Forest Ecology and Management 373 (2016) 100–107

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Landscape heterogeneity compensates for fuel reduction treatment effects on Northern flying squirrel populations

R. Sollmann [a,b,*], A.M. White [a], G.L. Tarbill [a,b], P.N. Manley [c], E.E. Knapp [d]

[a] USDA Forest Service, Pacific Southwest Research Station, 1731 Research Park Drive, Davis, CA 95618, USA
[b] Oak Ridge Institute for Science and Education, 1299 Bethel Valley Rd, Oak Ridge, TN 37830, USA
[c] USDA Forest Service, Pacific Southwest Research Station, 2480 Carson Rd., Placerville, CA 95667, USA
[d] USDA Forest Service, Pacific Southwest Research Station, 3644 Avtech Parkway, Redding, CA 96002, USA

A R T I C L E I N F O

Article history:
Received 5 February 2016
Received in revised form 6 April 2016
Accepted 18 April 2016
Available online 26 April 2016

Keywords:
Glaucomys sabrinus
Variable thinning
Even thinning
Prescribed burn
Distribution
Sierra Nevada

A B S T R A C T

In the dry forests of the western United States frequent fires historically maintained a diversity of habitats in multiple seral stages. Over the past century, fire suppression and preferential harvest of large trees has led to a densification and homogenization of forests, making them more prone to larger and more severe wildfires. In response, fuel reduction treatments have become common practice in the management of dry western forests. However, the effect of fuel reduction treatments on late seral forest species, such as the Northern flying squirrels, remains a management concern.

We captured and marked Northern flying squirrels within mixed conifer forest in the Stanislaus–Tuolumne Experimental Forest (California) on a continuous trapping grid (~1400 traps) spanning a 120-ha study landscape in which 24 4-ha units were subject to different fuel reduction treatments (variable thin, even thin, and control, all with or without prescribed burning). The study spanned two pre-thinning and three post-thinning years. We divided the study landscape into three blocks (two with treatments, one control only). For each block we analyzed data with spatial capture–recapture models to estimate Northern flying squirrel density, and tested whether canopy closure before and after thinning and percent area burned were important predictors of density.

Northern flying squirrel densities varied from 0.168 (SE 0.086) to 0.808 (SE 0.094) individuals/ha across blocks and years. Densities varied by year, independent of treatments. Percent area burned was not an important predictor of density. The effect of canopy closure was variable, but more consistently positive after thinning reduced overall canopy closure. When considered by treatment type, densities were highest in control and burn only units, and lowest in thinned units.

Whereas thinning had negative effects on Northern flying squirrel density on the scale of a thinning treatment unit, our results suggest that these effects were largely absorbed by the heterogeneous landscape, as animals shifted their distribution into un-thinned areas without a decline in overall density. This highlights the need to incorporate the landscape context when evaluating the effects of forest management on wildlife.

1. Introduction

Heterogeneity is a natural feature of landscapes and has long been recognized as an important factor in supporting diverse communities (Fahrig et al., 2011; Lindenmayer et al., 2006). In the dry forests of the western United States, fire historically maintained a variety of seral stages and forest structures through cycles of frequent disturbance and stand regeneration. Fire severity and extent varied as a function of vegetation/fuels, topography and climatic conditions, resulting in forests that were comprised of patches in multiple seral stages (Agee, 1993). With Euro-American settlement, a combination of fire suppression and preferential harvest of large-diameter trees led to considerable loss in structural and compositional heterogeneity and a predominance of young, dense and relatively homogenous forest (Knapp et al., 2013; Stephens et al., 2015). In addition, the accumulation and continuity of forest fuels have contributed to larger and more severe wildfires, which are projected to become even more common as the climate continues to warm (McKenzie et al., 2004; Westerling et al., 2006).

* Corresponding author at: University of California Davis, Department of Wildlife, Fish and Conservation Biology, 1088 Academic Surge, One Shields Avenue, Davis, CA 95616, USA.

E-mail addresses: rsollmann@ucdavis.edu (R. Sollmann), angelawhite@fs.fed.us (A.M. White), ginatarbill@fs.fed.us (G.L. Tarbill), pmanley@fs.fed.us (P.N. Manley), eknapp@fs.fed.us (E.E. Knapp).

http://dx.doi.org/10.1016/j.foreco.2016.04.041
0378-1127/

In response to the increased risks associated with wildfire, mechanical fuel reduction treatments have become common practice in the management of dry western forests, particularly in the wildland–urban interface (Schoennagel et al., 2009). These treatments aim to reduce the risks of high severity wildfire through the mechanical removal of understory vegetation and small trees ("thinning"). Further, these treatments can be used to create heterogeneity in forest structure on the landscape scale, both directly through manipulation of stands, and indirectly, by producing heterogeneous fuel loads so that future wildfires burn with patchy severity (Stephens et al., 2012). More recent silvicultural prescriptions are often designed specifically to promote stand-scale variability in forest structure while reducing fire hazard (North, 2012). A recent meta-analysis supports the notion that the heterogeneity created by fire disturbance (or its surrogates) is needed to maintain the full array of vertebrate species in forests with frequent-fire regimes (Fontaine and Kennedy, 2012).

In spite of this evidence supporting the value of reducing the risk of high severity wildfire, fuel reduction treatments are frequently seen as having a negative impact on habitat quality for species typically associated with late seral forests (i.e. old-growth specialists). A recent publication on California spotted owls (*Strix occidentalis occidentalis*), for example, states that fuel treatments "conflict with conservation of the spotted owl" (Lee and Bond, 2015), and a study on Pacific fishers (*Pekania pennanti*) showed lower persistence at thinned sites (though authors deemed this a temporary effect, Sweitzer et al., 2016). Northern flying squirrels (*Glaucomys sabrinus*) are also typically associated with late-seral habitat and play an important ecological role as dispersers of fungal spores and ectomycorrhizal bacteria (Caldwell et al., 2005) as well as the primary prey species for spotted owls and other predators (e.g., Forsman et al., 1984). Forest management activities that include tree removal may be detrimental to the highly arboreal Northern flying squirrel (Carey et al., 1992; Holloway et al., 2012; Lehmkuhl et al., 2006) because of their reliance on canopy for locomotion (Kelly et al., 2013; Scheibe et al., 2007), and because these activities can temporarily disrupt food availability (Carey, 2001). However, other studies found little to no effect of commercial thinning or secondary versus old-growth habitat on the species (Gomez et al., 2005; Ransome and Sullivan, 2002; Rosenberg and Anthony, 1992). Whereas some studies recognize the importance of the landscape context (Holloway et al., 2012; Lehmkuhl et al., 2006), no study to date has actually measured Northern flying squirrel response to mechanical treatment on a scale larger than the treatment unit.

In this study, we sampled Northern flying squirrel populations across a continuous area that was subject to fuel reduction treatments (mechanical thinning, prescribed burns, and combinations thereof) implemented in discrete patches across the landscape. Our objective was to determine the effects of fuel reduction treatments on Northern flying squirrel density and distribution and tease apart treatment scale from landscape scale effects. Based on the species' association with late seral forest habitat, we expected to find a positive relationship between Northern flying squirrel density and canopy closure, and, consequently, a negative relationship with thinning treatments, which reduce canopy. Our findings have important implications for forest management, providing a more complete picture of the effects of fire and fuel reduction practices on Northern flying squirrels, and wildlife in general.

2. Material and methods

2.1. Study area

The study was conducted in the Stanislaus–Tuolumne Experimental Forest (STEF), located on the western slopes of the central Sierra Nevada near Pinecrest, CA. Elevation ranges from 1585 to 1890 m a.s.l., with about 1020 mm of annual precipitation falling primarily as snow in the winter months. Temperatures range from −7 °C in January to 27 °C in July. The mixed-conifer forest on this site was last logged in the late 1920's. Originally, the forest was subject to a frequent low to moderate severity fire regime with fire return intervals between 5 and 8 years (Knapp et al., 2013), but fire has been excluded since the late 19th century. As a result of these changes, the forest today is composed of a greater proportion of shade-tolerant white fir (*Abies concolor*) and incense cedar (*Calocedrus decurrens*), and a reduced proportion of more shade intolerant sugar pine (*Pinus lambertiana*), and ponderosa pine (*Pinus ponderosa*). Density of trees >10 cm diameter at breast height (dbh) within the study area was 740/ha, with approximately 45% comprised by small trees (<20 cm dbh, Knapp et al., 2013). Shrub cover has declined dramatically over time, from about 28% pre-logging to about 2% today (Knapp et al., 2012).

2.2. Fuel reduction treatments

Small mammal trapping at STEF was part of a larger study that investigated the effects of two fuel reduction treatments (even and variable thinning) with an unthinned control, combined with prescribed fire, on a variety of ecological, fuels, and hydrological response variables. Twenty-four units (approximately 4 ha each) were arranged in a completely randomized split-plot design (variable, even, and unthinned nested within each burned/unburned split, with four replicates per treatment, Fig. 1). In addition, a 24-ha control block was established adjacent to the experimental landscape to serve as wildlife control area.

STEF management completed mechanical thinning between July and October, 2011. The goal of the variable thinning treatment was to create a highly heterogeneous forest structure similar to what existed historically, with larger trees arranged in distinct clusters, separated in space by small gaps or areas with far fewer and/or smaller trees. The thinning prescription thus created numerous small 0.04–0.2-ha gaps (approximately 1 per 0.8 ha) and varied the retained density and basal area within patches at an approximately 0.1 ha scale, similar in degree and scale to what was noted in the historic stands (Knapp et al., 2012; Lydersen et al., 2013). All snags >15″ (38 cm) dbh were retained unless they presented a hazard. Because of the current reduced proportion of pine trees compared with historical conditions, removal priority was fir followed by incense cedar, then pines. Details of the prescription are described in Knapp et al. (2012). The even thinning treatment more closely approximated a standard fuel reduction prescription, retaining the largest, most vigorous trees at a relatively even crown spacing, resulting in a more homogenous stand structure than the variable thinning treatment. The even thinning treatment had the same tree species priority, and target basal area of retention trees was similar for both the even and variable thinning treatments. Even though thinning increased the percentage of pines in the tree community, white fir remained the most abundant species in both thinning treatments, and contributed a similar proportion to stand basal area as was recorded in nearby stands in 1929 (Knapp et al., 2013). STEF management applied prescribed fire in November 2013, two years after thinning treatments. Units were ignited using strip-head fires, from highest to lowest elevation. In areas where the litter was too moist to carry fire well, pockets of heavy fuels were ignited, with the fire allowed to spread within the burn perimeter as the fine fuels dried.

We collected data on vegetation before thinning, after thinning, and after burning on a 30-m grid set up across the study area. We measured canopy closure at each grid point via 4 convex spherical densiometer readings taken from the grid point in each cardinal direction. To evaluate the impact of fire, we visually estimated