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Cover of tall trees best predicts California spotted owl habitat

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A B S T R A C T

Restoration of western dry forests in the USA often focuses on reducing fuel loads. In the range of the spotted owl, these treatments may reduce canopy cover and tree density, which could reduce preferred habitat conditions for the owl and other sensitive species. In particular, high canopy cover (≥70%) has been widely reported to be an important feature of spotted owl habitat, but averages of stand-level forest cover do not provide important information on foliage height and gap structure. To provide better quantification of canopy structure, we used airborne LiDAR imagery to identify canopy cover in different height strata and the size and frequency of gaps that were associated with owl nest sites, protected activity centers (PACs), and territories within four study areas and 316 owl territories. Although total canopy cover was high in nest stands and PAC areas, the cover in tall (> 48 m) trees was the canopy structure most highly selected for, while cover in lower strata (2–16 m) was avoided compared to availability in the surrounding landscape. Tall tree cover gradually decreased and lower strata cover increased as distance increased from the nest. Large (> 1000 m^2) gaps were not found near nests, but otherwise there was no difference in gap frequencies and sizes between PACs and territories and the surrounding landscape. Using cluster analysis we classified canopy conditions into 5 structural classes and 4 levels of canopy cover to assess the relationship between total canopy cover and tree size within nest sites, PACs, and territories. High canopy cover (≥70%) mostly occurs when large tree cover is high, indicating the two variables are often confounded. Our results suggest that the cover of tall trees may be a better predictor of owl habitat than total canopy cover because the latter can include cover in the 2–16 m strata – conditions that owls actually avoid. Management strategies designed to preserve and facilitate the growth of tall trees while reducing the cover and density of understory trees may improve forest resilience to drought and wildfire while also maintaining or promoting the characteristics of owl habitat.

1. Introduction

Historically dry western forests, on average, had lower tree densities, canopy cover and fuel loads than forests today largely due to the absence of frequent, low-severity fire for much of the 20th century (Knapp et al., 2013; Collins et al., 2015; Stephens et al., 2015; North et al., 2016). To increase resistance and resilience to current high-intensity wildfire and increasingly frequent and severe drought conditions (Graumlich, 1993; Asner et al., 2016; Margulis et al., 2016), managers often use mechanical thinning and managed fire to create

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some semblance of these historic stand conditions (Agee et al., 2000; Agee and Skinner, 2005; North et al., 2009). Such treated forests, however, often lack some of the structural features that have been linked with old-growth associated species such as the spotted owl (*Strix occidentalis*), fisher (*Martes pennanti*) and northern goshawk (*Accipiter gentillis*) (McClaren et al., 2002; Lee and Irwin, 2005; Purcell et al., 2009; North et al., 2010; Truex and Zielinski, 2013; Tempel et al., 2014; Sweitzer et al., 2016). In particular, throughout much of the western U.S., managing for the high canopy cover and tree density conditions of preferred spotted owl habitat may conflict with reducing ladder and canopy bulk density fuels, and stem density to improve a forest's fire and drought resilience (Zabel et al., 1995; North et al., 1999; Stephens et al., 2014; Jones et al., 2016; Stephens et al., 2016). The uncertainty about the effect of forest treatments on owls has often led to forest plans that separate landscapes into distinct restoration (i.e., managed to reduce fuels and stand density) and owl habitat zones (managed to preserve and increase high canopy cover) (Ager et al., 2007; Carroll and Johnson, 2008).

High (≥70%) levels of canopy cover within both owl territories and their core use areas (120 ha management designated Protected Activity Centers [PACs]) have been associated with greater owl occupancy and survival (Tempel et al., 2014; Tempel et al., 2015), and higher reproduction at nest sites (North et al., 2000). High canopy cover is commonly used to identify potential habitat areas and determine management options. Yet, canopy cover can be a difficult management target because estimates significantly vary depending on how many measurements are taken, the observer's viewing angle (i.e., closure vs. cover sensu Jennings et al., (1999)) and whether estimates are derived from direct field measurements (ex. spherical densiometer, densitometer, or 'moosehorn'), indirect interpretation (i.e., using aerial photographs or Landsat imagery) or modeled from non-spatial plot data (i.e., such as the Forest Service's estimates using the Forest Vegetation Simulator) (Fiala et al., 2006; Korhonen et al., 2006; Christopher and Goodburn, 2008; Paletto and Tosi, 2009). Field plots are used to record tree size and foliage characteristics, but sample size is often small, which makes it difficult to extrapolate across the large, diverse forest conditions used by owls.

Canopy cover estimates using Landsat imagery or interpreted aerial photographs can sample larger areas, but neither method can be used to identify the tree size or height of foliage cover, and must be categorized (e.g., 0–39%, 40–69% and ≥70%) to meet the wide variety of ages and structures of forests (Tempel et al., 2016). Given the challenges of measuring canopy cover, both managers and researchers have often resorted to coarse classifications such as the widely used California Wildlife Habitat Relationships (CWHR) classes (Tempel et al., 2014) that are known to simplify and only roughly correlate with patterns of actual animal use (Purcell et al., 1992; Block et al., 1994; Howell and Barrett, 1998). Regardless of how it is estimated as a stand-level characteristic, canopy cover does not provide information on the height and distribution of foliage or the size and frequency of forest gaps (Jennings et al., 1999). Consequently, it is unclear how foliage and gaps are either distributed within owl use areas, or how best to assess and then establish management objectives for sustaining and enhancing owl habitat.

In this study we use airborne LiDAR data to measure canopy structure both intensively and accurately within all owl territories (n = 316 territories within a cumulative 420,478 ha) found in four large study areas having a variety of management histories in the central and southern Sierra Nevada. Three of these locations are long-term owl demographic study areas, and include an area in Sequoia/Kings Canyon National Park (SEKI) where the only logging occurred 75–120 years ago in localized, limited areas. SEKI includes forests with restored fire regimes, and has the only known non-declining population of spotted owls that have been studied in California. The fourth site, Tahoe National Forest, while not a demographic study area, did survey owl occupancy and reproduction over an extensive area for which LiDAR data was collected. The LiDAR data allowed us to map forests in high fidelity, measuring total canopy cover, the distribution of cover by height strata, and opening sizes and frequencies. We analyzed habitat at three scales for each owl pair: nesting area (~4 ha), the surrounding Protected Activity Center (~120 ha), and the encompassing territory (~400 ha). Using the data on tree cover in different height strata and how they are associated, we used cluster analysis to identify common forest structural conditions. We then compared structural conditions between owl use areas and the surrounding forest with a complete LiDAR sampling of the landscape within a 5 km radius.

The goal of this study was to use our large sample size and high fidelity measurements over large areas to examine which attributes of forest structure are most strongly associated with California spotted owl habitat. Using LiDAR measures of forest structure, we examined the following specific questions:

- Which canopy structures are most strongly associated with different scales of owl habitat use, focusing on the nest, PAC and territory?
- How does the percentage of overstory tree canopy area in different height strata and gap sizes compare between owl use areas and across study areas?
- How strongly selected are different canopy attributes at nests compared to the available landscape and how does that change with distance from the nest?
- How are structure classes distributed between different owl use areas and what is the relationship between these structure classes and total canopy cover?

2. Methods

2.1. Study areas

The four study areas are located on the western slopes of California's Sierra Nevada Mountains in predominantly ponderosa pine (*Pinus ponderosa*) and mixed-conifer forests, and extend over a range of 3^0 latitude or about 320 km (Fig. 1). The Tahoe study area (311,930 ha) encompasses most of the Tahoe National Forest and is dominated by ponderosa pine, incense cedar (*Calocedrus decurrens*) and black oak (*Quercus kelloggii*) on drier, lower elevation locations, and a combination of ponderosa and sugar pine (*P. lambertiana)*, incense cedar, Douglas-fir (*Pseudotsuga menziesii*) and white and red fir (*Abies concolor* and *A. magnifica)* generally above 1300 m in more mesic conditions. At higher elevations (generally > 2000 m) and in the eastern-most portion of the owl use area, red and white fir and Jeffrey pine (*P. Jeffreyi*) dominate forest composition. Areas of the Tahoe NF are checkerboarded with private ownership and much of the forest has been heavily selectively logged over the last century, resulting in scattered large individual trees and small pockets of old growth (Taylor, 2004). Since about the 1930s almost all fires have been suppressed leaving forests often in a fuel-loaded condition with high stem density and canopy cover.

The Eldorado Study Area (40,549 ha) includes an owl demographic study area on the Eldorado National Forest (Tempel et al., 2016). It is located east of Georgetown on steep terrain surrounding the Rubicon and middle Fork of the American rivers between 300 and 2500 m elevation. It is primarily mixed conifer with occasional black and canyon live oaks (*Quercus chrysolepis*), tanoak (*Notholithocarpus densiflorus)* and bigleaf maple (*Acer macrophyllum*). At higher elevations some of the study area includes red fir and lodgepole pine (*Pinus contorta*). The Eldorado National Forest was logged selectively, often removing the largest trees, and fire suppressed through much of the last century (Darr, 1990). Portions of the demographic study area have a checkerboard of private land ownership, much of which is owned by SIMORG Forests LLC. About 50% of the owl study area burned, much of it at high severity, in the 2014 King Fire (Jones et al., 2016). The LiDAR data we use is from an acquisition completed before 2014.