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Importance of scale, land cover, and weather on the abundance of bird species in a managed forest

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ABSTRACT

Climate change and habitat loss are projected to be the two greatest drivers of biodiversity loss over the coming century. While public lands have the potential to increase regional resilience of bird populations to these threats, long-term data are necessary to document species responses to changes in climate and habitat to better understand population vulnerabilities. We used generalized linear mixed models to determine the importance of stand-level characteristics, multi-scale land cover, and annual weather factors to the abundance of 61 bird species over a 20-year time frame in Chippewa National Forest, Minnesota, USA. Of the 61 species modeled, we were able to build final models with R-squared values that ranged from 26% to 69% for 37 species; the remaining 24 species models had issues with convergence or low explanatory power (R-squared < 20%). Models for the 37 species show that stand-level characteristics, land cover factors, and annual weather effects on species abundance were species-specific and varied within guilds. Forty-one percent of the final species models included stand-level characteristics, 92% included land cover variables at the 200 m scale, 51% included land cover variables at the 500 m scale, 46% included land cover variables at the 1000 m scale, and 38% included weather variables in best models. Three species models (8%) included significant weather and land cover interaction terms. Overall, models indicated that aboveground tree biomass and land cover variables drove changes in the majority of species. Of those species models including weather variables, more included annual variation in precipitation or drought than temperature. Annual weather variability was significantly more likely to impact abundance of species associated with deciduous forests and bird species that are considered climate sensitive. The long-term data and models we developed are particularly suited to informing science-based adaptive forest management plans that incorporate climate sensitivity, aim to conserve large areas of forest habitat, and maintain an historical mosaic of cover types for conserving a diverse and abundant avian assemblage.

1. Introduction

Climate change and land-use change are projected to be the two greatest drivers of biodiversity loss over the coming century (Sala et al., 2000). Climate change has the potential to alter ecosystem structure and function and have significant global and regional impacts to biodiversity (Matthews et al., 2011; Grimm et al., 2013a,b; Urban et al., 2016). It is generally accepted that mean global temperatures are increasing and the largest temperature increases from climate change are currently found in the boreal and hemiboreal forests (Hansen et al., 1996; Balling et al., 1998; Serreze et al., 2000; IPCC, 2014). Significant changes in forest composition due to climate change and associated ecological processes have already been documented and are expected to increase in hemiboreal forests of the northern US (Iverson et al., 2008; Rodenhouse et al., 2009; Matthews et al., 2011; Wang et al., 2015). Drivers underlying these changes include overall increases in fire frequency, increases in insect infestation, and stand- and landscape-scale alteration of the mosaic composition of forests such as age, structure, and species composition (Mattson and Haack, 1987; Frelich and Reich, 1995; Fleming et al., 2002; Heilman et al., 2002; Wolter et al., 2012;

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Fisichelli et al., 2013; Hansen et al., 2013; Wang et al., 2015; Niemi et al., 2016). Further, recent changes to economics and ownership structures in the forest products industry have forced significant changes in forest ownership (Miles et al., 2011; Lönnstedt and Sedjo, 2012), resulting in parcelization, loss of forestlands, and fragmentation of the forest landscape (Heilman et al., 2002).

Climate change and land-use change are likely to have substantial consequences on avian populations and communities (Meynard and Quinn, 2008; Eglington and Pearce-Higgins, 2012; Riordan and Rundel, 2014). Over 300 North American bird species are predicted to have significant range reductions over the next century due to direct effects of climate change (Langham et al., 2014). Additionally, indirect effects of climate change, including alterations to habitat composition, are predicted to alter the suitability of forests, resulting in widespread population declines in many forest bird species (Niemi et al., 1998). Because boreal and hemiboreal forests are already experiencing significant ecological changes, birds breeding in these biomes are especially vulnerable to the effects of climate change (Grinde and Niemi, 2016a). Moreover, bird populations throughout the United States are experiencing increased pressures from human-induced changes to the landscape through habitat degradation, fragmentation, and loss (Yahner, 2000; Benítez-López et al., 2010; Sih et al., 2011; Wade et al., 2013). The direct and indirect effects of climate change will likely exacerbate the impacts of landscape-level habitat pressures on birds (Lawler et al., 2009; Rodenhouse et al., 2009; Stralberg et al., 2009; Bateman et al., 2016; LeBrun et al., 2016). However, the overall impacts of climate change and land-use change may affect species differently; some species may be vulnerable to habitat fragmentation while other species may be more susceptible to direct or indirect impacts of climate change.

Adaptive forest management has the potential to mitigate climate-induced changes to wildlife by conserving and cultivating critical habitats – particularly within large blocks of public lands where land-use change is greatly restricted. Adaptive silviculture techniques can promote forest resilience, preserve forest composition, increase adaptive capacity, and enhance carbon sequestration (Duveneck et al., 2014). However, to create successful adaptive management plans, managers need to understand how habitat at the local and landscape scale, climate, and potential interactions impact the abundance of forest-dependent species. To address this knowledge gap we used a large-scale, long-term dataset to assess patterns and commonalities of factors influencing avian species abundance in northern Minnesota's forests.

The Minnesota National Forest Breeding Bird Monitoring Program was established in 1995 in response to concerns about biodiversity and population declines of migratory passerines (Hanowski and Niemi, 1995; Niemi et al., 2016). The program was designed to provide an estimate of population trends for forest bird species in National Forests in Minnesota (Fig. 1). Data from this monitoring program provide a unique opportunity to investigate the relative roles that stand-level characteristics, land cover factors at multiple spatial scales, and climatic factors (as inferred by variability in weather; Eglington and Pearce-Higgins, 2012) had on bird species annual abundance over a 20-year timeframe. We predicted that bird species would respond uniquely to variation in local habitat, land cover, and weather, but hypothesized that there are likely common factors and scales associated with changes in abundance within trait-based guilds, and that species classified as climate sensitive by the Audubon Climate Report (Langham et al., 2014) would be more likely to retain weather variables within the species-specific models (Urban et al., 2016). Specifically, our objectives for this project were to: (1) build empirical statistical models to determine the influence of land cover and climatic factors on the abundance of 61 bird species over a 20-year time frame and (2) assess common factors associated with changes in abundance by guild and climate sensitivity.

2. Methods

2.1. Study area

This study was conducted from 1995 to 2014 in the Chippewa National Forest (NF). Chippewa NF is located in north-central Minnesota (Fig. 1), near the ecotone of boreal and northern temperate forests and is therefore best defined as "hemiboreal" with a mix of forest cover types. The most representative tree species in Chippewa NF are aspen (*Populus* spp.), paper birch (*Betula papyrifera*), spruce (*Picea* spp.), balsam fir (*Abies balsamea*), tamarack (*Larix laricina*) and pine (*Pinus* spp.) forests. Common cover types in Chippewa NF include upland deciduous (~35%), lowland conifer (~25%), upland coniferous (~35%, primarily pine and spruce plantations), and upland mixed forest (~2%; Niemi et al., 2016). This region supports approximately 155 breeding species of forest-dwelling birds (Green, 1995) – amongst the most diverse in North America (Robbins et al., 1986; Niemi et al., 1998).

2.2. Sampling

At the onset of the Minnesota National Forest Breeding Bird Monitoring Program, avian point count sampling locations were distributed across the forest mosaic in a stratified random manner (Fig. 1; Hanowski and Niemi, 1995). The sample of stands is therefore representative of the percent of forest cover found in Chippewa NF. Selected stands were large enough to accommodate three replicate sampling sites separated by a minimum of 220 m. Point count sampling in the Minnesota National Forest Breeding Bird Monitoring Program followed national and regional standards (Ralph et al., 1995; Howe et al., 1997). Ten-minute point counts were conducted at each site between late June and early July (Etterson et al., 2009; Niemi et al., 2016). Point counts were conducted by trained observers from approximately 0.5 h before to 4 h after sunrise on days with little wind ($< 15\ km\ hr^{-1}$) and little or no precipitation. All birds heard or seen from the site were recorded, and distance was estimated as 0–25 m, 25–50 m, 50–100 m, > 100 m (Howe et al., 1997, Niemi et al., 2016). We excluded birds recorded beyond the 100 m radius in our analyses to focus on birds observed in the forest stands we sampled.

2.3. Stand, land cover and weather variables

Forest birds are territorial during the breeding season and reported territory sizes vary depending on the species. Additionally, results from recent studies have shown that landscape factors at larger spatial scales were important drivers for many forest birds (Thogmartin, 2010; Streby et al., 2012; Lapin et al., 2013; LeBrun et al., 2016; Grinde and Niemi, 2016b). On the basis of this information and available land-cover data, we chose to calculate cover type and landscape variables at multiple spatial scales. A total of 48 predictor variables were used to build the statistical models, including 15 stand-level variables associated with a 100 m (3.14 ha) buffer around the site, 11 land cover variables calculated at the 200 m (12.5 ha) scale, seven land cover variables at the 500 m (78.5 ha) scale, nine land cover variables at the 1000 m (314.2 ha) scale, and six annual weather variables.

Land cover data were available from the Greater Border Lakes Region land cover classification and change detection project (Wolter et al., 2012). We used data from 1995 to 2000 as a base layer and extrapolated land cover layers for 2005 and 2010 using the University of Maryland's global forest change data (Hansen et al., 2013). Land cover data for 2005 and 2010 were therefore updated to include both forest loss and forest gain from 2000 to 2012. These 5-year increments of land cover data were summarized within various buffers for each site, where the closest year of land cover data available was used to correspond with the year in the bird samples. We also calculated road density as length (m) of road within a 1000 m buffer around each site based on