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Extension of landscape-based population viability models to ecoregional scales for conservation planning

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ABSTRACT

Landscape-based population models are potentially valuable tools in facilitating conservation planning and actions at large scales. However, such models have rarely been applied at ecoregional scales. We extended landscape-based population models to ecoregional scales for three species of concern in the Central Hardwoods Bird Conservation Region and compared model projections against long-term trend data from the North American Breeding Bird Survey. We used a spatially-explicit demographic model and structured the regional population into ecological subsections on the basis of habitat, landscape patterns, and demographic rates to assess species viability. Our model projections were within 2% of the Breeding Bird Survey trends over the last 40 years for each species. Wood thrush (*Hylocichla mustelina*) populations remained relatively stable over the simulation and worm-eating warbler (*Helmitheros vermivorus*) abundance increased throughout most of the time period until reaching carrying capacity. In contrast, the prairie warbler (*Dendroica discolor*) population steadily declined by 0.59% annually. The combination of habitat and demographic modeling allowed us to create models that address processes driving these populations at all scales, which is critical to understanding how regional populations respond to landscape processes such as habitat loss and fragmentation. Therefore, because it is spatially explicit and directly addresses population growth and viability, this approach provides a valuable foundation to planning conservation strategies, offering the ability to identify the most salient risks to viability and explore ways to address them.

1. Introduction

The ability of populations to sustain themselves in the face of global change and habitat fragmentation and loss depends on population processes that occur over large scales. As a result, avian conservation efforts increasingly target larger spatial scales (Boyd et al., 2008; Millspaugh and Thompson, 2009). Recognition that successful wildlife conservation and natural resources planning must consider more than just site-level management has led to collaboration across agency and ownership boundaries. The North American Bird Conservation Initiative plans and implements bird conservation in ecologically distinct Bird Conservation Regions (BCR) with similar bird communities, habitats, and resource management issues (US North American Bird Conservation Initiative Committee, 2000). Within each BCR federal, state, and local government agencies and non-government organizations form joint ventures that work to step down continental or national population goals to ecoregional scales and to implement conservation (Fitzgerald et al., 2009). Joint ventures use a conservation design approach to assess the current capability of landscapes to support species and to plan conservation actions to sustain species at desired levels (Fitzgerald et al., 2009; Will et al., 2005). Integral to this process is the development of landscape to regional-scale models to assess habitat availability, bird-species abundance, and population growth and viability under current and future conditions.

Landscape-scale population viability models are potentially valuable tools for conservation design because they integrate habitat- and demographic-modeling approaches at a relevant scale. Habitat suitability index (HSI) models can incorporate species' habitat requirements and landscape processes to assess habitat quality across a landscape (Dijak and Rittenhouse, 2009), or even BCRs (Tirpak et al., 2009a,b), but by themselves do not directly address abundance or growth. However, HSI models can identify suitability of habitat patches that can be used to spatially structure demographic models that project population growth (Akçakaya and Brook, 2009; Larson et al., 2004). Including environmental

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and demographic stochasticity in demographic models puts predictions in a probabilistic framework with which we can more realistically assess viability (Burgman et al., 1993; Lande, 2002). By implicitly considering risk, viability measures derived from these models are fundamental to making sound decisions when assessing and designing alternative management strategies (Millspaugh et al., 2009; Morris and Doak, 2002).

Landscape-based demographic models have rarely been applied at the scale of BCRs (but see Fitzgerald et al., 2009; Tirpak et al., 2009b). Estimating population growth at this scale requires models to consider large scale processes that are poorly understood. For example, source-sink dynamics are regarded as important drivers of populations (Faaborg et al., 2010a; Pulliam, 1988); however, we still lack complete understanding of these dynamics in regional populations (Faaborg et al., 2010b). Furthermore, integration of fine scale habitat data across extents as large as BCRs results in populations with spatial structures beyond the computational limits of many population modeling programs. Last, when developing models at the scale of BCRs, lack of comparable long-term datasets from similar scales has limited opportunities to verify that ecological processes are correctly and sufficiently embodied in models (i.e., do models behave in a realistic way) (Rykiel, 1996; Shifley et al., 2009), and validate the accuracy of their predictions against empirical observations (Beissinger, 2002). Therefore, an approach that can address important processes while avoiding these constraints is needed so that populations can be effectively modeled at ecoregional scales.

Our objective was to extend landscape-scale demographic models to an ecoregional scale for conservation planning. Implicit in this approach is our belief that models such as those developed here are useful for conservation even when based on imprecise parameters or assumptions about processes because they synthesize current knowledge in a transparent way, can be used to quantify uncertainty, and are required to assess viability at meaningful scales (Burgman and Possingham, 2000; Millspaugh et al., 2009). We developed and evaluated models for three priority species of breeding landbirds, wood thrush (*Hylocichla mustelina*), prairie warblers (*Dendroica discolor*), and worm-eating warblers (*Helmitheros vermivorus*), in the Central Hardwoods Bird Conservation Region (CHBCR). We selected the three species because of their priority in regional conservation and because they represent a variation in suitable habitats and life history strategies. We compared model projections to long-term trends from the North American Breeding Bird Survey (BBS) data to verify each model's results.

2. Study area

The CHBCR covers portions of 10 states that straddle the Mississippi River in the center of the conterminous United States (Fig. 1). Located between the 83 and 94 west longitudes and the 34 and 40 north latitudes this region is approximately 33-million ha in size. The entire area is dominated by oak (Quercus spp.)–hickory (Carya spp.) forests that provide habitat for many high-priority bird species (US North American Bird Conservation Initiative Committee, 2000). While much of the land that was forested historically remains so today—the region includes some of the most extensive forests in the middle of the continent—woodlands and other communities have been dramatically altered by wide-spread logging in the early part of the 20th century and fire suppression in subsequent decades (Fitzgerald et al., 2005). Glades, barrens, and extensive pine woodlands have largely converted to oak or oak-pine forests but are conservation priorities (US North American Bird Conservation Initiative Committee, 2000). Threats to the habitats of the region include agricultural conversion of floodplain habitats and urbanization.

Wood thrush, prairie warblers, and worm-eating warblers in the region are all regarded with conservation concern by Partners in Flight (Panjabi et al., 2005) or the US Fish and Wildlife Service (US Department of the Interior Fish and Wildlife Service, 2002). Declines in Midwestern populations of wood thrush and prairie warblers are linked to fragmenting landscapes (Robinson et al., 1995; Sauer et al., 2008) and loss of early-successional habitat (Nolan, 1978), respectively. As a result of the worm-eating warbler's area sensitivity when using forest interiors, Partners in Flight designates it as a management attention priority in the CHBCR (Panjabi et al., 2005).

3. Model development

We used a spatially-explicit demographic modeling approach (Beissinger et al., 2009) in which we treated ecological subsections as patches in our models. While these patches were not isolated patches of habitat in the typical metapopulation sense, they allowed for spatial structure based on ecologically relevant units while maintaining a reasonable number of patches (Fig. 1). Each patch represented a sub-population in the model and demographic parameters for that sub-population were derived from habitat attributes of the patch, using spatially-explicit suitability models. Key in this approach was summarizing cell level demographics in each patch to obtain patch level parameters for input into the demographic model (Fig. 2). The CHBCR is composed of 59 ecological subsections (Bailey et al., 1994) representing areas of similar landform and vegetation that occur in 145 distinct patches. We dropped 24 patches from consideration because of their small size (<1 ha), which was a result of intersecting the BCR boundaries with ecological subsection boundaries. The size of the remaining 121 patches ranged from 26.09 ha to >2.6 million ha (average patch size = 250 204.13 ha SD (399840.35).

3.1. Carrying capacity and initial abundances

We determined an initial abundance and carrying capacity (K) for a species in each patch using HSI models previously developed specifically for the CHBCR (Tirpak et al., 2009a,b). Tirpak et al. (2009a) developed the HSI models with knowledge from published studies and then verified and validated them with data from the BBS. The HSI models predict a value between 0 and 1 for each 30×30-m cell in the CHBCR where 0 represented non-habitat and 1 optimal habitat. Habitat suitability index values for each cell were based on the attributes of that cell which included landform, land cover, and forest successional stage and of the surrounding landscape such as patch size, interspersion and distance to edge (Tirpak et al., 2009b).

To calculate K of each patch (K_{patch})we first calculated K of each 30×30-m cell (K_{cell}) as the product of cell area (0.09 ha), bird density (pairs/ha) in optimal habitat, and the cell HSI value; we assumed bird density reached its maximum where HSI = 1 and declined linearly to zero pairs/ha where HSI = 0. We derived bird densities for optimal habitat from available literature (Appendix). To estimate K_{patch}, we used the Zonal Statistics in ArcGIS 9.3 to sum K_{cell} of each species across grid cells within each of 121 patches (Fig. 2). We calculated initial abundances as a percentage of K_{patch} based on current knowledge of the status of each species' population in relation to carrying capacity.

3.2. Stage-based matrix models

We used a Lefkovitch matrix model that included only females in two stages as