- We used a unique modeling method to represent conservation planning strategies.
- No single strategy was best for achieving all conservation goals.
- Effective planning requires assessment of tradeoffs between differing priorities.

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ABSTRACT

Land that is of great value for conservation can also be highly suitable for human use, resulting in competition between urban development and the protection of natural resources. To assess the effectiveness of proposed regional land conservation strategies in the context of rapid urbanization, we measured the impacts of simulated development patterns on two distinct conservation goals: protecting priority natural resources and limiting landscape fragmentation. Using a stochastic, patch-based land change model (FUTURES) we projected urbanization in the North Carolina Piedmont according to status quo trends and several conservation-planning strategies, including constraints on the spatial distribution of development, encouraging infill, and increasing development density. This approach allows simulation of population-driven land consumption without excluding the possibility of development, even in areas of high conservation value. We found that if current trends continue, new development will consume 11% of priority resource lands, 21% of forested land, and 14% of farmlands regionally by 2032. We also found that no single conservation strategy was optimal for achieving both conservation goals. For example, strategies that excluded development from priority areas caused increased fragmentation of forests and farmlands, while infill strategies increased loss of priority resources proximal to urban areas. Exploration of these land change scenarios not only confirmed that a failure to act is likely to result in irreconcilable losses to a conservation network, but that all conservation plans are not equivalent in effect, highlighting the importance of analyzing tradeoffs between alternative conservation planning approaches.

1. Introduction

Global increases in population and the use of natural resources are driving extensive changes in land use that alter biodiversity patterns and ecosystem function (Aronson et al., 2014; Foley et al., 2005; Grimm et al., 2008; McKinney, 2006). In the case of urbanization, growth within and on the outskirts of cities frequently overlaps with locations rich in biodiversity and natural resources (Chapin et al., 1997; McDonald, 2008; Ricketts & Imhoff, 2003). In addition to direct resource loss, the sprawling land use patterns that are common in many growing metropolitan regions of the United States cause increased landscape fragmentation (Miller & Hobbs, 2002), which can inhibit the movement and dispersal of plant and animal species (Krosby, Tewksbury, Haddad, & Hoekstra, 2010).

Although the establishment of protected areas remains a primary fixture in biodiversity conservation planning, alternative methods have emerged that may better account for current and

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future species distributions (Pressey, Cabeza, Watts, Cowling, & Wilson, 2007; Anderson & Ferree, 2010; Rands et al., 2010). For example, maintaining ecological connectivity within human modified landscapes has been proposed to encourage the movement and persistence of species, particularly under the threat of changing climate (Krosby et al., 2010). Additionally, improved quality of landscapes outside of protected areas can be important to species persistence (Prugh, Hodges, Sinclair, & Brashares, 2008), and at the same time provide important ecosystem functions (*e.g.* temperature regulation by urban green spaces). Slowing global biodiversity loss requires approaches that combine the establishment of protected areas with other strategies that incorporate landscapes used and modified by humans, and includes specific attention to landscape patterns (Naughton-Treves, Holland, & Brandon, 2005; Reyers, O'Farrell, Nel, & Wilson, 2012).

To effectively prepare for change, regional planners need information about how different land use policies may influence future landscapes. In the absence of empirical data, simulation models of land use and land cover change are powerful analytical tools that can be used to reveal unexpected impacts to biodiversity and environmental systems (Veldkamp & Verburg, 2004). These models enable scientists, planners, and policy makers to create and visualize trajectories for potential development that may result from alternative planning scenarios (Baker et al., 2004; Swart, Raskin, & Robinson, 2004) providing a starting point for discussion of alternatives (Checkland, 1995; Peterson, Cumming, & Carpenter, 2003), broadening perspectives (Peterson et al., 2003; Xiang & Clarke, 2003), and building consensus among stakeholders (Costanza, 1996). Land change modeling also enables the analysis of tradeoffs, a process that is increasingly important in planning for sustainability in socio-ecological systems (Turner, Lambin, & Reenburg, 2007). However these models are often limited by their capacity to adequately simulate non-stationary processes (in time and space), increasing uncertainty in outcomes when simulations are conducted over broad spatial or temporal scales (Meentemeyer et al., 2013; Sohl, Loveland, Sleeter, Sayler, & Barnes, 2010). The multifaceted nature of land change processes also presents challenges in balancing complexity with interpretability and computational intensity (Sohl et al., 2010). Additionally, some models are designed to project change in the location or amount of different land cover types but do not explicitly simulate changes to the spatial structure of the landscape, thus limiting our ability to quantify the impacts of change on landscape patterns that are relevant to conservation planners (Meentemeyer et al., 2013).

Given the uncertainty of future environmental conditions, scenario analysis via simulation modeling can be an effective tool to assess alternative outcomes for conservation of biodiversity. Simulation of future land change can be used to identify and prioritize areas under "high risk" of change that may require additional protection (Menon, Pontius, Rose, Khan, & Bawa, 2001; Theobald, 2003). Scenarios can also be developed that allow stakeholders to evaluate policies designed to protect biodiversity (Baker et al., 2004; Conway & Lathrop, 2005; Gude, Hansen, & Jones, 2007) and the potential effectiveness of alternative approaches (Ferrier, Faith, Arponen, & Drielsma, 2009). Additionally, scenario results can be used to identify potential threats to biodiversity from landscape change including loss of wildlife habitat (Baker et al., 2004; Theobald & Hobbs, 2002), changes in species populations (Hepinstall, Alberti, & Marzluff, 2008; Schumaker, Ernst, White, Baker, & Haggerty, 2004), and changes to landscape patterns that influence habitat fragmentation (Conway & Lathrop, 2005; Swenson & Franklin, 2000). Some studies also explore potential ways that land use change affects biodiversity and ecosystem services, as well as tradeoffs between the two (Nelson et al., 2009; Polasky, Nelson, Pennington, & Johnson, 2011), analyses that can be essential to conservation planning (Chan, Shaw, Cameron, Underwood, & Daily, 2006).

The application of conservation planning scenarios in land change modeling is often implemented by simply treating priority areas as protected, essentially removing them from eligibility for development (Conway & Lathrop, 2005; Gude et al., 2007). However, full protection of all priority resources is highly unlikely in urbanizing areas – particularly in regions with strong property rights cultures – where development is outcompeting other land use types and decreasing the effectiveness of purchasing land for conservation due to increasing costs (Newburn, Reed, Berck, & Merenlender, 2005). As an alternative to land acquisition for full protection, regulatory or policy-based approaches could be introduced, reducing the negative consequences of urban development to conservation priorities without hindering growth (Brueckner, 1997; Mayer & Somerville, 2000). Protection could also be incentivized through payment for ecosystem services (BenDor & Doyle, 2009), rewarding landowners that take action to preserve priority resources. These policies could discourage growth in priority areas in some cases, shifting the spatial distribution of new development to more ecologically suitable locations. In addition to localized policies aimed at protecting specific priority resources, broader policies and zoning measures that limit fragmentation of the landscape could benefit biodiversity over time. A combination of these approaches may be appropriate, with the choice dependent on the degree of threat to the conservation element of interest (Baldwin & deMaynadier, 2009).

In this study, we expand on previous applications of land change modeling for regional conservation planning. Using the FUTure Urban-Regional Environment Simulation (FUTURES) model, we investigate how patterns of future development, resulting from hypothetical conservation-based planning policies, may (1) impact the conservation of priority natural resources and (2) influence landscape patterns and connectivity. FUTURES (Meentemeyer et al., 2013) is specifically designed to represent the spatial structure of urban growth, making it an ideal framework with which to assess potential tradeoffs between these two conservation goals. In this application, we also introduce a development *constraint* parameter into the model that enables the inclusion of policies, such as new regulations or fees, which could infer some protection to priority resources without completely excluding those areas from future development.

2. Methods

2.1. Study system

The study extent (Fig. 1), known as the greater Uwharrie region (1148,434 ha), is located within the Piedmont physiographic province of Central North Carolina, also embedded within the "Charlanta" mega-region (Florida, Gulden, & Mellander, 2008). It lies at the intersection of three rapidly expanding metropolitan areas: Charlotte, the Research Triangle (Raleigh, Durham, Chapel Hill), and the Piedmont Triad (Greensboro, Winston-Salem, High Point). Unplanned expansion of these cities is of particular concern to land managers and conservation practitioners due to a culture of strong property rights and very few regulations in place for protecting the landscape features that make the Piedmont unique (North Carolina Wildlife Resources Commission, 2008). The value of the natural resources in the Piedmont is often overlooked in comparison to the Appalachian Mountains to the west and the Coastal Plain to the east. However, it is a highly productive and diverse eco-region, home to numerous endangered or threatened species, natural heritage areas, and exceptional aquatic resources (North Carolina Natural Heritage Program, 2013).