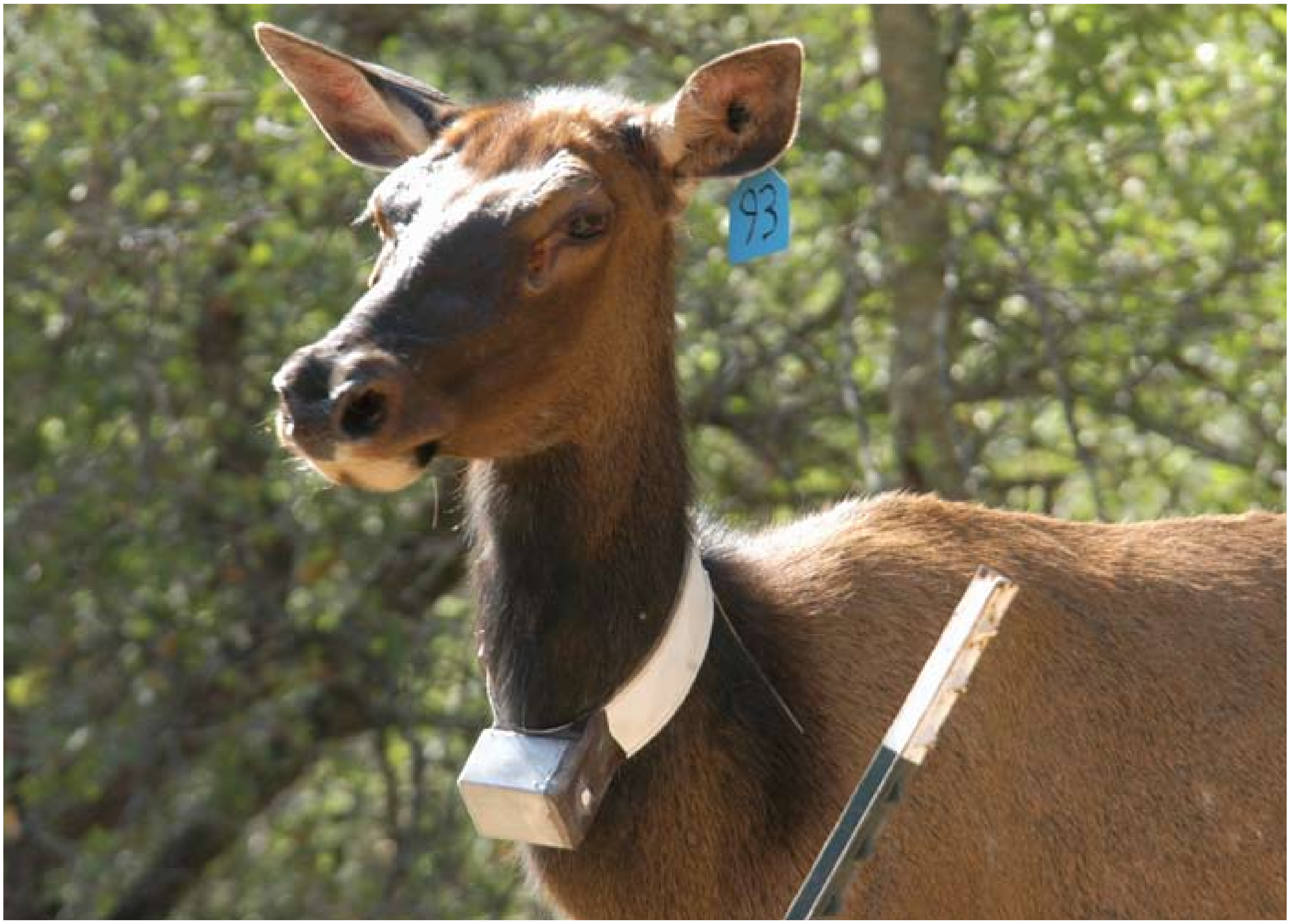

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Female Elk *(Cervus elaphus)* Habitat Use After the Rodeo-Chediski Fire in Northeast Arizona

Federal Aid in Wildlife Restoration
Project: W-78-R

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Arizona Game and Fish Department Mission

To conserve, enhance, and restore Arizona's diverse wildlife resources and habitats through aggressive protection and management programs, and to provide wildlife resources and safe watercraft and off-highway vehicle recreation for the enjoyment, appreciation, and use by present and future generations.

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EXECUTIVE SUMMARY

Between 18 June and 7 July 2002, the Rodeo-Chediski fire burned a total of 184,096 ha of United States Forest Service, state, private, and White Mountain Apache Reservation land along the Mogollon Rim of Arizona. Before 1880, Arizona's ponderosa pine (*Pinus ponderosa*) forest communities, and the elk (*Cervus elaphus*) that inhabit them, were subjected to large-scale (>5,000 ha) episodic fires approximately every 2-10 years. Aggressive suppression of wildfires, livestock grazing, and even-aged timber management have rendered Arizona ponderosa pine forests densely stocked. The over-accumulation of fuels coupled with persistent drought conditions have resulted in several stand replacing fires, which could be considered ecologically abnormal. Understanding the impacts of these stand replacing fires on elk habitat and how elk use areas recovering from fire could provide insights to improve forest and fire management to protect and enhance wildlife habitat.

Beginning 3 years after containment, we investigated habitat selection and modeled habitat use by female elk (n=11) within the boundary of the Rodeo-Chediski fire. Female elk selected Ponderosa pine habitats with 40-60% canopy cover that were classified as subjected to heavy to extreme burn intensity. Favorable precipitation in years following the fire, increased light transmission to the forest floor, and enhanced soil condition likely enhanced the vigorous growth of forbs and shrubs that improved forage conditions and attracted elk. Increased elk use (≥150 locations/km^2) was associated with higher proportion (≥ 0.50/1km^2) of preferred habitat (Ponderosa pine, 40-60% canopy, heavy to extreme burn). Due to the speed and intensity of the Rodeo-Chediski fire, a mosaic of forest types that correspond well to the habitat preferences of elk were left.

Elk habitat quality is a function of cover and forage and their full utilization of available habitats is limited by road density and vehicle traffic. We found elk selected openings left by the fire but this use was reduced during autumn and mid-day hours when vehicle traffic was likely increased. The benefits of fire to elk habitats are well known, many researchers have reported an increase in elk forage production after forest thinning and burning. Forest treatments and prescribed fire designed to reduce canopy cover to 40-60% in a mosaic pattern (ROMPA ≥0.50) while minimizing the impacts of roads and vehicle traffic would likely improve habitat conditions for elk in ponderosa pine communities.

INTRODUCTION

Arizona ponderosa pine (*Pinus ponderosa*) forest communities, and the elk (*Cervus elaphus*) that inhabit them, evolved with large-scale (>5,000 ha) episodic fires approximately every 2-10 years pre 1880 (Swetnam and Betancourt 1990). These naturally occurring fires are important for native ungulates because forage conditions after a burn are often improved by increased availability of forbs and grasses (Thill et al. 1990, Kucera and Mayer 1999). Furthermore, rapidly growing young or resprouting browse is usually more nutritious for ungulates than older browse.

Aggressive suppression of wildfires, livestock grazing, and even-aged timber management have rendered many Arizona ponderosa pine forests densely stocked (>3,000 stems/ha), with closed canopies that preclude sunlight from reaching the forest floor (Mast 2003). The resulting accumulation of litter increases fuels for wildfire, and inhibits growth of new grasses and forbs. Trees, browse, forbs, and grasses have to compete for limited nutrients, and this becomes more intense when extensive beds of organic litter cover the ground (Covington and Moore 1994, Kolb et al. 1994). Forests containing overly dense small trees become further stressed by drought, enabling pathogens and insects to reach levels high enough to kill trees, further increasing fuels for wildfire.

The constant accumulation of fuels eventually results in stand replacing fires, which could be

Figure 1. Aerial view of a portion to the Rodeo-Chediski fire on the Apache-Sitgreaves National Forest in east-central Arizona. The fire left a mosaic of burned and unburned habitats above the Mogollon Rim, elk habitat selection study 2005-2007.

considered ecologically "abnormal". Such large-scale fires, exacerbated by fire suppression, could negatively effect elk populations, either directly via high fire mortality, or indirectly by inhibiting vegetation succession, and decreasing the amount of cover necessary to avoid predators (Singer et al. 1997).

The Rodeo Fire started June 18, 2002 and burned 50,000 ha in just 3 days. The Chediski Fire started on June 20 in close proximity to the Rodeo Fire, burning 4,400 ha the first day. The two fires merged on June 23, and had burned a total of 132,536 ha. On July 7, the largest fire in Arizona history was declared contained. Below the Mogollon Rim the Rodeo-Chediski fire burned a total of 110,534 ha on the White Mountain Apache Reservation and 4,308 ha on the Tonto National Forest. Above the Mogollon Rim, the fire burned a total of 65,776 ha on the Apache Sitgreaves National Forest, 3,469 ha on private lands, and 9.2 ha on AGFD land; totaling 184,096 ha burned. High winds above the Mogollon Rim pushed the fire quickly and erratically resulting in many unburned islands, and leaving a mosaic of vegetation stands on the Apache Sitgreaves National Forest (Fig. 1). Twenty-seven percent of the 70,084 ha burned on United States Forest Service (USFS) lands was considered high severity burn, and 26% was considered moderate. In contrast, 7% of the land was unburned and 40% was considered a low severity burn (Fig. 2).

During the fire, 2 aerial surveys were conducted along the perimeter on July 2 and 5 to note animal movement, and no large groups or movements were noted. On July 23, AGFD and USFS personnel surveyed the burn area above (north of) the Mogollon Rim in 10 sections. Over 85 kilometers of foot surveys and 351 kilometers of vehicle routes, surveyors detected few dead animals within the perimeter of the fire. During the 139 person hours 2 cow and 1 calf elk, 2 young black bears (*Ursus americanus*), 1 tassel-eared squirrel (*Sciurus aberti*), and 3 unidentified rodents were found. Over 40 tassel-eared squirrels, 27 elk, 18 mule deer (*Odocoileus hemionus*), and > 200 birds were seen alive during the same survey. In a separate search, one group of 31 elk were found dead in a narrow canyon below the Mogollon Rim adjacent to the AGFD Canyon Creek Fish Hatchery.

Effects of Fire on Ungulate Forage

Habitat for large ungulates is often benefited from fire by improved forage quantity, quality, structure, and composition (Dills 1970, Hobbs and Spowart 1984, Carlson et al. 1993, Main and Richardson 2002). Fire generally results in increased diversity of forage species and phenology, which may improve selective foraging opportunities (Riggs et al. 1996). Early successional grass and shrub leaves are usually more palatable than stems and branches because as plants age, their concentrations of digestible fiber, minerals, and proteins decrease (Wilms et al. 1981). Fires of low to high intensity help to remove accumulated litter which can result in increased growth of herbaceous vegetation (Hulbert 1988). Additionally, the increased nutrients deposited in ash, increased light intensity, and warmer soil temperatures can promote the growth of surviving plants (Pearson et al. 1972).

Several studies have documented short-term (6 months to 2 years) increases in nutritional quality of ungulate forage after fires (Meneely

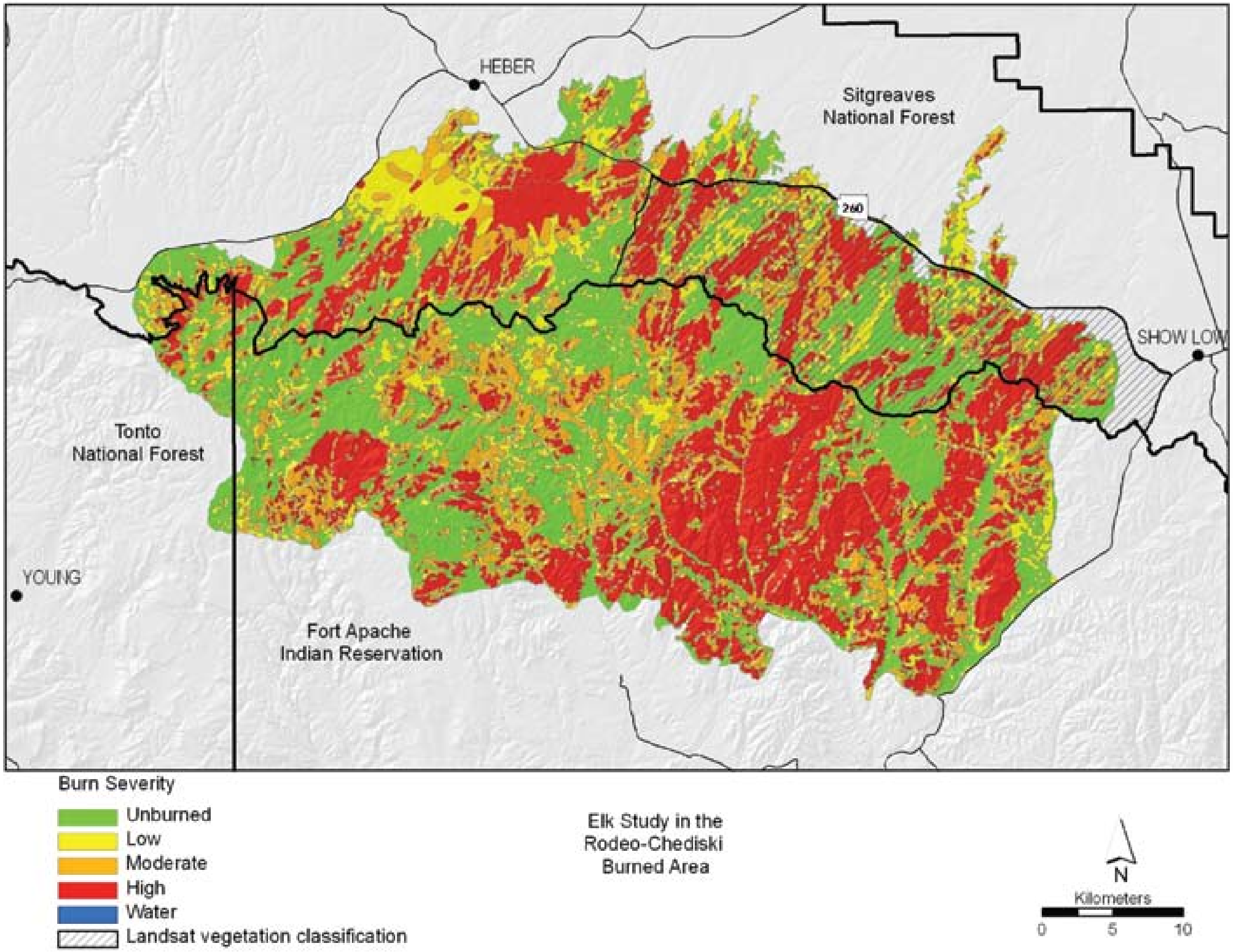

Figure 2. Study location showing burn severity estimates within the perimeter of the Rodeo-Chediski fire on the Apache-Sitgreaves National Forest in east-central Arizona, elk habitat selection study 2005-2007.

and Schemnitz 1981, Hobbs and Spowart 1984, Wood 1988), forage quantity (Dills 1970, Carlson et al. 1993), and increased use of prescribed burn habitat by elk (Singer et al. 1989). However, stand replacing fires can have varied effects on wildlife. After the stand replacing Yellowstone fire, Singer et al. (1989) hypothesized rapid elk population growth. However, they found that the elk population decreased post-fire with increases in predation because of the lack of cover and the production of weak, underweight calves as drought conditions continued (Singer et al. 1997).

The mosaic of different forest stands left above the Mogollon Rim after the Rodeo-Chediski fire might have improved habitat quality for elk. Kie et al. (2002) found that landscape heterogeneity was the most important variable in reducing the size of mule deer home ranges, potentially indicating better habitat quality. Various approaches, including the quantification of patch area, spatial dispersion, degree of habitat loss (Andren 1994), and proportion of suitable habitat have been used to assess landscape heterogeneity (Wiens et al. 1993, Bowers and Matter 1997, Kie et al. 2002).

Andren (1994) and others (Krohne 1997, Bowers and Matter 1997, Dodd 2003) have found that there are wildlife population and habitat use thresholds associated with reductions in suitable habitat. At some threshold, usually < 30% of suitable habitat for many species, the isolation of populations accelerates and the deleterious affects of suitable habitat loss greatly increases (Andren 1994). Up until this point, influences of suitable habitat patches and landscape isolation are secondary to the proportion of suitable habitat available (Gardner et al. 1987, Andren 1994). The assessment of proportional suitable elk habitat, or ratio of optimum to marginal patch area (ROMPA; Krohne 1997) could be very useful in determining the effects of the Rodeo-Chediski fire as well as providing guidelines for forest treatments to enhance elk habitat.

Study Objectives – The Rodeo-Chediski fire may have improved habitat conditions for elk along the Mogollon Rim. Certainly, the number, size, and shape of different overstory patches, along with the amount of edge habitat would have increased within the Rodeo-Chediski fire perimeter. Furthermore, it is reasonable to expect that forage abundance (including some key species) was increased with a reduction in overstory in areas of suitable soil conditions. However, it is unknown if the 27% of highly burned and 26 % of moderately burned habitat will reduce thermal or hiding cover to unacceptable levels. To answer those questions and to provide general insights to the effects of wildfire on elk habitat after 3-5 years, we conducted a research project with the following objectives:

1) investigate female elk use of current condition forest and areas exposed to different burn intensities;
2) model landscape scale habitat selection of female elk across a varied habitat including burned and unburned areas;
3) evaluate the effects of landscape scale metrics such as patch size and ROMPA on elk habitat selection;
4) help evaluate forest stand structure, and guide silvicultural treatments that reflect elk habitat needs.

STUDY AREA

We conducted this project in east-central Arizona on the Apache-Sitgreaves National Forest (Fig. 2), where the Rodeo-Chediski fire burned 65,776 ha in June 2002. The center of the burn perimeter is located 171 km northeast of Phoenix, Arizona and is bordered to the north primarily by U. S. Highway 260. The towns of Payson to the west, Heber-Overgaard to the north, and Show Low to the east lie on or near the study border. Elevations range from 1,519 m to 2,356 m. Mean annual precipitation, measured at the Heber Ranger station along the northern boundary of the fire, was 43.9 cm with 98.8 cm of snowfall. Mean temperature ranged from 0.4° F in January to 20.2° F in July.

We captured elk in the burned sites (N110°22’30”, W34°15’00”) between FS 300 where it intersects with US Highway 260 to the west and Juniper Ridge to the east. The northern boundary was Highway 260 and the southern is the White Mountain Apache Tribal lands. Total study area was ultimately determined by where elk traveled within the boundaries of the fire.

Pre-fire habitat in this area was comprised primarily of ponderosa pine forest, with smaller patches of meadow-like openings, oak (*Quercus gambellii*), and pinyon (*Pinus edulis*) – juniper (*Juniperus deppeana*). Despite the high intensity of the fire below the Mogollon Rim, the high speed of the fire above the Mogollon Rim created a diverse mosaic of forest conditions. As mentioned above, preliminary analysis indicated high burn intensity on 27% of the area, 26% moderate intensity, 40% low intensity, and 7% of the area within the burn perimeter was not burned. The fire mosaic on the forest at the landscape scale (e.g., 4,000 ha) ranged from areas totally dominated by high intensity burn to mosaics of relatively small patches of unburned and high, moderate, and low intensity burned forest. The large size of the Rodeo-Chediski fire provided the opportunity to assess stand replacing wildfire effects on elk across a forest landscape.

METHODS AND FINDINGS

Capture and Monitoring – Between July 2005 and February 2006 we captured female elk using clover traps baited with mineral blocks and alfalfa. Each animal was fitted with a Telonics (Mesa, AZ) global positioning system (GPS) radiocollar and unique ear tags. Each GPS radiocollar was programmed to attempt location acquisition every 5 hours throughout the monitoring period. The radiocollars sampled ambient temperature at location fixes, and all sampled data were stored on internal memory. Motion sensors with VHF beacons allowed us to aerially monitor signals once a month to determine if the radiocollared animal was still alive. Radiocollars were programmed to fall off after 400 or 745 days for retrieval and data downloading.

We calculated seasonal (Winter 15 Dec. - 15 Mar., Spring 16 Mar. - 14 Jun., Summer 15 Jun. - 13 Sep., and Autumn 13 Sep. - 14 Dec.) and annual minimum convex polygons (MCP) to estimate home ranges of individual female elk (Hayne 1949). We also calculated a master minimum convex polygon outlining the annual home range of all elk to delineate the boundaries of the study area. We calculated the number of elk locations within each annual and seasonal home range and generated a similar number of random sites within that home range to establish availability of each habitat variable.

Between August 2005 and February 2006, we captured 14 female elk. We deployed 4 Spread Spectrum radiocollars for approximately 340 days each and 10 store-on-board radiocollars for approximately 480 days each. We were unable to recover 1 radiocollar, 2 of the elk were legally harvested by hunters, and 1 radiocollar failed to obtain any location fixes during deployment. For habitat selection we used only those locations that overlapped the areas where we had classified habitat with remote sensing (study area). We downloaded 20,543 locations from the 13 recovered radiocollars and although 20,070 fell within the perimeter of the burn, only 9,555 fell within the study area (Appendix 1). Because of our small sample size ($n \leq 11$ elk) we advise caution in interpretation of our data, as it may not be representative of elk behavior across their range or even within this population.

Habitat Classification – The USFS Burned Area Emergency Rehabilitation (BAER) team created a burn severity geographic information system (GIS) cover (map) for all the land within the perimeter of the Rodeo-Chediski fire. The map was derived from Landsat 7™ Satellite imagery acquired on July 7, 2002, from USGS EROS Data Center, Sioux Falls, SD. Using spectral classification modeling each 900 m^2 area was assigned a burn severity class: High, Moderate, Low, and Unburned. The map was field verified but only on the USFS portion of the burn. We were interested in elk use of habitats after recovery from fire, and because the BAER burn severity map was developed immediately following the fire with limited ground verification we chose to create an additional habitat classification map.

We used remote sensing to delineate post-fire vegetation conditions because of the size of the project area and the scope of the analysis. The initial step in any image classification process is to determine the number and types of categories classified. There are two major levels of classification categories: informational classes and spectral classes. Informational classes are those categories of interest in the classification. We selected 3 levels of informational classes: vegetation (ponderosa pine, pine/oak, pinion-juniper, and open grassland), canopy cover (CC, defined by USFS canopy cover data), and burn intensity (unburned, light, moderate, high). Spectral classes are groups of pixel brightness values that are uniform with respect to the informational classes across several spectral bands of the imagery. Groupings of homogenous pixels were identified using both point and spatial classifiers. We used supervised classification for habitat analysis. This approach uses samples of known identity to classify pixels of unknown identity, where: 1) samples of known identity are those pixels located within training areas,

2) training areas are clearly identifiable areas of the imagery that have known properties on the landscape, 3) spectral properties of the imagery typify the properties of the informational class, and are homogeneous, and 4) the training areas are clearly identifiable both on the imagery and on the landscape.

We selected 15 3-ha training areas for each possible combination of informational class (vegetation X canopy cover X burn intensity), for a total of 1350 training areas. To ensure that that training areas represented individual informational classes, each was located a minimum of 200 m away from any boundary between informational classes. We recorded the location and extents of each training area using a GPS point averaging option to insure 1 m accuracy. We reviewed all training areas based on their informational class to ensure separation of spectral signatures. When necessary, additional training areas were collected to insure separation of spectral signatures.

We used 2 types of imagery to identify habitat class: Landsat 7 thematic mapper and MODIS ASTER. We performed spectral classification analysis using ERDAS Imagine and ENVI image processing software. To classify the project area we used a maximum likelihood classifier at the 95% level. The resulting habitat classification was assessed for accuracy at the $\alpha = .05$ level using 778 random sites. We formatted the output of the classification as ArcGIS compatible GeoTiff raster layers of post fire habitat availability. Additional GIS layers were accessed to provide information on elevation, percent slope, and slope aspect for the study area.

Based on remote sensing, we classified habitat of the 109.67 km^2 study area into 6 different vegetation/canopy cover/burn intensity classes (Appendix 2). Ponderosa/oak, 40-60% CC, heavy to extreme burn intensity was the most common habitat type (Fig. 3).

Habitat Selection – To establish availability of habitat characteristics we generated 9,389 random sites across the study area using ArcGIS. We overlaid all elk locations and random sites on available GIS habitat characteristic covers and recorded values for each of the following habitat variables; BAER burn severity, Elevation, Slope, Aspect, Habitat class (Vegetation/canopy/burn intensity), and Habitat patch size. To predict annual and seasonal habitat use of female elk we developed logistic regression models (Hosmer and Lemeshow 1989) using habitat variables that were not correlated ($\alpha < 0.1$). We developed probable models a priori, and calculated Akaike's Selection Criterion (AIC) to select the most parsimonious model (Burnham and Anderson 1992) and assigned 0.5 as the cutpoint for classification of use and random sites.

We developed 5 different a priori habitat selection models based on competing theories of factors affecting elk use (Table 1). The global model including all available habitat variables was the most parsimonious model describing annual (Table 1) and seasonal (Tables 2-5) female elk habitat selection. We found female elk habitat use within the perimeter of the Rodeo-Chediski fire differed from availability with respect to habitat type (vegetation type, canopy cover, and burn severity). However, this selection and avoidance was less evident than that for many ungulates (Ockenfels et al. 1991, Ockenfels et al. 1994, Bristow et al. 1996). Elk habitat use is characteristic of availability and they can occupy and use a wider range of habitats than many ungulates (Hobbs and Hanley 1990). This low selectivity with regards to habitat is likely why our global habitat model best explained female elk habitat selection, the selection for any one habitat variable was not strong enough to accurately classify use and random sites by itself. Although elk seasonal habitat selection is affected by topography (Edge and Marcum 1991), slope (Zahn 1974) elevation (Beall 1974), and slope aspect (Mackie 1970), these effects are usually associated with forage availability, thermal factors and cover.

To determine habitat selection by female elk we compared the Bonferroni 90% simultaneous confidence interval (Byers et al. 1984) of the

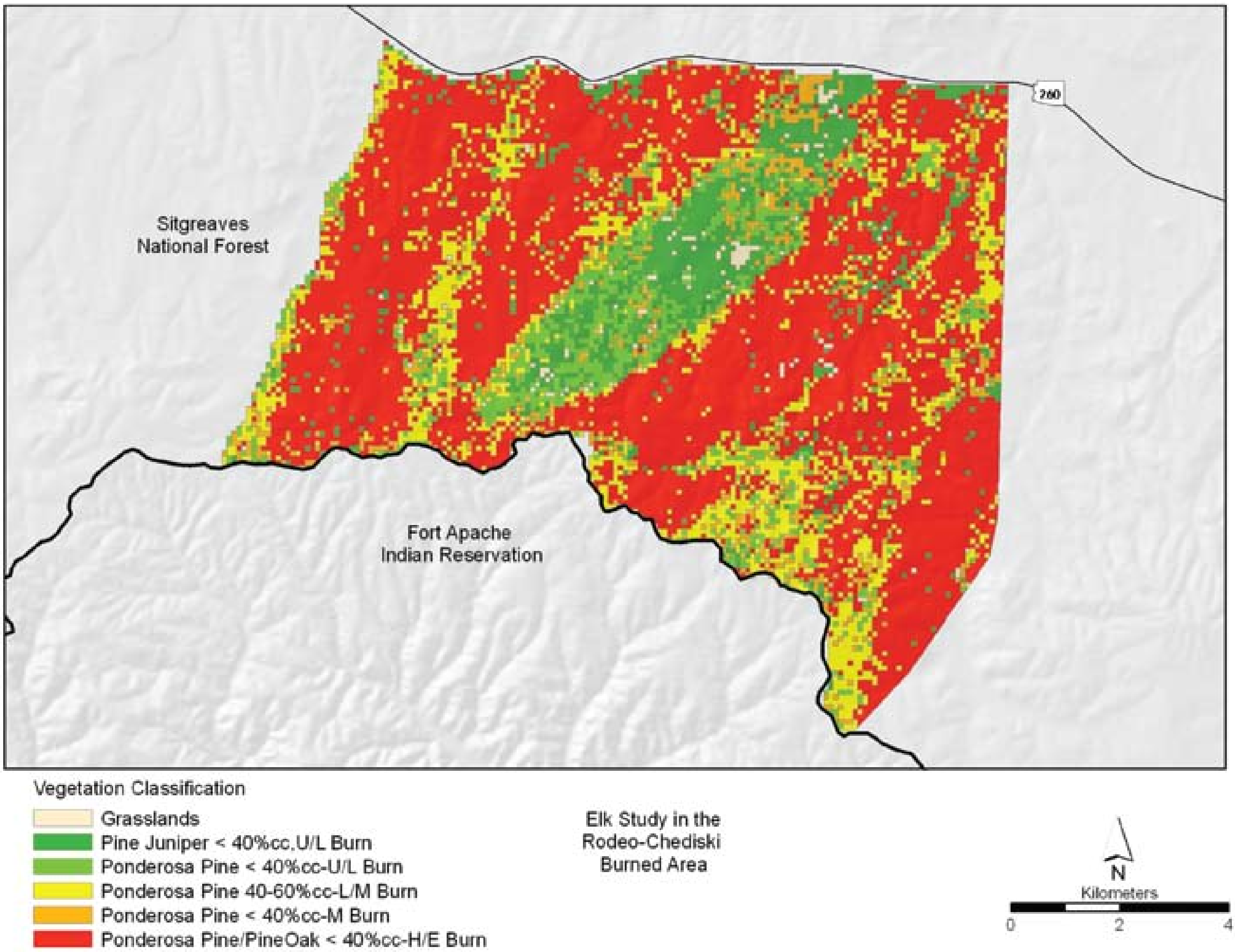

Figure 3. Map of study area showing habitat type classifications for areas within the annual home range of female elk (n = 9) on the Apache-Sitgreaves National Forest in east-central Arizona, 2005-2007.

percentage of locations in each BAER burn severity, and habitat class to the expected frequency distribution, based on random sites. We calculated Jacob's *D* (Jacob 1974) values (-1.0 to 1.0) to examine the extent of selection or avoidance. Negative values indicate avoidance; positive values indicate selection, and the closer the value is to 1.0 or –1.0 from 0, the stronger the relationship. We used the same methods to determine landscape habitat selection among seasons and time of locations (nighttime-2 hours post sunset to 2 hours pre-sunrise, crepuscular-2 hours pre sunrise/sunset to 2 hours post, and daytime >2 hours post sunrise to 2 hours pre-sunset).

Within the perimeter of the Rodeo-Chediski fire female elk selected for areas that were classified as moderate to high burn severity, and avoided areas classified as unburned or low burn severity by the BAER team (Table 6). Female elk selected for the Ponderosa/oak, 40-60% CC, heavy to extreme burn intensity habitat type (Table 7). All other habitat types were avoided or used according to availability (Fig. 4). This habitat selection pattern was consistent across the winter, spring, and summer seasons (Table 8-10), as well as during nocturnal (Table 11) and crepuscular (Table 12) times of day. During autumn female elk shifted their selection to the Ponderosa/oak, 40-60% CC, light to medium burn intensity habitat type, and all

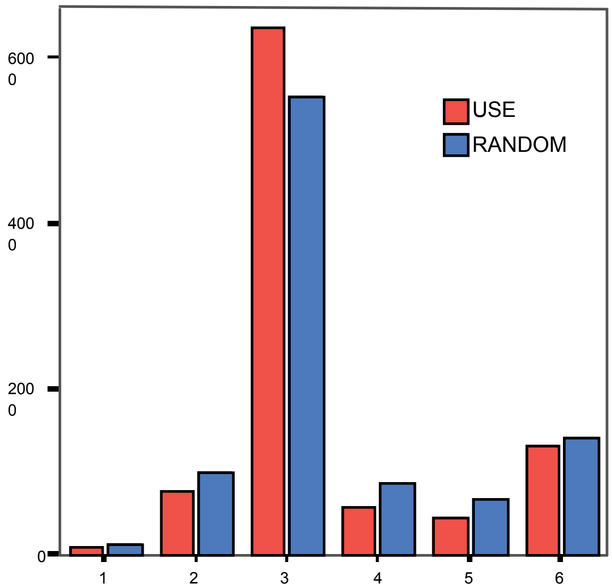

Figure 4. Annual use of habitat type (vegetation X canopy cover X burn intensity) by female elk (n = 9) compared to random sites on the Apache-Sitgreaves National Forest in east-central Arizona, elk habitat selection study 2005-2007. Elk (n = 9) selected for habitat type #3 and other habitat types were used according to availability.

other habitat types were avoided or used according to availability (Table 13). During daytime female elk selected for the Ponderosa/oak, 40-60% CC, heavy to extreme burn intensity habitat type to a lesser degree than other times of day and selected the Ponderosa/oak, 40-60% CC, light to medium burn intensity habitat type more strongly (Table 14). Female elk avoided all other habitat types during the day (Table 14).

In summer, elk seek out thermal cover provided by shaded areas to bed during mid-day hours (Beall 1974, Brown 1994). We found female elk avoided areas with lower canopy cover throughout most seasons and times of day. During mid-day periods elk selected areas that were burned less intensively which would ostensibly have more tree cover and consequently greater canopy cover. However, use of these areas during summer was not different from availability, suggesting a relationship to security cover, rather than thermal cover availability. Thomas et al. (1988) considered canopy cover in excess of 70% acceptable and 40-70% marginal in terms of providing thermal cover for elk. However, Cook et al (1998) could not find evidence of a positive energetic benefit of thermal cover to elk body mass or condition. Additionally, Strohmeyer and Peek (1996) and Merrill (1991) have demonstrated that elk can exist in areas lacking any classically defined thermal cover. The benefit of thermal cover relative to elk habitat use warrants further investigation.

We found that female elk selected the most intensively burned habitats with less canopy cover during crepuscular and evening hours, when elk usually feed. Many investigators have found that elk feed in more open canopy habitats, using denser canopy areas for resting and escape (Marcum 1976). After the Rodeo-Chediski fire, favorable precipitation within the intensively burned areas produced vigorous forb and shrub growth, improving the forage conditions for elk and other ungulates (Fig. 5). Since the selection for these areas was most pronounced during crepuscular and evening hours, this selection was likely due to improved forage conditions.

Improved forage conditions often increase elk use of burned areas in forested ecosystems (Bartos and Mueggler 1979, Leege and Godbolt 1985, Canon et al. 1987). Canon et al. (1987) interpreted the increased use of burned aspen stands as evidence of improved forage palatability. Rowland et al. (1983) found no difference in nutritive quality of available forage in burned and unburned ponderosa pine forests in New Mexico. However, elk foraging in burned habitats had improved nutrient contents of their diet and greater body weights (Rowland et al. 1983). Burned habitats may provide foraging advantages to elk through increased forage availability and diversity which would improve quality simply through increased quantity. Feeding site selection by elk optimizes nutrient intake while reducing energy expenditure (Wambolt and McNeal 1987, McCorqodale 1993), thus improved forage conditions evidenced by foraging habitat selection should allow elk to optimize food intake improving body condition, and survival.

Deposition and distribution of burned logs and debris (slash) can affect availability of forage to

Figure 5. Typical condition of forested habitat (Ponerosa/oak 40-60% canopy, heavy to extreme burn intensity) immediately (a) and 5 years after (b) the Rodeo-Chediski fire on the Apache-Sitgreaves National Forest in east-central Arizona, elk habitat selection study 2005-2007. The growth of forbs, grasses and shrub forage following favorable precipitation in the years post fire likely attracted elk use.

elk and impede movements (Dyrness 1965, Lyon and Jensen 1980). The Rodeo-Chediski fire burned with such intensity that some trees were entirely consumed but other areas had accumulated enough slash that it may have affected elk use. Dyrness (1965) felt that accumulated slash in excess of 50% ground coverage precluded elk use of clear cuts in Oregon. Numbers of elk pellet groups were reduced by more than 50% in Montana clear cuts when slash depth was greater than 0.5 m (Lyon and Jensen 1980).

Elk habitat selection can also be affected by human activities (Irwin and Peek 1983). During autumn hunting seasons elk seek out areas with higher canopy cover and visual obstruction to avoid detection (Morgantini and Hudson 1979). We found elk use of more open intensively burned areas was reduced during daylight hours and autumn when human activity likely increased especially in the well-roaded areas. Researchers have found that elk tend to avoid areas immediately adjacent (0.4 km -2.9 km) to roads, especially during periods of increased traffic (Marcum 1976, Morgantini and Hudson 1979). Black et al. (1976) recommended maintaining 20-30% hiding cover and 10-20% thermal cover in elk habitat in patches of 2.6-10.5 ha. Conversely we found elk used much larger habitat patches averaging 31 km^2 (SD = 14.5). This difference in patch size may be more related to the scale of our habitat classification rather than reflecting elk habitat selection.

We used linear regression to evaluate the existence of thresholds in elk habitat use along a ROMPA gradient (Neter et al. 1996). We delineated all marginal and optimum habitats on our GIS Habitat classification maps using the remote sensing data by determining which habitat classes elk preferred (objective 1). We then identified landscape scale (1 km^2) areas within the burn perimeter with varying degrees of ROMPA. We used ROMPA as the independent variable, and the number of locations per landscape “window” (area) as the dependant variable.

Female elk use of 1 km^2 areas within the burn perimeter was poorly related to ROMPA values (Fig. 6) except at the most intense levels of use (>150 locations/km^2) where ROMPA values were usually in excess of .50 (Fig. 7). The mosaic of different forest stands left above the Mogollon Rim after the Rodeo-Chediski fire likely improved habitat quality of the area relative to elk use. We found intensive elk use of habitat along a ROMPA gradient to be significantly correlated as elk use approached 150 locations/km^2. For

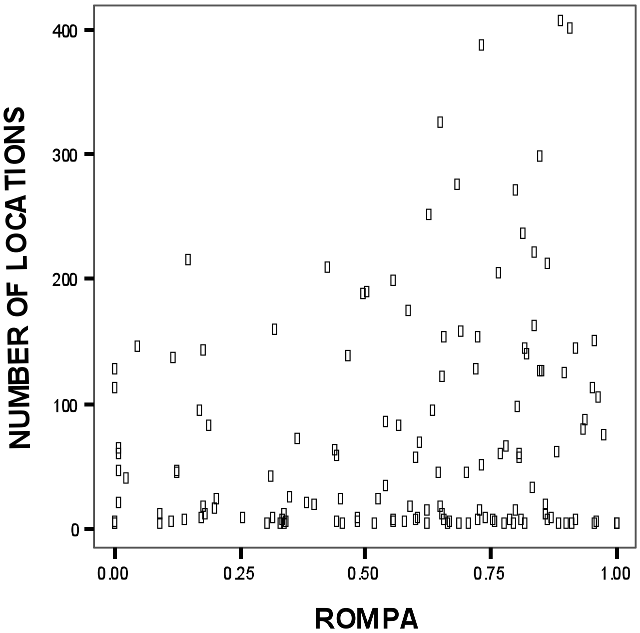

Figure 6. Relationship between female elk use and landscape-scale (1 km²) ratio of optimal to marginal patch area (ROMPA) on the Apache-Sitgreaves National Forest in east-central Arizona, elk habitat selection study 2005-2007.

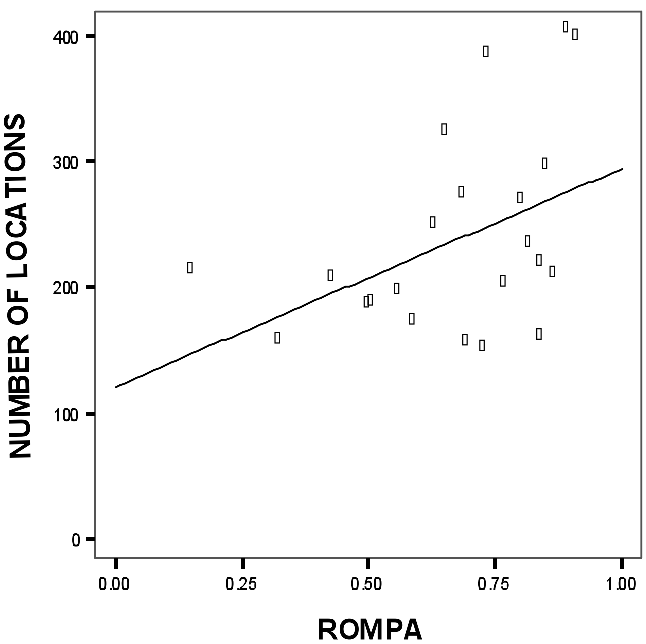

Figure 7. Relationship between intensive (>150 locations/1 km²) female elk use and landscape-scale (1 km²) ratio of optimal to marginal patch area (ROMPA) on the Apache-Sitgreaves National Forest in east-central Arizona, elk habitat selection study 2005-2007.

an area to receive intensive use (>150 locations/ km^2) the ROMPA values were usually in excess of .50. Similarly, Thomas et al. (1976) suggested a 40:60 ratio of hiding cover to feeding areas for elk in Ponderosa pine/mixed conifer forests in Oregon. These values correspond with the habitat availability after the Rodeo-Chediski fire based on our habitat classification as well as the BAER team.

Kie et. al. (2002) were able to explain 57% of the variation in mule deer home ranges based on spatial heterogeneity of habitat in 8 discrete mule deer populations, associating better habitat quality with increased spatial heterogeneity. However, their analysis did not include other important variables including season, reproductive status, and availability of food and water, further indicating the importance of a mosaic of habitat types (Boyd 2001). Spatial heterogeneity is a structural feature of landscapes that can be defined as the complexity of variability in space of the properties of the ecological system (Li and Reynolds 1994). A more advanced landscape analysis including edge density, patch shape, patch richness density, edge contrast index, and nearest suitable patch (McGarigal and Marks 1995), could provide more in depth information on how elk use habitat within their home ranges. This information could become extremely important in protecting or even enhancing elk habitat as forest restoration (thinning) projects continue in Arizona.

RECOMMENDATIONS

Forest treatments designed to improve elk habitat should consider canopy cover, habitat patch size, slash treatments, hiding cover availability, and road densities. We found that although elk used a variety of habitats with respect to canopy cover, within Ponderosa pine communities the areas with 40-60% canopy cover were selected during all times of day and seasons. The use of intensively burned areas by elk suggests that increased forage production documented in many studies likely attracted elk use. Prescribed fire is a common treatment to improve elk habitat quality that has been largely successful when properly applied (Leege and Hickey 1971).

Prescribed fire with intense burn severity similar to the Rodeo-Chediski fire improved sprouting of desirable forage plants in Idaho, and Lyon (1971) predicted the increased forage availability would benefit mule deer and elk for 20 years. Forest treatments and prescribed fire designed to reduce canopy cover to 40-60% in a mosaic pattern (ROMPA ≥0.50) would likely improve forage conditions for Arizona elk in ponderosa pine communities. Reseeding and fertilization might improve growth of forage species and increase elk use (Leege and Godbolt 1985). Slash accumulation should be kept below 50% ground coverage and <0.5 m depth (Dyrness 1965, Lyon and Jensen 1980). Efforts to limit roads and reduce vehicle traffic will improve access to available habitat for elk (Morgantini and Hudson 1979).

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Table 1. Ranking of logistic regression models[1] for female elk (n = 9) annual habitat use within the perimeter of the Rodeo-Chediski fire on the Apache-Sitgreaves National Forest in east-central Arizona, 2005-2007.

Model	K	-2 log likelihood	% elk correctly classified	% randoms correctly classified	AIC	Delta AIC
1 Global	5	25938.36	59.2	56.1	25948.36	0.00
2 Habitat/patch size	2	26138.86	55.9	58.7	26140.86	192.50
3 Migratory	3	26192.72	60.3	50.3	26198.72	250.36
4 Habitat type	1	26305.02	66.7	42.1	26307.02	358.66
5 Landform	3	26328.40	57.0	50.1	26334.40	386.04

[1]*P*-values for all models were <0.001 (n = 9,555), and degrees of freedom was equal to the number of variables included in the model. Models are presented in order of parsimony:

1 Global model; Habitat type, elevation, percent slope, slope aspect, and patch size

2 Habitat/patch size model; Habitat type and patch size

3 Migratory model; Habitat type, elevation, and slope

4 Habitat type model; Habitat type only

5 Landform model; Elevation, slope, and slope aspect

Table 2. Ranking of logistic regression models[1] for female elk (n = 9) winter habitat use within the perimeter of the Rodeo-Chediski fire on the Apache-Sitgreaves National Forest in east-central Arizona, 2005-2007.

Model	K	-2 log likelihood	% elk correctly classified	% randoms correctly classified	AIC	Delta AIC
1 Global	5	7338.28	65.1	54.7	7348.28	0.00
2 Migratory	3	7430.31	63.4	53.6	7436.31	88.03
3 Habitat/patch size	2	7497.97	64.9	53.8	7501.97	153.69
4 Landform	3	7542.33	61.3	52.5	7548.33	200.05
5 Habitat type	1	7570.33	69.6	43.1	7572.33	224.05

[1]*P*-values for all models were <0.001 (n = 2,798), and degrees of freedom was equal to the number of variables included in the model. Models are presented in order of parsimony:

1 Global model; Habitat type, elevation, percent slope, slope aspect, and patch size

2 Migratory model; Habitat type, elevation, and slope

3 Habitat/patch size model; Habitat type and patch size

4 Landform model; Elevation, slope, and slope aspect

5 Habitat type model; Habitat type only

Table 3. Ranking of logistic regression models[1] for female elk (n = 9) spring habitat use within the perimeter of the Rodeo-Chediski fire on the Apache-Sitgreaves National Forest in east-central Arizona, 2005-2007.

Model	K	-2 log likelihood	% elk correctly classified	% randoms correctly classified	AIC	Delta AIC
1 Global	5	9312.26	62.1	52.2	9322.26	0.00
2 Landform	3	9439.10	63.1	50.0	9445.10	112.84
3 Migratory	3	9432.07	61.1	50.6	9438.07	115.81
4 Habitat/patch size	2	9463.05	70.8	41.4	9467.05	144.79
5 Habitat type	1	9530.28	76.8	29.5	9532.28	210.02

[1]*P*-values for all models were <0.001 (n = 3,467), and degrees of freedom was equal to the number of variables included in the model. Models are presented in order of parsimony:

1 Global model; Habitat type, elevation, percent slope, slope aspect, and patch size

2 Landform model; Elevation, slope, and slope aspect

3 Migratory model; Habitat type, elevation, and slope

4 Habitat/patch size model; Habitat type and patch size

5 Habitat type model; Habitat type only

Table 4. Ranking of logistic regression models[1] for female elk (n = 8) summer habitat use within the perimeter of the Rodeo-Chediski fire on the Apache-Sitgreaves National Forest in east-central Arizona, 2005-2007.

Model	K	-2 log likelihood	% elk correctly classified	% randoms correctly classified	AIC	Delta AIC
1 Global	5	6091.78	68.3	47.1	6101.78	0.00
2 Migratory	3	6126.12	73.1	40.1	6132.12	30.34
3 Habitat type	1	6151.12	73.7	38.5	6153.12	51.34
4 Habitat/patch size	2	6145.20	73.7	38.5	6149.20	47.42
5 Landform	3	6225.00	56.3	52.3	6231.00	129.22

[1]*P*-values for all models were <0.001 (n = 2,289), and degrees of freedom was equal to the number of variables included in the model. Models are presented in order of parsimony:

1 Global model; Habitat type, elevation, percent slope, slope aspect, and patch size

2 Migratory model; Habitat type, elevation, and slope

3 Habitat type model; Habitat type only

4 Habitat/patch size model; Habitat type and patch size

5 Landform model; Elevation, slope, and slope aspect

Table 5. Ranking of logistic regression models[1] for female elk (n = 8) autumn habitat use within the perimeter of the Rodeo-Chediski fire on the Apache-Sitgreaves National Forest in east-central Arizona, 2005-2007.

Model	K	-2 log likelihood	% elk correctly classified	% randoms correctly classified	AIC	Delta AIC
1 Global	5	2672.71	59.7	49.1	2682.71	0.00
2 Migratory	3	2686.19	59.8	46.9	2692.19	9.48
3 Landform	3	2690.25	59.8	49.9	2696.25	13.54
4 Habitat	1	2701.13	84.1	22.5	2702.13	19.42
5 Habitat/patch size	2	2699.94	80.7	26.0	2703.94	21.23

[1]*P*-values for all models were <0.001 (n = 1,001), and degrees of freedom was equal to the number of variables included in the model. Models are presented in order of parsimony:

1 Global model; Habitat type, elevation, percent slope, slope aspect, and patch size

2 Migratory model; Habitat type, elevation, and slope

3 Landform model; Elevation, slope, and slope aspect

4 Habitat type model; Habitat type only

5 Habitat/patch size model; Habitat type and patch size

Table 6. Annual use of habitat classified by burn severity[1] by female elk (n = 12) compared to random locations within the perimeter of the Rodeo-Chediski fire on the Apache-Sitgreaves National Forest in east-central Arizona, elk habitat selection study 2005-2007.

Burn severity class	No. of locations observed	No. of locations expected	Bonferroni 90% CI	Jacobs' D[2]
High	7,030	5,583	11,035 – 11,336	0.23
Moderate	4,573	3,532	11,196 – 11,477	0.25
Low	3,381	4,049	9,005 – 9,286	-0.18
Unburned	5,116	6,936	8,402 – 8,683	-0.29

[1]Burn severity estimated from Landsat 7 TM Satellite imagery acquired on July 7, 2002, from USGS EROS Data Center, Sioux Falls, SD. by the US Forest Service Bruned Area Emergency Rehabilitation team.

[2]Jacobs' *D* represents Magnitude of selection or avoidance, from 1.0 to –1.0.

Table 7. Annual use of habitat type (vegetation X canopy cover X burn intensity) by female elk (n = 9) compared to random locations within the perimeter of the Rodeo-Chediski fire on the Apache-Sitgreaves National Forest in east-central Arizona, elk habitat selection study 2005-2007.

Habitat type	No. of locations observed	No. of locations expected	Bonferroni 90% CI	Jacobs' *D*[1]
Grasslands, 0% canopy, Unburned-extreme burn intensity	73	113	57 – 96	-0.20
Pinyon-Juniper, <40% canopy, Unburned-light burn intensity	782	1,078	716 – 850	-0.18
Pipo[2] – Quga[3], 40-60% canopy, Heavy –extreme burn intensity	6,376	5,512	6,268 – 6,478	0.19
Pipo – Quga, <40% canopy, Unburned-light burn intensity	568	935	506 – 621	-0.27
Pipo – Quga, <40% canopy, Medium burn intensity	461	610	411 – 506	-0.15
Pipo – Quga, 40-60% canopy, Light – medium burn intensity	1,295	1,307	1,223 – 1,376	

[1]Jacobs' *D* represents Magnitude of selection or avoidance, from 1.0 to –1.0.

[2]Ponderosa Pine *(Pinus ponderosa)*

[3]Gambels' Oak *(Quercus gambellii)*

Table 8. Winter use of habitat type (vegetation X canopy cover X burn intensity) by female elk (n = 9) compared to random locations within the perimeter of the Rodeo-Chediski fire on the Apache-Sitgreaves National Forest in east-central Arizona, elk habitat selection study 2005-2007.

Habitat type	No. of locations observed	No. of locations expected	Bonferroni 90% CI	Jacobs' *D*[1]
Grasslands, 0% canopy, Unburned-extreme burn intensity	19	34	8 – 31	-0.27
Pinyon-Juniper, <40% canopy, Unburned-light burn intensity	199	342	168 – 229	-0.29
Pipo[2] – Quga[3], 40-60% canopy, Heavy –extreme burn intensity	1,947	1,593	1,891 – 2,003	0.27
Pipo – Quga, <40% canopy, Unburned-light burn intensity	153	283	126 – 176	-0.32
Pipo – Quga, <40% canopy, Medium burn intensity	147	173	120 – 176	
Pipo – Quga, 40-60% canopy, Light – medium burn intensity	333	373	294 – 373	

[1]Jacobs' *D* represents Magnitude of selection or avoidance, from 1.0 to –1.0.

[2]Ponderosa Pine *(Pinus ponderosa)*

[3]Gambels' Oak *(Quercus gambellii)*

Table 9. Spring use of habitat type (vegetation X canopy cover X burn intensity) by female elk (n = 9) compared to random locations within the perimeter of the Rodeo-Chediski fire on the Apache-Sitgreaves National Forest in east-central Arizona, elk habitat selection study 2005-2007.

Habitat type	No. of locations observed	No. of locations expected	Bonferroni 90% CI	Jacobs' *D*[1]
Grasslands, 0% canopy, Unburned-extreme burn intensity	34	59	21 – 49	-0.26
Pinyon-Juniper, <40% canopy, Unburned-light burn intensity	361	416	319 – 402	-0.08
Pipo[2] – Quga[3], 40-60% canopy, Heavy –extreme burn intensity	2,182	1,979	2,115 – 2,247	0.12
Pipo – Quga, <40% canopy, Unburned-light burn intensity	246	326	211 – 281	-0.15
Pipo – Quga, <40% canopy, Medium burn intensity	164	222	135 – 191	-0.16
Pipo – Quga, 40-60% canopy, Light – medium burn intensity	480	465	430 – 527	

[1]Jacobs' *D* represents Magnitude of selection or avoidance, from 1.0 to –1.0.

[2]Ponderosa Pine *(Pinus ponderosa)*

[3]Gambels' Oak *(Quercus gambellii)*

Table 10. Summer use of habitat type (vegetation X canopy cover X burn intensity) by female elk (n = 8) compared to random locations within the perimeter of the Rodeo-Chediski fire on the Apache-Sitgreaves National Forest in east-central Arizona, elk habitat selection study 2005-2007.

Habitat type	No. of locations observed	No. of locations expected	Bonferroni 90% CI	Jacobs' *D*[1]
Grasslands, 0% canopy, Unburned-extreme burn intensity	14	11	5 – 21	
Pinyon-Juniper, <40% canopy, Unburned-light burn intensity	113	188	87 – 137	-0.27
Pipo[2] – Quga[3], 40-60% canopy, Heavy –extreme burn intensity	1,673	1,397	1,623 – 1,724	0.27
Pipo – Quga, <40% canopy, Unburned-light burn intensity	76	228	55 – 96	-0.53
Pipo – Quga, <40% canopy, Medium burn intensity	106	133	82 – 128	-0.12
Pipo – Quga, 40-60% canopy, Light – medium burn intensity	307	332	268 – 346	

[1]Jacobs' *D* represents Magnitude of selection or avoidance, from 1.0 to –1.0.

[2]Ponderosa Pine *(Pinus ponderosa)*

[3]Gambels' Oak *(Quercus gambellii)*

Table 11. Nighttime (2 hours post sunset to 2 hours pre-sunrise) use of habitat type (vegetation X canopy cover X burn intensity) by female elk (n = 9) compared to random locations within the perimeter of the Rodeo-Chediski fire on the Apache-Sitgreaves National Forest in east-central Arizona, elk habitat selection study 2005-2007.

Habitat type	No. of locations observed	No. of locations expected	Bonferroni 90% CI	Jacobs' *D*[1]
Grasslands, 0% canopy, Unburned-extreme burn intensity	32	35	17 – 46	
Pinyon-Juniper, <40% canopy, Unburned-light burn intensity	302	324	263 –339	
Pipo[2] – Quga[3], 40-60% canopy, Heavy –extreme burn intensity	2,013	1,681	1,956 – 2,072	0.25
Pipo – Quga, <40% canopy, Unburned-light burn intensity	160	266	130 – 188	-0.27
Pipo – Quga, <40% canopy, Medium burn intensity	136	171	110 – 162	-0.12
Pipo – Quga, 40-60% canopy, Light – medium burn intensity	251	417	214 – 287	-0.28

[1]Jacobs' *D* represents Magnitude of selection or avoidance, from 1.0 to –1.0.

[2]Ponderosa Pine *(Pinus ponderosa)*

[3]Gambels' Oak *(Quercus gambellii)*

Table 12. Crepuscular (2 hours pre sunrise/sunset to 2 hours post) use of habitat type (vegetation X canopy cover X burn intensity) by female elk (n = 9) compared to random locations within the perimeter of the Rodeo-Chediski fire on the Apache-Sitgreaves National Forest in east-central Arizona, elk habitat selection study 2005-2007.

Habitat type	No. of locations observed	No. of locations expected	Bonferroni 90% CI	Jacobs' *D*[1]
Grasslands, 0% canopy, Unburned-extreme burn intensity	24	45	13 – 32	-0.34
Pinyon-Juniper, <40% canopy, Unburned-light burn intensity	280	402	241 –318	-0.20
Pipo[2] – Quga[3], 40-60% canopy, Heavy –extreme burn intensity	2,212	1,787	2,150 – 2,272	0.28
Pipo – Quga, <40% canopy, Unburned-light burn intensity	192	357	161 – 222	-0.32
Pipo – Quga, <40% canopy, Medium burn intensity	137	199	112 – 164	-0.19
Pipo – Quga, 40-60% canopy, Light – medium burn intensity	369	424	328 – 411	-0.08

[1]Jacobs' *D* represents Magnitude of selection or avoidance, from 1.0 to –1.0.

[2]Ponderosa Pine *(Pinus ponderosa)*

[3]Gambels' Oak *(Quercus gambellii)*

Table 13. Autumn use of habitat type (vegetation X canopy cover X burn intensity) by female elk (n = 8) compared to random locations within the perimeter of the Rodeo-Chediski fire on the Apache-Sitgreaves National Forest in east-central Arizona, elk habitat selection study 2005-2007.

Habitat type	No. of locations observed	No. of locations expected	Bonferroni 90% CI	Jacobs' *D*[1]
Grasslands, 0% canopy, Unburned-extreme burn intensity	6	11	3 – 11	
Pinyon-Juniper, <40% canopy, Unburned-light burn intensity	109	134	86 – 132	-0.12
Pipo[2] – Quga[3], 40-60% canopy, Heavy –extreme burn intensity	574	544	537 – 609	
Pipo – Quga, <40% canopy, Unburned-light burn intensity	93	97	72 – 114	
Pipo – Quga, <40% canopy, Medium burn intensity	44	80	29 – 59	-0.31
Pipo – Quga, 40-60% canopy, Light – medium burn intensity	175	134	147 – 203	0.16

[1]Jacobs' *D* represents Magnitude of selection or avoidance, from 1.0 to –1.0.

[2]Ponderosa Pine *(Pinus ponderosa)*

[3]Gambels' Oak *(Quercus gambellii)*

Table 14. Daytime (>2 hours post sunrise to 2 hours pre-sunset) use of habitat type (vegetation X canopy cover X burn intensity) by female elk (n = 9) compared to random locations within the perimeter of the Rodeo-Chediski fire on the Apache-Sitgreaves National Forest in east-central Arizona, elk habitat selection study 2005-2007.

Habitat type	No. of locations observed	No. of locations expected	Bonferroni 90% CI	Jacobs' *D*[1]
Grasslands, 0% canopy, Unburned-extreme burn intensity	17	38	7 – 28	-0.38
Pinyon-Juniper, <40% canopy, Unburned-light burn intensity	200	355	169 – 231	-0.30
Pipo[2] – Quga[3], 40-60% canopy, Heavy –extreme burn intensity	2,151	2,044	2,085 – 2,216	0.07
Pipo – Quga, <40% canopy, Unburned-light burn intensity	216	307	183 – 252	-0.19
Pipo – Quga, <40% canopy, Medium burn intensity	188	238	159 – 221	-0.12
Pipo – Quga, 40-60% canopy, Light – medium burn intensity	675	465	620 – 727	0.22

[1]Jacobs' *D* represents Magnitude of selection or avoidance, from 1.0 to –1.0.

[2]Ponderosa Pine *(Pinus ponderosa)*

[3]Gambels' Oak *(Quercus gambellii)*

APPENDICES

1. Number of locations for radiocollared elk that overlapped the study area during Winter (15 Dec. - 15 Mar.), Spring (16 Mar. - 14 Jun.), Summer (15 Jun. - 13 Sep.), and Autumn (13 Sep.- 14 Dec.) in east-central Arizona, 2005-2007.

SEASON					
Animal	**Winter**	**Spring**	**Summer**	**Autumn**	**Σ**
1	583	598	422	418	2021
2	409	406	427	64	1,306
3	107	252	236	3	598
4	372	295	273	0	940
5	640	618	423	242	1,923
6	208	475	3	15	701
8	131	133	177	13	454
9	339	538	328	246	1451
13	9	152	0	0	161
Σ	2,798	3,467	2,289	1,001	9,555

2. Area (Km^2) of habitat types (vegetation X canopy cover X burn intensity) classified using remote sensing within the female elk habitat selection study area, east-central Arizona, 2005-2007.

HABITAT TYPE				
Type	**Vegetation**	**Canopy cover**	**Burn intensity**	**Km^2**
1	Grasslands	0 %	Unburned to extreme	1.23
2	Pinyon-Juniper	< 40 %	Unburned to light	11.02
3	Ponderosa pine – Gambel's oak	40-60%	Heavy to extreme	64.32
4	Ponderosa pine – Gambel's oak	< 40 %	Unburned to light	8.21
5	Ponderosa pine – Gambel's oak	< 40 %	Medium	7.66
6	Ponderosa pine – Gambel's oak	40-60%	Light to Medium	17.23
Σ				109.67