Variability in Nest Density, Occupancy, and Home Range Size of Western Bluebirds after Forest Treatments

Sarah Hurteau, Thomas Sisk, Brett Dickson, and William Block

Abstract: Complex land use and fuels management histories have resulted in significant changes in composition, structure, and function of southwestern forests and subsequent changes in the extent and quality of wildlife habitats. We evaluated how several currently used fuel reduction treatments (e.g., mechanical thinning and prescribed fire alone and in combination) affect nest attributes, nest density, nest tree occupancy, and home range size of Western Bluebirds (*Sialia mexicana*) in ponderosa pine (*Pinus ponderosa*)-dominated forests of northern Arizona. Nest attributes, such as number of eggs or nestlings, varied among treatments, but did not differ statistically. Western Bluebird nest density was significantly influenced by treatment, with densities higher in treated areas, even though snag density was lower in treated areas than in control areas. The average (± SE) area of the 50% contour, across all treatment units, was 0.42 ± 0.07 ha, and the average area of the 90% contour was 2.36 ± 0.30 ha. Home range sizes for both probability contours evaluated were 1.5 times larger in the thin-only treatments than in the control units. Conversely, home range area in thin-and-burn treatments was approximately 30% smaller than in control units. The largest home ranges occurred in the burn-only treatments. Our results suggest that forest treatments, such as thinning and prescribed fire are, in general, beneficial to Western Bluebirds, but that low snag retention may be problematic in areas receiving prescribed fire as part of their treatment action. FOR. SCI. 56(1):131–138.

Keywords: prescribed fire, thinning, *Sialia mexicana*, Western Bluebird, forest treatments, mechanical

A COMPLEX HISTORY of land use and fuels management practices has resulted in significant changes in the composition, structure, and function of southwestern ponderosa pine forests (Covington et al. 1997, Stone et al. 1999, Allen et al. 2002) and dramatic changes in the extent and quality of wildlife habitats (Germaine and Germaine 2002, Bock and Block 2005, Saab and Powell 2005). Many researchers have concluded that before Euro-American settlement in the late 1800s, the structure of ponderosa pine (*Pinus ponderosa*) forests in the southwestern United States was characterized by small groups of large fire-resistant trees with a well-developed herbaceous understory (Cooper 1960, Covington and Moore 1994, Stone et al. 1999). Natural disturbances, such as fire, drought, insect infestation, and pulses of tree regeneration, maintained considerable variability and heterogeneity that shifted temporally and spatially across forest landscapes (Allen et al. 2002). Ponderosa pine forests exhibit adaptation to recurrent low- to moderate-intensity surface fires, which burned at intervals of 2–20 years, before fire suppression became a dominant land management practice (Harrington and Sackett 1988, Covington and Moore 1994). Settlement of the West and intensive logging removed many larger diameter trees from southwestern forests with the resulting landscape supporting relatively even-aged stands of small diameter trees (Harrington and Sackett 1988, Allen et al. 2002). Contemporary fire suppression efforts further distorted presettlement disturbance patterns, leading to heavy fuel accumulations and larger high-severity wildfires (Allen et al. 2002).

The aim of US Forest Service management plan revisions is to reduce tree densities and fuel loads while maintaining plant and animal diversity (US Forest Service 2008). Restoring the structure of southwestern ponderosa pine forests to conditions approximating those that occurred before the interruption of natural fire regimes has been suggested to reverse the current trend toward more destructive wildfires (Covington 2000, Meyer et al. 2001). An important assumption in returning forest structure to some reference condition is that native wildlife will benefit from restoration treatments (Block et al. 2001, Allen et al. 2002, Chambers and Germaine 2003). However, the impact of restoration treatments on wildlife is relatively understudied, and the implications of proposed management actions are poorly understood.

In the Southwest, research on the effects of fuel reduction and restoration treatments on ecosystem attributes has been increasing in recent decades. For example, studies

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conducted after postfire salvage logging (Kotliar et al. 2002), stand-replacing wildfire (Hutto 1995, Saab et al. 2004), prescribed burning (Horton and Mannan 1988, Hurteau et al. 2008, Dickson et al. 2009), thinning treatments of various intensities (Szaro and Balda 1986, King and DeGraaf 2000), or a combination of thinning and burning in a restoration framework (Germaine and Germaine 2002, Wightman and Germaine 2006) have provided new information and working hypotheses describing avian responses to contemporary forest treatment alternatives. Specifically, research on prescribed fire in southwestern ponderosa pine forests showed minimal impacts on cavity-nesting birds (Horton and Mannan 1988). More recently, research on restoration-based thinning and burning treatments in northern Arizona suggests that treatments that reduce ponderosa pine density and increase herbaceous cover and bare ground may increase invertebrate abundance and diversity, which may, in turn, increase habitat quality for cavity-nesting birds, including Western Bluebirds (*Sialia mexicana*) (Germaine and Germaine 2002, Wightman and Germaine 2006).

As part of the Fire and Fire Surrogate (FFS) research program (Edminster et al. 2000), we examined variation in home range size, nest attributes, cavity occupancy, and density of the Western Bluebird after experimental forest fuel reduction treatments were implemented. The Western Bluebird is an insectivorous, cavity-nesting species that has declined across parts of its range (Ehrlich et al. 1988), including Arizona (Sauer et al. 2005), in response to intensive urbanization, logging, livestock grazing, and fire suppression activities (Hall et al. 1997). For this research, our goal was to improve understanding of bluebird breeding biology and effects of forest fuel reduction treatments. Specifically, our objectives were to evaluate differences in nest success among three fuel reduction treatments and a control, determine how nesting density and proportion of suitable cavities occupied by Western Bluebirds varied among treatments, and quantify differences in home range size of breeding male Western Bluebirds among treatments.

Methods

Study Area

We conducted this research during the summer breeding seasons of 2005 and 2006 on three study sites established by the Southwestern Plateau portion of the FFS program. The FFS program is a national study with 12 sites throughout the United States that was designed to quantify the effects of prescribed fire and mechanical thinning, alone and in combination, on a broad set of ecological response variables. The three sites were located on the Kaibab (K.A. Hill: 35°12.0′33.9″ latitude and 111°44.0′32.2″ longitude) and Coconino National Forests (Powerline: 35°12.0′ 33.9″ latitude and 111°45.0′32.2″ longitude and Rudd's Tank: 35°14.0′05.9″ latitude and 111°44.0′58.4″ longitude), west of Flagstaff, Arizona, USA. At each site, overstory composition was dominated by ponderosa pine and occasionally included Gambel oak (*Quercus gambelii*), alligator juniper (*Juniperus deppeana*), and one-seed juniper (*Juniperus monosperma*). Previous timber harvest activities resulted in a forest structure characterized by small (<25 cm diameter) ponderosa pine trees, with larger (≥50 cm diameter) trees occurring in small groups (Dickson et al. 2004). Common understory vegetation included blue grama (*Bouteloua gracilis*) and Arizona fescue (*Festuca arizonica*). Mean site elevation was 2193 m (1 SD ± 100), and all three sites had a slope of ≤5% with little variability in aspect. For the period of 2005–2006 the average annual temperature was 6.5 ± 10.6°C and the average annual precipitation was 53.1 ± 0.8 cm) (Huebner 2006).

Experimental Design

The FFS Southwestern Plateau sites used a modified before-after control-impact (Green 1979, Stewart-Oaten et al. 1986, Stewart-Oaten et al. 1992) experimental design to assess responses of the avian community to fuel reduction treatments (Hurteau et al. 2008). The data used in this article were collected after the treatments were completed between the fall of 2002 and 2003. The three study sites were established in a blocked design, and each represented a single replicate (n = 3). Each replicate was then divided into four units, including three experimental fuel reduction treatments (thin only, prescribed burn only, and thin followed by prescribed burn) and a control (untreated). Typically, treatments were randomly assigned to units within the block. However, in some blocks, random assignments of treatment locations were constrained to one of two units. Study sites ranged in total size from 67 ha (Rudd's Tank) to 121 ha (Powerline) (Table 1). The aim of treatments was to reduce stem density from an average of 540 to 116 trees ha^{-1} and basal area from 28 to 13 m^2 ha^{-1} (Faiella and Bailey 2007). After treatment, basal area in the thin-only and thin-and-burn units was reduced by approximately 50%, and basal area in the burn-only and control units was reduced only slightly (J.D. Bailey, Oregon State University, unpublished data 2006, Faiella and Bailey 2007) (Table 2). Tree density also changed little in the control and burn-only units (<10%) (Faiella and Bailey 2007). However, the numbers of trees per ha were reduced by 60–70% in the thin-only and the thin-and-burn units (J.D. Bailey, Oregon State University, unpublished data 2006, Faiella and Bailey 2007).

Nest Monitoring

We located nests by systematically searching each treatment unit and watching for nesting or territorial behavior, beginning the first week in May. Nests were confirmed

Table 1. Area (hectares) of each experimental treatment unit and total area at each of the three study sites in northern Arizona, 2005–2006

Treatment types	Study sites		
	Rudd's Tank	KA Hill	Powerline
	. . . .(ha)		
Control	16.10	25.45	33.55
Thin-only	15.95	19.65	37.28
Burn-only	16.56	22.94	36.69
Thin and burn	17.98	31.61	23.70
Total	66.59	99.64	131.21

Table 2. Average basal area and number of trees measured before and 1 year after experimental treatments across three study sites in northern Arizona, 2005–2006

Treatment type	Basal Area		Trees	
	Pretreatment	Posttreatment	Pretreatment	Posttreatment
	. . . . .m^2ha^{-1}		. . . . .ha^{-1}	
Control	30.3 (4.2)	31.2 (4.8)	674 (258)	664 (263)
Thin Only	29.9 (2.2)	14.8 (1.6)	592 (213)	194 (41)
Burn Only	30.1 (3.7)	30.4 (2.9)	618 (295)	604 (282)
Thin & Burn	24.9 (4.4)	13.0 (3.4)	451 (151)	151 (28)

Data are average (SD).

using a wireless video cavity-camera system (Huebner and Hurteau 2007). Once an active nest was located, the nest was monitored every 3–4 days (Dudley and Saab 2003) using the cavity-camera system. During each visit, we recorded presence or absence of the adults and a description of any territorial, foraging, or feeding behavior, in addition to the nesting stage (courtship, nest building, egg laying, incubation, nestlings, or fledglings). When nest contents were visible, we also recorded the number of eggs or nestlings and nestling age. If we were unable to view the contents inside the nest cavity because the cavity was too high or too narrow, we used adult bird behavior near the nest to infer nesting stage (Dudley and Saab 2003). For example, males looking in cavities indicated incubation, whereas adults making frequent trips to the nest or removing fecal sacs indicated that nestlings were present. For visible nests, we determined clutch size by the maximum number of eggs observed during each nesting attempt. We quantified nestlings as the greatest number present at any visit over the monitoring period, and we assumed that the number of fledglings equaled the number of nestlings present just before fledging. Nest fate was identified using evidence of failure due to predation or unhatched eggs. A nest was considered successful if the nestlings were observed at ≥80% of their mean fledging age (Dudley and Saab 2003) or if fledglings were observed within the home range of the adults. We did not use a nest success estimator because we systematically searched each treatment unit and visually inspected all potential cavities for nests.

Each treatment unit was searched systematically for live and dead trees that contained potential nest cavities to determine the rate at which cavities were occupied. When a tree with cavities was identified, spatial coordinates were recorded using a handheld global positioning systems (GPS) (Garmin GPS Map60; Garmin International, Inc., Olathe, KS). The observer rated the quality of each cavity (qualitative classes 1–4) (Table 3) based on seven characteristics, including decay class of the tree (1–5) (Raphael and White 1984, Schreiber and deCalesta 1992), cavity entrance diameter (1->8 cm) (Arsenault 2004) and shape (round versus irregular), tree dbh (>15 or >30 cm) and tree height (>7m or any height) (Raphael and White 1984, Schreiber and deCalesta 1992, Spiering and Knight 2005). The observer then mapped the locations of all potential nest trees for each treatment unit using a geographic information system (ArcMap version 9.0; Environmental Systems Research Institute, Redlands, CA). A second person systematically searched each unit again within several weeks, verifying the

Table 3. Criteria used to determine "available" nest trees that contained cavities on three study sites in northern Arizona, 2005–2006

Criteria	Cavity quality rating			
	1	2	3	4
Cavity diameter (cm)	2.5–6.4	2.5–7.6	>7.6	Any
Cavity shape	Round	Round, narrow crack or keyhole	Jagged hole	Any
Snag decay class	2–3	1–4	1–5	1–5
Chamber present	Yes	Yes	Yes	No
Tree dbh (cm)	>30	>15	Any	Any
Tree height (m)	>7	Any	Any	Any
Cavity height (m)	<10	<12	<12	Any

Cavities that satisfied criteria for a quality rating of 1 or 2 were considered available as potential nest sites for Western Bluebirds. Cavities >12 m above ground level were not evaluated because that was the maximum height of the cavity-camera system used to verify that the cavity contained a nest chamber. The classification set forth by Raphael and White (1984) was used for decay class of snags. dbh is defined as tree diameter at breast height 1.3 m above ground.

presence of mapped trees and searching for any additional cavities not located during the first search. Finally, a third search was conducted using the cavity-camera system to ensure that identified cavities had a chamber suitable for nesting. When necessary, maps and cavity quality ratings were updated after each search effort. Typically, no more than one pair of Western Bluebirds will nest in a given tree even if the tree has several suitable cavities (S. Hurteau, pers. observation). Therefore, if a tree had multiple cavities, we included only the cavity with the highest quality rating in our database. The maximum obtainable height of the camera was 12 m and thus limited the number of nests and cavities we were able to visually confirm. The average nest height on all sites was 6.3 m, well within the range of the cavity-camera system, which excluded <5% (n = 4 nests) of total nests for 2005. Only trees containing cavities with a quality rating of 1 or 2 were considered "available" nesting cavities. Generally, trees with quality ratings of 3 had a cavity entrance that was too large for Western Bluebirds (Arsenault 2004) and trees with a quality rating of 4 had no nest chamber.

Home Range Sampling

We evaluated space use and estimated the home ranges of male Western Bluebirds during the summer breeding season (late May through early August) of 2005 and 2006. Because females are more sedentary and difficult to relocate regularly during the breeding season, we estimated home range sizes for males only. Although it is not known whether male and female bluebirds have differing home range sizes or use patterns, males probably demonstrate higher fidelity for an area because of their territorial behavior. Males were captured using mist nets placed in a "V" formation around the nest entrance during the incubation and hatching phases of the nesting period. Males were individually weighed and marked with a US Fish and Wildlife Service band and two color bands, permitting subsequent visual identification. An alcohol swab was used to moisten and move feathers on the back, between the wings, so that a small patch was exposed and feathers clipped for the attachment of a radio transmitter. Transmitters (Holohill Systems, Ltd., Carp, ON, Canada, or Wildlife Track, Caldwell, ID) weighing 0.64–1.02 g were attached to the skin using nontoxic glue (Kenward 2001). The radio transmitter did not exceed 4% of the body mass, and in most cases was $<3\%$. Signals could be detected from up to 1 km away and lasted approximately 20–40 days. Locations were collected throughout the lifespan of the battery, with tracking efforts focused on daily movements of individuals during the nestling and immediate postfledging periods. All field methods were approved and in accordance with Protocol 04-011 issued by the Animal Care and Use Committee at Northern Arizona University.

Radio tracking began at least 24 hours after the transmitter was affixed to the bird to allow the individual to return to typical behavior (White and Garrott 1990). We tracked between 5:30 am and 3:30 pm, using a standard homing technique, until the bird was visually located (Mech 1983, White and Garrott 1990) and recorded the point location of the bird using the GPS. All field technicians participated in training exercises to standardize data collection methodology. The maximum allowable position dilution of precision was ± 7 m. If the position dilution of precision was less than ± 7 m, the observer would flag the location and return to record the coordinates when satellite configuration improved. Although tradeoffs exist between maximizing the number of relocations per individual and the autocorrelation between successive points, several authors have argued that increased sample size is more important than eliminating autocorrelation between points (McNay et al. 1994, De Solla et al. 1999, Seaman et al. 1999, Marzluff et al. 2004). We attempted to balance these factors by separating tracking episodes by a minimum of 30 minutes. We only estimated the home range of individuals for which we were able to acquire >30 point locations (Seaman et al. 1999).

Statistical Analysis

We used a nonparametric Benard and Van Elteren rank test (Benard and Van Elteren 1953) to compare treatment effects on clutch size, nestlings per nest, and fledglings per nest for first clutches. A nonparametric approach was used to analyze these data because the data could not be transformed to meet the assumptions (i.e., normality and homogeneity of variance) of a one-way analysis of variance (ANOVA) (Sokal and Rohlf 1995). We tested for differences in nest success among treatments and among sites using G-tests (test statistic $= \chi^2$) (Sokal and Rohlf 1995). We used JMP-IN (version 4.0; SAS Institute, Inc., Cary, NC) to conduct all statistical analyses ($\alpha = 0.05$).

We also used the nesting data to determine Western Bluebird nest density. Nest density was calculated by dividing the number of nests in a given treatment unit by that unit's area. We transformed the data using the square root of the density to satisfy assumptions of normality and homogeneity of variance. We then used an ANOVA, blocking by site, to determine whether there was a difference in nesting density among treatments. A χ^2 test was used to evaluate the effects of treatments on the rate at which nests were occupied (test statistic $= \chi^2$).

To compute home range area, we used a fixed-kernel estimator and a smoothing parameter value selected by least-squares cross validation. For each individual with an adequate sample size (>30 point locations), we used the Animal Movement extension (Hooge and Eichenlaub 2000) to ArcView (version 3.2; Environmental Systems Research Institute, Redlands, CA) to calculate kernel estimates for the 50% and 90% probability contours. We used log-transformed data for both the 50% and 90% area contour estimates to satisfy the assumptions of normality and homogeneity of variance. For each estimate, we pooled among years and used an ANOVA to determine the effect of each treatment on home range area (test statistic $= F$; $\alpha = 0.05$).

Results

Nest Success and Occupancy

We monitored 151 Western Bluebird nests during the 2005 and 2006 breeding seasons (Table 4). Seventy-four percent ($n = 126$) of these nests were successful. We found >1.5 times more nests on the thin-only and burn-only treatment units than on the control unit. Clutch size difference did not exceed 0.9 egg among treatments and did not differ statistically (Benard-van Elteren = 4.41, $P = 0.22$). Similarly, mean number of young per nest differed little, with differences <0.7 young/nest (Benard-van Elteren = 2.73, $P = 0.44$). Number of fledglings also did not differ among treatments (Benard-van Elteren = 1.50, $P = 0.68$), nor did we find statistical differences in nest success among treatments ($\chi^2 = 1.82$, df = 3, $P = 0.61$). However, there

Table 4. Summary of total number of nests, nest attributes (mean ± SE), and successful nests for Western Bluebirds on three forest treatment units in Northern Arizona, May–August 2005–2006

	Control	Thin only	Burn only	Thin and burn
No. of nests	27	47	42	35
Clutch size	4.0 ± 0.2	4.2 ± 0.1	4.4 ± 0.1	4.5 ± 0.1
No. of nestlings per nest	3.3 ± 0.3	3.8 ± 0.2	4.0 ± 0.2	3.8 ± 0.3
No. fledged per nest	3.1 ± 0.3	2.6 ± 0.3	3.1 ± 0.3	3.1 ± 0.4
Successful nests (%)	77	70	76	77

No statistical difference was found in nesting attributes among treatments.

was significantly higher nest success at the K.A. Hill and Powerline sites, with 80% success, whereas nest success at Rudd's Tank was only 60% ($\chi^2 = 8.99$, df = 2, $P = 0.01$).

Nesting density was significantly different among treatments, with nearly double the nesting density in the thin-only treatments than in the control units ($F_{3,18} = 3.46$, $P = 0.04$) (Figure 1). Similarly, there was a significant difference in the rate at which cavities were occupied among treatments ($\chi^2 = 38.9$, df = 3, $P < 0.005$) (Figure 2). Sixty-eight percent of available cavities were occupied by Western Bluebirds in the burn-only and thin-and-burn treatments, compared with only 42% of available cavities in the control units.

Home Range

We calculated home range estimates for 28 breeding male Western Bluebirds tracked using radio telemetry (Figure 3). The average ± SE area of the 50% contour, across all treatment units, was 0.42 ± 0.07 ha, and the average area of the 90% contour was 2.36 ± 0.30 ha (Figure 4). There was no statistical difference in home range size among treatments (50%: $F_{3,24} = 2.23$, $P = 0.11$; 90%: $F_{3,24} = 2.79$, $P = 0.06$). Home range size for both 50% and 90% contours followed similar patterns: average home range area in thin-only treatments (50%: 0.45 ± 0.11; 90%: 2.88 ± 0.53) was 1.5 times larger than average home ranges in control units (50%: 0.29 ± 0.10; 90%: 1.88 ± 0.49). Conversely, average home range area in thin-and-burn treatments was approximately 30% smaller than in control units (50%: 0.21 ± 0.05; 90%: 1.32 ± 0.35).

Discussion

Untreated control units had lower nesting density, fewer nests, and lower rates of occupied nests, suggesting that treatments created characteristics preferred by bluebirds. In other studies, ground cover variables (i.e., percent grass, forbs, and bare ground) have been found to be the best

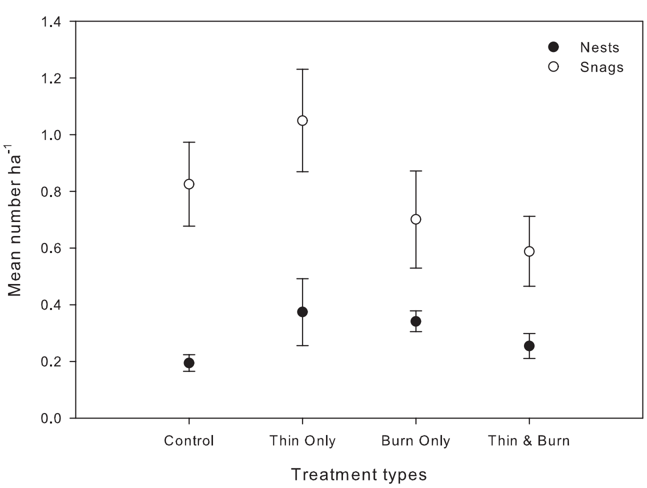

Figure 1. Mean ± SE of nest (nests ha^{-1}) and snag (snag ha^{-1}) density by treatment type for Western Bluebirds on forest treatment units in northern Arizona, May–August 2005–2006. Nesting density was significantly different among treatments ($P < 0.05$), with the control units having the lowest nesting density.

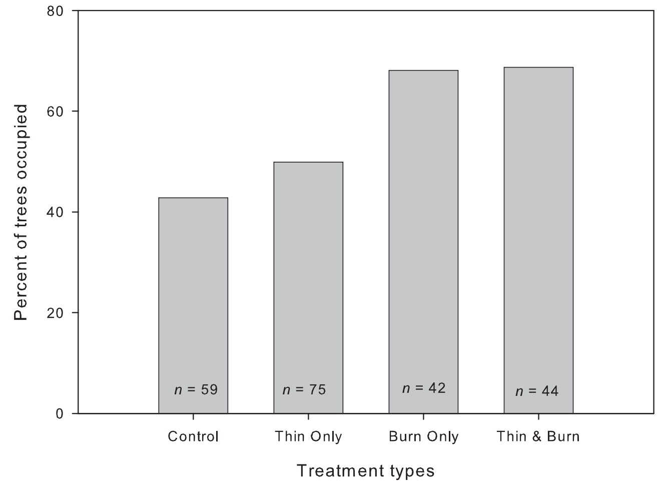

Figure 2. Percentage of trees (live or dead) occupied by nesting Western Bluebirds (for criteria, see Methods and Table 2) on four treatment units across three sites in northern Arizona, May–August 2005–2006. Occupied trees were those trees that contained at least one Western Bluebird nest. Differences in occupancy among treatments were statistically different ($P < 0.005$). Those units that received prescribed fire as part of their management action had a reduced number of available nesting locations.

predictor of Western Bluebird nest success (Wightman and Germaine 2006). It is plausible that restoration treatments improved herbaceous ground cover and increased the abundance and diversity of the invertebrate community, as suggested for similar ponderosa pine forests in the region (Wightman and Germaine 2006). Site fidelity may also play a role in the return and continued use of habitats in the study region. Forest vegetation structure at local (100-m radius) and meso scales (300-m radius) were previously found to be important in the occurrence of various cavity-nesting species (Warren et al. 2005). Given that we only recaptured a single bird in 2006 that was banded in 2005, it appears that Western Bluebirds on our sites are not returning to the same nest year after year. Thus, Western Bluebirds may be selecting nest site locations at a scale similar to the size of the home range, treatment unit, or greater.

Because prescribed fire has been shown to reduce snag numbers (Horton and Mannan 1988), increased nest occurrence in treated sites is probably due to the loss of snags in the burned units and the subsequent use of the remaining snags by an increased number of birds (Figures 1 and 2). Our finding is consistent with that of Horton and Mannan (1988), who found that nearly half the snags ≥15 cm dbh on their study plots in southeastern Arizona burned down or were partially burned by prescribed fire. In the short-term, reduction in the numbers of suitable nest sites may reduce productivity by secondary-cavity nesters. Although tree mortality caused by thinning and burning treatments has the potential to create suitable nesting substrates for birds in the short term, other studies have suggested that it may be 5 years or more before a snag becomes suitable for cavity nesting birds (Cunningham et al. 1980, Ganey and Vojta 2004). This transition from short-term impact to long-term effects deserves further investigation.

Rates of occupied nest cavities by Western Bluebirds

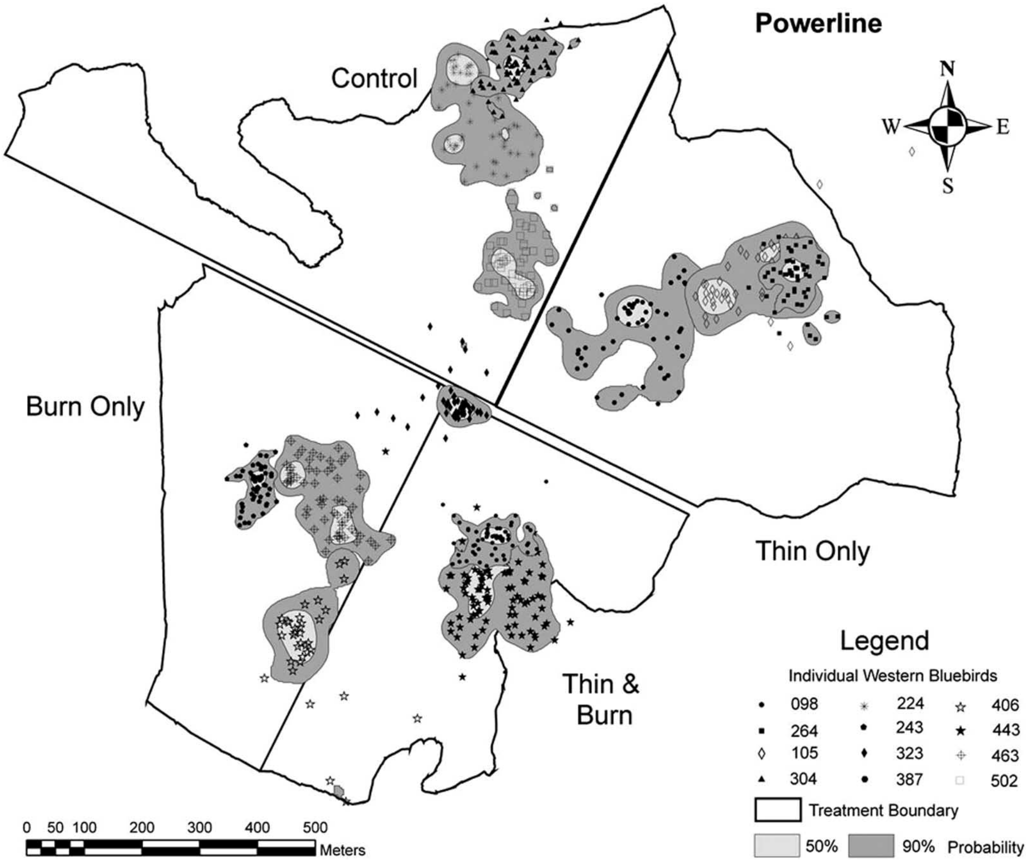

Figure 3. Map of all point locations and the 50% and 90% contours for 12 individual home range estimates at the Powerline site in northern Arizona, May–August 2005–2006. This map illustrates the high degree of variation in the size and shape of breeding male Western Bluebird home ranges, which was typical across all three study sites.

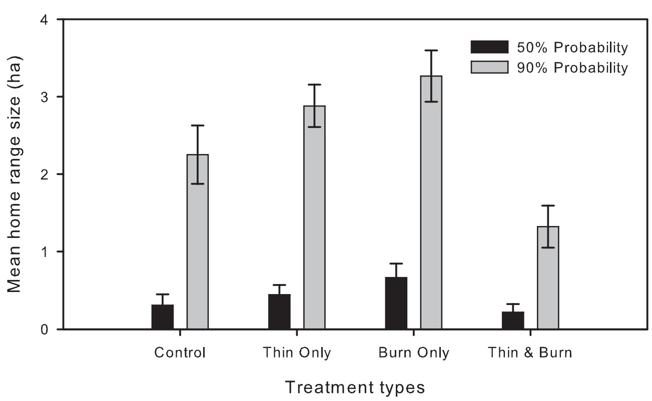

Figure 4. Mean ± SE home range size (in ha) for the 50% and 90% contours of 28 male Western Bluebirds on three study sites in Northern Arizona, May–August 2005–2006.

were lowest in the control units, indicating that many apparently suitable cavities were not used, and suggests a lack of suitable habitat surrounding possible nest sites in the control units. Alternatively, these results could indicate that our definition of "available" cavities and nest trees was problematic or that resources other than nest sites limited populations in control areas. All suitable cavities contained Western Bluebird nests in two units: the burn-only unit at Powerline (n = 12 nests) and the thin-and-burn unit at Rudd's Tank (n = 8). The burn-only and thin-and-burn treatments had a relatively high proportion of snags occupied, given the low snag density in these treatment types. High rates of occupied nest trees in these areas suggest that prescribed fire may create forest characteristics that are preferred by this species, especially when these characteristics are in close proximity to suitable snags in control area that were unused. The relatively high nest density in these treatment units also suggests that the abundance of food or other important resources may have increased after fire (Saint-Germain et al. 2004, Wightman and Germaine 2006). These results are consistent with Fretwell and Lucas' (1970) concept of ideal free distributions, in which individuals will saturate the habitat of highest suitability, before occupying less-suitable habitat. Against this conceptual framework, we expected the highest nesting density and/or rate of occupied cavities to be in the thin-and-burn treatment units. However, the number of available nest trees was limited in this treatment type, and virtually all suitable cavities were occupied, so breeding pairs probably had to place their nests elsewhere.

Our estimates of home range size and space use of Western Bluebirds showed little difference among treatments. This result, however, may have been due to the high within-treatment variation we observed in both the 50% contour (0.08–1.80 ha) and 90% contour (0.45–6.76 ha) kernel estimates of home range area. The small size of the treatment units and their close proximity relative to the size of a bluebird home range may have also contributed to this variation. We observed frequent use of multiple treatments by foraging individuals, demonstrating that other, unmeasured factors probably influence nest placement.

We believe that the placement of Western Bluebird home range boundaries is ultimately constrained by the location of suitable nest sites and the proximity of these sites to other nesting pairs. Nests and, therefore, home ranges can be spatially or temporally separated. For example, home ranges in the burn-only unit (Figure 3) were spatially separated with very little overlap during the nesting period. In contrast, home range areas overlap considerably in the thin-only treatment but were temporally separated. One individual (264) established his nest/home range earlier than the other individual (105). When male 264 completed his nesting cycle and left the area, male 105 took over the vacated home range. It seems reasonably clear that these individuals selected a location with preferred characteristics. Likewise, individuals that established their home range in more densely forested treatments (e.g., control or burn-only) often nested near small openings in the canopy.

Forest treatments may alter the size distribution and availability of snags in complex ways, influencing temporal availability and quality of nest sites, as well as the quality of surrounding foraging habitat. Because Western Bluebirds and other songbirds are sensitive to changes in preferred forest structural characteristics (Beedy 1981, King and DeGraaf 2000), restoration treatments are expected to exert great influence on habitat quality. However, seemingly beneficial changes in forest structure may pose challenges to cavity-nesting species because the large snag retention objectives established by the US Forest Service are rarely met (Ganey 1999). A restoration-based approach to the management of ponderosa pine forests should include protection of snags and live trees with cavities. This will require an integrated plan for the appropriate staging of treatments, such that patches containing cavity-bearing snags are retained, even when these are smaller trees in dense stands. Interspersion of these patches with more intensive treatments could combine sufficient nesting resources with generally improved habitat characteristics at appropriate spatial scales. This approach would ensure suitable nesting locations, not only for Western Bluebirds but also for many other secondary cavity-nesting species, during the transition period when restoration treatments can introduce dramatic, rapid, and widespread changes to wildlife habitats.

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