

Microhabitat Selection of Bark-Foraging Birds in Response to Fire and Fire Surrogate Treatments

Kerry L. Farris, Steve Zack, Andrew J. Amacher, and Jennifer C. Pierson

Abstract: We examined the short-term response of the bark-foraging bird community to mechanical thinning, prescribed fire, and thinning/prescribed fire combination treatments designed to reduce fuel loads at study sites throughout the continental United States as part of the national Fire and Fire Surrogate (FFS) project. We modeled the effects of study site, treatment, treatment category, and time since treatment on the foraging encounter rate of four individual species (red-breasted nuthatch [*Sitta canadensis*], mountain chickadee [*Poecile gambeli*], hairy woodpecker [*Picoides villosus*], and brown creeper [*Certhia americana*]) and assessed the relative importance of several tree and snag characteristics in the selection of foraging trees by these same species. The foraging encounter rate of all four species responded inconsistently across both treatment categories and study sites. Substrate diameter was the strongest and most consistent characteristic positively influencing the selection of foraging habitat structures for all species across all treatment categories. Other influential variables included the presence of bark beetles for red-breasted nuthatches, hairy woodpeckers, and brown creepers in control and burn-only treatment areas and tree species for brown creepers in burn-only and thin-only treatment areas. Although this study did not detect any major negative treatment response by any species, our results suggest that there is substantial variability in the reaction of this particular bird community to fuel reduction treatments and that managers may need to evaluate the effects of these treatments on a site-by-site and species-by-species basis. FOR. SCI. 56(1):100–111.

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THE PROBLEMS ASSOCIATED WITH the unnaturally high fuel loads characterizing many of today's fire-dependent forests have been extensively documented over the last decade (Covington and Moore 1994, Swetnam et al. 1999, Allen et al. 2002). Key among these are an increase in the number, size, and severity of fires (Dahm and Geils 1997, Swetnam and Betancourt 1998), long-term type conversion from forest to shrub and/or grassland (Allen et al. 2002), and the destruction of both human communities and critical wildlife habitat (Allen et al. 2002). In response to these adverse conditions, many forest management activities are focused on treating fire-dependent forests with fuel reduction techniques designed to minimize wildfire hazard. In addition, legislation such as the Healthy Forest Restoration Act of 2003 (US Public Law 108–148), which mandates a reduction in fuel loads across federal forest lands, has further increased the use of these practices. Fuel reduction treatments are often comprised of mechanical thinning, prescribed burning, or a combination of both (Agee and Skinner 2005). Although the effectiveness of these treatments, applied either separately or collectively, in the reduction of fuel load and fire risk has been documented (Omi and Martinson 2004, Fulé et al. 2001a, 2001b, Agee and Skinner 2005, Stephens and Moghadas 2005), the

effects of such treatments on ecological function are relatively unknown (but see Noss et al. 2006, Pilliod et al. 2006).

In response to this information need, the Fire and Fire Surrogate (FFS) project was implemented in 2000 to evaluate the response of soils, fuels, vegetation, insects, and wildlife to four distinct experimental treatments—(1) prescribed fire, (2) mechanical thinning, (3) thinning followed by prescribed fire, and (4) control, no management intervention—across an integrated network of 12 study sites situated in forests historically experiencing frequent, low-intensity fires (Weatherspoon 2000). Two fundamental goals of the FFS study were to examine whether thinning operates as an ecological “surrogate” for prescribed fire or whether the three different treatment types have significantly different ecological effects and whether general conclusions could be drawn about treatment effects across the entire suite of 12 study sites. Consistency in treatment effects across study sites would strengthen the ability of land managers to predict the outcome of fuel reduction activities. Further details of this project are available (Fire Research And Management Exchange System 2009).

The functional response of the bark-foraging bird community was specified as a key variable within the wildlife component of the FFS study. The reaction of this bird

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group, which for the purposes of this study included the red-breasted nuthatch (*Sitta canadensis*), mountain chickadee (*Poecile gambeli*), hairy woodpecker (*Picoides villosus*), and brown creeper (*Certhia americana*), is of particular interest to resource managers in coniferous forests because they are the primary predators of several tree-killing insects such as the western pine beetle (*Dendroctonus brevicomis*) (Otvos 1965, Koplín 1972). Additionally, the hairy woodpecker and red-breasted nuthatch excavate their own nest cavities each year, which provide numerous other wildlife species with essential nesting and denning sites (Bull et al. 1997).

The red-breasted nuthatch is a common resident in the boreal and temperate mixed coniferous forests of North America where it gleans, flakes, and pecks for surface and subsurface-dwelling arthropods on the trunks and branches of fir, spruce, larch, and pine trees using the characteristic “head down” nuthatch maneuver (Ghalambor and Martin 1999). Nests are constructed in snags with decay adequate enough to permit cavity excavation, often in broken-topped fir (Ghalambor and Martin 1999), but they will sometimes use already existing cavities.

The mountain chickadee has the most restricted distribution of the four species included in this community. A resident of montane coniferous forests from the Yukon Territory South to Baja California, this species forages primarily on the foliage, branches, and cones of pine, fir, and cedar. Mountain chickadees use either naturally occurring cavities or cavities previously occupied by nuthatches or woodpeckers (McCallum et al. 1999).

Of the four species examined in this study, the hairy woodpecker has the most extensive distribution and is found in the widest variety of habitat types, from the boreal forests in Canada to the tropical forests of Panama. In the dry forests of the west, this species forages on large pine and fir trees primarily in search of subsurface beetle larva but also takes surface dwelling arthropods and conifer seeds (Jackson et al. 2002). Because this species can excavate multiple nest and roost cavities each year, hairy woodpeckers are a critical provider of nesting and denning habitat for secondary cavity nesting species (Jackson et al. 2002).

The brown creeper also has an extensive distribution in both north and central America where it inhabits coniferous and coniferous-deciduous forests from Alaska south to Nicaragua (Hejl et al. 2002), gleaning bark-dwelling insects from the crevices of large live trees (Hejl et al. 2002). The brown creeper constructs a hammock-type nest under loose pieces of bark on large diameter snags, typically in stands of dense, old growth (Hejl et al. 2002). Because of its specialized habitat requirements, this species has suffered declines in many areas of the west and has a “protected” status in Idaho and Montana (Hejl et al. 2002).

While previous studies have separately examined the effects of wildfire (Hutto 1995, Smucker et al. 2005, Kotliar et al. 2007) or mechanical thinning after wildfire (e.g., “salvage” [Thompson et al. 2003, Saab et al. 2007, 2009]) on the abundance and/or nest success of these four species, there are relatively few studies that explore how these birds might alter their foraging habitat selection patterns in response to treatments specifically designed to reduce fuel

loads such as prescribed fire and mechanical thinning (however, see Lyons et al. 2008, Pope et al. 2009). Estimating the general treatment responses of the bark-foraging bird community, coupled with identifying the specific aspects of foraging habitat selected by these species, will provide managers with a more detailed portrait of the resource needs of this community in the face of fuel reduction treatment activities.

The principal objective of this research was to examine the initial responses of the bark-foraging bird community to mechanical thinning, prescribed fire, and combination thinning/prescribed fire treatments across a suite of five western FFS project study sites. Specifically, we wanted to answer three primary research questions: Do thinning, prescribed fire, and combination thinning/prescribed fire treatments differ in their effects on the foraging encounter rate of red-breasted nuthatches, mountain chickadees, hairy woodpeckers, and brown creepers? Are these effects generally similar across study sites? Do the characteristics of the foraging habitat used by these species differ with treatment type?

Because this study encapsulates results from several discrete field sites, differences in the timing of treatments, data collection, and bird species are to be expected. It was not our goal to describe or explain this variation but rather to search for general patterns in bird responses across the entire western study region. If the effects of the treatments are found to be consistent across study areas, the ability of land managers to predict the responses of this bird community to such treatment activities will be improved. If not, then site-specific analysis may still be necessary before implementation of treatment activities.

Methods

Experimental Design

The national FFS network consists of 12 study sites distributed across the United States on lands managed by federal and state governments and universities in 10 separate states. In this study we examined data from a subset of 5 study sites spanning 3 western states. The remaining 7 study sites either did not specifically collect bird foraging data or did not have adequate samples for evaluation of our research objectives.

The core experimental design at each of the study sites consisted of treatments, experimental unit size, replication, and response variables common to all 12 study sites (McIver et al. 2008). Treatment categories included untreated control, prescribed fire, mechanical thinning, and a combination of mechanical thinning followed by prescribed fire. Each treatment was replicated at least three times at each study site, creating a minimum of 12 experimental units, each at least 10 ha in size and surrounded by a 50-m buffer of similar treatment type. A permanent 50-m grid system was used for geo-referencing during data collection. For more detailed study site descriptions and design information, see McIver et al. (2008).

Study Sites

The Northern Rocky Mountains study site (NORM) was located near Missoula, Montana, on the Lubrecht Experimental Forest managed by the University of Montana and typified intermountain mixed conifer forests consisting of ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*). The site was organized in a randomized block design with 12 experimental units made up of four treatments and three replicates. Thinning was conducted between January and March 2001, and slash was scattered. Burning was conducted between May and June 2002. Foraging observations were conducted between late May and early July of 2001 and 2004.

The Blue Mountains study site (BLMO) was located near Enterprise, Oregon, on the Wallowa-Whitman National Forest. Vegetation at this site was characterized as mixed conifer forest and consisted primarily of ponderosa pine and Douglas-fir. The study site included 16 experimental units organized in a completely randomized design with four treatments and four replicates. Thinning was conducted between August and October 1998, and slash was scattered. Prescribed burn occurred in the third week of September 2000. Bird observations were conducted between late May and early July of years 2000–2004.

The Southern Cascades study site (SCAS) was located near Weed, California, on the Klamath National Forest and was also characterized as a mixed conifer forest type. This site was dominated by ponderosa pine and white fir (*Abies concolor*) and comprised 12 experimental units in a completely randomized design with four treatments and three replicates. Thinning was conducted between June and August of 1999, and slash was scattered. The three thin-burn units were burned in October 2001, whereas the three burn-only units were burned in October 2002. Observations of bark-foraging birds were conducted between late May and early July during the years 2001, 2003, and 2004.

The Central Sierra Nevada (CESN) study site was located near Georgetown, California, on the Blodgett Forest and was managed by the University of California–Berkeley. Vegetation at this site was characterized as Sierra mixed conifer forest and consisted of ponderosa pine, sugar pine (*Pinus lambertiana*), white fir, incense cedar (*Calocedrus decurrens*), Douglas-fir, and California black oak (*Quercus kelloggii*). The study site comprised 12 experimental units in a completely randomized design with four treatments and three replicates. Thinning was conducted between August and October 2001, and slash was masticated and scattered during the summer and fall of 2002. Prescribed burning was conducted between October and November 2002. Avian foraging observations were conducted between early May and early July in 2003.

The Southern Sierra Nevada (SOSN) study site was located within Sequoia National Park in east-central California, in mixed conifer forest dominated by ponderosa pine, sugar pine, and white fir. The study area consisted of nine experimental units that were not grouped into study sites. The treatments consisted of early (spring) and late (fall) season burning; thinning was not conducted in the national park. The two burning treatments were combined

in this analysis. Fall burns were conducted in the fall of 2001; spring burns were conducted in the spring of 2002. Foraging observations were conducted between late May and early July of the years 2003 and 2004.

Field Methods

We measured the foraging encounter rate (number of foraging observations per hour) and micro-habitat selection patterns of bark-foraging birds by adapting techniques outlined by Weikel and Hayes (1999) and Remsen and Robinson (1990). We systematically surveyed each unit between 4 and 10 times throughout the season by walking along the established grid-point system during 2-hour observation periods and searching for foraging individuals using focal animal sampling. Once a foraging bird was located, observers waited 10 seconds before recording any data to reduce the bias toward conspicuous behaviors (Hejl et al. 1990). After the 10-second period, observers waited until the bird was foraging, then recorded the species and a suite of structural variables describing characteristics of the tree or snag where the foraging bird was located including: (1) TRSPP, a class variable describing the species grouping of the targeted tree and comprising three species groups: (a) fir, which included *A. concolor*, *Abies magnifica*, and *Pseudotsuga menziesii*; (b) pine, which included *Pinus ponderosa*, *Pinus jeffreyi*, *Pinus lambertiana*, and *Pinus contorta*; and (c) other, which included species that were typically only recorded on a minority of sites and a minority of observations including *C. decurrens*, *Larix occidentalis*, and *Q. kelloggii*; (2) DBH, a discrete variable describing a tree or snag's diameter at breast height measured with a centimeter tape; (3) BEETLE, a binary variable describing the presence or absence of signs of bark beetle use on a given tree or snag; (4) FIRE, a binary variable describing the presence or absence of fire damage on a given tree or snag; (5) FOLIAGE, an interval variable describing the amount of foliage remaining (only applicable for dead trees); and (6) BARK, an interval variable describing the amount of bark remaining (only applicable for dead trees).

Because of the documented interspecific differences in foraging abilities and preferences, the true availability of resources probably differed among species within the bark-foraging community. For example, black-backed woodpeckers predominately use burned patches (Hutto 1995, Murphy and Lehnhausen 1998), whereas brown creepers are often located in patches of large, live trees (Adams and Morrison 1993, Weikel and Hayes 1999). Consequently, systematically measuring habitat characteristics within treatment units and pooling them together into a broad category of “available habitat” could have masked the fine-scale microhabitat selection patterns we were hoping to examine during this study (Addicott et al. 1987). To rectify this problem, we used a nearest neighbor design to define the available habitat structures for each species. Once we completed data collection on the tree used by the foraging bird, we recorded the same six structural variables on a randomly located tree at least 10 m, but not more than 50 m away from the original foraging tree and at least 1.4 m in height. Consequently, each bark-foraging species ended up

with a unique set of available habitat structures that were more reflective of the species' typical foraging patch and permitted a more thorough evaluation of fine-scale micro-habitat preferences.

Data Sets and Formulation of Candidate Model Sets

We used an information-theoretic approach to develop several model sets addressing questions based on the three research questions. Each model set used various subsets of the overall national data set. These subsets of data were selected based on taxonomic groupings and sample size guidelines for regression modeling outlined by Hosmer and Lemeshow (2000). For our first two research questions (whether the three implemented treatments differ in their effects on the foraging encounter rate and whether the effects were similar across study sites) we established the criteria that a particular species had to contribute a minimum of 40 observations from at least 3 study sites or a minimum of 120 observations total. These criteria led to the consideration of four subsets of data examining the four species introduced earlier.

Using these focal species, we created a single model set that considered three types of treatment effects: no treatment effect (null); a treatment effect common across all treatment types (i.e., thinning is a true "surrogate" for fire with respect to foraging encounter rate, so effects do not vary by treatment type [TREAT]); and (3) a treatment effect varying by treatment type (TMTCAT). We also considered models with only site effects (SITE), additive models with site and treatment effects, and models with treatment effects nested within study site [TREAT(SITE) and TMTCAT(SITE)]. The effect of time since treatment was also considered but only when nested within a particular study site [TIME(SITE)] to account for the variability in data collection timelines at each location. Finally, we also considered both the null model and global models. This process resulted in a total of 12 different models in the foraging encounter rate model set (Table 1).

The second study objective was to evaluate whether the

Table 1. Candidate model list used in the analysis of the effects of study site, treatment, treatment category, and time on the frequency of bark-foraging bird observations across five western study sites as part of the National Fire and Fire Surrogate study

	Model
1	null
2	SITE
3	TREAT
4	TMTCAT
5	TIME(SITE) ^a
6	TREAT(SITE)
7	TMTCAT(SITE)
8	SITE + TREAT ^b
9	SITE + TMTCAT
10	TIME (SITE) + TREAT
11	TIME (SITE) + TMTCAT
12	Global

^a Parentheses denotes a nested relationship between the effects.

^b Plus sign denotes an additive relationship between effects.

structural variables of trees selected by foraging birds differed with tree condition class (live or dead) and treatment type. This evaluation involved creating a maximum of eight model sets per species grouping (live tree models and dead tree models within each of the four treatment types). For these eight model sets, our criteria for species inclusion were at least 40 observations within a tree condition class and within a treatment category. Use of these criteria resulted in not all species being evaluated within each tree condition class. For example, we only had enough observations to run live tree models on red-breasted nuthatches, brown creepers, and mountain chickadees and only dead tree models for hairy woodpeckers.

Using this subset of data, we created model sets for live trees and model sets for dead trees within each treatment type that used subsets and combinations of the habitat structural variables described previously. The model set examining the treatment differences on the selection of live trees evaluated the relative importance of four variables: TRSPP, DBH, BEETLE, and FIRE. Because the emphasis of this portion of the analysis was to assess the relative importance of each variable in influencing the selection of live tree-foraging substrates and not the identification of a single best fitting model, we considered all possible additive combinations of the included factors within each balanced model set (Burnham and Anderson 2002), including a null and global model, for a total of 16 models in the live tree selection model set (Table 2). The snag selection model set included the four variables used in the live tree model set and two additional variables: FOLIAGE and BARK (Table 2). This model set again included all possible additive combination of the six variables plus null and global models for a total of 63 models in the snag selection model set (Table 2).

Data Analysis

We used generalized linear modeling techniques to model the effects of site, treatment, treatment category, and time on the foraging encounter rate of bark-foraging birds (Table 1). A combination of Akaike differences, Akaike

Table 2. Candidate model sets used in the analysis of the effects of live and dead tree structural variables on the micro-habitat selection of bark-foraging birds observed at five western study sites as part of the National Fire and Fire Surrogate study

Model set	Total no. of models	Variables included
Live	16	TRSPP
		DBH
		BEETLE
		FIRE
Dead	63	TRSPP
		DBH
		BEETLE
		FIRE
		FOLIAGE
		BARK

For each model set, we evaluated all possible additive combinations of the variables listed.

model weights, evidence ratios, and 95% confidence intervals on regression coefficients were used as a basis of inference for this portion of the analysis. Akaike information criterion (AIC) differences and weights are considered important in ranking models, whereas evidence ratios can help to sharpen the evidence for or against each model and are computed by calculating the ratio of Akaike weights between the top model and the model of interest. Generally, greater evidence ratios indicate less support for a particular model (Burnham and Anderson 2002). To focus our discussion of effects, we used a combination of Akaike weights (w), AIC_c differences (ΔAIC_c), and evidence ratios (w_1/w_j). Specifically, we report estimates for all effects that appeared in models with Akaike weights ≥ 0.10 but focus our discussion of effects on those variables that appeared in models with evidence ratios < 2.0 . We treated the time since treatment variable (TIME) as a fixed effect and did not use a repeated-measures design for this portion of the analysis because tests using the Durbin-Watson statistic (d) revealed no evidence of temporal autocorrelation (Draper and Smith 1998). However, the variable TIME was only considered when it was nested within a particular study site to account for the variability in data collection between study sites.

Logistic regression was used to model the effects of tree structural variables on foraging habitat selection within each treatment category and tree condition class (Table 2). Because the emphasis of this portion of the analysis was to assess the influence of each variable on the selection of foraging substrates and not the identification of a single best model, we used relative importance values and 95% confidence intervals on regression coefficients as the primary basis for our inference. Relative importance values, which are calculated by summing the Akaike weights over all models in a balanced set that include a given factor (Burnham and Anderson 2002), can be used to rank the influence of factors in predicting the outcome interest. Factors with relative importance values ≥ 0.40 were considered influential following Converse et al. (2006) who cited unpublished data indicating this to be an adequate threshold.

For all sections of the analysis, we calculated model-averaged effect estimates and their associated 95% confidence intervals on all variables of interest according to Burnham and Anderson (2002), and those with confidence intervals not including 0 were considered strong. In addition, we

tested the sampling variance within each model set for overdispersion by calculating the variance inflation factor (\hat{c}) computed by dividing the chi-square goodness of fit statistic (χ^2) by the degrees of freedom (df) of the global model within each set. If values of (\hat{c}) exceeded 4.0 for a particular set, we adjusted for the presence of overdispersion by using $QAIC_c$ for model selection and inference (Burnham and Anderson 2002).

Results

We recorded a total of 1,799 foraging observations of four species across the five study sites. Species recorded from most to least common included red-breasted nuthatch ($n = 744$), mountain chickadee ($n = 439$), hairy woodpecker ($n = 367$), and brown creeper ($n = 249$). Of all observations 32% were made in burn-only units ($n = 668$), 25% were in thin-burn units ($n = 511$), 23% were in thin-only units ($n = 477$), and 20% were in control areas ($n = 415$). Proportional use of live and dead trees was skewed toward the use of live with 78% of all observations occurring on live trees ($n = 1,611$).

Effect of Treatment on Frequency of Foraging Observations

Based on a combination of AIC weights (≥ 0.10) and evidence ratios (< 2.0), we determined that the observed foraging encounter rate of foraging red-breasted nuthatches, mountain chickadees, hairy woodpeckers, and brown creepers was most influenced by study site and the implementation of fuel reduction treatments (Table 3). The two top-ranked models for red-breasted nuthatches included effects of study site and treatment category (Table 3). This species was detected most frequently at NORM and least frequently at CESN (Table 4). Relative to control units, foraging red-breasted nuthatches were detected more frequently in thin-only treatments and less frequently in burn-only and thin-burn treatments (Table 4; Figure 1). However, the model-averaged effect estimates for treatment category were weak, with 95% confidence intervals including 0 (Table 4; Figure 1).

The foraging encounter rate of mountain chickadees was also influenced by study site and the implementation of fuel

Table 3. Model selection results describing the effects of study site, treatment, treatment category, and time since treatment on the foraging encounter rate of four bark-foraging bird species (red-breasted nuthatch, mountain chickadee, hairy woodpecker, and brown creeper) based on data collected across five western Fire and Fire Surrogate study sites

Model set	Model	K	AIC_c	ΔAIC_c	AIC weight	Evidence ratio
Red-breasted nuthatch	SITE	5	-76.526	0.000	0.404	—
	SITE + TMTCAT	8	-76.577	0.506	0.313	1.291
	SITE + TREAT	6	-75.274	1.410	0.199	2.030
Mountain chickadee	SITE	4	-45.898	0.000	0.548	—
	SITE + TREAT	5	-44.739	1.159	0.307	1.785
Hairy woodpecker	SITE + TREAT	6	-119.877	0.000	0.699	—
	SITE + TMTCAT	8	-116.575	3.303	0.134	5.216
Brown creeper	TREAT (SITE)	10	-208.189	0.000	0.736	—
	SITE	5	-204.812	3.377	0.136	5.411

Models accounting for ≥ 0.10 Akaike weight are ranked from the most to least plausible based on their ΔAIC_c score. Shown are the number of parameters contained in each model (K), AIC_c , ΔAIC_c , relative model weights, and evidence ratios.

Table 4. Estimated effects of variables included in top-ranked models (from Table 3) on the foraging encounter rate of four bark-foraging bird species (red-breasted nuthatch, mountain chickadee, hairy woodpecker, and brown creeper) across five western sites within the National Fire and Fire Surrogate network

Model set	Variable	Effect	SE	95% CI
Red-breasted nuthatch	SITE-CESN	0.214	0.073	0.068, 0.362
	SITE-BLMO	0.322	0.061	0.200, 0.445
	SITE-NORM	0.503	0.083	0.337, 0.669
	SITE-SCAS	0.295	0.072	0.150, 0.439
	SITE-SOSN	0.346	0.082	0.183, 0.510
	TMTCAT-B ¹	-0.010	0.028	-0.065, 0.045
	TMTCAT-T ¹	0.014	0.029	-0.044, 0.073
Mountain chickadee	TMTCAT-TB ¹	-0.021	0.034	-0.090, 0.047
	SITE-CESN	0.071	0.067	-0.062, 0.205
	SITE-BLMO	0.310	0.046	0.219, 0.402
	SITE-SCAS	0.447	0.060	0.327, 0.567
	SITE-SOSN	0.174	0.058	0.059, 0.290
	TREAT	0.018	0.033	-0.049, 0.085
	Hairy woodpecker	SITE-CESN	0.089	0.057
SITE-BLMO		0.106	0.039	0.027, 0.185
SITE-NORM		0.056	0.037	-0.017, 0.130
SITE-SCAS		0.172	0.054	0.063, 0.281
SITE-SOSN		0.222	0.064	0.094, 0.350
TREAT		0.052	0.041	-0.030, 0.134
Brown creeper		TREAT(CESN)	0.141	0.084
	TREAT(BLMO)	0.076	0.044	-0.011, 0.164
	TREAT(NORM)	0.008	0.019	-0.030, 0.046
	TREAT(SCAS)	0.172	0.094	-0.017, 0.360
	TREAT(SOSN)	0.215	0.119	-0.022, 0.452

¹ TMTCAT-B, the treatment category “burn-only”; T, “thin-only”; TB, “thin-burn.”

Included are the model-averaged effect size estimates (Effect), standard errors (SE), and 95% confidence intervals (CI). Variables with confidence intervals not including 0 are considered strong effects.

reduction treatments; however, the effect of treatment was not specific to treatment category (Table 3). Chickadees were detected most often at SCAS and least often at CESN (Table 4). Mountain chickadees were detected more frequently on treatment units, regardless of treatment type, but the model-averaged effect of treatment was weak (Table 4; Figure 1).

The single, top-ranked model explaining hairy woodpecker foraging encounter rate included a positive effect of study site and an effect of treatment not specific to treatment category (Table 3). This species was detected most frequently at SOSN and least frequently at NORM (Table 4). Model-averaged effect estimates of treatment were weak but suggested that foraging observations of this species increased on treatment units on all study sites, irrespective of treatment category (Table 4; Figure 1).

Brown creepers had a single, top-ranked model that included a positive effect of treatment that was specific to study site (Table 3). Brown creepers were detected most frequently in the treated areas at SOSN and least frequently in the untreated areas at NORM (Table 4; Figure 1). However, the model-averaged effects of treatment were weak, with 95% confidence intervals including 0 in all instances (Table 4; Figure 1).

Effect of Tree Condition and Structural Variables on Foraging Habitat Selection

Relative importance values (≥ 0.40) and model-averaged effect estimates used in the analysis of both live- and dead-tree model sets indicated that each species was se-

lected for specific structural attributes and that the importance of those attributes differed with treatment category (Table 5).

Red-Breasted Nuthatch

Live-tree modeling results for the red-breasted nuthatch highlighted the importance of tree diameter, the presence of bark beetles, and the presence of fire damage in the foraging habitat selection of this species. Tree diameter was the most influential factor and had strong positive effects (confidence intervals did not include 0), with nuthatches selecting larger diameter trees than those available across all treatment categories (Table 5; Figure 2). The presence of fire damage was the second most influential factor affecting the foraging habitat selection of red-breasted nuthatches (Table 5), but just in burn-only units, where nuthatches selected live trees that were more severely burned than those available (Table 5). Finally, the presence of bark beetle activity was a weakly important factor determining the selection of live trees by red-breasted nuthatches, but only in control units where nuthatches selected for live trees that exhibited evidence of bark beetle use (Table 5).

Mountain Chickadee

Live-tree use by mountain chickadees was influenced only by tree diameter (Table 5). This species selected larger diameter trees in control, thin-only, and thin-burn treatment categories, but effects were only strong in control treatments (Table 5; Figure 2).

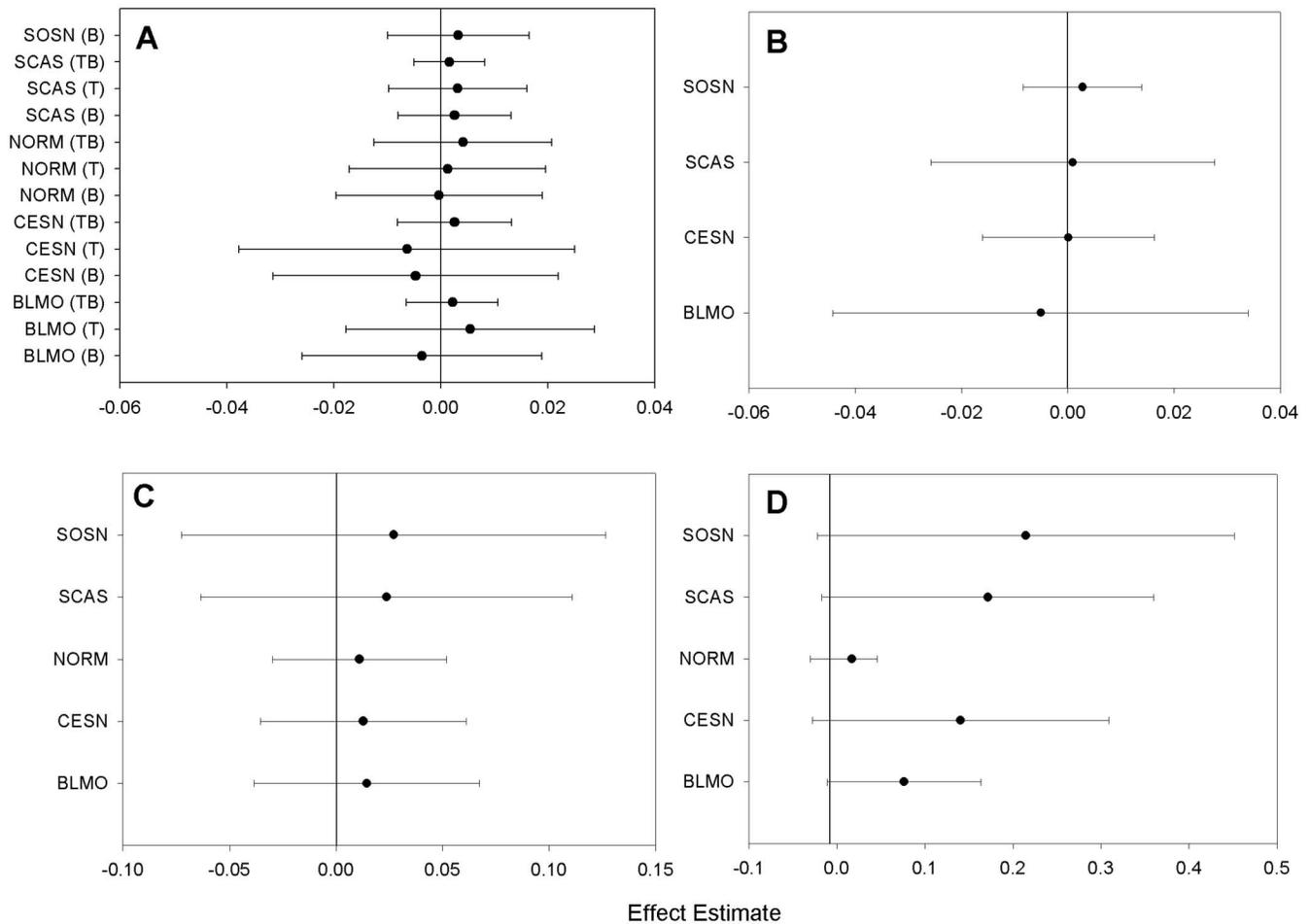


Figure 1. Effects of prescribed burning (B), mechanical thinning (T), and thinning/burning combination treatments (T/B) relative to control treatments on the foraging encounter rate of four bark-foraging species (red-breasted nuthatch [A], hairy woodpecker [B], hairy woodpecker [C], and brown creeper [D]) observed at five western study sites as part of the FFS national project. Note, in the cases of B, C, and D, species responded to a treatment effect not specific to treatment category and therefore only sites are listed.

Hairy Woodpecker

Of the six variables in the dead-tree model set, snag diameter and beetle use most influenced the selection of snags by foraging hairy woodpeckers (Table 5). Snag diameter was the strongest factor and determined selection in burn-only and thin-burn treatments where hairy woodpeckers consistently foraged on larger snags (Table 5; Figure 2). The presence of beetle activity was the second most influential factor determining snag use but just in burn-only units where woodpeckers tended to select snags that exhibited a previous history of bark beetle activity (Table 5).

Brown Creeper

Live-tree use by brown creepers was influenced by diameter, tree species, and the presence of bark beetles (Table 5). Tree diameter was an influential factor in all treatment categories except thin-only where brown creepers selected larger live trees as foraging substrates (Table 5; Figure 2). The presence of bark beetles was the second most important factor determining the selection of live trees by brown creepers in all treatment categories except thin-burn. In control units, creepers selected against live trees with evi-

dence of beetle use, whereas in burn-only and thin-only treatment units they selected for beetle-inhabited trees (Table 5). Finally, tree species was also an important factor in both burn-only units, where creepers selected against fir trees in favor of pine, and in thin-only units, where creepers selected against both pine and fir in favor of other species such as cedar, larch, or oak (Table 5).

Discussion

We found no strong evidence to suggest that mechanical thinning, prescribed fire, and mechanical thinning/prescribed fire combination treatments have consistently predictable effects on the foraging encounter rate of red-breasted nuthatches, hairy woodpeckers, and brown creepers across the suite of western study sites investigated here. However, our analysis of specific foraging habitat selection patterns highlighted several key structural attributes important to each species and thus provides valuable information on how fuel reduction treatments might indirectly affect this group of birds.

Most published information examining the effects of fire and/or thinning on the bark-foraging and/or cavity-nesting

Table 5. Effect of microhabitat characteristics on the probability of tree and snag use by four species of bark-foraging birds (red-breasted nuthatch, mountain chickadee, hairy woodpecker, and brown creeper) observed at five western study sites as part of the National Fire and Fire Surrogate study

Species and Variable	Control			Burn			Thin			Thin and burn		
	RI	Effect	CI _{95%}	RI	Effect	CI _{95%}	RI	Effect	CI _{95%}	RI	Effect	CI _{95%}
Red-breasted nuthatch												
TRSPP-FIR ^a	0.12	-0.01	-0.16, 0.15	0.14	0.03	-0.20, 0.25	0.18	0.03	-0.20, 0.26	0.13	0.04	-0.17, 0.24
TRSPP-PINE ^a	0.12	-0.00	-0.14, 0.14	0.14	0.05	-0.23, 0.33	0.18	0.05	-0.23, 0.33	0.13	0.01	-0.14, 0.15
DBH	0.98	0.05	0.03, 0.06	0.98	0.02	0.01, 0.03	0.98	0.02	0.01, 0.03	0.98	0.04	0.02, 0.05
BEETLE	0.43	-0.17	-0.71, 0.36	0.31	0.06	-0.20, 0.32	0.31	0.06	-0.20, 0.32	0.37	0.11	-0.27, 0.48
FIRE	0.33	-0.13	-0.65, 0.39	0.45	0.18	-0.35, 0.72	0.26	0.18	-0.35, 0.72	0.37	0.17	-0.43, 0.76
Mountain chickadee												
TRSPP-FIR ^a	0.27	-0.14	-0.76, 0.49	0.12	0.04	-0.23, 0.31	0.23	0.17	-0.54, 0.87	0.28	0.09	-0.44, 0.62
TRSPP-PINE ^a	0.27	-0.24	-1.10, 0.62	0.12	0.03	-0.21, 0.27	0.23	0.08	-0.44, 0.60	0.28	-0.07	-0.54, 0.40
DBH	0.91	0.02	0.00, 0.04	0.29	0.00	-0.00, 0.01	0.74	0.01	-0.01, 0.03	0.61	0.01	-0.01, 0.03
BEETLE	0.28	0.05	-0.26, 0.37	0.36	0.11	-0.30, 0.51	0.25	-0.01	-0.20, 0.19	0.28	-0.04	-0.32, 0.22
FIRE	0.26	0.00	-0.36, 0.36	0.27	-0.03	-0.26, 0.20	0.34	0.24	-0.66, 1.15	0.27	-0.03	-0.28, 0.22
Hairy woodpecker												
TRSPP-FIR ^a	—	—	—	0.22	0.01	-0.53, 0.56	0.29	0.47	-1.16, 2.11	0.28	0.65	-2.84, 1.54
TRSPP-PINE ^a	—	—	—	0.22	0.15	-0.67, 0.96	0.29	0.51	-1.20, 2.21	0.28	0.10	-1.50, 1.32
DBH	—	—	—	0.99	0.03	0.01, 0.05	0.34	0.01	-0.01, 0.02	0.99	0.06	0.02, 0.10
BEETLE	—	—	—	0.86	1.03	-0.16, 2.22	0.34	0.16	-0.45, 0.76	0.32	0.16	-0.53, 0.86
FIRE	—	—	—	0.27	0.08	-0.48, 0.65	0.33	0.25	-0.79, 1.30	0.25	-0.07	-0.68, 0.54
BARK	—	—	—	0.29	-0.05	-0.30, 0.20	0.28	0.04	-0.17, 0.25	0.25	-0.02	-0.18, 0.15
FOLIAGE	—	—	—	0.37	0.06	-0.14, 0.26	0.25	-0.01	-0.16, 0.15	0.27	-0.03	-0.20, 0.14
Brown creeper												
TRSPP-FIR ^a	0.11	-0.05	-0.33, 0.23	0.64	-0.17	-1.25, 0.92	0.58	-1.81	-4.77, 1.15	0.19	-0.20	-0.99, 0.60
TRSPP-PINE ^a	0.11	-0.02	-0.25, 0.21	0.64	0.50	-0.78, 1.78	0.58	-1.50	-4.13, 1.14	0.19	-0.04	-0.41, 0.32
DBH	0.97	0.04	0.01, 0.07	0.45	0.01	-0.01, 0.02	0.35	0.01	-0.02, 0.03	0.73	0.02	-0.01, 0.05
BEETLE	0.53	-0.48	-1.68, 0.71	0.80	0.77	-0.11, 1.65	0.32	-0.19	-0.93, 0.56	0.61	0.83	-0.52, 2.18
FIRE	0.39	0.34	-0.79, 1.48	0.24	-0.02	-0.34, 0.30	—	—	—	0.26	0.05	-0.44, 0.53

Reported are the relative importance values (RI), model-averaged effect estimates (Effect), and 95% confidence intervals (CI) for each specific tree/snag characteristic within each of the four species categories. Blank cells occur effects were inestimable because of lack of data. Variables with confidence intervals not including 0 are considered strong effects and are outlined in bold type.

^a The variable TRSPP compares the relative strength of categories FIR and PINE to OTHER (e.g., when selecting dead trees in control units by the entire community, FIR and PINE were used in greater frequencies than OTHER species).

bird communities relies on specific case studies from wild-fires (Saab and Powell 2005) and postfire salvage activities, not from replicated experiments, making a direct comparison of our results difficult. However, Lyons et al. (2008), who examined the response of red-breasted nuthatches, mountain chickadees, hairy woodpeckers, and brown creepers (among other bark-foraging bird species) to fuel reduction treatments in the northern Cascades of Washington, found similarly weak and generally inconsistent responses with respect to the effects of prescribed fire, mechanical thinning, and prescribed fire/mechanical thinning combination treatments on the foraging observation rates of this bird group.

The responses of bark-foraging birds to fuel reduction activities are likely related to treatment-induced changes in tree characteristics routinely documented as high-quality foraging habitat including species, diameter, and the presence of bark and wood-boring beetles (Raphael and White 1984, Morrison et al. 1987, Weikel and Hayes 1995, Murphy and Lehnhausen 1998, Powell 2000). In this study, tree diameter was overwhelmingly the strongest factor influencing the selection of foraging trees across all bird species and all treatment types. Bark-foraging birds are routinely associated with both large diameter live trees (Raphael and White 1984, Adams and Morrison 1993, Weikel and Hayes 1999), which conceal greater amounts of surface arthropod

prey within their complex and deeply furrowed bark (Jackson 1979, Parker and Stevens 1979, Cline et al. 1980), and large diameter snags, which harbor greater populations of subsurface bark and wood-boring beetles. Previous research examining the specific attributes of foraging habitat important to bark-foraging birds active within prescribed burned and mechanically thinned areas have similarly identified tree diameter as an influential factor (Lyons et al. 2008, Pope et al. 2009). All treatment types implemented with the FFS study resulted in an increase in the mean diameter of live trees, with the greatest improvements occurring in the thin-burn treatment units (Schwilk et al. 2009), suggesting that fuel reduction treatments may generally enhance this aspect of the foraging habitat for red-breasted nuthatches, mountain chickadees, and brown creepers. It should be noted that the observed increase in the mean diameter of live trees is mostly due to the death and/or removal of smaller diameter trees. So, although the treatments do not produce larger trees immediately, the removal and/or burning of smaller diameter understory trees can increase the vigor, health, and eventually size of those trees remaining in the overstory (Zhang et al. 2007), thereby enhancing the habitat for bark-foraging birds.

The fuel reduction treatments implemented with the FFS study had variable effects on snag diameter. Although the burn-only treatments increased snag density, most of the

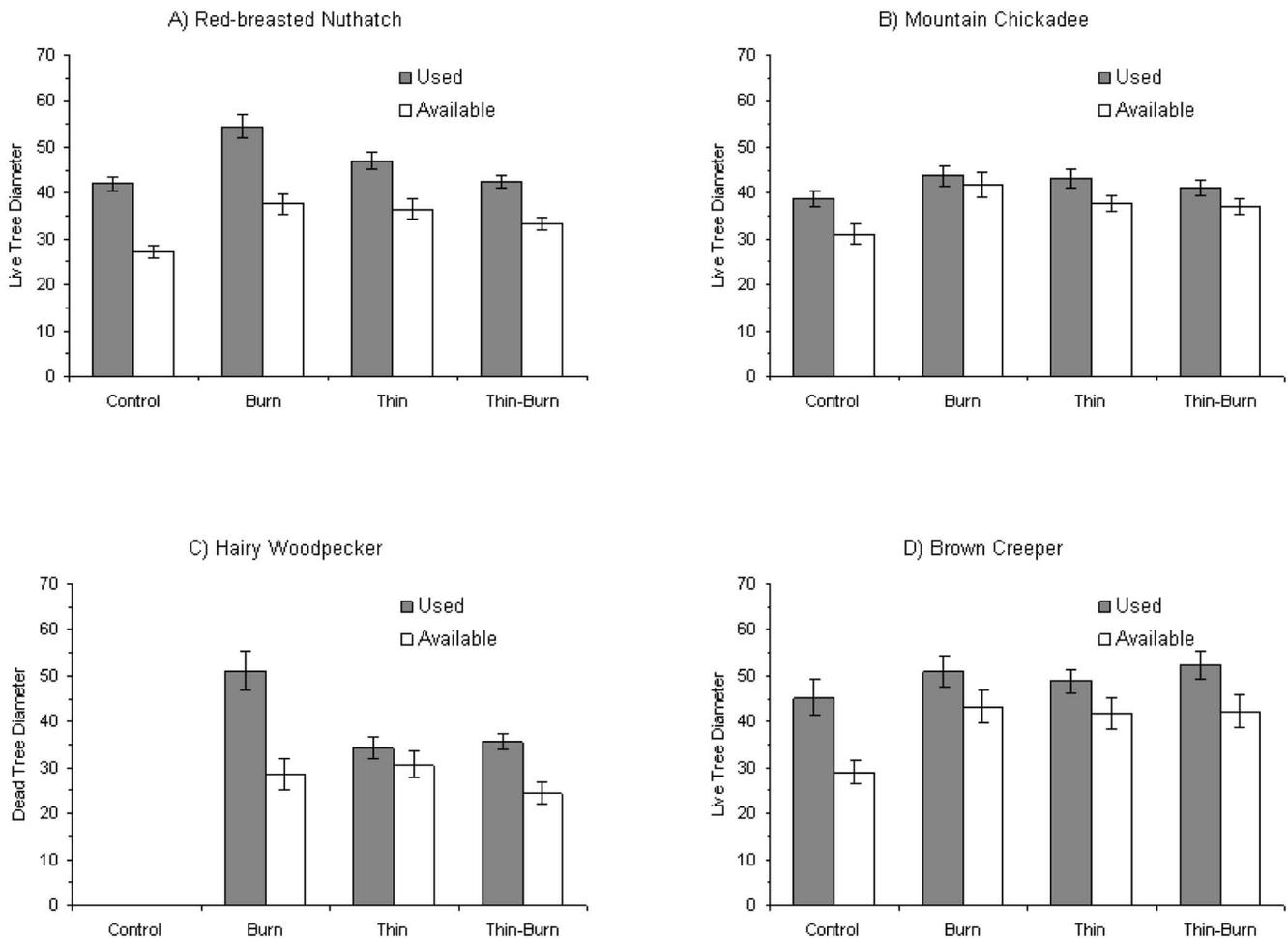


Figure 2. Substrate diameters of trees and snags used by four species of bark-foraging birds compared with diameters of those available across four fuel reduction treatment types implemented on five western study sites as part of the National FFS project.

recruitment was a result of understory mortality in the small diameter classes, thus producing a negative shift in the overall mean snag diameter (Schwilk et al. 2009). Thinning followed by burning produced the greatest increases in mean snag diameter, whereas thinning alone also resulted in an increase; albeit not as dramatic (Schwilk et al. 2009). The selection by hairy woodpeckers for larger snags in burn-only and thin-burn treatments is consistent with the shift in diameters resulting from both treatments and suggests that this species could benefit from these specific fuel reduction treatment types.

The presence of bark beetles was an influential, albeit weak, factor determining foraging habitat selection for red-breasted nuthatches, hairy woodpeckers, and brown creepers. The importance of beetle-infested trees to bark foraging birds has been extensively documented in western North America, especially in burned areas (Raphael and White 1984, Murphy and Lehnhausen 1998, Powell 2000, Powell et al. 2002, Covert-Bratland et al. 2006). Generally, prescribed fire treatments tend to increase bark beetle activity, and this relationship is positively correlated with the amount of crown scorch (Fettig et al. 2007), so lower or mixed severity fires may not produce as much initial insect prey as higher severity fires (Wallin et al. 2003, Parker et al. 2006). Entomological data from the SCAS study site documented

the lowest incidence of post treatment beetle-induced mortality in the mechanically thinned treatment units and the control areas (Fettig et al. 2010), which is also where both red-breasted nuthatches and brown creepers avoided using beetle-infested trees. Both red-breasted nuthatches and brown creepers specialize in the procurement of surface arthropods, so this observation is not surprising; especially considering that untreated stands across our study areas were characterized by more closed canopies and a greater stocking of smaller and medium diameter trees, conditions that often favor greater populations of surface-dwelling insects (Fettig et al. 2007). In contrast, brown creepers selected for trees containing bark beetles when foraging in burn-only and thin-burn treatment areas, as did hairy woodpeckers in the burn-only treatments. These observations coincide with the greater frequencies of beetle-infested trees found in both burn-only and thin-burn treatment areas (Fettig et al. 2010) and are consistent with observations in other prescribed burned areas (Lyons et al. 2008, Pope et al. 2009). Combined, these observations suggest that the implementation of fuel reduction treatments, especially prescribed burning, might increase the frequency of beetle-infested trees and snags and therefore could be beneficial to both the brown creeper and hairy woodpecker.

Finally, tree species was an influential, albeit weak,

factor influencing the selection of live trees by brown creepers in burn-only treatment types where this species selected pine, incense cedar, larch, and oak and in thin-only treatment areas where they foraged on incense cedar, larch, and oak. Incense cedar has been shown to be particularly valuable to brown creepers in the Sierra Nevada (Morrison et al. 1987, Adams and Morrison 1993), where it tends to conceal greater abundances of arthropod prey than other tree species of similar size (Morrison et al. 1985, Adams and Morrison 1993). Use of western larch by brown creepers has also been documented, but primarily as nesting habitat (Steeger and Hitchcock 1998, McClelland and McClelland 2000, Hejl et al. 2002). The effects of mechanical thinning and prescribed burning on tree species composition can be highly variable depending on management objectives, but typically treatments favor fire-tolerant species such as pine over shade-tolerant, later seral species such as true fir and cedar (Brown et al. 2004, Agee and Skinner 2005). In the case of the FFS study treatments, posttreatment tree species composition was altered to all but eliminate western larch at BLMO (Youngblood et al. 2006) and reduce incense cedar at CESN (Stephens and Moghaddas 2005). Consequently, some fuel reduction treatments may adversely affect this aspect of brown creeper foraging habitat.

Conclusions

One of the primary goals of the national FFS study was to examine the relative effects of different fuel reduction treatments and to determine whether these effects were consistent across the study area network. The variable responses of the bark-foraging bird community examined here indicate that the capability of managers to accurately predict how individual bark-foraging bird species might respond to specific fuel reduction treatments is presently restricted. Although we were unable to identify consistent response patterns in the bark-foraging bird community in this particular study, other published FFS research has documented reliable treatment responses in vegetation structure (Schwilk et al. 2009) and insects (Fettig et al. 2010); some of which are likely to have indirect effects on the habitat selection patterns of bark-foraging birds.

In general, the fuel reduction treatments implemented as part of the FFS project tended to create stand conditions that our study found to be generally positive for bark-foraging bird species. Of particular note are the consistent increases in both the mean diameter of live trees and the frequency of beetle-killed trees in the treated areas, predominantly those that are prescribed burned. Enhancement of these two important aspects of bark-foraging bird habitat may result in an overall benefit to this bird group in areas where fuel reduction activities are implemented.

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