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Characteristics of mule deer day-bed and forage sites in current-condition and restoration-treated ponderosa pine forest

Stephen S. Germaine, Heather L. Germaine, and Susan R. Boe

Abstract We characterized microhabitat (structure and microclimate) at 236 mule deer (*Odocoileus hemionus*) day-beds, 152 diurnal forage sites, and 439 random locations during summers of 1998–2000. Our objectives were to 1) identify important microhabitat characteristics of day-beds and forage sites in untreated forest, 2) compare relative availability of bed and forage sites having these characteristics between forest types, 3) determine whether mule deer selected either forest type disproportionately for these activities, and 4) compare characteristics of day-bed and forage sites between forest types. Mule deer selected bed and forage sites with specific characteristics in untreated forest each year. Site temperature and canopy closure were the most influential attributes in bed-site selection, while forage availability best described forage sites. Availability of characteristic day-bed microhabitat was reduced 50–100%, while forage characteristics increased 31–66% each year in treated forest. Foraging mule deer selected treated forest in 1 year but demonstrated no preference in 2 years. Mule deer continued to use day-beds in both forest types each year as expected based on proportional area of each forest type, but did so in treated forest in 1999 by utilizing a novel suite of microhabitat features. Bed sites in each forest type had similar levels of midstory canopy closure, but treated forest bed sites were warmer in one year, exclusively located under oaks (*Quercus gambelii*) rather than conifers, and less concealed than untreated forest beds. Small oak stands were the only dense patches retained in the restoration prescription we examined and provided marginal thermal and hiding cover for day-bed use by female mule deer. These differences may increase thermoregulatory stress and the potential for increased disturbance and predation of female mule deer and fawns during summer. We recommend retaining >0.04-ha patches of dense bedding and hiding cover in areas where both forest restoration and mule deer are management concerns.

Key words Arizona, day-bed, forage, forest restoration, gambel oak, mule deer, *Odocoileus hemionus*, *Pinus ponderosa*, ponderosa pine, *Quercus gambelii*

After several decades of growth during the early and mid-1900s, many mule deer (*Odocoileus hemionus*) populations recently have declined (Julander and Low 1976, Clements and Young 1997). Population persistence within a particular habitat depends upon availability of resources to

meet critical needs of members of the population (e.g., Smith 1980). Critical needs of mule deer include protection from predators and weather (Miller 1970, Smith and LeCount 1979, Smith et al. 1986, Parker and Gillingham 1990) and high-quality forage (Dietz and Nagy 1976). Bed sites afford deer

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protection from both weather and predators (Geist 1981, Armstrong et al. 1983, Kufeld et al. 1988, Ockenfels and Brooks 1994) and are located non-randomly within the range of habitat structure present (Smith et al. 1986, Kufeld et al. 1988, Gerlach and Vaughan 1991). Forage availability and quality on summer range determines body condition of mule deer as they head into winter (Snider and Asplund 1974). Forage composition on summer range also affects doe productivity and lactation as well as fawn survival and growth, and determines productive capacity of mule deer habitat (Swank 1958, Zwank 1976, Pederson and Harper 1978).

Ponderosa pine (*Pinus ponderosa*) is an important vegetative type that is commonly included within summer home ranges of mule deer (Urness et al. 1975, Currie et al. 1977, Pederson and Harper 1978). However, decades of fire suppression and even-aged timber management have rendered ponderosa and other coniferous forests densely stocked, with closed canopies that preclude growth of shrubs and herbs (Covington and Moore 1994, Kolb et al. 1994). Reductions in herbaceous and shrub productivity and diversity, senescence of existing browse, and stand-type conversions from fire-tolerant to intolerant vegetation have all contributed to mule deer declines in recent decades (Julander and Low 1976, Clements and Young 1997, Carpenter 1998).

Independent of mule deer concerns, current forest conditions and related risk of catastrophic wildfires have motivated efforts to improve ponderosa pine forest health and reduce fire danger, and restorative treatments are now proposed for >81,000 forested hectares (ha) annually in Arizona and New Mexico by 2010 (Anonymous 2001). Restoration treatments attempt to mimic tree spatial distributions, canopy closure, fire return frequencies, and herbaceous composition believed present prior to Euro-American settlement (Covington et al. 1997, Fulé et al. 1997, Mast et al. 1999). To effect these changes, restoration treatments reduce basal area, overstory canopy, stem density of unnaturally overstocked stands, and organic litter, and increase productivity and diversity of understory vegetation. In addition, prescribed fire also is being proposed at frequent intervals (6–7 years) to maintain understory vegetation in a grass-herb-dominated state.

Treatments of this type have great potential to affect mule deer living in ponderosa pine forest habitats. Silvicultural prescriptions that open tree

canopies often increase forage abundance and diversity (Patton 1974, Masters et al. 1993). Conversely, restoration treatments may reduce hiding cover for mule deer and alter microclimatic and physical characteristics of potential bed sites in treated forests (Germaine 1998). In addition, restoration treatments are planned for large areas ($\geq 4,000$ ha; Anonymous 2001, United States Department of Agriculture, Forest Service 2001) that could preclude use by mule deer if all critical resource needs are not met within treated areas (Kufeld et al. 1988).

We examined the response of day-bedding and foraging female mule deer to forest restoration treatments in a ponderosa pine forest in northwestern Arizona, during and immediately following fawning season. We wished to identify important habitat characteristics of day-bed and forage sites in an untreated, current-condition ponderosa forest, then evaluate relative availability of sites having similar characteristics between untreated and restoration-treated forest. We expected that if locally characteristic day-bed or forage-site microhabitat was altered in treated forest, female mule deer would either alter diurnal use of these areas for one or both activities or accept sites containing a different suite of characteristics. To address these questions, we determined whether mule deer selected untreated or treated forest for diurnal bed placement or foraging, and identified habitat characteristics of diurnal bed and forage sites in treated forest. We define habitat in this paper as the structural and microclimatic features describing day-bed, forage, and random sites.

Our objectives were to 1) identify microhabitat characteristics of used day-beds and forage sites from the range of features available in untreated ponderosa pine forest; 2) compare relative availability of day-bed and forage microhabitat between untreated and treated forest; 3) determine whether female mule deer selected either forest type disproportionately for day-bed use or diurnal foraging; and 4) compare microhabitat characteristics of used day-beds and forage sites between forest types.

Study area

We observed bedded and foraging deer within the Mt. Trumbull Resource Conservation Area (RCA) on the Arizona Strip, in the southern portion of the Uinkaret Plateau. Elevation within the study

area ranged from 1,980–2,448 m. Major vegetative communities included pure ponderosa pine forest and ponderosa pine–deciduous forest composed of Gambel oak (*Quercus gambelii*) and New Mexican locust (*Robinia neomexicana*). Pinyon pine (*Pinus edulis*) and juniper (*Juniperus osteosperma*) occurred sporadically throughout the area and dominated south-facing slopes. Precipitation in the area was greatest during winter and summer, with spring and fall being relatively dry. Average minimum and maximum daily temperatures during June were 14.3°C and 32.1°C, with an average annual precipitation of 32.9 cm during 1971–2000 (Western Regional Climate Center 2000).

Pioneers settled the area circa 1870. Typical of much of the American Southwest, commercial logging and livestock grazing began almost immediately and continue today. Naturally occurring fires in the Mt. Trumbull area have been suppressed for much of the past century through removal of flammable ground cover by grazing and through federal fire-prevention programs (Covington and Moore 1994).

Methods

Restoration prescription

Restoration treatments began in 1996 and were scheduled for 1,093 ha. The restoration prescription applied to the Mt. Trumbull RCA was similar to that of many proposed projects in the Southwest, and baseline data were collected by the Ecological Restoration Institute at Northern Arizona University. They conducted on-site tree-core sampling to develop size–age–class relationships for all species and searched for all evidences (logs, stumps, stump holes, living trees) of presettlement (1870)-aged trees. When found, they replaced non-living old-growth remnants with 1.5–3 living trees from within an 18.3-m radius, then marked these and living presettlement trees for retention. They replaced each juniper and pinyon pine remnant with 2 trees within 4.6 m. They did not thin gambel oak and New Mexican locust, and took care to avoid damaging oak trees during thinning because of their demonstrated value to wildlife (Reynolds et al. 1970). They used commercial logging and post-commercial thinning to remove unmarked trees. They then burned and reseeded logged sites with a native herb mix dominated by grasses. In this manner, pre-treatment stand densities (\bar{x} = 666 trees/ha \pm 283 SE) were reduced by up to 87%, to densities (\bar{x}

= 88/ha \pm 48 SE) estimated to approximate presettlement conditions (Covington et al. 1997, Ecological Restoration Institute, unpublished data).

Data collection

We captured and attached radiotransmitters to female mule deer throughout the Mt. Trumbull RCA between May–September 1997–2000. Observations of bedded and foraging mule deer were collected by trained, camouflaged observers between 0700 and 1800 hours Mountain Standard Time daily between 27 May–11 September during 1998–2000. We did so because, while deer may spend $\geq 20\%$ of daytime foraging, they remain within or near escape cover during daytime (Kufeld et al. 1988), and escape cover may be limited in treated areas. We rotated observation attempts incrementally among all marked mule deer, with no individual mule deer observed $> 1/\text{day}$. Each observation was classified as a bedded or foraging deer only if the doe was seen in or leaving a bed or foraging and not disturbed by the observer's approach. Once we observed a target deer, we approached the focal site quietly, flagged the site, and permanently recorded the location using a Trimble® (Sunnyvale, Calif.) GeoExplorer II GPS receiver. We occasionally accepted random observations of nontelemetered deer when encountered en route to a telemetered animal.

Upon documenting a day-bed, we immediately recorded wind speed (Beaufort scale) and direction. Temperature (°C) was recorded 2.5 cm into the bed substrate and also 30 cm above ground both over the center of the bed and in the nearest full sun. We also recorded percent cloud cover and whether the deer had been shaded or sunlit ($> 80\%$ sunlit) at time of observation. We then randomly located a paired site between 0–360° and 25–135 m from the used site, flagged it, and subjected it to the same measurements within 10 minutes of data collection at the bed site. The goal of our study was to compare used and available habitat characteristics on a fine scale of differentiation, so we constrained random sites to fall within the same vegetative cover type as bed and forage sites.

Within 2 weeks of each observation, we collected vegetative data from both the bed or forage site and a random point. We measured slope and aspect within a 1-m radius of the focal point and also for a 10-m radius about the focal point. We categorized dominant vegetative cover (mixed conifer, ponderosa, pinyon–juniper, meadow, oak, locust) and

landform type (drainage bottom, hillside, bench, ridge top, open flat, or canyon bottom) and noted whether each site was within untreated or restoration-treated forest. Overstory and midstory canopy closure were scored as deciduous, coniferous, or absent at 20 evenly spaced points (2-m intervals) in the 4 cardinal directions about the focal point. Height and species of vegetative structure directly over beds were recorded. We measured ground cover (%) in 9 categories (grass, log, slash, shrub or cacti, organic litter, bare, forb, rock, cobble) at 40 points located at 1-m intervals along the 4 cardinal directions about bed and feed sites. For feed sites, we also pooled grass, forb, and shrub or cacti into a category called live ground cover. We used point-quarter sampling (Smith 1980) to estimate density of shrubs, trees, and logs, and average shrub height and log volume at all sites. At feed and feed-random sites, we also estimated grass patch density, height, and diameter, and tallied number of grass, forb, and shrub species present within 3.6 m of the focal point. At bed sites we tallied total number of trees by species within a 200-m² plot with corners oriented along the cardinal directions. Finally, we estimated concealment distance as the average of the distance (m) at which a sitting person was no longer visible to a standing observer in each cardinal direction from the bed site.

Data analysis

We developed logistic regression models to identify the micro-climatic (for beds), forage and topography (for feed sites), and habitat structure variables that best differentiated used from available sites in untreated forest each year (Objective 1). We chose candidate predictor variables based on published accounts of bed site (Gerlach and Vaughan 1991, Ockenfels and Brooks 1994) and foraging habitat (Boeker et al. 1972, Currie et al. 1977, Collins and Urness 1983) and on our own knowledge of our study area. We prescreened candidate variables via box-plots to eliminate those not differing between used and random sites from further consideration (Wilkinson et al. 1996). Variables with a high degree of interquartile overlap were dismissed. We submitted remaining variables to an iterative, backward-stepwise logistic regression analysis to identify the model that best differentiated used bed and forage sites from random sites, while avoiding over-fitting with irrelevant variables (Hosmer and Lemeshow 1989, Systat 1999). We assessed goodness-of-fit of final models by examin-

ing deciles of risk tables and Hosmer-Lemeshow statistics (Hosmer and Lemeshow 1989, Systat 1999), with alpha set at 0.05 for Hosmer-Lemeshow tests. We first developed logistic regression models using data from untreated forest areas to identify microhabitat characteristics that best distinguished used from random sites. In this fashion, we used the logistic regression models as a descriptive tool: variables included in the best model contributed most to the classification of sites and therefore were assumed important to deer in choosing day-bed and forage sites.

We next compared relative availability of day-bed and forage microhabitat between the 2 forest treatment types each year using variables retained in logistic regression models (Objective 2). We defined day-bed microhabitat each year as being within the interquartile range of variability (± 25 th percentile around median) for variables describing used day-beds in untreated forest. We described foraging microsites each year as we did for bed sites (median ± 25 th percentiles) for all biotic nonforage variables at forage sites in untreated forest. We then evaluated percent of randomly sampled microsites in each forest type that were similar to used sites in untreated forest. To be deemed suitable, a forage microsite must have had \geq the median value of potential forage items (forbs, grasses, shrubs) and also have been within the interquartile range of nonforage variables. We then determined percent of randomly sampled sites in each forest type for which values of all variables simultaneously met the criteria for bed and forage sites. To maximize sample size for comparisons of forage microsite availability, we included 14 foraging observations from uncollared does in 1998, 6 in 1999, and 7 in 2000, all of which were encountered while radiotracking collared animals.

We determined whether the distribution of used day-bed and forage sites was proportionally similar to area of untreated and treated forest available each year (Objective 3). We generated minimum convex polygons (mcp) describing each mule deer's summer home range and overlaid them on GIS maps of treatment status of the study area each year to identify deer that had both forest types available within home ranges. We pooled locations of these deer to develop a master mcp, within which we summed area of both forest types and tallied bed and forage-site locations between forest types (Thomas and Taylor 1990). We then compared the proportion of observed bed and forage

sites in each forest type to binomial 90% confidence intervals (Zar 1996) on expected proportions to determine whether selection for or against each forest type was being demonstrated.

We next contrasted characteristics of used bed and forage sites between forest types (Objective 4). For bed sites we considered variables retained in logistic regression models in >1 year most important and determined whether they varied between forest types using Mann-Whitney (M-W) tests (Zar 1996). Forbs provide high-quality nutrition for female mule deer during the summer fawning season, while browse is nutritionally sufficient and grasses are of less value (Smith 1952, Boeker et al. 1972, Collins and Urness 1983). We therefore used number of species and percent ground covered by forbs and shrubs to characterize forage microsites and tested for differences between forest types in Mann-Whitney tests (Zar 1996). Finally, to identify how used bed sites differed most between forest types, we developed new logistic regression models to identify variables that best differentiated used sites between forest types. To increase sample size for model-building, we considered habitat treated when tree removal had occurred, whether an area had been burned or not. Forage-site sample sizes were too small to model in this manner.

Results

Forty-three ha were treated by 1998, 84 ha had been treated by 1999, and 203 ha had been treated by 2000, including doubling the size of an area treated earlier. We collected bed-site data from treated units and 1,500 ha of untreated forest surrounding them. Treatments ranged from 1-4 years post-treatment age during our study.

We described day-bed microhabitat characteristics at 117 sites in 1998, 60 sites in 1999, 59 sites in 2000, and an equal number of random sites each year. We measured habitat characteristics at 74 foraging microsites in 1998, 39 sites in 1999, and 39 sites in 2000, and from 203 random sites during this period. We collected data from 19 telemetered deer: 13, 12, and 13 deer each year, respectively. Individual deer contributed between 1 and 14% of the observations obtained each year.

In untreated forest in 1998, day-bed sites had lower soil temperatures and percent ground covered by forbs and higher shrub height and midstory canopy cover than random sites (Figure 1a). The logistic regression model was significant (log-likeli-

hood = 33.76; $\chi^2 P < 0.001$), and classified 59.8% (used = 60.0%, random = 59.5%) of all sites correctly. The model provided an acceptable fit to the data (Hosmer-Lemeshow $P = 0.187$). Used day-beds in untreated forest in 1999 were best predicted by lower soil temperature in beds, lower air temperature 30 cm above beds, and lower overstory canopy closure over beds than at random sites (Figure 1b). This model was significant (log-likelihood = 17.63; $\chi^2 P = 0.001$), classified 59.0% (used = 61.1%, random = 56.7%) of all sites correctly and fit the data well (Hosmer-Lemeshow $P = 0.469$). We retained 2 variables in the model that best classified day-bed sites in untreated forest in 2000. Used day-bed sites were best described by higher percent ground covered by organic litter and lower air temperature 30 cm above beds than found at random sites (Figure 1c). The model was significant (log-likelihood = 11.66; $\chi^2 P = 0.003$), classified 55.4% (used = 56.7%, random = 54.1%) of all sites correctly and fit the data well (Hosmer-Lemeshow $P = 0.620$).

Forage sites in untreated forest in 1998 were characterized by higher numbers of forb species, trees/ha, and acorn presence than random sites (Figure 2a). The logistic regression model was significant (log-likelihood = 17.42; $\chi^2 P = 0.001$), classified 57.9% (used = 52.4%, random = 62.3%) of all sites correctly and provided an acceptable fit to the data (Hosmer-Lemeshow $P = 0.535$). Forage sites in untreated forest in 1999 were best distinguished from random sites by having greater deciduous midstory canopy closure and being on microsites oriented in a southeasterly aspect, while random microsites tended to be oriented northeasterly (Figure 2b). The logistic regression model was significant (log-likelihood = 11.72; $\chi^2 P = 0.003$) and classified 58.6% (used = 51.3%, random = 64.0%) of all sites correctly. The model fit the data (Hosmer-Lemeshow $P = 0.884$). In 2000 3 variables were retained in the model that best classified diurnal forage sites in untreated forest. Forage sites were best described by greater deciduous midstory canopy cover, live ground cover, and number of grass species than random sites (Figure 2c). The model was significant (log-likelihood = 22.70; $\chi^2 P < 0.001$), classified 61.7% (used = 58.9%, random = 64.1%) of all sites correctly and fit the data (Hosmer-Lemeshow $P = 0.736$).

Availability of day-bed microhabitat was restricted in treated forest compared to untreated forest in all 3 years. In untreated forest suitable day-bed microhabitat was present in 14.0% ($n = 86$), 17.6%

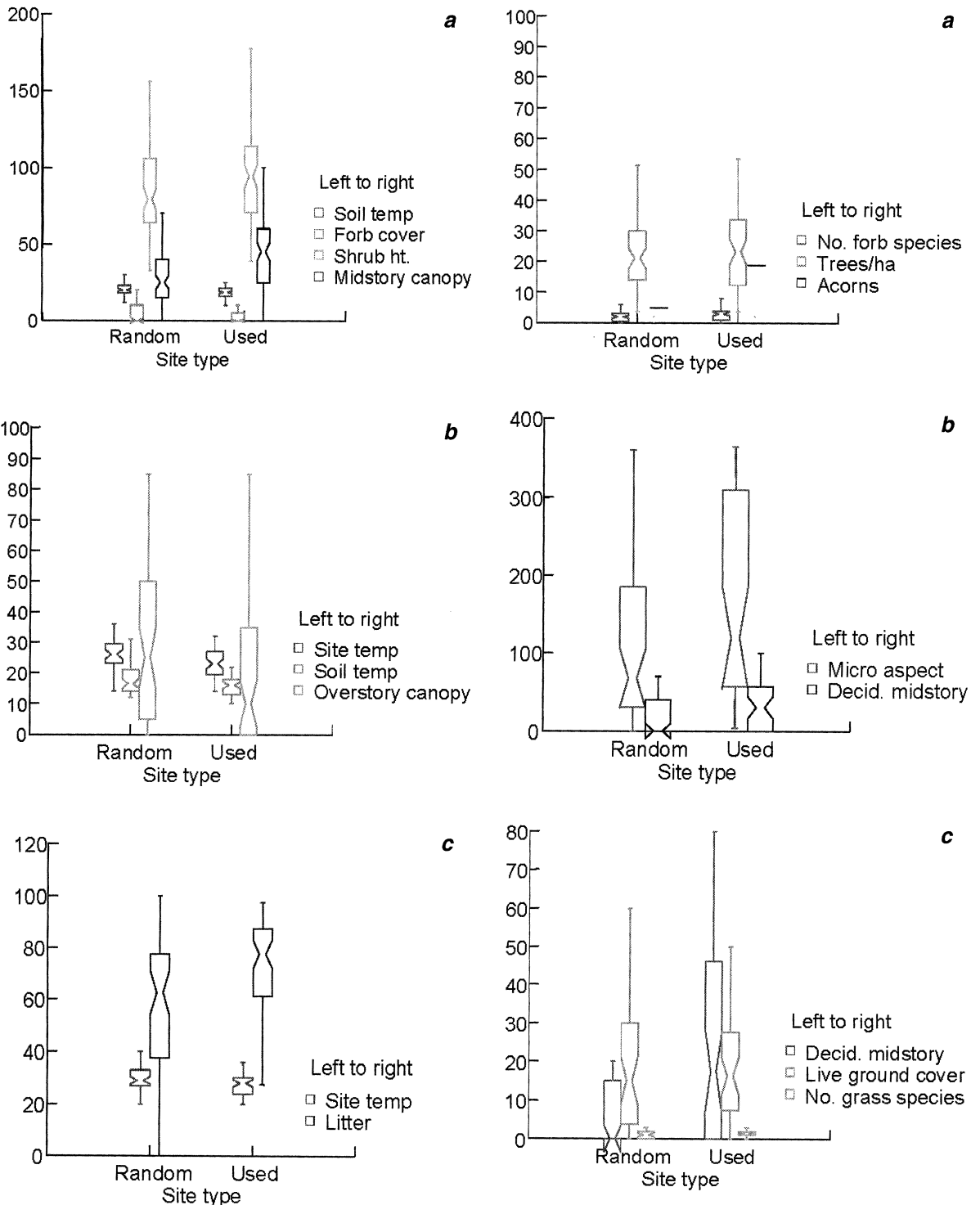


Figure 1a–c. Median ± 25th percentile values for variables retained in logistic regression models characterizing used daybeds and random locations in current-condition pine-oak forest, northern Arizona, 1998–2000. Notch identifies median ± 95% confidence intervals; box ends demonstrate 25th and 75th percentiles. Whiskers show the range of observed values that fall within $1.5 \times$ the interquartile range. Forb cover values multiplied $2 \times$ for display only.

Figure 2a–c. Median ± 25th percentile values for variables retained in logistic regression models characterizing diurnal mule deer forage microsites and random locations in current-condition pine-oak forest, northern Arizona, 1998–2000. Notch identifies median ± 95% confidence intervals; box ends demonstrate 25th and 75th percentiles. Whiskers demonstrate range of observed values falling within $1.5 \times$ interquartile range. When confidence interval exceeds percentile, box ends appear inverted. Acorns (Figure 2a) depict proportion of sites containing acorns.

($n=51$), and 17.0% ($n=53$) of all random plots sampled during 1998–2000, respectively. In treated forest suitable day-bed microhabitat was present at 6.5% of random sites sampled in 1998 ($n=31$), none in 1999 ($n=19$), and 8.3% in 2000 ($n=12$), constituting a 54%, 100%, and 51% reduction in availability of sites having the characteristics of used beds in untreated forest each year, respectively.

Conversely, forage microsite availability was greater in treated forest than in untreated forest in all years. In 1998 forage microsites contained ≥ 3 forb species and between 152–1,130 trees/ha. Forage microsites in 1999 had 1–58% deciduous midstory canopy cover, while microsites in 2000 had 1–41% deciduous midstory canopy cover, 8–28% live ground cover, and ≥ 1.5 grass species present. In untreated forest, forage microsites were present at 17.2% ($n=64$), 38.1% ($n=42$), and 10.6% ($n=47$) of all randomly sampled microsites in each year, respectively. In treated forest, 28.6% of sites sampled in 1998 were suitable microforage sites ($n=35$), 50.0% were in 1999 ($n=10$), and 16.7% were in 2000 ($n=6$). Thus, forage microsite availability increased in treated forest by 66%, 31%, and 58% each year, respectively.

Table 1. Proportion of female mule deer day-bed and forage locations, and 90% binomial confidence intervals bounding expected use values in untreated and restoration-treated forest at Mt. Trumbull, Arizona, 1998–2000.

		% area each forest type ^a	Proportion of locations ^b	90% CI ^c		
Bed	1998	Current condition	92.2	0.808	0.776	0.986
		Restoration treated	7.8	0.192	0.014	0.224
	1999	Current condition	94.7	0.903	0.808	0.988
		Restoration treated	5.3	0.097	0.012	0.192
	2000	Current condition	82.5	0.857	0.661	0.927
		Restoration treated	17.5	0.143	0.073	0.339
Forage	1998	Current condition	92.2	0.815	0.784	0.987
		Restoration treated	7.8	0.185	0.013	0.216
	1999	Current condition	94.7	0.783*	0.808	0.998
		Restoration treated	5.3	0.217*	0.002	0.192
	2000	Current condition	82.5	0.722	0.623	0.953
		Restoration treated	17.5	0.278	0.047	0.377

^a Availability determined each year within minimum convex polygons (mcp) of pooled locations of deer having individual mcps encompassing both untreated and treated forest.

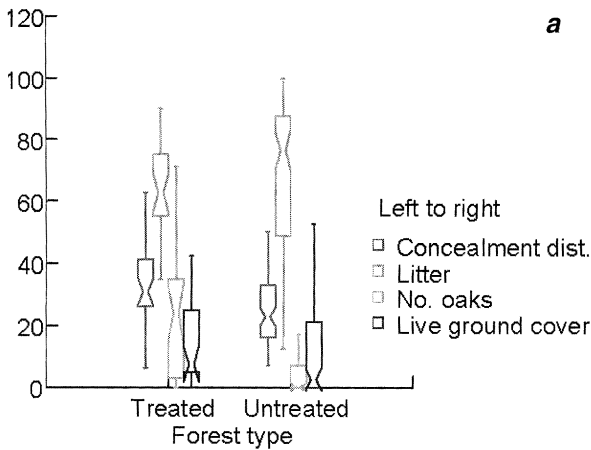
^b Proportion of locations in each forest type; * outside bounds of confidence interval.

^c Left column = lower, right column = upper 90% binomial confidence interval on expected use.

Despite reduced availability of bed-site microhabitat in treated forest, frequencies of occurrence of mule deer day-beds between forest types did not differ from that expected based on area of each forest type available each year (Table 1), indicating that a comparison of microsite features at used beds between the 2 forest types was warranted. Similarly, despite increased forage microsite availability in treated forest in all years and increased forb abundance and species richness in 1998, mule deer did not demonstrate selection for either forest type while foraging in 1998 or 2000. However, in 1999 foraging mule deer selected treated forest and avoided untreated forest (Table 1).

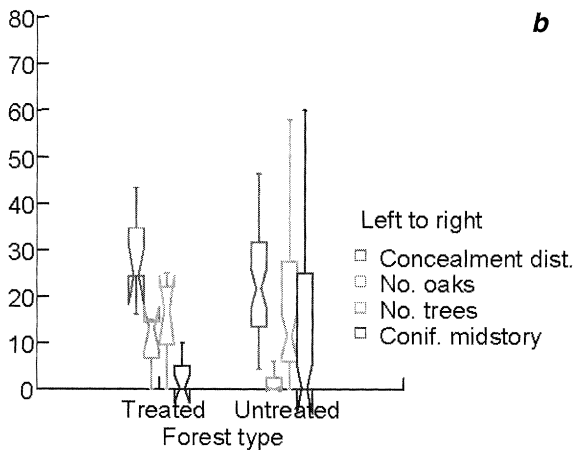
Regression models retained 3 variables describing day-bed sites in untreated forest in >1 year, and we compared these variables between forest types for years they loaded into models. Midstory canopy cover did not differ between forest types in either 1998 or 1999 (M-W $U=1182.5$, $P=0.55$; M-W $U=188.5$, $P=0.95$), respectively (see Figure 1 for untreated forest value), nor did ambient temperature at beds (M-W $U=112.0$, $P=0.80$; M-W $U=68.5$, $P=0.69$) in 1999 or 2000, respectively. However, in 2000 ambient temperature was recorded in only 3 beds in treated forest. Soil temperature in beds did not differ in 1998 (M-W $U=1168.0$, $P=0.67$) but averaged 4°C higher in beds in treated forest in 1999 (M-W $U=153.0$, $P=0.06$).

The model that best discriminated used day-beds between forest types in 1998 contained 4 variables. Average concealment distance, live ground cover, and number of oak trees were greater, while percent ground covered by organic litter was lower at beds in treated forest than those in untreated forest (Figure 3a). This model was significant (log-likelihood = 57.20; $\chi^2 P < 0.001$) and classified 80.6% (60.8% untreated, 87.1% treated) of all sites correctly. The model fit the data (Hosmer-Lemeshow $P=0.124$). Location of used day-beds in 1999 was best predicted by higher concealment distance, number of oak trees, number of all trees, and by lower percent coniferous midstory canopy at beds in treated forest than at those in untreated forest (Figure 3b). The model was significant (log-likelihood = 16.64; $\chi^2 P < 0.003$), correctly predicted 85.3% (37.2% treated, 91.7% untreated) of all sites correctly, and satisfied fit-to-data requirements (Hosmer-Lemeshow $P=0.158$). In 2000 too few day-beds occurred in treated forest to model differences between forest types. However, median concealment distance (cd) and number of oak trees



a (oak), both of which loaded into models in 1998 and 1999, were higher at day-beds in treated forest ($cd=30.3$ m, oak=36) than in untreated forest ($cd=23.6$ m, oak=1; Figure 3c).

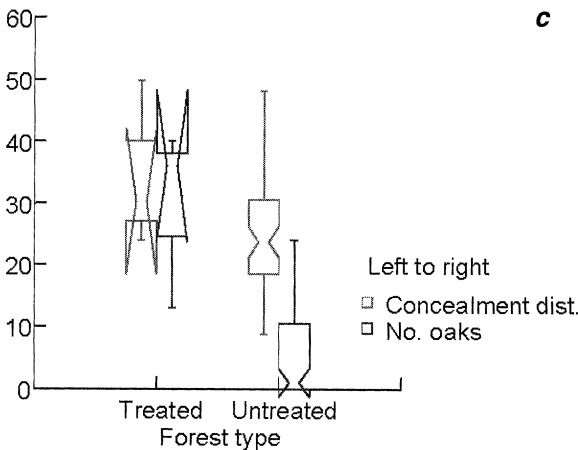
Characteristics of forage at microsites increased in treated forest relative to untreated forest in 1998 but not 1999, with number of observations in treated forest too small to test in 2000. In 1998 median number of forb species ($M-W U=827.5, P=0.008$) and percent ground covered by forbs ($M-W U=791.0, P=0.023$) were greater in treated forest. In 1999 neither forb variable differed, and number of shrub species was higher at forage sites in untreated forest than in treated forest ($M-W U=49.0, P=0.036$).



b

Discussion

Bed-site temperature and canopy closure had the most influence on bed placement in untreated, current-condition forest. Used beds were cooler than random sites in all years, while canopy closure loaded into models in 2 years. In 1998 midstory canopy cover at bed sites was higher than at random sites. In 1999 overstory canopy was lower at bed sites. However, an inverse relationship existed between overstory and midstory canopy, and we found midstory canopy significantly higher at used beds ($M-W U=0.044$), despite not loading in the 1999 model.



c

Mule deer select day-beds to assist thermoregulation (Lindsdale and Tomich 1953, Short 1981) and to avoid predation (Geist 1981, Gerlach and Vaughan 1991). Gerlach and Vaughan (1991) found that mule deer fawn bed sites in southwestern Colorado had greater concealment cover, canopy closure, and abundance of shrubs and grasses than random sites. Ockenfels and Brooks (1994) found that day-bed sites of white-tailed deer (*Odocoileus virginianus*) in southeastern Arizona had lower air and soil temperatures and higher canopy closure than random sites. High tree densities common in our untreated study area increased bed concealment, and selecting sites to aid thermoregulation appeared a higher priority for deer in untreated forest.

Figure 3a–c. Median \pm 25th percentile values for variables retained in logistic regression models characterizing used day-beds in untreated and restoration-treated pine–oak forest, northern Arizona, 1998–2000. Notch identifies median \pm 95% confidence intervals; box ends demonstrate 25th and 75th percentiles. Whiskers show the range of observed values that fall within $1.5 \times$ the interquartile range. When confidence interval exceeds percentile, box ends appear inverted. Number of trees in figure 3b is square-root transformed for display.

Diurnal forage sites likely were chosen within concealment and thermoregulation constraints. This may result in less optimal sites foraged in daytime than at night and may have affected each model's ability to classify forage micro-sites in untreated forest. Nonetheless, increased forage

availability at used sites loaded into models in 2 of 3 years. In addition, percent deciduous midstory canopy was greater at used forage sites in 2 years. Percent ground covered by forbs, grass, live ground cover, and number of forb species were significantly greater at sites having \geq median value of deciduous midstory canopy cover in both years, and we conclude deer were selecting for these characteristics.

In treated forest relative availability of suitable day-bed microhabitat was reduced by 50-100%, while availability of foraging microhabitat was 30-60% higher than in untreated forest. Deer did not avoid treated forest for day-bed use, demonstrating sufficient behavioral plasticity to utilize novel microhabitat conditions in treated forest. Whether there is long-term cost or benefit associated with bedding in restoration-treated forest needs to be investigated.

Deer that continued to bed in treated forest experienced warmer bed-site temperatures than those in untreated forest. Soil temperature was up to 4°C warmer in beds in treated forest, and this difference may increase thermoregulatory stress for deer and fawns during summer (Parker and Gillingham 1990). In all years ambient daytime air temperatures were $\geq 25^{\circ}\text{C}$, a temperature above which deer may experience thermoregulatory stress during summer (Parker and Robbins 1984), and in 2 years ambient air temperatures in treated forest were $\geq 1^{\circ}\text{C}$ warmer than in untreated forest.

Whereas thresholds of concealment distance are not static, we found they averaged 25% greater in treated forest. This resulted from the type and size of remnant tree stands retained in treated areas. Conifers were the primary cover type at beds in untreated forest, but almost all beds in treated forest were under small oak stands. Oak stands afforded the only remaining patches of midstory canopy in treated forest and as such were the primary factor in shading treated forest day-beds. However, oak stands were poor at concealing bed sites. Understory regeneration may eventually increase bed concealment in treated areas, but regeneration is slow in the Southwest. In contrast, coniferous tree boles and limbs contributed most to concealing bedded mule deer in untreated forest, and Smith et al. (1986) reported that mule deer appeared to prefer bedding in association with coniferous trees.

Forb abundance and species richness were higher in treated forest in 1998 and similar between forest types in 1999. Forbs are important to does during reproduction and lactation due to their high mois-

ture content, digestibility, and nutrient levels (Smith 1952, Boeker et al. 1972, Main and Coblenz 1996), and Dietz and Nagy (1976) reported that forbs become a nutritionally important food item in summer for both does and fawns. We did not evaluate nutritional value of forbs, but assumed that increased species richness equated to increased forage quality. Forage productivity increased in other areas where forest canopy had been reduced (Currie et al. 1977, Kufeld et al. 1988), and Patton (1974) and Collins and Urness (1983) reported increased use of such areas by mule deer. Given increased forage availability in restoration-treated forest, we expected female mule deer to select these areas for diurnal foraging. In 1999 they did so but not in 1998 or 2000.

Kufeld et al. (1989) determined that $>60\%$ of home ranges were escape cover. At <5 years post-treatment, hiding was reduced well below this level in treated forest. Kufeld et al. (1988) found that while mule deer fed in large open areas at night, they avoided these areas during daytime. Boeker et al. (1972) found positive correlations between availability and consumption of forage items, but deer must not only maximize energy intake, they must avoid predators and successfully reproduce (King and Smith 1980, Kie et al. 1991).

Management implications

Restoring the grand forests of the 1800s probably is not possible due to changes in human populations, global climate, demands for forest products, invasive exotic flora, and numerous other factors (reviewed by Wagner et al. 2000), but improving forest health and primary productivity while reducing catastrophic fire risk are. At the same time, single-species management generally is outdated (Carpenter 1998), and societal expectations for recreational opportunities involving mule deer and other big game need to be properly put in the larger context of landscape ecology and ecosystem health. Forest restoration prescriptions that retain critical habitat components of locally important or imperiled wildlife hold the best promise for improving forest health while retaining or increasing local biodiversity.

Benefit of forest restoration to female mule deer will depend both on herbaceous recovery and retention of bed and escape cover (Griffith and Peek 1989, Kufeld et al. 1989). Fire-return intervals, domestic grazing pressure, and microsite features such as soils, exposure, aspect, and moisture will dictate the extent to which forbs and shrubs suc-

ceed in treated areas. As treated areas become large enough to incorporate entire home ranges, it is unclear how mule deer reproductive success, survival, or distribution in these areas will be affected by changes in bed-site temperatures and concealment. It is imperative that this question be addressed before restoration treatments are applied across large forest expanses. Juxtaposing both forest types and retaining dense patches of untreated forest within treated areas may be necessary if use by mule deer is a management goal.

We expect forage and day-bed microhabitat will respond similarly in other ponderosa pine forests of the southwestern United States receiving similar treatment prescriptions. Therefore, we recommend that stands of sapling and pole-sized trees having >40% midstory canopy closure be retained in treated forest. Deer day-bedded in stands as small as 0.02–0.04 ha in our study but were less concealed; we therefore recommend retaining stands >0.04 ha in size and retaining deciduous and coniferous trees to meet both foraging and concealment needs. Retaining conifers that have low branches will further enhance concealment. Forage quality and quantity both increased in treated forest areas, and if treatment prescriptions are adapted to increase retention of hiding and bedding cover, the goals of both forest restoration and mule deer management will be better served.

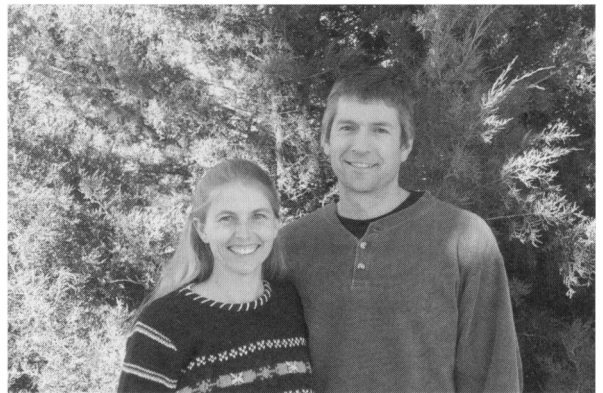
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