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Terrain and vegetation structural influences on local avian species richness in two mixed-conifer forests

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ABSTRACT

Using remotely-sensed metrics to identify regions containing high animal diversity and/or specific animal species or guilds can help prioritize forest management and conservation objectives across actively managed landscapes. We predicted avian species richness in two mixed conifer forests, Moscow Mountain and Slate Creek, containing different management contexts and located in north-central Idaho. We utilized general linear models and an AIC model selection approach to examine the relative importance of a wide range of remotely-sensed ecological variables, including LiDAR-derived metrics of vertical and horizontal structural heterogeneities of both vegetation and terrain, and Landsat-derived vegetation reflectance indices. We also examined the relative importance of these remotely sensed variables in predicting nesting guild distributions of ground/understory nesters, mid-upper canopy nesters, and cavity nesters. All top models were statistically significant, with adjusted R^2s ranging from 0.05 to 0.42. Regardless of study area, the density of the understory was positively associated with total species richness and the ground/understory nesting guild. However, the relative importance of ecological predictors generally differed between the study areas and among the nesting guilds. For example, for mid-upper canopy nester richness, the best predictors at Moscow Mountain included height variability and canopy density whereas at Slate Creek they included slope, elevation, patch diversity and height variability. Topographic variables were not found to influence species richness at Moscow Mountain but were strong predictors of avian species richness at the higher elevation Slate Creek, where species richness decreased with increasing slope and elevation. A variance in responses between focal areas suggests that we expand such studies to determine the relative importance of different factors in determining species richness. It is also important to note that managers using predictive maps should realize that models from one region may not adequately represent communities in other areas.

1. Introduction

Biodiversity is central to ecosystem functioning worldwide (Hooper et al., 2005). As human influences on the environment continue to grow, understanding and quantifying the factors driving biodiversity have received increased attention to support management and conservation efforts (Vitousek, Mooney, Lubchenco, & Melillo, 1997). Although numerous factors can affect biodiversity, vegetation structure is frequently identified as an important driver at the local scale (Farley, Ellis, Stuart, & Scott, 1994; Goetz, Steinberg, Dubayah, & Blair, 2007; MacArthur & MacArthur, 1961; Sallabanks, Haufler, & Mehl, 2006). Greater vegetation structural complexity is thought to maintain higher biodiversity across a range of taxonomic groups by providing a variety of microclimates and microhabitats (Carey, 1998; MacArthur & MacArthur, 1961; Müller & Brandl, 2009; Verschuyl, Hansen, McWethy, Sallabanks, & Hutto, 2008; Vierling et al., 2011). Different aspects of vegetation structure may be important to wildlife species for life history needs, such as reproduction, cover from predation and weather, and foraging (Bradbury et al., 2005).

Light Detection and Ranging (LiDAR) is an effective technique for acquiring fine-resolution, three-dimensional vegetation structure data relevant to the study of animal diversity, yet with wider spatial extent than field-based measures (Hyde et al., 2005; Müller, Stadler, & Brandl, 2010; Vierling, Vierling, Gould, Martinuzzi, & Clawges, 2008; Vierling et al., 2011). The well-documented relationships between bird diversity and field-sampled vegetation structure

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(MacArthur & MacArthur, 1961; MacArthur, Recher, & Cody, 1966) have made this taxonomic group a focus of many studies exploring the relationship between LiDAR-derived three-dimensional vegetation structure in modeling wildlife habitat associations (Clawges, Vierling, Vierling, & Rowell, 2008; Goetz et al., 2007; Müller et al., 2010). The diversity of birds is of particular interest in a wide array of studies, owing to the importance of birds as indicators of ecological function and degradation (Carignan & Villard, 2002).

While many of the studies utilizing LiDAR data to examine bird diversity relationships agree with previous findings indicating that some metric of foliage height diversity is a strong predictor of bird diversity (e.g. MacArthur & MacArthur, 1961; MacArthur et al., 1966), there is great variability in the metrics included. Some studies utilize LiDAR in addition to other sources of remotely sensed data (Clawges et al., 2008; Goetz et al., 2007; Jones, Arcese, Sharma, & Coops, 2013), while others incorporate LiDAR metrics alone (e.g. Lesak et al., 2011; Müller et al., 2010) in their analyses. Additionally, the studies have been conducted in a variety of different forest types (Mueller & Vierling, 2014), and there are a diversity of non-LiDAR metrics incorporated in the studies. For example, Flaspohler et al. (2010) incorporated the size of forest fragments in their study of Hawaiian bird diversity, and the incorporation of landscape characteristics such as patch size, patch shape, and horizontal heterogeneity of vegetation structure are limited in the existing LiDAR-based studies of bird diversity. It is important to consider additional environmental characteristics in these studies because although vertical vegetation structure is undoubtedly an important influence on avian diversity in some communities, the responses of bird communities to vegetation structure may also be influenced by a variety of ecological variables such as topographic gradients (Rompré, Robinson, Desrochers, & Angehr, 2007), landscape patterns (Saab, 1999), and management regimes (Twedt, Wilson, Henne-Kerr, & Hamilton, 1999).

Our main objective was to explore local species richness patterns in western North America, where only two studies have examined the relationships between LiDAR structure and bird diversity in conifer-dominated forests (Clawges et al., 2008; Jones et al., 2013). These studies have shown that LiDAR-derived variables are useful predictors of species richness, and our objective was to expand upon these studies in two fundamental ways. First, few studies have simultaneously included vertical and horizontal structural heterogeneities, terrain, and vegetation reflectance features within the same analysis of bird species richness. Second, although a few LiDAR-based studies have grouped avian species by broad habitat associations (Goetz et al., 2007; Jones et al., 2013), the use of forest-specific nesting guilds for examining LiDAR-derived forest structure relationships has yet to be explored. Finally, it is important to determine whether the same ecological variables that are important in one mixed-coniferous forest might differ in another mixed-coniferous forest. Our objectives therefore were to model total species richness and nesting guild richness (ground/understory nester, mid-upper canopy nester, and cavity nester) using a wide variety of environmental metrics, and to compare the relative importance of metrics in predicting species richness between two different study areas of mixed-coniferous forest.

2. Methods

2.1. Study areas

We sampled two study areas in north-central Idaho: Moscow Mountain and the Slate Creek drainage. Moscow Mountain is a ~20,000-ha peninsula of mixed conifer forest bordered on three sides by agricultural lands located ~20 km northeast of the city of Moscow, Idaho (46°49′N, 116°50′W). The majority of ownership belongs to private industrial logging companies with additional minority ownership of lands divided among the University of Idaho Experimental Forest, the City of Troy watershed, and small private landowners. Forest tree species include Western red cedar (*Thuja plicata*), Grand fir (*Abies grandis*), Douglas-fir (*Pseudotsuga menziesii*), Ponderosa pine (*Pinus ponderosa*), Western larch (*Larix* occidentalis), Lodgepole pine (*Pinus contorta*), Western hemlock (*Tsuga heterophylla*), Engelmann spruce (*Picea engelmannii*), Western white pine (*Pinus monticola*), and Subalpine fir (*Abies lasiocarpa*). The managed landscape is a mosaic of forest successional stages with the majority of the landscape ranging from recently logged to mature multi-story, with a small proportion of old multi-story stands (Falkowski, Evans, Martinuzzi, Gessler, & Hudak, 2009), and elevations ranging from 816 to 1242 m.

The Slate Creek study area is located on public land held by the National Forest Service within the Salmon River Ranger District of the Nez Perce National Forest of central Idaho (45°38′N, 116°2′W). In this landscape, our study focused upon a subset of the National Forest in the Slate Creek drainage ~30,000 ha in extent, with elevations ranging from 1125 to 2250 m. Higher elevation survey locations were located in the Gospel Hump Wilderness. Slate Creek includes the same tree species as Moscow Mountain, but with different relative proportions (dominant species at Moscow Mountain were Western red cedar and Grand fir while Douglas-fir and Lodgepole pine were dominant at Slate Creek). Slate Creek differs from Moscow Mountain in that it has larger topographic gradients and is less intensively managed with the full range of successional stages represented and a greater proportion within late-seral stages. While the Moscow Mountain study area is situated along the forest-agricultural land ecotone at the western extreme of the coniferous forest belt of north-central Idaho, the Slate Creek study area occurs within this coniferous forest belt.

2.2. Bird surveys and richness calculations

We randomly selected point count locations from study area maps stratified by forest structure. We used handheld Garmin Global Positioning System (GPS) units in conjunction with aerial photographs to locate the predetermined sample points in the field. Due to the 4-year gap between LiDAR acquisition and bird surveys at Slate Creek, sample sites within recently disturbed forest stands were relocated to an alternative random location within that stratum.

Avian point count surveys were conducted in the Moscow Mountain and Slate Creek study areas during the breeding seasons of 2009 and 2010, respectively following Vogeler, Hudak, Vierling, and Vierling (2013). Each of the 151 survey sites on Moscow Mountain and 164 survey sites at Slate Creek were visited twice during the season to increase the likelihood of detecting the majority of breeding bird species. Each survey point was separated by at least 250 m, and we used 8-minute variable-radius point count methods, where all bird individuals identified by sight or sound were recorded and distances were estimated (Reynolds, Scott, & Nussbaum, 1980). A single observer (Vogeler) conducted the point counts at Moscow Mountain in 2009 while two observers were used at Slate Creek for the 2010 surveys (Vogeler plus one technician). For the 2010 Slate Creek survey with two observers, there was intensive pre-season training to calibrate species identification and distance estimation between the observers. Additional details on the point count methodology used in this study can be found in Vogeler et al. (2013).

Point specific species richness was calculated using the birds that were detected within 75 m from the point count center. Recent studies have shown that low detectability at this spatial scale can be attributed to low occurrence and not the product of detectability issues (Dorazio, Royle, Soderstrom, & Glimskar, 2006, but see Alldredge, Pollock, Simons, & Shriner, 2007), including one study occurring in a geographic region with comparable forest structure (Verschuyl et al., 2008). To reduce the bias of rare species that may only be passing through the site, we adjusted our species richness values by removing any species with fewer than three independent detections during the season. Individuals recorded while flying