



## Original Article

# Summer Habitat Use by Adult Female Mule Deer in a Restoration-Treated Ponderosa Pine Forest

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**ABSTRACT** Across ponderosa pine—(*Pinus ponderosa*) dominated forests of northern Arizona, USA, large-scale restoration and fuels treatments are being implemented or planned to reduce wildfire threat and severity and improve ecosystem health. It is important to understand how these activities will affect animal populations, including species of economic and social importance, such as mule deer (*Odocoileus hemionus*). Forest treatments may improve foraging habitat for mule deer by opening forest canopy and stimulating shrub and herbaceous production, but also may reduce availability of day-bed sites. In this context, we used a generalized linear mixed-model approach and utilization distributions to estimate post-treatment relative intensity of summer (Apr–Sep) use of multiple habitat attributes by adult female mule deer on the Grand Canyon-Parashant National Monument in northern Arizona between 2003 and 2005. Based on 5,776 Global Positioning System collar locations from 10 individuals ( $\bar{x}$  = 580 locations/individual), we identified intensive use of areas that received a thin-and-burn treatment in the previous season, were located on gentle slopes, and were proximate to reliable water sources. Female mule deer likely selected thin-and-burn treatment areas to take advantage of increased forage abundance. Because thin-and-burn treatments did not remove Utah juniper (*Juniperus osteosperma*) or Gambel oak (*Quercus gambelii*), substantial shrub and mid-story vegetation cover remained post-treatment. Our results indicated the potential value of a mosaic approach to ponderosa pine forest restoration, where untreated areas, as well as treated areas that retain Gambel oak and juniper, are heterogeneously distributed across the landscape. This approach also would provide important concealment cover and forage after thin-and-burn and thin-only treatments. © 2013 The Wildlife Society.

**KEY WORDS** Arizona, forest restoration, mule deer, *Odocoileus hemionus*, *Pinus ponderosa*, ponderosa pine.

Ponderosa pine (*Pinus ponderosa*) forests of the American Southwest (AZ, NM, and adjoining portions of UT and CO) have experienced major changes in structure, composition, and function because of recent human activities (Allen et al. 2002). More than a century of livestock grazing, fire suppression, logging, road construction, and exotic-species introductions have altered most of these forests from conditions that had prevailed for thousands of years (Covington and Moore 1994, Swetnam et al. 1999). Contemporary ponderosa pine forests tend to be dominated by relatively homogeneous, dense stands of younger trees with a depauperate herbaceous and shrub understory, and increased vulnerability to high-intensity crown fire (Covington and Moore 1994).

In the Southwest, forest restoration prescriptions in ponderosa pine-dominated ecosystems typically seek to recreate conditions characteristic of those present prior to Euro-American settlement (pre-1870), including tree-species composition and spatial arrangement (Covington et al. 1997, Fulé et al. 1997). These restoration treatments are designed to reduce tree density and overstory canopy, while increasing productivity and diversity of understory vegetation (Fulé 2003). Animal species will respond differently to these changes based on their home-range requirements, mobility, and degree of habitat specificity (Chambers and Germaine 2003).

Mule deer (*Odocoileus hemionus*) populations in the Southwest have experienced declines in the past 50 years (Clements and Young 1997) due to habitat degradation from fire suppression, exotic species invasion, and increased livestock grazing (Gill 1999). Habitat requirements of mule deer include an abundance of high-quality herbaceous forage (Dietz and Nagy 1976), vegetation cover that provides protection from predators and weather (Parker and Gillingham 1990), and access to reliable water sources.

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Summer forage availability and quality determines body condition of deer prior to a resource-limited winter (Snider and Asplund 1974, Mule Deer Working Group 2003), affects doe productivity and lactation, and fawn survival and growth; therefore, high-quality summer habitat is essential for maintaining healthy populations (Zwank 1976, Pederson and Harper 1978).

In northern Arizona, mule deer summer home ranges commonly include ponderosa pine-dominated vegetation types (Urness et al. 1975, Pederson and Harper 1978), including extensive areas where large-scale restoration treatments have been implemented or are currently being planned. Restoration treatments and timber harvest activities that open tree canopies in ponderosa pine and mixed-conifer forests often increase forage abundance and diversity and subsequent use by wildlife (Clary and Ffolliot 1966; Patton 1974, 1976; Masters et al. 1993). Although mule deer can respond favorably to restoration treatments due to increased forage production, these treatments may also reduce hiding cover and alter the microclimate and physical characteristics of day-bed sites (Germaine et al. 2004).

For a managed herd of mule deer occupying ponderosa pine-dominated and recently treated areas in the Grand Canyon-Parashant National Monument in northern Arizona, we sought to examine the effects of forest restoration on the relative intensity of summer habitat-use patterns. Within a rigorous statistical modeling framework, we leveraged high temporal and spatial resolution Global Positioning System (GPS) collar data. Specifically, our objectives were to 1) spatially define individual home range and core areas, 2) develop a spatially explicit statistical model of intensity of habitat use, and 3) make recommendations that will help land managers provide essential forage and cover attributes for mule deer while restoring forest structure and reducing the risk of uncharacteristic, high-intensity wildfire. Furthermore, and in the statistical context of multiple habitat variables, we hypothesized that adult female mule deer would use treated areas, irrespective of treatment type, more intensely than untreated areas.

## STUDY AREA

We conducted our study within the Mt. Trumbull Resource Conservation Area of the Grand Canyon-Parashant National Monument in northwestern Arizona (Fig. 1). The 1,200-ha study area was managed by the U.S. Department of the Interior Bureau of Land Management. Elevations ranged from 1,675 m to 2,620 m and major vegetation communities included pure ponderosa pine forest and ponderosa pine-deciduous forests containing Gambel oak (*Quercus gambelii*), New Mexican locust (*Robinia neomexicana*), and quaking aspen (*Populus tremuloides*). Pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) were less common in the study area. Logging and cattle grazing were introduced to the region during Euro-American settlement circa 1870 and the Mt. Trumbull Resource Conservation Area has been fire-suppressed for much of the past century (Covington and Moore 1994).

Throughout the study area, forest restoration treatments were initiated in 1996. The restoration prescription followed pre-1870 reference conditions for tree-species composition and spatial arrangement (Covington et al. 1997). Treatments were designed to include thinning, burning, and reseeding with a native herb mix dominated by grasses (see Covington et al. 1997, Waltz et al. 2003). All old-growth ponderosa pine trees (>120 yr old) and all Gambel oak, Utah juniper, and New Mexican locust were retained during thinning treatments. By 2003, >450 ha of ponderosa pine forest had received thin-and-burn treatment and an additional 320 ha were thinned-only. An untreated control area of approximately 500 ha was present in the southeastern portion of the study area, along with 5 10–30-ha controls embedded among treated areas.

## MATERIALS AND METHODS

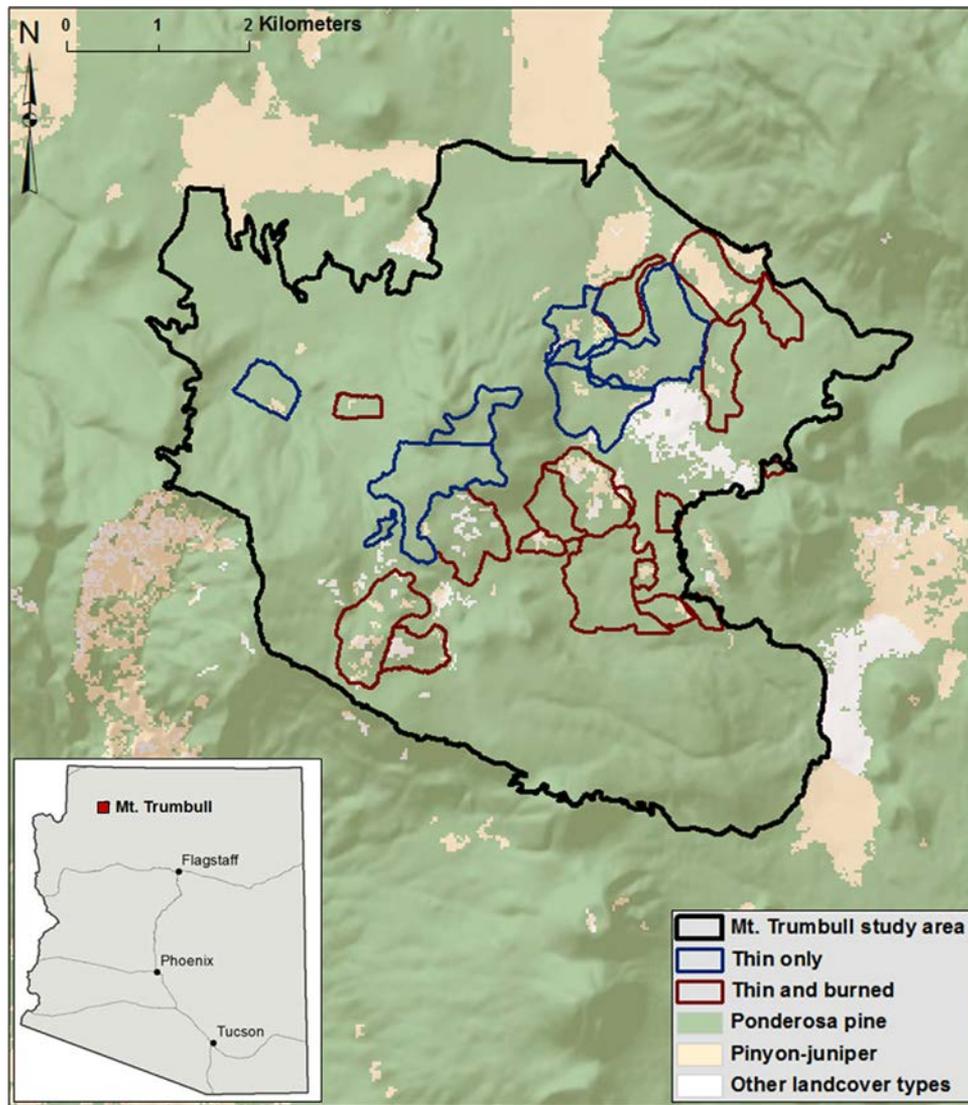
### Deer Capture and Location Data

We captured 15 adult (>2 yr) female mule deer using drop-nets or chemical immobilization between 12 June 2003 and 31 July 2003. We fitted deer with store-on-board GPS collars (Model no. TWG 3500 with CR2A collar release; Telonics, Inc., Mesa, AZ). Collars were programmed to record 1 location every 5 hours from 1 May to 30 September. Collars were programmed to release after 3 years of operation. Global Positioning System locations had a locational accuracy of  $\pm 15$  m according to manufacturer specifications. Locations with dilution of precision values >8 and 2-dimensional fixes were considered insufficiently accurate and removed prior to analysis (Lewis et al. 2007).

### Habitat Variable Development

We selected a set of 7 habitat predictor variables influenced by restoration treatments and identified in previous studies of mule deer ecology and habitat use (King and Smith 1980, Kufeld et al. 1988, Carpenter 1998, Cunningham et al. 2005, Heffelfinger 2006). We used data from the 2006 National Land Cover Data (30-m-pixel resolution; Fry et al. 2011) and a geographic information system (GIS; ArcGIS v10.0) to derive a layer of dominant land-cover types across the study area. We further consolidated these data into 3 dominant land-cover types: ponderosa pine forest, pinyon-juniper forest, or "other," which included aspen stands, meadows, or lava fields. Within the GIS, terrain variables characterizing elevation, slope, ruggedness, and "northness" were derived at a 30-m resolution using topographic data obtained from the LANDFIRE Project website ([www.landfire.gov](http://www.landfire.gov)). Ruggedness was derived using the standard deviation of all slope values in a  $3 \times 3$ -pixel neighborhood. Northness (i.e., the tendency of a pixel to be facing toward true north, scaled between 0 and 1) was derived using a cosine transformation of aspect (Roberts 1986).

We also used the GIS to estimate the Euclidean distance of all known reliable water sources (i.e., ephemeral or typically available in the summer of most years on the study area). Water source locations originated from Bureau of Land Management and Arizona Game and Fish Department records and were verified in the field.



**Figure 1.** Map of Mount Trumbull Resource Conservation Area in Northwest Arizona, USA, illustrating dominant land-cover types and the boundaries of forest treatments between 2003 and 2005.

We obtained a spatial database containing perimeters of forest treatments applied on the study area between 1996 and 2005 from the Ecological Restoration Institute at Northern Arizona University. Although prescriptions were intended to include thinning followed by burning, treatments occurred in stages; in many cases, several years passed between the thin-and-burn stages. Over the course of our study, several areas were not burned and considered thin-only treatments. We considered thin-only and thin-and-burn treatments as binary predictor variables in our models. Areas were considered treated and available to mule deer one season after treatments were completed (i.e., spring treatments available in summer).

Within the GIS, we derived all predictor variables as a 30-m pixel-resolution grid. To accommodate uncertainty in GPS locations and the precise value of a predictor variable assigned to a given pixel, we smoothed all continuous variable grids using a  $3 \times 3$  focal mean or majority filter operation prior to modeling.

### Home-Range and Core-Area Estimation

For the summer period 1 May–30 September, 2003–2005, we analyzed GPS location data for individual mule deer to spatially define individual home-range and core-area perimeters. For each individual, we used a kernel-based approach to estimate a probabilistic utilization distribution and 95% and 50% fixed-kernel (FK) isopleths, defining the perimeter of the home range and core areas, respectively, and when  $\geq 30$  locations were obtained in a given period (Seaman et al. 1999). We derived these estimates using a likelihood-based smoothing parameter (CVh; Horne and Garton 2006) and a kernel estimation extension to ArcGIS (30-m grid-cell size; Beyer 2012). The continuous values of the utilization distribution were used as a proxy for determining the relative intensity of habitat use in the models described below. We used a 1-way analysis of variance (test statistic =  $F$ ,  $\alpha = 0.05$ ) to test for among-year differences in home-range and core-area size.

## Models of Habitat Use

We used a generalized linear mixed-model framework and hierarchical approach to quantify patterns of individual habitat use as a function of the habitat predictor variables described above. We were interested in estimating the relative *intensity* of habitat use (*sensu* Jennrich and Turner 1969); therefore, we related individual mule deer GPS locations to the height of the utilization distribution by intersecting each utilization distribution with all of the locations used to derive it (Dickson et al. 2013). We treated the continuous value of this utilization-distribution height as the dependent variable in our models of habitat use. We accounted for spatial and temporal structuring (e.g., positive spatial and serial autocorrelation, respectively) in the location data by treating individual animals within years as a subject-level random effect and using a first-order autoregressive covariance structure (Little et al. 2006, Gutzwiller and Riffell 2007). In addition, we computed the variance-covariance matrix of our habitat parameters using the empirical Huber-White “sandwich” estimator, which allowed us to relax the assumption of independence between locations within subjects and account for unknown covariance structure (Huber 1967, Williams 2000, Wooldridge 2009).

Within this generalized linear mixed-model framework, we used an information-theoretic approach and multi-model inference to estimate and contrast the importance of individual habitat variables (i.e., fixed effects; Burnham and Anderson 2002). Because we were interested in quantifying the relative importance of these variables, rather than evaluate the performance of a candidate set of competing models, we considered only a single “global” model that included all of our habitat variables and used all subsets modeling to estimate model-averaged regression coefficients ( $\bar{\beta}$ ) and unconditional standard errors for each variable (Burnham and Anderson 2002). We used these values to estimate the effect size (based on a *Z*-statistic, or  $\bar{\beta}/SE$ ) and rank the relative importance of each habitat variable. We considered  $|Z|$  values  $\geq 2.0$  for a given variable to be indicative of a strong response by mule deer to that variable. We used an information-theoretic approach to model selection and inference, so we did not compute *P*-values. We used an intercept-only model (including random effect and covariance structure) and the difference in Akaike’s Information Criterion ( $\Delta AIC$ ) values to help evaluate how well our global model approximated (and fit) the data (Anderson 2008).

Prior to statistical analysis, we standardized values for all continuous habitat variables to a mean of zero and unit variance. Because no univariate comparisons of these variables had a Pearson correlation coefficient  $>0.60$ , none were excluded from our analysis. We implemented all analyses and models in SAS PROC MIXED (v9.2; SAS Institute, Inc., Cary, NC).

## RESULTS

### Location Data

Over the period of study, we successfully retrieved 13 collars, which included 10 adult female deer whose home ranges

were wholly or largely contained within the study area. Our final spatial database included 5,776 locations from these 10 individuals. We obtained 95–250 ( $\bar{x} = 199$ ,  $SD = 50$ ) locations for 10 individual deer in 2003, 178–329 ( $\bar{x} = 281$ ,  $SD = 50$ ) locations for 8 deer in 2004, and 214–320 ( $\bar{x} = 257$ ,  $SD = 41$ ) locations for 6 deer in 2005, representing 24 unique subject levels in our statistical models of habitat use.

### Home-Range Estimation

We derived 24 estimates of home range and core areas for 10 deer (Table 1). The 95% FK estimates of individual home-range area ranged from 96 ha to 1,090 ha and averaged 368 ha ( $SD = 282$ ). Individual core areas (50% FK) ranged from 13 ha to 209 ha and averaged 66 ha ( $SD = 49$ ). Deer were observed in all treatments across the study area. Home-range estimates and core areas differed among 3 years of this study, but none were statistically significant. The average 95% FK estimate was 343 ha ( $SD = 301$ ) in 2003, 308 ( $SD = 205$ ) in 2004, and 489 ( $SD = 345$ ) in 2005. The average core-area estimate was 64 ( $SD = 58$ ) in 2003, 55 ( $SD = 33$ ) in 2004, and 84 ( $SD = 55$ ) in 2005. On average, deer core areas overlapped 56%, 37%, and 7% with control areas, thin-and-burn treatments, and thin-only treatments, respectively.

### Models of Habitat Use

Our global model of habitat use was considerably better (i.e., lower;  $\Delta AIC > 472$ ) than the intercept-only model. Slope,

**Table 1.** Space-use statistics for 10 individual mule deer monitored between April and October (the summer season) of 2003–2005 in and around the Mount Trumbull Resource Conservation Area, northern Arizona, USA. The 95% and 50% fixed-kernel (FK) estimates delineate areas defined as home range and core areas, respectively.

Animal ID	Year	No. of locations	CVh <sup>a</sup>	95% FK (ha)	50% FK (ha)
9050	2003	144	147	269	48
9050	2004	317	116	278	45
9050	2005	256	81	212	39
9100	2003	193	94	155	36
9450	2003	232	162	517	82
9450	2004	301	133	399	64
9580	2003	182	170	837	209
9580	2004	277	182	752	126
9580	2005	320	128	714	122
9650	2003	240	60	118	28
9650	2004	178	65	117	22
9680	2003	246	69	96	13
9680	2004	317	83	168	37
9680	2005	228	253	307	62
9770	2003	250	135	154	36
9770	2004	279	80	134	29
9770	2005	230	170	246	43
9830	2003	95	243	274	53
9830	2004	246	156	338	50
9830	2005	214	129	365	58
9850	2003	225	84	117	25
9870	2003	186	241	890	106
9870	2004	329	92	279	65
9870	2005	291	243	1,090	178
Mean (SD):		241 (59)	138 (61)	368 (282)	66 (49)

<sup>a</sup>Smoothing parameter estimated using a likelihood-based cross-validation.

thin-and-burn treatment areas, and ponderosa pine-dominated land cover were the strongest ( $|Z| \geq 2.0$ ) predictors of relative intensity of mule deer summer habitat use on our study area (Table 2). Distance to reliable water, pinyon-juniper land cover, and rugged areas were moderate predictors. Elevation, northness, and thin-only areas were all less important predictors when compared with other variables.

## DISCUSSION

As hypothesized, our results indicated that deer used thin-and-burn treatment areas more intensely within their home range. Greater use within thinned and burned stands may have been due to the greater variability of forest structure in those areas due to the timing and size of treatments. In general, individual treatments were small (10–150 ha) and interspersed with untreated control areas, creating a mosaic of dense tree patches adjacent to more open areas. Treatments spanned >10 years, creating additional variability in forest and shrub structure, because some treated areas were completed 8–10 years prior to the start of other treatments. Roccaforte et al. (2010) found that post-treatment forest structure within stands in the Mt. Trumbull Resource Conservation Area ranged from extremely open patches with a minimum of 10 trees/ha to dense patches with a maximum of 1,581 trees/ha.

Treatment prescriptions that decrease canopy cover usually create an increase in forage abundance and diversity, thereby making treated areas more preferred by mule deer than untreated areas (Kufield et al. 1988, Masters et al. 1993). Treated areas experienced an increase in Gambel oak and other shrub and forb species, resulting in increased forage availability (Roccaforte et al. 2010). In 2003, Gambel oak made up 56% of the total trees/ha in treated areas, while control areas were dominated by ponderosa pine (73% of the total trees; Roccaforte et al. 2010). The post-treatment increase in small understory trees, including Gambel oak, New Mexican locust, and juniper, also provided deer with adequate forage and concealment cover. These woody species were not removed during thinning and exhibited vigorous growth thereafter. Similarly, Germaine et al. (2004) found that the majority of bedded mule deer observed in treated

areas were in patches of Gambel oak or New Mexican locust. Other studies have found similar results, indicating that stand diversity and dense pockets of trees are important factors in providing concealment cover for day-bed sites and protection from predators (King and Smith 1980, Gerlach and Vaughan 1991).

Mule deer have previously been observed to select for gentle slopes (Lendrum et al. 2012). The use of more gentle slopes during the summer season may have been related to the absence of dense vegetation more typical on steeper slopes. Steep slopes in the study area were not thinned and tended to consist of dense New Mexican locust and few forage species. Other studies also have found that dense vegetation can restrict deer movement and limit forage production (Watkins et al. 2007).

We found that mule deer intensively used areas closer to reliable water sources. Boroski and Mossman (1996) also reported that deer tended to be distributed close to water sources. Reliable water sources on our study area were not abundant; therefore, relatively intense use of these features, especially during the summer season, was not surprising. Indeed, lactating females have an increased need for water during this time of year (Hervert and Krausman 1986, Boroski and Mossman 1996).

Although differences were not statistically significant, we observed variation in mule deer home-range and core-area sizes among years. Home-range size of ungulates, including mule deer, can be influenced by multiple factors, such as age (Relyea et al. 2000), reproductive status (Long et al. 2009, van Beest et al. 2011), availability of forage (Dussault et al. 2005), availability of water (Heffelfinger 2006, Marshal et al. 2006), and intraspecific competition (Rosenzweig 1991). We found that average home-range and core-area size for deer was similar during 2003 and 2004, but greater during 2005. The larger average home-range and core-area sizes we estimated in 2005 likely resulted from a decrease in forest cover availability due to restoration treatments conducted during our period of study. More area was treated in 2005 (286 ha) than in previous years (89 and 106 ha in 2003 and 2004, respectively), so individual deer may have expanded their home ranges and core areas in order to find adequate cover and avoid thinning activities (Nicholson et al. 1997, Bender et al. 2007). Because the majority of core areas overlapped control areas, an increase in the percentage of the landscape treated likely contributed to an increase in home-range size to include more control areas or areas with greater cover.

Overall, our results for habitat use were similar to those indicated by other studies in the region (Germaine et al. 2004, Cunningham et al. 2005). However, one result from our study that differs from previous research was that thin-only areas were not as intensively used as thin-and-burn areas. This may have been due to a reduction in cover and forage production in these areas immediately following thinning. In the Southwest, vegetation growth can be slow (Fulé et al. 2005) and a substantial increase in forage may not have occurred until after the prescribed burn. If a regular fire interval (e.g., 5–9 yr; Covington et al. 1999) is not

**Table 2.** Standardized model-averaged regression coefficients  $\hat{\beta}$ , unconditional standard errors (SE), and Z-statistics (Z) for habitat variables used to model relative intensity of habitat use by mule deer in and around the Mount Trumbull Resource Conservation Area, northern Arizona, USA, 2003–2005.  $|Z|$  values  $\geq 2.0$  for a given variable were indicative of a strong response by mule deer to that variable.

Habitat variable	$\hat{\beta}$	SE	Z
Ponderosa pine land cover	3.291	1.198	2.747
Slope (%)	-0.720	0.313	-2.302
Thin-and-burn treatment	4.137	1.816	2.278
Distance to reliable water	-1.643	0.837	-1.962
Pinyon-juniper land cover	1.913	1.020	1.876
Ruggedness	-0.350	0.217	-1.615
Northness	-0.419	0.308	-1.360
Thin only treatment	-2.288	1.730	-1.323
Elevation	0.950	1.004	0.946

maintained, the use of these areas may decrease due to the lack of new forage. Without subsequent burns, the increased regeneration of locust and oak could lead to a deciduous-dominant landscape (Barton 2002, Roccaforte et al. 2010). Our models used higher spatial and temporal resolution GPS data compared with previous studies in the area using Very High Frequency transmitters, so our results likely revealed habitat relationships that might have otherwise been masked by lower resolution data and less sophisticated statistical methods.

## MANAGEMENT IMPLICATIONS

Our results suggest the importance of a mosaic approach to forest restoration for mule deer management; therefore, managers should consider treatments that provide adequate concealment cover and day-bed sites. This could be accomplished by staggering the time of treatments, maintaining a diversity of trees, and keeping small pockets of dense trees and untreated patches. We also recommend maintaining the surface fire regime to stimulate herbaceous understory vegetation, which is an important dietary component for mule deer in the summer months. These areas would be further enhanced by retention of oak stands within treated areas. Oak stands can be the primary midstory canopy component in a treated ponderosa pine forest (Germaine et al. 2004); therefore, managers should develop treatment prescriptions that promote the retention of this species (Roccaforte et al. 2010).

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