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HABITAT USE BY ABERT'S SQUIRRELS (*SCIURUS ABERTI*) IN MANAGED FORESTS

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ABSTRACT—Ponderosa pine (*Pinus ponderosa*) forests of the southwestern United States have changed dramatically over the past century, primarily in response to grazing, logging, and fire suppression practices. As a result, forest restoration treatments are gaining attention as a forest management tool for reducing fire risk and improving ecological function of the forest. We trapped and radiocollared Abert's squirrels (*Sciurus aberti*) in restoration-treated ponderosa pine forests to determine changes in home range sizes as a result of restoration treatments. We report evidence that winter vs. nonwinter home range of Abert's squirrels was not different pre- vs. posttreatment. These results are important for land managers in designing forest treatments that reduce the risk of stand-replacing wildfire while providing habitat for the Abert's squirrel.

RESUMEN—Los bosques de pino ponderosa (*Pinus ponderosa*) del suroeste de los Estados Unidos han cambiado drásticamente en el último siglo, principalmente en respuesta al pastoreo, tala y prácticas para evitar incendios forestales. Como resultado, los tratamientos de restauración del bosque llegan a ser importantes como herramienta de manejo para disminuir el riesgo de incendios y para mejorar la función del bosque en el ecosistema. Atrapamos y les pusimos collares de radiotransmisores a ardillas de Abert (*Sciurus aberti*) en los bosques de pino ponderosa con tratamiento de restauración para determinar cambios en los tamaños de rangos de hogar resultantes de los tratamientos de restauración. Reportamos que el rango de hogar del invierno versus no invierno de la ardilla Abert no fue diferente antes o después del tratamiento. Estos resultados son importantes para los administradores del terreno para diseñar los tratamientos de los bosques que reduzcan el riesgo de incendios forestales mientras provean el hábitat a la ardilla Abert.

The Abert's squirrel (*Sciurus aberti*) is dependent on ponderosa pine (*Pinus ponderosa*) for food and cover (Keith, 1965; Farentinos, 1972; Dodd et al., 2003). Their diet consists almost exclusively of ponderosa pine tissue (seeds, seeds from cones, and phloem) or plants and fungi closely associated with ponderosa pine (Keith, 1965; Stephenson, 1975; States et al., 1988; Austin, 1990; Snyder, 1992). Nests are typically placed in the upper branches of large (37.5–57.5-cm diameter at breast height) ponderosa pines (Halloran and Bekoff, 1994; Snyder and Linhart, 1994). Although squirrels depend upon the pine throughout the year, habitat quality is especially critical in winter when their primary food source is the phloem of a chemically unique subset of trees containing physiologically important elements (Hall, 1981; Zhang and States, 1991; Snyder, 1992). These "feed trees" are typically found in clumps that are distributed throughout a forest patch (States et al., 1988; Linhart, 1989). The ability of a squirrel to access these clumps via interlocking canopy corridors becomes increasingly important during winter when snow accumulation can impede ground travel and increase susceptibility to predation (Stephenson and Brown, 1980). Previous studies have suggested that winter survival is the limiting factor for Abert's squirrel populations (Loberger et al., 2011).

Over the past 150 years, ponderosa pine forests of the American Southwest have shifted from relatively open, park-like stands with clumps of large-diameter trees (Cooper, 1960; White, 1985) to dense stands of small-diameter trees with very few open areas (Covington and Moore, 1994). Because these dense stands are vulnerable to high-intensity wildfires, managers of ponderosa pine forests in the American Southwest have responded by attempting to restore presettlement stand structure and return low-intensity fire to this fire-adapted landscape (Allen et al., 2002). This management approach can reduce basal area and trees per acre (Fulé et al., 2001) and allow the herbaceous understory to reestablish (Moore et al., 2006). The resulting forest is more open, allows for a more productive understory, and has a mosaic forest structure of tree clumps of varying densities and sizes.

Previous studies have suggested that landscape-scale restoration treatments could potentially decrease density

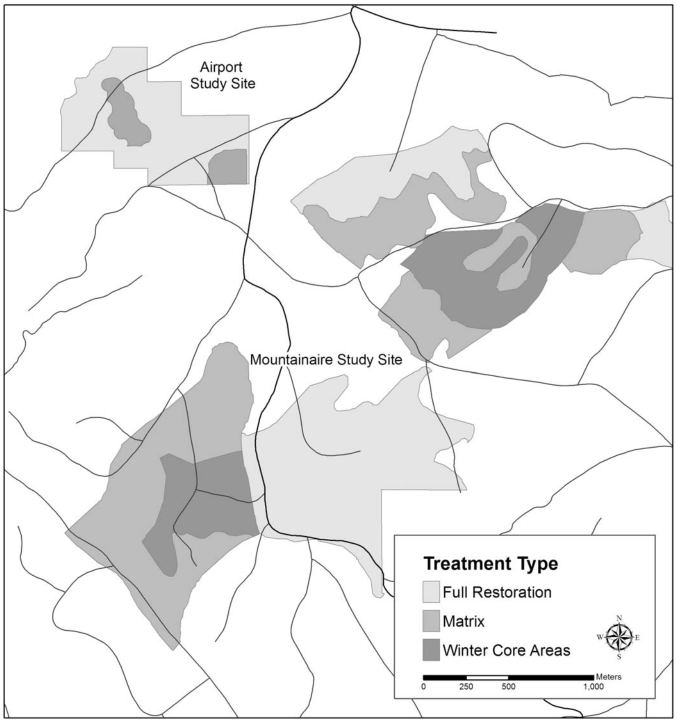

FIG. 1—Map of Abert's squirrel (*Sciurus aberti*) tracking study areas during 2005-2010 at the Airport and Mountainaire near Flagstaff, Arizona.

and recruitment of Abert's squirrels if treatments cause overall basal area and the number of interlocking tree canopies to fall below critical levels (Dodd et al., 2006). In addition to reducing food and nest site availability, forest restoration could increase squirrel mortality by reducing the amount of interlocking canopies that squirrels use as pathways for escaping predators (Austin, 1990; Dodd et al., 2003). Although some researchers have suggested that up to 75% of a forested landscape can be treated and still provide suitable squirrel habitat if treatments are applied as a mosaic of patches (Dodd et al., 2006), few studies have examined how individual squirrels respond in forests where restoration treatments have been conducted. Further, few have examined the appropriate size or configuration of denser patches for the Abert's squirrel. In this study we evaluated seasonal home range and quantified habitat selection by Abert's squirrel in a treated landscape.

MATERIALS AND METHODS—*Study Area*—We conducted the study at two sites: Mountainaire and Airport. The Mountainaire study site (35°12′N, 111°66′W; Fig. 1) was located southeast of Flagstaff, Arizona, between Lake Mary Road and Interstate 17. The area includes 6,180 ha of Coconino National Forest on the Mormon Lake Ranger District and 539 ha of private land. The Mountainaire study site was an experimental prescription that included three distinct forest components: winter core areas (WCAs, formerly referred to as "meso-reserves"), matrix (minimally thinned), and full restoration (Dodd et al., 2003), which was modified to accommodate existing stand conditions and fuel reduction objectives specific to the Mountainaire Project (United States Forest Service, 2013). The description of the three forest components is based on Dodd et al. (2003), but varies slightly from those recommendations to accommodate existing stand conditions and fuel reduction needs specific to the Mountainaire Project. The WCAs were 20–36 ha each, with a basal area ranging from 10 to 15 m^2ha and canopy closure ranging from 55% to 72%. This combination of prescriptions was developed to maximize squirrel density and recruitment while meeting other ecological restoration goals, such as reduction of risk to wildfire, and improved tree vigor. The WCAs had higher basal area and extensive interlocking canopies that provide habitat for squirrel nest placement, movements, and protection from predators.

The Airport study site (35°13′N, 111°67′W; Fig. 1) encompassed approximately 54 ha immediately adjacent to Pulliam Airport, east of Interstate 17, on lands owned by the city of Flagstaff, Arizona. The management of this area was developed by the Flagstaff Fire Department, Arizona Game and Fish Department, Greater Flagstaff Forests Partnership, and Northern Arizona University Ecological Restoration Institute and School of Forestry. The prescription emphasized mechanical thinning to recreate presettlement forest conditions on 43 ha. Tree-thinning treatments were based on site-specific reconstruction of prefire exclusion forest density and spatial arrangement using principles described by Moore et al. (1999).

All trees >24-cm diameter at breast height in the treatment areas were retained during treatment operations performed by the U.S. Forest Service. Groups and clumps of ponderosa pine trees varied in shape, size, and number of trees, and were irregularly shaped. Groups were located perpendicular to prevailing wind to reduce fire hazard. Slash from harvested trees was chipped and hauled off-site. The prescription included retention of 2 WCAs (4 and 7 ha) within the treatment area. These WCAs were considerably smaller than those implemented on the Mountainaire project (27–90 ha) and were spatially arranged within the treatment to observe squirrel use of smaller, dense patches nested within a larger treatment area. Treatments were completed in September 2009.

Collection and Analysis of Data—From 21 April 2010 to 15 June 2010, we captured squirrels using wire-mesh box traps (Model 202; Tomahawk Live Trap Co., Tomahawk, Wisconsin) baited with shelled, unsalted, raw peanuts. We baited the traps in the morning and checked in the late afternoon. To incorporate several combinations of forest restoration patches, we placed 4 10 × 10 trap grids on the study area. We placed the traps 50 m apart.

We immobilized captured squirrels with an inhalation anesthetic, isoflurane (IsoFlo; Abbott Laboratories, North Chicago, Illinois), and fitted each with a 15-g VHF radio-transmitter (Model CHP-3P; Telonics, Mesa, Arizona). In all cases, transmitters were <3% of body mass. We weighed and determined sex of each captured squirrel and classified those weighing >550 g as adults (Keith, 1965; Farentinos, 1972; Dodd et al., 2003). We released squirrels at the capture site after a 15-min anesthetic recovery period.

We used a directional hand-held antenna to track squirrels throughout the year for 18 months, locating each squirrel ≥2 times/week and scheduling searches to equally sample morning, afternoon, and late-afternoon periods. We recorded each animal's location using Universal Transverse Mercator coordi-

TABLE 1—Individual Abert's squirrel (*Sciurus aberti;* $n = 5$) fixed-kernel density estimate (FKDE) home ranges from posttreatment study (ha) in Flagstaff, Arizona, during 2009–2010.

Frequency	Sex	Study site	Season	No. of locations	50% FKDE	85% FKDE
9.580	M	Mountainaire	Nonwinter	30	2.48	8.07
			Winter	24	2.88	8.04
9.302	F	Mountainaire	Nonwinter	39	1.37	4.50
			Winter	22	3.00	7.97
9.201	M	Mountainaire	Nonwinter	25	4.32	11.03
			Winter	21	1.79	5.03
8.602	M	Airport	Nonwinter	41	2.83	9.18
			Winter	21	3.71	9.33
8.562	M	Airport	Nonwinter	36	1.59	5.00
			Winter	22	1.15	3.45

nates obtained from a hand-held Global Positioning System unit after the unit achieved an accuracy of ≤8 m.

We produced fixed-kernel seasonal core areas and 85% fixed-kernel seasonal ranges (Worton, 1989) using ArcGIS 9.3.1 Home Range Tool adapted from ArcView 3.3 Home Range Extension (Rogers and Carr, 1998) with a least-squares cross-validation smoothing parameter (Worton, 1995; Seaman and Powell, 1996; Seaman et al., 1999) for six squirrels that were tracked in 2005, 2006, and 2007 at the Mountainaire study site. These data were collected during a previous study. We focused our analysis efforts on the posttreatment results but used pretreatment data for comparison purposes.

We partitioned location data from 2005 to 2007 and 2010 to 2011 into two seasons: winter (1 November–31 March) and nonwinter (1 April–31 October), based on snowfall and seasonal shifts in squirrel diet. For each season, we estimated 50% fixed-kernel seasonal core areas and 85% fixed-kernel seasonal ranges (Worton, 1989) using ArcGIS 9.3.1 Home Range Tool adapted from ArcView 3.3 Home Range Extension (Rogers and Carr, 1998) with a least-squares cross-validation smoothing parameter (Worton, 1995; Seaman and Powell, 1996; Seaman et al., 1999).

We determined that home range estimates stabilized after 21 locations were used (Seaman et al., 1999), and we subsequently calculated home ranges only for squirrels with ≥21 locations in each season. We tracked only adult squirrels and had only one female with ≥21 locations. We pooled all squirrels within sites, consistent with *t*-test results from Loberger et al. (2011). Data were normal based on Shapiro–Wilk's tests. We used a Welch analysis of variance (Welch, 1938) to test for homogeneity of variance (JMP 10; SAS Institute Inc., Cary, North Carolina). We obtained raster data for basal area and canopy cover with a 1-m resolution from Forest-ERA (Forest Ecosystem Restoration Analysis, Flagstaff, Arizona). We assigned 3 canopy classes (0–30%, 31–40%, ≥41%) and 5 basal-area classes (0–35, 36–75, 76–100, 101–125, ≥126). We used ArcGIS 9.3.1 to determine the proportion of all squirrel locations recorded in each of the treatment types at the two study sites.

We estimated second-order availability of forest structure characteristics at home range scale (Johnson, 1980), based on the relative amounts of three canopy-cover classes and five basal-area classes within the minimum convex polygon created from all radiolocations of squirrels captured in each study area (Guthery et al., 2005). We estimated second-order use as either the composition within the 50% fixed-kernel core area or within the 85% fixed-kernel home range. We compared composition within each individual 50% core area or 85% kernel home range to the composition within the broader study area. We evaluated third-order selection by considering the habitat within an individual's seasonal 85% fixed-kernel home range as available and habitat at each individual radiolocation as use.

We used compositional analysis to determine whether habitat use differed from random and to rank habitat preference when statistically significant differences existed between availability and use (Aitchison, 1986; Aebischer et al., 1993). Compositional analysis avoids the problems of radiolocation serial correlation by using the animal as the sampling unit and addresses the issue of nonindependence by using log-ratio transformation of the habitat proportions (Aebischer et al., 1993). Compositional analysis is recommended for sample sizes ≥10 individuals (Aebischer et al., 1993); we included all squirrels with ≥15 locations in this analysis, which gave us 8 total individuals. We followed Bingham and Brennen (2004), substituting values of 0.007, rather than 0.0 for habitat classes where a squirrel was never located. We used a MANOVA analysis in SAS to determine whether use differed from random for habitat selection at the second and third orders.

RESULTS—We calculated fixed-kernel-density home-range estimates for five squirrels. We captured 20 at the Mountainaire study site and 12 at the Airport study site, yet we could only use 5 for the analysis. We found no difference in 85% home range or 50% core range between the two study sites (Table 1). We used a Student's *t*-test to compare 50% core and 85% home ranges for squirrels at the Mountainaire study site with those at the Airport study site and found no difference ($P > 0.05$). We found that the mean 85% fixed-kernel home range for winter (6.76 ha, $SD = 2.43$) was not significantly different from that for nonwinter (7.56 ha, $SD = 2.85$). The mean 50% fixed-kernel core area for winter (2.51, $SD = 1.02$) was not significantly different from the mean in nonwinter (2.52 ha, $SD = 1.18$). Squirrels used 50% core areas with basal area ≥101 m^2/ha more than expected in winter ($F = 361.86$, $P < 0.0001$) and used 85% home ranges with basal area ≥101 more than expected in nonwinter ($F = 7.05$, $P < 0.05$) when compared with availability within the study area. Squirrels selected 50% core home ranges with canopy cover ≥31% more often than expected in both

TABLE 2—Average Abert's squirrel (*Sciurus aberti*) fixed-kernel density estimate (FKDE) home ranges (ha) in pretreatment ($n = 5$; 2005) and posttreatment ($n = 5$; 2010) studies in the Mountainaire study area near Flagstaff, Arizona.

	Nonwinter 50% FKDE		Winter 50% FKDE		Nonwinter 85% FKDE		Winter 85% FKDE	
Year	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
2005	2.9275	1.2434	0.7200	0.3147	8.1450	3.0370	2.2520	1.002
2010	2.5180	1.1753	2.5060	1.0229	7.6020	2.8500	6.7640	2.4319

seasons (nonwinter: $F = 6.75$, $P = 0.0291$; winter: $F = 15.79$, $P = 0.0041$). We pooled all squirrels within sites, consistent with *t*-test results from Loberger et al. (2011).

We found no support for selection for specific basal area (winter: $F = 2.50$, $P = 0.1987$; nonwinter: $F = 1.14$, $P = 0.4499$) or canopy cover (winter: $F = 0.71$, $P = 0.5302$; nonwinter: $F = 1.92$, $P = 0.2225$) categories in either season when selection was based on individual radio-locations (third-order selection). During those pretreatment years, we found that squirrels had smaller home ranges in winter than in nonwinter; our posttreatment data from the Mountainaire study site show no difference in home range size by season (Table 2).

DISCUSSION—Based on a sample size of 10, we found that there was no difference in home range size of squirrels across seasons or across years. This is of importance because of the varied size of WCAs across study sites. Our research illustrates that it is plausible to provide habitat for wildlife that require denser forest conditions while also reducing the risk of stand-replacing wildfire. A stand-replacing fire is a fire that kills all or most of the living upper canopy layer and initiates success or regrowth (Smith, 2000). The Airport study site WCAs were much smaller than the Mountainaire WCAs (4 and 7 ha vs. 40 ha). The difference in WCA size is also relevant in regard to forest restoration and providing habitat requirements for squirrels. Although many studies have shown that forest restoration activities result in a decline in squirrel abundance, our results show that treated areas that contain smaller WCAs (i.e., areas with high basal area and canopy cover) can provide winter habitat and still reduce the risk of stand-replacing wildfire. These areas are thought to be especially important during winter months when snow impedes squirrel movements. However, we did not see heavy snow amounts during our study.

The differences in home range size for pre- and posttreatment could indicate changes in squirrel habitat selection posttreatment. Squirrels may have needed to travel farther distances posttreatment during winter to forage or to find necessary habitat requirements, and they were able to do so because of the comparatively lower snowfall during our study (1,026 cm in 2005–2007, 978 cm in 2010–2011) compared with the 50-year average of 1,351 cm (Western Regional Climate Center; http://www.wrcc.dri.edu/). We found average posttreatment nonwinter home-range sizes to be consistent with the pretreatment study results (Table 2), which adds support for current ponderosa pine forest management approaches related to squirrel habitat.

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