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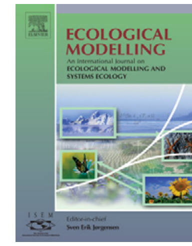

A multi-model framework for simulating wildlife population response to land-use and climate change

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ABSTRACT

Reliable assessments of how human activities will affect wildlife populations are essential for making scientifically defensible resource management decisions. A principle challenge of predicting effects of proposed management, development, or conservation actions is the need to incorporate multiple biotic and abiotic factors, including land-use and climate change, that interact to affect wildlife habitat and populations through time. Here we demonstrate how models of land-use, climate change, and other dynamic factors can be integrated into a coherent framework for predicting wildlife population trends. Our framework starts with land-use and climate change models developed for a region of interest. Vegetation changes through time under alternative future scenarios are predicted using an individual-based plant community model. These predictions are combined with spatially explicit animal habitat models to map changes in the distribution and quality of wildlife habitat expected under the various scenarios. Animal population responses to habitat changes and other factors are then projected using a flexible, individual-based animal population model.

As an example application, we simulated animal population trends under three future land-use scenarios and four climate change scenarios in the Cascade Range of western Oregon. We chose two birds with contrasting habitat preferences for our simulations: winter wrens (*Troglodytes troglodytes*), which are most abundant in mature conifer forests, and song sparrows (*Melospiza melodia*), which prefer more open, shrubby habitats. We used climate and land-use predictions from previously published studies, as well as previously published predictions of vegetation responses using FORCLIM, an individual-based forest dynamics simulator. Vegetation predictions were integrated with other factors in PATCH, a spatially explicit, individual-based animal population simulator. Through incorporating effects of landscape history and limited dispersal, our framework predicted population changes that typically exceeded those expected based on changes in mean habitat suitability alone. Although land-use had greater impacts on habitat quality than did climate change in our simulations, we found that small changes in vital rates resulting from climate change or other stressors can have large consequences for population trajectories. The ability to integrate bottom-up demographic processes like these with top-down constraints

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imposed by climate and land-use in a dynamic modeling environment is a key advantage of our approach. The resulting framework should allow researchers to synthesize existing empirical evidence, and to explore complex interactions that are difficult or impossible to capture through piecemeal modeling approaches.

1. Introduction

Predicting how animal populations will respond to landscape change, climate change, and other anthropogenic and non-anthropogenic stressors is critical to making effective environmental management and conservation decisions. Animal populations are increasingly exposed to multiple natural and anthropogenic threats including habitat loss and fragmentation, direct exploitation, chemical stressors (pesticides, fertilizers, and pollutants), and exotic invasions. A growing concern among wildlife managers and conservationists is that climate change may exacerbate current threats to wildlife through a suite of mechanisms, including (but not limited to) range shifts, habitat loss, changes in food resources, phenological changes, or changes in ecological communities and species interactions (e.g., Crick and Sparks, 1999; Hughes, 2000; McCarty, 2001; Root and Schneider, 2002; Walther et al., 2002; Parmesan and Yohe, 2003; Root et al., 2003; Travis, 2003). These impacts, when coupled with non-climate threats, may increase the vulnerability of at-risk animal populations and will certainly complicate efforts to forecast their responses to proposed resource development or conservation activities. Indeed, predicting how wildlife populations might respond to future environmental changes against a backdrop of changing climate is one of the major contemporary challenges in conservation biology (Hill et al., 1999; Warren et al., 2001; Norris et al., 2004).

Yet assessments of threats or benefits from management actions are typically driven by a single management question, and they rarely address cumulative or interactive effects of climate and other factors that will affect species of concern. Thus, making scientifically defensible environmental management and conservation planning decisions will require the development of modeling strategies that track how multiple biotic and abiotic factors interact to affect animal populations through time, both through habitat modifications and through other mechanisms. Part of this challenge involves translating impacts on ecosystem processes resulting from land-use and climate change into temporal trends in wildlife habitat. Doing so requires the linkage of mechanistic models of climate, land-use, vegetation, and demographic responses of animal populations to habitat characteristics (Holt et al., 1995). Because habitat pattern is a key driver of wildlife population dynamics (Gilpin, 1987; Dunning et al., 1995; Turner et al., 1995; Hansen et al., 1999; Wiegand et al., 1999), such modeling frameworks must explicitly consider the influence of spatial heterogeneity on population performance (Cairns, 1993; Johnson, 2002; Schumaker et al., 2004; Topping and Odderskær, 2004). Additionally, because changes in mean habitat suitability often correlate poorly with population performance (Lawler and Schumaker, 2004; Schumaker et al., 2004), assessments should project actual population sizes of species of concern. Finally, whereas most efforts to predict population responses to land-use or climate change have involved simulating populations in static landscapes representing some future condition (e.g., Schumaker et al., 2004; Jepsen et al., 2005), a more accurate representation of the complex, non-linear responses of populations will require dynamic landscape simulations that track the interaction of habitat changes and non-habitat-mediated factors through time (Dunning et al., 1995; Holt et al., 1995; Root and Schneider, 2002).

Here we illustrate how recent advances in individual-based plant and animal population models can help achieve these goals. The first objective of this study was to develop a modeling framework for simulating dynamic spatial and temporal changes in habitat and animal populations in response to climate change, land-use and other stressors occurring within complex landscapes. The framework is spatially explicit, incorporates mechanisms that act either via habitat modifications or directly on various aspects of species' life histories, and is not landscape-, species-, or threat-specific.

Our second objective was to apply the framework to a 500 km^2 forested watershed in the western Oregon Cascades to illustrate its use for projecting and analyzing long-term (1990–2060) population trends for two bird species having contrasting habitat requirements. We modeled population trajectories of winter wrens (*Troglodytes troglodytes*) and song sparrows (*Melospiza melodia*) as they responded to three future land-use scenarios and four climate change scenarios. The resulting simulations illustrate a flexible modeling approach incorporating effects of diverse factors interacting within a real landscape and producing spatially explicit projections of changes in habitat quality and wildlife populations through time. We demonstrate how the framework improves upon previous approaches, discuss its limitations, and suggest potential improvements.

2. Methods

2.1. Model framework

Our modeling framework (Fig. 1) combines top-down constraints (climate and land-use) and bottom-up processes (e.g., tree growth and competition, individual birth, death, and dispersal events of animals) to model trends in animal habitat and population dynamics through time. First, predictions from climate models are downscaled to predict future climate patterns in the region of interest under various future climate scenarios. These are integrated with predictions of future land management actions under alternative development scenarios using an individual-based tree growth model. The model produces a time series of maps of vegetation structure and composition, which are then converted into maps of