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Predicting impacts of future human population growth and development on occupancy rates of forest-dependent birds

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ABSTRACT

Forest loss and fragmentation are among the largest threats to forest-dwelling wildlife species today, and projected increases in human population growth are expected to increase these threats in the next century. We combined spatially-explicit growth models with wildlife distribution models to predict the effects of human development on 5 forest-dependent bird species in Vermont, New Hampshire, and Massachusetts, USA. We used single-species occupancy models to derive the probability of occupancy for each species across the study area in the years 2000 and 2050. Over half a million new housing units were predicted to be added to the landscape. The maximum change in housing density was nearly 30 houses per hectare; however, 30% of the towns in the study area were projected to add less than 1 housing unit per hectare. In the face of predicted human growth, the overall occupancy of each species decreased by as much as 38% (ranging from 19% to 38% declines in the worst-case scenario) in the year 2050. These declines were greater outside of protected areas than within protected lands. Ninety-seven percent of towns experienced some decline in species occupancy within their borders, highlighting the value of spatially-explicit models. The mean decrease in occupancy probability within towns ranged from 3% for hairy woodpecker to 8% for ovenbird and hermit thrush. Reductions in occupancy probability occurred on the perimeters of cities and towns where exurban development is predicted to increase in the study area. This spatial approach to wildlife planning provides data to evaluate trade-offs between development scenarios and forest-dependent wildlife species.

1. Introduction

Human modifications of natural landscapes have reached most corners of the globe. Activities such as agriculture, development, and resource extraction historically and presently continue to transform land (Dale et al., 2000; Turner et al., 2001). Of particular concern are the many adverse effects land transformation can have on wildlife (Vitousek et al., 1997; Gutzwiller, 2002; Foley et al., 2005; Brown and Laband, 2006) through changes in land use (how land is utilized) and land cover (the physical appearance of the land surface) (Turner et al., 1994). Land use changes can be caused by natural processes, but human-induced modifications are by far the most significant modern forces behind land transformation (Forman, 1995; Lindenmayer and Franklin, 2002). This presents challenges for how wildlife conservation will remain compatible with increased human development as the global population is projected to grow to over 9 billion people within the next four decades (United Nations, 2011).

In the northeastern USA, the populations of Vermont, New Hampshire, and Massachusetts are predicted to grow 16.9%, 33.2%, and 10.4%, respectively, between the years 2000 and 2030 (U.S. Census Bureau, 2011), collectively adding 1.2 million people. Importantly, the relationship between population growth and land use conversion differs across regions worldwide. For example, in Vermont the rate of land conversion is happening 260 times faster than population growth (Vermont Forum on Sprawl, 1999), and in Massachusetts residential housing accounts for 87% of land use change even in areas where population growth is roughly flat (DeNormandie et al., 2009).

Wildlife biologists and other conservation professionals are pressed to estimate the risk fauna populations will face in response to this projected human growth and increase in development. Wildlife abundance, distribution, and viability can be intricately

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tied to the condition of the landscape mosaic (Forman, 1995; Lindenmayer and Franklin, 2002). For example, landscapes with low amounts of forest cover have significantly more nest predation and lower bird densities as compared with unfragmented landscapes (Robinson et al., 1995, Donovan et al., 1997, Rosenberg et al., 1999). Bird species occurrence can also decrease in proximity to roads (Brotons and Herrando, 2001).

Because many wildlife species are responsive to both forest loss and fragmentation, there is a great need to predict where human growth and development is likely to occur, and the resulting consequences to wildlife. Some progress has been made with respect to land use change modeling (e.g., overview by Voigt and Troy, 2008), however, developing quantitative metrics that allow decision makers to link predicted land use changes with changes in forest-dependent wildlife species remains a pressing need.

Our goal in this paper is to predict changes in forest bird distribution patterns to the year 2050 as a result of increased development, and determine how the current network of reserves contributes to species' distribution patterns overall. The objectives of our study were to: (1) spatially quantify projected increases in human housing units in the study area to the year 2050, (2) based on projected human housing growth, forecast changes in four landscape variables: percent development, road density, percent forest cover, and distance to developed edge, (3) quantify the changes in probability of occupancy in each 30 m pixel for 5 forest interior bird species across the study area and in individual towns, and (4) evaluate the probability of occupancy within and outside of protected lands for the 5 bird species to the year 2050.

2. Methods

2.1. Study area and target species

The study area was the three-state region of Vermont (VT), New Hampshire (NH), and mainland Massachusetts (MA), USA (26,800 square miles). It was approximately 68% forested, 9% agriculture, and 11% developed, according to the 2001 National Land Cover Dataset (NLCD) (Multi-Resolution Land Characteristics Consortium, 2001), which was produced in a similar timeframe as the bird observations (Schwenk and Donovan, 2011). The majority of the study area occurred within the same ecoregion (Adirondack-New England highlands, province M212) (Bailey, 1995). The mean percent forest cover was 0.72 (VT), 0.78 (NH), and 0.52 (MA); the mean percent evergreen forest cover was 0.14 (VT), 0.22 (NH), and 0.12 (MA).

We selected 5 forest interior bird species for analysis based on habitat preferences and sensitivities to forest loss and fragmentation. The species were (1) black-throated blue warbler (*Setophaga caerulescens*), (2) black-throated green warbler (*Setophaga virens*), (3) ovenbird (*Seiurus aurocapillus*), (4) hermit thrush (*Catharus guttatus*), and (5) hairy woodpecker (*Picoides villosus*). In Vermont, the probability of a forest interior bird species occupying a site is dependent largely on the percent forested landscape around a site, as well as road density, distance to an edge, and percent development in the landscape (Schwenk and Donovan, 2011).

2.2. Housing density projections (Objective 1)

Projections of housing density in the study area were derived from the Spatially Explicit Regional Growth Model (SERGoM) (Theobald, 2005; Bierwagen et al., 2010). SERGoM inputs include data on housing units within each census block, county-level historic population, land cover types, and transportation infrastructure; the primary output is a 1 ha raster depicting housing density for the years 2000 and 2050.

We allocated the historic (defined as year 1990) and current (defined as year 2000 throughout the manuscript) housing density on the landscape (defined as the number of housing units per hectare) in three steps within SERGoM (Fig. 1). First, we obtained the number of housing units per census block in the year 2000 from the U.S. Census Bureau (Fig. 1a). Census blocks vary in size from roughly 1–2 ha in urban areas to 100–1000 ha in rural areas (Theobald, 2005). Second, we allocated housing units within each census block using a GIS raster that reflected patterns of growth from 1990 to 2000 upon which the new housing units were allocated (Fig. 1j). This required the identification of land potentially available for development (Fig. 1e). We removed water features such as lakes, reservoirs, and wide rivers to ensure no housing units were placed on those features (Fig. 1c). Like the water features, housing units were not placed on lands that prohibit development like parks and other public lands (Fig. 1b). Third, we considered the influence of roads on the spatial distribution of housing units within a census block. Existing major roads (Esri, 2009) were converted to road density (Fig. 1d), defined as the density of roads within 800 meters of each pixel (Fig. 1f) because undeveloped lands with a high road density tend to be more readily developed (and have effects on wildlife habitat) (Forman et al., 2003). Thus, the final allocation of housing units per hectare (Fig. 1g) resulted from available developable lands and road density (Bierwagen et al., 2010), and the total number of housing units within a block were not assigned homogeneously throughout a block.

We estimated future housing density on the landscape for each hectare in the next decadal time step (Fig. 1l). We used county-level population forecasts (Fig. 1k; Bierwagen et al., 2010) to estimate the increased population size for each county, which are based on a gravity-based model that relate amenity variables such as public land as well as recent county-to-county migration patterns. This was a non-spatial rate of growth that needed to be applied spatially to housing units. We allocated new housing units to each 1 ha pixel in several steps. Location-specific growth rates were computed for 16 development classes (from Theobald, 2005) which were combinations of housing density classes (urban: <0.1 ha/housing unit, suburban: 0.1 to 0.68 ha/housing unit, exurban: 0.68–16.18 ha/housing unit, and rural: >16.18 ha/housing unit) and accessibility classes (measured as travel time from the nearest urban core: 0–10, 10–30, 30–60, and >60 min) (Fig. 1h). The allocation of housing units were adjusted based on proximity to urban areas (Fig. 1i), expressed in the amount of travel time from an urban center along major roads. Finally, we added the newly allocated housing units to a map of current housing units to forecast the future housing unit density. In other words, the calculated housing units for time $t + 1$ were added to the housing units at time t.

The number of houses per ha in the study area was derived decadally between the years 2000 and 2050, but we report only on 2000 and 2050. We then applied a moving window analysis to sum the number of houses within a 1 km radius circle for each 1 ha pixel; thus, each pixel indicated the total number of houses within a 1 km radius circle. This radius was selected because it is strongly associated with avian occurrence (Bakermans and Rodewald, 2006) and was used to develop the bird occupancy models in this analysis (Schwenk and Donovan, 2011). Finally, we produced current (year 2000) and future (year 2050) housing unit maps from the outputs of SERGoM (number of housing units summed to 1 km radius circles) for Objective 2.

2.3. Landscape change scenarios (Objective 2)

Increases in housing density will affect landscape features such as land cover. We developed a landscape change model to predict changes in road density (km of roads within a 1 km radius circle),