Abert's Squirrel (*Sciurus aberti*) Monitoring on Carson National Forest, New Mexico, 2006

A Final Contract AG-83A7-P-06-0023 Completion Report

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EXECUTIVE SUMMARY

Purpose

- The purpose of this study was to provide a fourth year of monitoring of Abert's squirrels on Carson National Forest and to provide general habitat data in order to establish long-term trends in populations and habitat.

Methods

- An index of Abert's squirrel density was sampled using methods developed by the Arizona Game and Fish Department.
- Over-winter feeding sign was sampled in 256 1 m^2 sampling quadrants situated on a 1,607 ft x 1,607 ft. grid (i.e., monitoring plot) in each forest stand.
- A total of 37 monitoring plots were established in ponderosa pine stands across the 6 Carson National Forest districts. These included 31 plots that had been monitored during previous years and 6 new plots established in the Valle Vidal Unit.
- Abert's squirrel density on each plot was calculated by using a feeding sign index regression model curve supplied by Arizona Game and Fish Department.
- In order to describe general habitat features of each plot, habitat data were collected on 10 random 32.8 x 57.4 ft (10 x 17.5 m) belt transects within each monitoring plot during 2004 - 2006. Habitat variables included: slope, aspect, canopy closure, litter depth, ground cover (of forbs, grasses, litter, bare, and other), woody understory species and cover, number, diameter and species of each tree, number and diameter of snags, and number and diameter of cut stumps.

Results

- On the 31 previously existing monitoring plots, Abert's squirrel density was the highest yet recorded and ranged from 0 to 0.06 per hectare with an overall mean of 0.012 squirrels per hectare (= 1 squirrel per 247 acres).
- Abert's squirrel density on the 6 new monitoring plots in the Valle Vidal Unit were significantly higher than on the 31 previously existing plots and ranged from 0.01 to 0.09 per hectare with a mean of 0.07squirrels per hectare (= 1 squirrel per 35 acres).
- Mean Abert's squirrel density across all 37 monitoring plots was 0.02 per hectare (= 1 squirrel per 123 acres).
- In comparing the 30 plots that were annually monitored between 2003-2006, Abert's squirrel density was significantly higher in 2005 and 2006 as

compared with 2003 and 2004, although densities were not significantly different within each pair of years.

- There was significant variation in habitat measured among years. For most variables, this likely was a reflection of the small area sampled for habitat in each plot during each year. Consequently, habitat data were combined across years for subsequent analyses.
- Habitat characteristics of the three general vegetation types used by Abert's squirrels were assessed including ponderosa pine forest, the piñon-juniper woodland ecotone, and the mixed coniferous forest ecotone.
- Abert's squirrel densities were higher at the upper, more productive mixed coniferous forest ecotone and lower at the lower, more arid piñon-juniper woodland ecotone.
- In general, Abert's squirrel density was related to higher densities of medium and large ponderosa pine, canopy cover, litter depth and inversely related to understory cover, oaks, juniper and bare ground. Density of 12 – 16 inch DBH ponderosa pine was the single best predictor of squirrel density.
- The lower piñon-juniper woodland ecotone was associated with lower plot occupancy and density of Abert's squirrel.
- When the influence of the lower piñon-juniper woodland zone was controlled for in statistical analyses, Abert's squirrel density was positively related to density of medium and large diameter ponderosa pines and presence of Douglas fir, but inversely related to understory cover
- The high squirrel densities on the new Valle Vidal plots was likely due to these forests being at the more productive mixed conifer forest ecotone.
- The positive relationships between cut stump density and squirrel density was likely a spurious result of squirrels preferring habitats (i.e., productive upper mixed coniferous forest ecotone) that are also preferred for tree cutting.
- It was concluded that the potential for inadvertently recording red squirrel feeding sign as Abert's squirrel has little influence on statistics related to Abert's squirrel density.

Discussion and Conclusions

- Abert's squirrel populations experienced dramatic regional declines in the early 2000's as a result of drought conditions, which may reduce availability of important foods (i.e., ponderosa pine cones and hypogeous fungi).
- Increased precipitation was likely responsible for the increase in Abert's squirrel distribution and density during 2005 and 2006.
- Compared to other studies conducted at the same time, Abert's squirrel densities observed on Carson National Forest during 2003-2006 were low.
- Reasons for the apparent low densities of Abert's squirrel on Carson National Forest may be due to: 1) the random selection of forest stands for monitoring; 2) geographic variation in topographic features associated with the development of ponderosa pine forest; 3) geographic variation in climate/weather patterns; 4) spatial and temporal variation in ponderosa pine chemistry; and 5) past forest management.

- The influence of general habitat conditions and management actions on Abert's squirrel densities on Carson National Forest remains unknown and requires additional study.

Recommendations

Continued monitoring

- Annual over-winter spring feeding sign monitoring of Abert's squirrel should continue long-term using methodology consistent with those used in 2003 - 2006.
- Annual over-winter spring feeding sign monitoring should include all or a consistent subset of plots sampled during 2003 - 2006 in all subsequent monitoring strategies.
- More plots should be monitored in order to increase representation of forest conditions and increase sample size.
- As much as feasible, maintain consistency in field crewmembers to reduce observer biases.
- Data should be collected by teams of two rather than by single individuals. This will increase safety and will help reduce sampling bias and data recording errors.

Additional study

- Forest Service stand exams should be completed at each monitoring plot. Stand exams would provide detailed data about habitat conditions in terms more relevant to forestry management. Such data would allow for more detailed analyses on the influence of forest conditions on Abert's squirrel densities and would allow for an analysis of relationships between stand exam variables and data collected during habitat monitoring.
- Management history of all monitoring plots should be determined and included in analyses. These data would help assess causal relationships between management history and current habitat conditions and squirrel densities. Such information would be particularly helpful in identifying relationships between timber harvesting, thinning, and fire events with squirrel distribution and abundance.
- Additional studies should be initiated that are designed to assess the impacts of specific forest management strategies on Abert's squirrel populations.
- Studies to monitor ponderosa pine seed and hypogeous fungi production should be conducted in conjunction with Abert's squirrel monitoring.

INTRODUCTION

The Abert's squirrel (*Sciurus aberti*), also called tassel-eared squirrel, is endemic to southwestern North America. Its range includes the Southern Rocky Mountains and Colorado Plateau in the United States and portions of the Sierra Madre in northwestern Mexico (Hall 1981). This tree squirrel almost exclusively occurs in ponderosa pine (*Pinus ponderosa*) forests (Bailey 1931, Findley et al. 1975). On occasion Abert's squirrel also will occur below the ponderosa pine zone in the upper edge of piñon (*Pinus*)-juniper (*Juniperus*) woodland and above the ponderosa pine zone in the lower edge of mixed conifer forest (Findley 1999). In mountain ranges where red squirrels (*Tamiasciurus hudsonicus)* are absent, Abert's squirrel may extend higher into the mixed conifer forest zone. Optimum Abert's squirrel habitat consists of groups of even-aged ponderosa pine spaced within an uneven-aged stand. For example, Flyger and Gates (1982) recommended that these stands should have open understories and densities of 496 - 618 ponderosa pines per hectare with an average diameter at breast height (DBH) of 11-13 inch (28-33 cm) DBH and include one or two large 12-14 inch (30-36 cm) DBH Gambel oaks (*Quercus gambelii*). However, there are no known studies of habitat requirement for this species that have been conducted in New Mexico. Thus, recommendations for habitat based on studies in other locations may not be appropriate for Carson National Forest. For example, large diameter Gambel oaks are not an evident part of ponderosa pine forests on Carson National Forest.

Abert's squirrel is ecologically dependent on ponderosa pine for both nesting sites and food (Keith 1965). Nests are usually located 20-59 ft (5-18 m) above the ground on the south side of a ponderosa pine that has a crown comprising 35-55% of the total tree height and greater than 14 in DBH (36 cm DBH; Farentinos 1972a, Flyger and Gates 1982). Suitable nest trees are generally greater than 100 years old and located adjacent to trees of similar size with interlocking canopies to provide escape routes (Flyger and Gates 1982, Brown 1984). Nests are typically constructed of twigs or excavated in dwarf mistletoe (*Arceuthobium pusillum*) "witches broom" infections (Farentinos 1972a, 1972b). Abert's squirrels eat the seeds, inner bark, terminal buds, twigs, and flowers of ponderosa pine in addition to other foods such as mushrooms, fungi, piñon pine, acorns, carrion, and cones raided from red squirrel middens (Flyger and Gates 1982). There is seasonal variation in food habits. Hypogeous fungi (i.e., truffles) that have a symbiotic relationship with ponderosa pine roots are an important and consistent part of the diet, and represent a major part of the diet during summer and early fall (Rasmussen et al. 1975, States et al. 1988). During fall, pine seeds harvested from cones are a major food item (States et al. 1988). During winter and early spring apical buds and inner bark (i.e., phloem) of ponderosa pine twigs are the major food (States et al. 1988). In spring and early summer ponderosa pine staminate (male) flowers and seeds are important (Rasmussen et al. 1975, Brown 1984). Because Abert's squirrels are so dependent on ponderosa pine, their density fluctuates in response to various aspects of this tree such as cone production (Flyger and Gates 1982). This density variation is both temporal and spatial (Bailey 1931).

BACKGROUND AND PURPOSE

Carson National Forest designated the Abert's squirrel as a management indicator species (MIS) for ponderosa pine forest with interlocking canopies in the 1986 Carson Forest Plan. Consequently, information is needed on their distribution and abundance on the forest. A long-term monitoring study for Abert's squirrel was initiated in 2003 in order to track population changes and to assess the impacts of forest management practices on this species. In 2004 a protocol was developed to collect habitat data that could be rapidly and efficiently collected in conjunction with Abert's squirrel monitoring on each plot. Habitat data were intended to describe the general habitat of the plot and to provide for long-term monitoring of habitat conditions.

The purpose of this study was to provide a fourth year of monitoring for Abert's squirrel and their habitat on Carson National Forest. More specifically, the objectives were to implement monitoring protocols, to determine occurrence and density of Abert's squirrel, to determine the relationship between Abert's squirrel density and general habitat characteristics, and to provide a fourth year of data for a long-term monitoring program.

METHODS

Squirrel density

Over-winter feeding sign.—The technique for monitoring Abert's squirrel was developed by the Arizona Game and Fish Department (Dodd undated, Dodd et al. 1998, Norris Dodd personal communication). This monitoring technique provides an indirect population index based on sign consisting of the remains of Abert's squirrel over-winter feeding activity. This technique has been demonstrated to be reliable, consistent, efficient, and cost-effective (Dodd 1998).

The Abert's squirrel monitoring technique is dependent on the ability of the field crew to accurately identify over-winter feeding sign made by Abert's squirrel. Feeding sign includes the clipped terminal ends of ponderosa pine limbs, peeled ponderosa pine twigs, ponderosa pine cone cores, evidence of feeding on ponderosa pine staminate cones, flowers, and apical buds, and hypogeous fungi digs (Dodd no date, Dodd et al. 1998). Other feeding sign found on Carson National Forest includes peeled twigs and clipped terminal ends of piñon pine and Douglas fir cone cores. Feeding sign made by Abert's squirrel can be confused with sign made by red squirrel, porcupine (*Erethizon dorsatum*), other small mammals (especially chipmunks), twig boring insects, and other factors (Rasmussen et al. 1975). A particularly helpful resource for distinguishing Abert's squirrel sign was the key provided by Rasmussen et al. (1975). However, even with this resource, accurate identification of all types of sign is not immediately possible. Consequently, several steps were taken to insure that the field crew was able to accurately identify all feeding sign types. Prior to initiating fieldwork, field crew were provided general instruction on the nature and identification of feeding sign and were provided with instruction and field practice using the Rasmussen et al. (1975) key. Finally, data were collected on several plots as a group. At the conclusion of this training period, all field crewmembers were confident in their ability to accurately distinguish the different types of feeding sign.

Dodd et al. (1998) found that the spring period (mid-March to late May) was the only season with a consistent relationship between feeding sign and squirrel density in Arizona. However, in 2004 it was recommended that monitoring on Carson National Forest be delayed until early May in order to avoid snow on the ground, which precludes this monitoring technique.

Monitoring plots.—Carson National Forest determined that the establishment of Abert's squirrel monitoring plots in each of 24 ponderosa pine forest stands was adequate for establishing base-line estimates of Abert's squirrel densities on the forest. During 2003, Carson National Forest provided maps and coordinates of stand centers for a randomly selected suite of ponderosa pine stands that were at least 198 acres (80 ha) in size and within 1 mile of established roads. Specific stands for establishing monitoring plots were selected from this suite based primarily on logistical considerations. These considerations included distributing plots among the 6 forest districts, accessibility, and drive time among plots. In addition, the stand had to consist of ponderosa pine as the dominant tree species. Once a stand was selected, the specific location of the monitoring plot within the stand was determined by use of maps and stand center coordinates. Monitoring plots were situated so that the entire plot (1,607 ft x 1,607 ft [490 m X 490 m]) fell within the stand and so that roads and habitat types other than ponderosa pine forest were avoided where possible.

During 2003, a total of 31 monitoring plots were established (7 more than required by Carson National Forest). The sampling effort in 2004 - 2006 included a repeat of all plots monitored during 2003, with the exception of Plot 54 on the Camino Real District, which was not repeated after 2003 because the site was predominantly piñon-juniper woodland rather than ponderosa pine forest. A new site (El Pato) in a nearby stand of ponderosa pine was monitored instead of plot 54 during 2004 - 2006. In 2006, new monitoring plots were established in 6 stands within the Valle Vidal Unit. These stands were selected from a suite of ponderosa pine stands identified by Carson National Forest that were at least 198 acres (80 ha) in size, within 1 mile of established roads, and that had a fire intensity of none, light, or moderate.

The sampling design followed those developed and recommended by Norris Dodd (Dodd et al. 1998, Norris Dodd no date, Norris Dodd personal communication). The monitoring plot consisted of an 8 x 8 grid made up of 64 "intervals", each 230 ft (= 70 m) in length. Feeding sign was recorded within 1.0 m^2 (= 10.8 square feet) sample quadrants. Within each interval, four 1.0 m^2 (= 39 in. x 39 in.) sample quadrants were spaced 57 ft. (17.5 m) apart (i.e., at 0, 17.5, 35.0, and 52.5 m along each interval). This resulted in a total of 256 1.0 m^2 feeding sign sampling quadrates per monitoring plot.

The UTM coordinate of the starting point (a plot corner) was determined with a hand-held global positioning system unit and the cardinal direction of the first transect was determined with a compass. The starting location was considered interval 1 at the 0 m sample quadrant. At this point, a 1 m^2 open-front PVC sample quadrate frame was placed on the ground in front of the observer's feet. Presence or absence of Abert's squirrel feeding sign within, or touching, the sampling quadrate frame was recorded. Subsequent sampling locations (i.e., each 17.5 m) were paced with bearing maintained by compass. Observers pace was periodically measured and checked with a meter tape. Coordinates of each of the three remaining plot corners were obtained and recorded as encountered. Following completion of the plot, a map of the study area was drawn and notes about habitat and animals observed were recorded. In addition, other evidence of current or past occupancy of the stand by Abert's squirrel was noted.

Habitat

The collection of habitat data was based on a modification of protocols developed for describing red squirrel habitat on Carson National Forest (Frey 2003). Habitat data were collected on 10 randomly placed belt transects on each monitoring plot. Each belt transect was 32.8 x 57.4 ft (10 m x 17.5 m) and was positioned between adjacent feeding sign sample quadrates. Together, the 10 random belt transects sampled a 0.43 acre (0.17 ha) area of a monitoring plot. Slope and aspect of the surrounding terrain were visually estimated. At each end of the belt transect, a spherical densitometer was used to assess canopy closure in the 4 cardinal directions and a ruler was used to measure litter depth. The observer slowly walked the transect recording the species and DBH size class of each tree, snag, and cut stump at least 50% within the belt. All trees were placed into 7 size classes based on diameter at breast height (DBH) including: < 4 in (= 10 cm), 4-8 in (= 10-20 cm), 8-12 in (= 20-30 cm), 12-16 in (= 30-40 cm), 16-20 in (= 40-50 cm), 20-24 in (= 50-60 cm), and > 24 in (= 60 cm). The number of standing dead trees (snags) and cut stumps were counted for 2 diameter size classes including < 8 in (= 20 cm) and > 8 in (= 20 cm). In 2006, the large stump size class was subdivided into 2 classes including: 8-16 inch (= 20-40 cm) and > 16 inch (= > 40 cm). All tree, snag, and stump densities were reported as the mean number within a 1,883 ft^2 (= 175 m^2) area. To calculate the mean density of trees per acre, use the following formula: density = mean number of trees per plot / 0.043. Percent ground cover was visually estimated on the plot. Ground cover classes included forbs, grasses, litter, bare ground, downed logs, and other. Percent cover classes were: 1 (0-5 % cover), 2 (5-25 % cover), 3 (25-50 % cover), 4 (50-75 % cover), 5 (75-95 % cover), and 6 (95-100 % cover). Using the same cover classes, understory cover of woody shrubs and saplings < 39 in (= 1 m) tall were visually estimated. Dominant understory species were recorded.

Data analysis

Squirrel density estimation.—The incidence of feeding sign encountered on each monitoring plot was used as an index of Abert's squirrel density. On each monitoring plot, the percentage of the 256 1.0 m^2 sampling quadrates containing feeding sign was calculated. Density was then estimated using a previously determined feeding sign index regression model curve supplied by Norris Dodd (Figure 1). This model represents the relationship between the percentage of quadrates containing feeding sign and the density of the squirrel population. Density estimates and prediction intervals were calculated for each monitoring plot. To convert density of squirrels per hectare to squirrels per acre, divide the displayed density by 2.471.

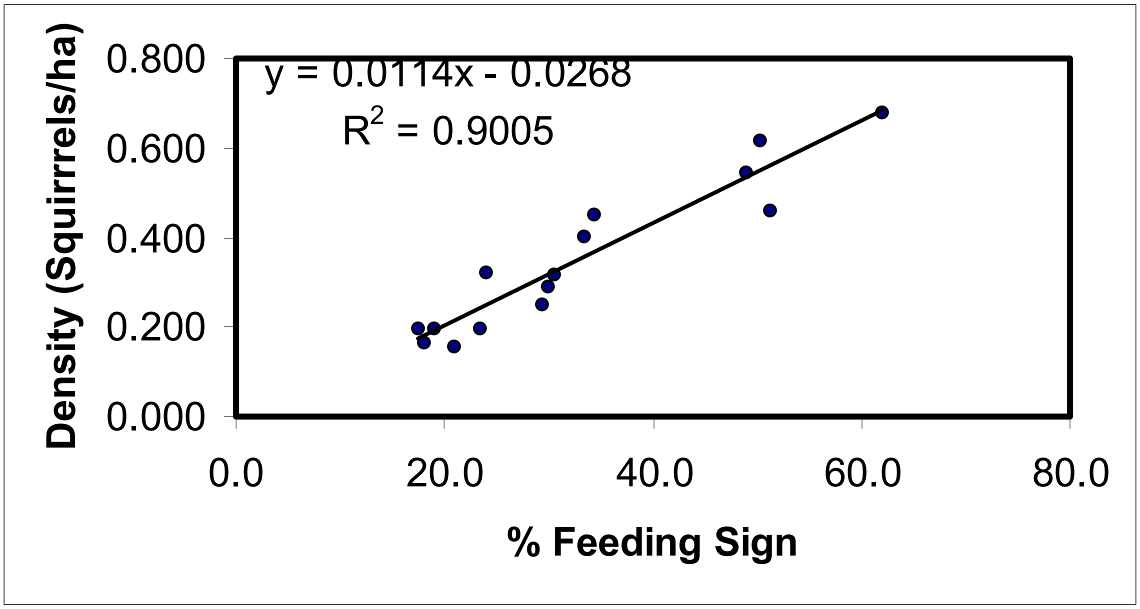

Figure 1. *Regression model between percentage feeding sign and Abert's squirrel density developed by Norris Dodd in Arizona.*

The percent of plots occupied by squirrels and squirrel density were non-normal based on one-sample Kolmogorov-Smirnov tests with Lilliefors significance correction for small sample sizes and Shapiro-Wilk tests. Consequently, nonparametric statistics were used where possible in analyses involving these variables. To test for annual differences in Abert's squirrel plot occupancy and density, Kruskal-Wallis tests were used for comparisons among the 4 years and Mann-Whitney tests were used for comparisons between pairs of years.

Habitat.—Habitat variables across all 3 years were checked for normality using a one-sample Kolmogorov-Smirnov test. All variables were non-normal ($P < 0.05$) except canopy closure, grass cover, herbaceous cover (= sum of grass and forb cover) and litter cover. Consequently, nonparametric tests were used for non-normal variables where possible.

Differences in each habitat variable across the 3 years (2004 – 2006) were tested using ANOVA for normal variables and Kruskal Wallis tests for non-normal variables. To test for multivariate differences in habitat among years, a principal components analysis was used to reduce the number of variables into gradient component variables. The component variables were then subjected to discriminant function analysis. A chi-square transformation of the Wilks' lambda obtained from the discriminant analysis was used to determine significance of any differences among the years.

Spearman correlations were used to assess univariate relationships between Abert's squirrel density and habitat variables. Spearman and Pearson correlations were used to assess univariate relationships among all pair-wise comparisons of habitat variables. This included an assessment of habitat features associated with general vegetation zones. Abert's squirrels are typically associated with the mid-elevation ponderosa pine forest zone. However, the species' distribution also includes the lower elevation ecotone with piñon-juniper woodland zone (dominated by junipers and piñons) and the higher elevation mixed coniferous forest zone (dominated by Douglas fir and white fir). For these analyses, ponderosa pine forest was defined by the sum of all ponderosa pine size classes, piñon-juniper woodland was defined by the sum of all piñon and juniper size classes, and mixed coniferous forest was defined by the sum of all Douglas fir and white fir size classes.

Principal components analysis was used to describe habitat of the 30 repeated monitoring plots in relation to one another. The number of variables was reduced *a priori* by reviewing all pair-wise correlations among squirrel density and habitat variables. The final ratio of the number of plots to the number of variables (3:1) in the principal components analysis was deemed suitable for descriptive purposes (McGarigal et al. 2000). Only components that had eigenvalues > 1.0 were extracted because these usually sufficiently describe the variance in the variables. Loadings with a minimum absolute value of 0.40 were considered significant and were used to describe patterns (McGarigal et al. 2000). Components retained for interpretation were based on the scree plot criterion, wherein a dramatic break in the curve of a plot between the component number and eigenvalue serves to identify those components for retention. (McGarigal et al. 2000, McCune and Grace 2002).

Stepwise multiple regression (probability of F to enter = 0.05 and F to remove = 0.10) was used to produce models to predict Abert's squirrel density based on habitat variables.

Stands were classified as Abert's squirrel present or absent. To test whether habitat variables differed in stands where squirrels were present at any monitoring period between 2004 and 2006 versus stands where squirrels were always absent, ANOVA tests were used for normal variables and Mann-Whitney tests were used for non-normal variables. Abert's squirrel plot occupancy was calculated as the proportion of years when squirrels were detected on each of the 30 monitoring plots replicated between 2004 and 2006. Stepwise multiple regression was used to determine the best predictors of plot occupancy.

All descriptions, data, analyses, results, and recommendations presented in this report supersede those presented in earlier reports.

Results

Squirrel Distribution and Density

Year 2006

A total of 37 monitoring plots were sampled across the 6 forest districts from 17 May to 8 June 2006 (Appendix 1 and 2). These included 31 existing plots that had been monitored during previous years and 6 new plots on the Valle Vidal Unit. Of the 31 previously existing monitoring plots, fresh Abert's squirrel feeding sign was found in at least 1 of the 256 1-m^2 sampling quadrants on 20 (64.5 %) of the 31 monitoring plots. However, of the 11 plots where feeding sign was not recorded in a sampling quadrant, other fresh off-quadrant sign of Abert's squirrel was observed on 6 of the plots. Thus, a total of 26 (83.9 %) of the 31 previously existing monitoring plots had evidence of Abert's squirrel use, which was higher than in 2005. The percent of the 256 quadrants on the 31 existing monitoring plots that had feeding sign ranged from 0 to 7.81 % with a mean of 1.64 % (SD = 2.22). Abert's squirrel density on each of the existing monitoring plots ranged from 0 to 0.06 per hectare (= 0 - 0.148 per acre), with a mean of 0.01 per hectare (= 0.025 per acre) or 1 squirrel per 100 ha (= 1 squirrel per 247 acres). However, 11 (35%) of the 31 plots had a density of 0 (Appendix 1). The 90 % prediction intervals of the density estimates overlapped among all the plots, indicating that squirrel densities were not significantly different among plots (see Appendix 1).

Of the 6 newly established plots on the Valle Vidal Unit, fresh Abert's squirrel feeding sign was found on at least 1of the 256 1-m^2 sampling quadrants on all of the plots. The percent of the 256 quadrants on each of the 6 new plots that had feeding sign ranged from 3.13 to 10.55 % with a mean of 8.01 % (SD = 2.78). Abert's squirrel density on the new plots ranged from 0.01 to 0.09 per hectare (= 0.025 - 0.222 per acre), with a mean of 0.07 per hectare (= 0.173 per acre) or 1 squirrel per 14.3 ha (= 1 squirrel per 35 acres). Four of these plots had the highest densities yet observed on Carson National Forest (Appendix 2). Density on the 6 new plots was significantly higher than on the 31 existing plots during 2006 ($Z = -3.397$, $P < 0.001$).

When considering all 37 plots monitored during 2006 on Carson National Forest, squirrel density ranged from 0 to 0.09 per hectare, with a mean of 0.02 per hectare (= 0.049 per acre) or 1 squirrel per 50 ha (= 1 squirrel per 123 acres).

Annual variation

When comparing the 30 sites that were annually monitored between 2003 and 2006, significant differences in plot occupancy (i.e., the percentage of plots occupied by Abert's squirrels) and density of Abert's squirrel were found (Table

1). In general, there has been an overall trend towards increasing distribution and abundance of squirrels, despite a slight decrease in plot occupancy in 2004 (Table 1, Figure 2). Plot occupancy and mean squirrel density were highest in 2006, although the range of density was higher in 2005 (Table 1). There was no significant difference in density or percent occupancy between 2003 and 2004 (Z = -0.654, P = 0.513; Z = -0.772, P = 0.440), or between 2005 and 2006 (Z = -0.421, P = 0.674; Z = -0.932, P = 0.351). However, there was a significant difference in squirrel density between 2003 and 2005 (Z = -2.510, P = 0.012) and between 2004 and 2005 (Z = -2.016, P = 0.044). Further, there was a significant difference in density and plot occupancy between 2003 and 2006 (Z = -2.550, P = 0.011; Z = -1.989, P = 0.047) and between 2004 and 2006 (Z = -2.159, P = 0.031; Z = -2.716, P = 0.007).

Table 1. *Comparison of the mean percent of plots occupied by Abert's squirrels and the Abert's squirrel density on 30 plots monitored between 2003 and 2006 on Carson National Forest. Kruskal-Wallis test results are presented for differences among the 4 years.*

	2003	2004	2005	2006	X^2	P
Percent plot occupancy	60.0	50.0	73.3	83.3	8.627	0.035
Density (squirrels/ha)						
mean	0.005	0.005	0.010	0.012	11.083	0.011
SE	0.002	0.001	0.002	0.003		
range	0 - 0.05	0 - 0.01	0 - 0.07	0 - 0.06		

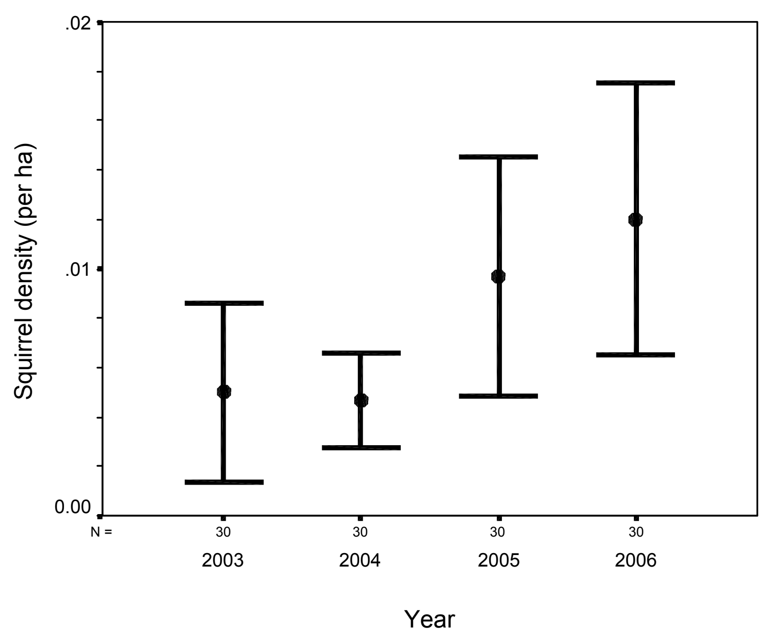

Figure 2. *Abert's squirrel density on 30 repeated monitoring plots on Carson National Forest during 2003 - 2006. Dots represent means and error bars represent 1 standard error around the mean.*

Habitat

Annual variation

Univariate analyses revealed that 15 of 49 habitat variables (30.6%) exhibited significant ($P < 0.05$) differences among the years. The multivariate discriminant function analysis of 16 component variables (that together accounted for 80.2 % of the variation) also resulted in a significant difference in habitat among the years ($\lambda = 0.119$, $X^2 = 167.161$, $df = 32$, $P = 0.000$). In the case of one variable (understory cover), it was determined that variation among the years was due to methodological differences between 2004-2005 and 2006. There are several additional factors that may account for differences in habitat measured among the years. A primary reason is likely due to the relatively small area of each plot sampled for habitat each year (i.e., during each year only 0.73 % of the area of each plot was sampled for habitat). Other reasons may include difference in field crewmember makeup leading to observer bias; slight shifts in plot locations due to poor GPS reception and bearing drift; and actual differences in vegetation as a result of weather or climate. Consequently, for all subsequent analyses habitat data and squirrel densities from all 3 years were combined and averaged, except understory cover for which only 2004 and 2005 were combined.

Vegetation zones

Ponderosa pine forest was significantly associated with more Douglas fir (0-12 inch DBH size classes) and more cut stumps of all size classes. These results reflect the common co-occurrence of Douglas fir within ponderosa pine forests and the history of tree cutting in these stands. In contrast, piñon-juniper woodland ecotone was significantly associated with denser understory cover, greater numbers of small oaks (0-8 inch DBH), steeper slopes, and deeper litter depth. These results primarily reflect the more common occurrence of thickets of the shrub form of Gambel oak within this vegetation zone. This is a successional scrubland that follows disturbance in piñon-juniper woodland and lower ponderosa pine forest (Dick-Peddie 1993). Steeper slopes may be associated with increased aridity and disturbance due to erosion, which may promote growth of more arid-adapted junipers and piñons. Finally, the mixed coniferous forest ecotone was significantly associated with cut stumps of larger size classes (i.e., > 12 inches diameter) and higher canopy closure. The higher density of cut stumps reflects the history of timber harvesting in this forest type.

Squirrel distribution

Three of the 30 repeated monitoring plots (J8, J9, SA13) did not have Abert's squirrels from 2003-2006. These 3 plots had significantly ($P < 0.05$) lower canopy closure, density of ponderosa pine, and density of cut stumps, but significantly higher bare ground, understory cover, and density of piñon pine. Stepwise multiple regression revealed density of 12-16 inch DBH ponderosa pine as the best predictor of Abert's squirrel plot occupancy ($r^2 = 0.463$, F = 24.173, $P < 0.001$; Figure 3). The only additional significant variable that improved this model ($r^2 = 0.548$, F = 16.378, $P < 0.001$) was "other ground cover", which consisted primarily of downed woody debris.

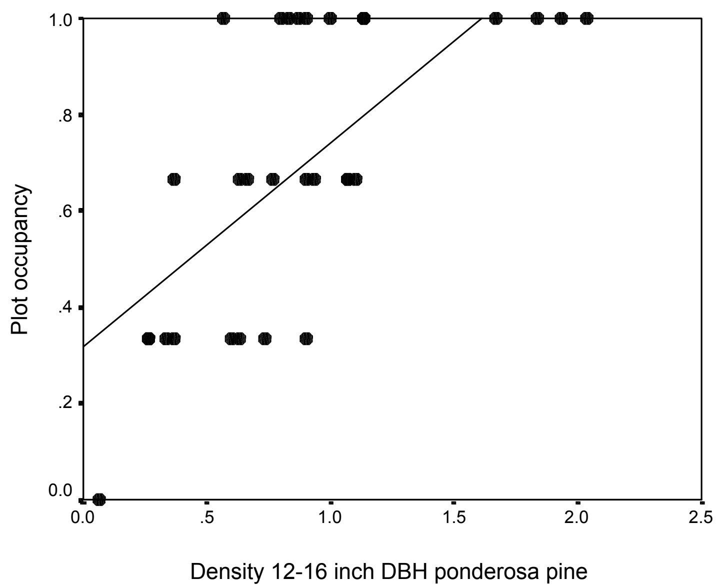

***Figure 3.** Relationship between density of 12-16 inch DBH ponderosa pine and Abert's squirrel plot occupancy on 30 monitoring plots sampled during 2004 to 2006 on Carson National Forest.*

Squirrel density

Univariate relationships.—Mean Abert's squirrel density exhibited the strongest significant positive correlations with 12-16 inch DBH ponderosa pine ($r_s = 0.686$; $P < 0.001$; Figure 4), 16-20 inch DBH ponderosa pine ($r_s = 0.657$; $P < 0.001$), and 20-24 inch DBH ponderosa pine ($r_s = 0.542$; $P = 0.002$). Weaker significant positive correlations with squirrel density included canopy closure ($r_s = 0.454$, $P = 0.012$), litter depth ($r_s = 0.433$; $P = 0.017$), and 0-4 inch DBH ponderosa pine ($r_s = 0.423$; $P = 0.020$). In contrast, Abert's squirrel density exhibited significant negative correlations with 4-8 inch DBH oak ($r_s = -0.464$; $P = 0.010$), 4-8 inch DBH juniper ($r_s = -0.459$; $P = 0.011$), understory cover ($r_s = -0.390$; $P = 0.033$), and bare ground ($r_s = -0.383$; $P = 0.037$).

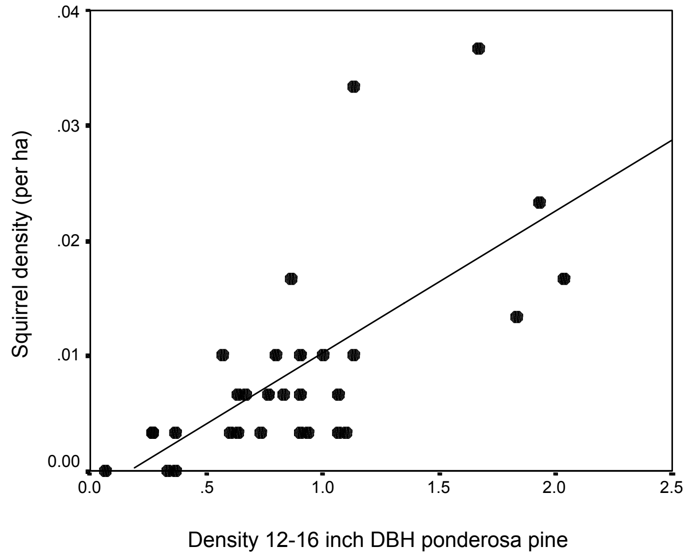

Figure 4. *Significant relationship between 12-16 inch DBH ponderosa pine and Abert's squirrel density on Carson National Forest during 2004-2006.*

Principal components analysis.—In order to maintain an appropriate ratio of samples to variables (i.e., ca > 3:1) in the principal components analysis, 10 variables were selected that exhibited high correlations with squirrel density and that had low correlations (i.e., < 0.7) with other variables. Variables included in the analysis were: canopy closure, understory cover, bare ground cover, herbaceous cover (= sum of forb and grass cover), 0-4 inch DBH ponderosa pine, 12-16 inch DBH ponderosa pine, 20-24 inch DBH ponderosa pine, total piñons and junipers of all size classes (i.e., piñon-juniper woodland), total Douglas fir and white fir of all size classes (i.e., mixed coniferous forest), and 8-16 inch diameter cut stumps. The principal components analysis resulted in the extraction of 4 significant components, which together accounted for 81.6 % of the variance. The scree plot criterion indicated that the first 2 components (57.2 % of total variation) should be retained for interpretation.

On component 1, variables with significant positive loadings (listed from highest to lowest) included 12-16 inch DBH ponderosa pine, canopy closure, 20-24 inch DBH ponderosa pine, 8-16 inch diameter cut stumps, 0-4 inch DBH ponderosa pine, and total Douglas fir/white fir. Variables with significant negative loadings included bare ground cover and herbaceous ground cover. In order to interpret these results it was necessary to further explore habitat variables that were associated with bare ground and herbaceous ground cover. Correlations revealed highly significant negative correlations ($r_s < -0.6$) among bare ground, litter ground cover, and herbaceous ground cover. Bare ground cover was associated with piñon woodland, litter ground cover was associated with ponderosa pine forest, and herbaceous ground cover was associated with meadows (i.e., open canopy with low slope) or aspen. Further, bare ground had a significant positive correlation with piñon and significant negative correlations with ponderosa pine, Douglas fir, canopy closure, litter depth, litter ground cover, and cut stumps. Thus, component 1 likely represents a vegetation zone gradient of plots on relatively mesic, mature ponderosa pine forest (especially near the mixed conifer forest ecotone) to plots at the more arid piñon-juniper ecotone and those with more canopy openings (e.g., meadows). On this component, plots with the highest squirrel densities had positive scores, while those with low densities had negative scores (Figure 5).

On component 2, variables with significant positive loadings (listed from highest to lowest) included total piñons/junipers and understory cover. Variables with significant negative loadings included herbaceous ground cover and 0-4 inch DBH ponderosa pine. Thus, component 2 likely represents a successional gradient of plots in open sites within the ponderosa pine forest zone with ponderosa pine recruitment to plots in the lower piñon-juniper woodland ecotone with oak recruitment. The highest squirrel densities tended to have intermediate to negative scores on this axis (Figure 5).

A scatter plot of the 30 monitoring plots on components 1 and 2 revealed that plots with the highest squirrel densities tended to be clustered on the right middle part of the graph (circled area on Figure 5). Based on axis gradients, these plots tended to be mature upper ponderosa pine forests. In contrast, plots with very low squirrel densities tended to be in the piñon-juniper woodland ecotone with a dense successional understory of oaks.

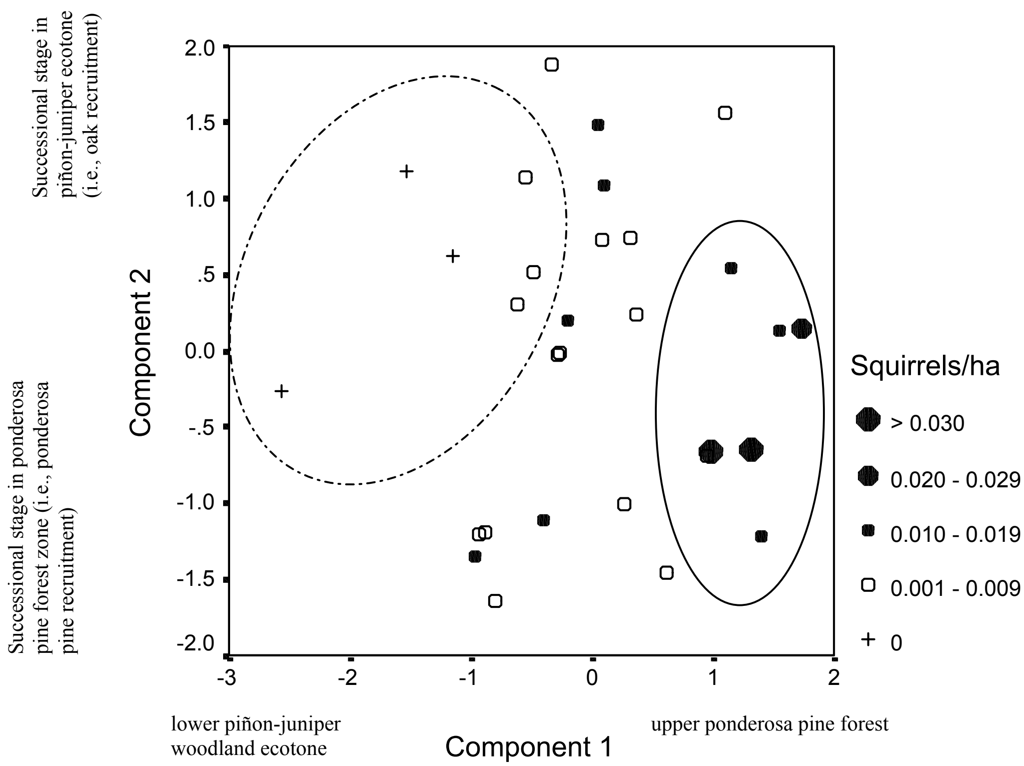

Figure 5. *Scatter plot of habitat characteristics on principal components 1 and 2 for 30 Abert's squirrel monitoring plots sampled during 2004 to 2006 on Carson National Forest. Variables contributing to each axis gradient are indicated in small font. Clusters of plots with high squirrel densities (solid line) and low squirrel densities (dashed line) are indicated with ovals.*

***Regression models.*—**The stepwise multiple regression produced 4 highly significant models for predicting Abert's squirrel density ($P \leq 0.001$; Table 2). The simplest model contained a single predictor of Abert's squirrel density, which was the density of 12-16 inch DBH ponderosa pine (Table 2, model #1). However, this model had a low r^2, indicating that the model only accounted for a small proportion of the variation in density (i.e., the model does not fit the data well). Other models with higher r^2 values contained additional significant predictor variables including 0-4 DBH Douglas fir, understory cover, and 16-20 inch DBH ponderosa pine. Understory cover was the only predictor variable that was negative. Models with increasing numbers of predictor variables also have higher r^2 values. However, a larger number of variables can cause a model to be over fit and more difficult to interpret and use. Model 3, which contained 3 variables (density of 12-16 inch DBH ponderosa pine, density of 0-4 inch DBH Douglas fir, understory cover) was deemed the best model for predicting Abert's squirrel density based on its high r^2 value, significance of all coefficients, low number of variables that represent different major components of forest structure, and relatively low r^2 change for model 4.

Table 2. *Statistics for significant ($P \leq 0.001$) regression models of Abert's squirrel density produced through stepwise selection of all habitat variables collected on 30 monitoring plots on Carson National Forest during 2004 to 2006. Nonsignificant coefficients ($P > 0.05$) are indicated with an asterisk.*

Model	*R*	r^2	ANOVA F	Variable[1]	Coefficient	SE
1	0.674	0.455	23.331	constant	-0.00207*	0.003
				PP 12-16	0.01234	0.003
2	0.799	0.639	23.899	constant	-0.00263	0.226
				PP 12-16	.01167	0.000
				DF 0-4	0.01480	0.001
3	0.862	0.742	24.962	constant	0.01027	0.027
				PP 12-16	0.01017	0.000
				DF 0-4	0.01515	0.000
				Understory	-0.00562	0.003
4	0.889	0.791	23.626	constant	0.01083	0.013
				PP 12-16	0.00649	0.010
				DF 0-4	0.01631	0.000
				Understory	-0.00601	0.001
				PP16-20	0.00672	0.024

[1]Letters abbreviations represent ponderosa pine (PP) and Douglas fir (DF); numbers are diameter at breast height (inches) size classes.

Valle Vidal unit

Squirrel density on the 6 new monitoring plots established on the Valle Vidal Unit was significantly higher than on the 31 existing plots (Mann-Whitney test: $Z = -3.397$, $P < 0.001$; Figure 6). Based on Mann-Whitney tests, the new plots had significantly ($P < 0.05$) higher densities of 4-12 inch DBH ponderosa pine, 0-12 inch DBH Douglas fir, and > 12 inch diameter snags, but significantly lower densities of 0-8 inch DBH juniper and > 16 inch diameter cut stumps. The positive relationship with Douglas fir density and negative relationship with juniper density indicate that the new Valle Vidal plots were located in the higher mixed coniferous forest ecotone. Results of other analyses have suggested that Abert's squirrel densities tend to be higher in such ecotone forest stands. Without additional information it is not possible at this time to interpret the cause of the lower density of large diameter cut stumps or the higher density of large snags or their relationship with squirrel density on these plots.

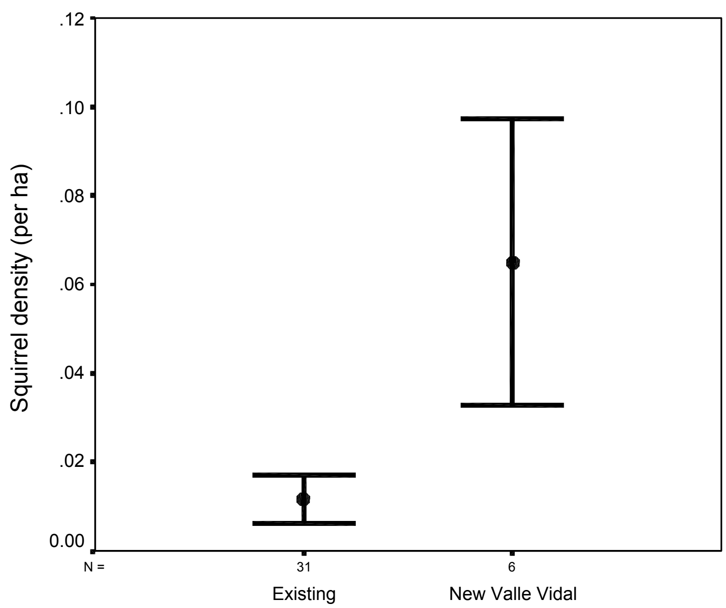

***Figure 6.** Abert's squirrel density on 31 existing monitoring plots and on 6 new monitoring plots in the Valle Vidal Unit during 2006. Dots represent means and error bars represent 1 standard error around the mean.*

Cut stumps

The principal components and plot occupancy analyses suggested a positive relationship between density of cut stumps and squirrel density. The correlation between density of 8-16 inch diameter cut stumps and squirrel density and was nearly significant ($r_s = 0.325$, $P = 0.080$). Thus, it is possible that past tree cutting has had a positive effect on Abert's squirrel densities. However, in the vegetation zone analysis, it was found that the piñon-juniper ecotone had significantly fewer cut stumps, ponderosa pine forests had significantly more cut stumps of all size classes, and the mixed coniferous forest ecotone had significantly more cut stumps of large size class. Thus, because of the great variation in forest types sampled, it is possible that the relationship observed between density of cut stumps and density of squirrels was a spurious result of squirrels preferring habitat types that also happen to be habitat types where trees are more likely to be cut.

To evaluate potential reasons for the relationship between cut stump density and squirrel density, it was necessary to control for forest type, especially the influence of the lower elevation piñon-juniper woodland ecotone. This was accomplished by creating a new variable (percent piñon-juniper), which was the percentage of the summed density of all sizes classes of piñon and juniper trees in relation to the summed density of all size classes of ponderosa pine trees. Plots with higher values of percent piñon-juniper had greater influence of the piñon-juniper zone. Partial correlations were then used to control for the percent piñon-juniper in evaluating the relationship between densities of cut stumps and squirrels. The resulting relationships between stump densities of all size classes and squirrel density were highly insignificant ($P > 0.4$). This result is interpreted that the apparent relationship between the density of cut stumps and density of squirrels in this study was likely a spurious result of Abert's squirrels preferring relatively mesic ponderosa pine stands, which also happen to be those where past tree cutting has occurred. Thus the results do not reveal any relationships between the intensity of past cutting (as evidenced by current density and size class of cut stumps) and current Abert's squirrel density.

Partial correlations controlling for percent piñon-juniper revealed significant relationships between density of cut stump and certain forest stand variables. For example, there was a significant positive correlation between densities of all size classes of stumps with density of < 4 inch DBH ponderosa pine, which suggests recruitment of ponderosa pine in areas that have been cut. In contrast, there was a significant negative correlation between density of all size classes of stumps with density of > 24 inch DBH ponderosa pine, indicating that larger diameter ponderosa pine occurred in areas with less past tree cutting. There were no other significant correlations between density of cut stumps and other size classes of ponderosa pine. However, there was a significant positive relationship between the density of small diameter (<12 inch) cut stumps and the density of small (0-8 inch DBH) Douglas fir. This suggests that Douglas fir recruitment has occurred in areas where there has been cutting of small diameter trees. In addition, there was a significant positive relationship between density of all size classes of stumps and the density of large (16-20 inch DBH) Douglas fir. Reasons for this relationship are unknown, but could result from ecological release or association with highly productive areas.

Piñon-juniper ecotone

Further analyses of percent piñon-juniper on a plot provided additional insight into factors associated with Abert's squirrel distribution and density. First, the 3 plots where Abert's squirrels were never recorded had significantly higher percent piñon-juniper than plots where squirrels have been recorded (Mann-Whitney test: $Z = -2.398$, $P < 0.016$). Further, there was a significant negative correlation between percent piñon-juniper and squirrel density during 2006 ($r_s = -0.300$, $P = 0.015$). These data indicate that Abert's squirrels are less likely to be found and have lower densities at the piñon-juniper ecotone. Inclusion of plots in these relatively poor quality habitats influences the overall mean squirrel density reported for Carson National Forest. If only the 22 plots with the lowest percent piñon-juniper (< 20) are included, mean squirrel density is increased from 0.02 to 0.03 squirrels per hectare across the forest (= 1 squirrel per 82 acres).

Variables found to be significantly correlated with squirrel density, while controlling for percent piñon-juniper included: 12-16 inch DBH ponderosa pine ($r_{[\%\ p\text{-}j]} = 0.6250$, $P < 0.001$); 16-20 inch DBH ponderosa pine ($r_{[\%\ p\text{-}j]} = 0.4892$, $P = 0.007$); 0-4 inch DBH Douglas fir ($r_{[\%\ p\text{-}j]} = 0.4538$, $P = 0.013$); 8-12 inch DBH Douglas fir ($r_{[\%\ p\text{-}j]} = 0.4508$, $P = 0.014$); and understory cover ($r_{[\%\ p\text{-}j]} = -0.3968$, $P = 0.033$). Variables nearly significant ($P < 0.10$) included: canopy closure ($r_{[\%\ p\text{-}j]} = 0.3625$, $P = 0.053$). 20-24 inch DBH ponderosa pine($r_{[\%\ p\text{-}j]} = 0.3508$, $P = 0.062$), and litter depth($r_{[\%\ p\text{-}j]} = 0.3283$, $P = 0.082$). The inclusion of small diameter Douglas fir as a positive correlate with Abert's squirrel density emphasizes that squirrel densities are likely higher at the upper edge of the ponderosa pine zone (i.e., at the mixed conifer forest ecotone).

Red squirrel feeding sign

Analyses revealed a relationship between the density of Douglas fir and the density of Abert's squirrel. It is possible that this relationship might be influenced by inadvertently recording some red squirrel feeding sign as Abert's squirrel feeding sign. Although red squirrels often remove cone scales closer to the core, cone cores discarded by both species are similar and it is not always possible to discriminate between them. Red squirrels are typical inhabitants of mixed coniferous forest and their distribution can overlap with Abert's squirrel in the ponderosa pine-mixed conifer ecotone, which is characterized by the presence of Douglas fir and white fir. During field monitoring, observations of red squirrels (including sightings, vocalizations, middens, and cone cores) were recorded. During 2006 red squirrel sign was reported on, or near, 5 plots (SA38, SA44, SA55, V3, V6). However, there was no significant difference ($P > 0.05$) in the proportion of the different types of squirrel feeding sign (e.g., cone cores, peeled twigs, cut terminal needle clusters, fungal digs) between sites where red squirrels were observed or not observed. Thus, the potential inclusion of red squirrel sign likely has little influence on statistics related to Abert's squirrel density.

DISCUSSION

Comparisons with other studies

Although mean Abert's squirrel density in 2006 was the highest yet reported for Carson National Forest (i.e., 1 squirrels per 50 ha; = 1 per 123 acre), mean density remained low in relation to other studies (Table 3). Maximum Abert's squirrel densities in high quality, uncut forests can exceed 1 squirrel per 2.4 ha (= 41.7 squirrels per 100 ha; 1 squirrel per 5.9 acre; Brown 1984) and a local high density in excess of 1 squirrel per 0.8 ha (=125 squirrels per 100 ha; 1 squirrel per 2.0 acre) has been reported (Keith 1965). However, more typical levels are 1 squirrel per 20 to 40 ha (= 2.5 to 5.0 per 100 ha; 1 squirrel per 8 to 16 acres; Brown 1984).

However, data collected by similar methods in adjacent states during recent years suggest that Abert's squirrel densities have been relatively low regionally. For example, a 50 to 70% decline in density of Abert's squirrel was documented in Arizona from 2001 to 2002 (Norris Dodd personal communication). Similarly, at 7 sites in Utah, Abert's squirrel densities experienced a population crash between 2001 and 2002 with continued lowering of densities in 2003. Densities at the Utah sites averaged 0.14 squirrels/ha in 2001, 0.04 squirrels/ha in 2002, and 0.01 squirrels/ha in 2003 (Norris Dodd personal communication). In southwest Colorado, similar declines occurred between 2003 and 2004 (R. Ghormley personal communication). Abert's squirrel density on Carson National Forest during 2005 and 2006 was similar to that during 2003 and 2004 in Utah and Colorado (Table 3).

Regionally low squirrel densities

In comparing Abert's squirrel monitoring results on Carson National Forest with other recent studies conducted in adjacent states, two patterns are apparent (Table 3). First, it appears that the entire region experienced declines in Abert's squirrel densities from 2001 to 2004. These regional declines are probably attributable to drought conditions. Climate in the Southwest is closely tied to the El Niño-Southern Oscillation (ENSO) phenomenon in the central tropical Pacific Ocean. Pacific warm phases (i.e., low southern oscillation index), called El Niño events, produce wet periods in the Southwest, while Pacific cold phases (high southern oscillation index), called La Niña events, produce dry periods. Palmer Drought Indices from the NOAA National Climate Data Center (available at http://lwf.ncdc.noaa.gov/oa/climate/research/drought/palmer-maps/ and at http://lwf.ncdc.noaa.gov/oa/climate/onlineprod/drought/main.html) were reviewed to assess climate patterns (Table 4, Figure 7). In north-central New Mexico,

Table 3. *Examples of reported Abert's squirrel densities. Moisture is reported as the representative Palmer drought severity index.*

Year	Location	Conditions	Moisture	Density (per 100 ha)	Method	Reference
1941	Coconino NF, northern Arizona	"heavily cutover"	moist (+6)	4.8	trapping	Keith 1965
	Coconino NF, northern Arizona	virgin stand	moist (+6)	20.2	trapping	Keith 1965
1954	Coconino NF, northern Arizona	"heavily cutover"	drought (-2)	0.6	trapping	Keith 1965
	Coconino NF, northern Arizona	virgin stand	drought (-2)	2.0	trapping	Keith 1965
1970	Black Forest, east-central Colorado	unknown	moist (+3)	4.9	unknown	Ramey 1973
	Boulder County, north-central Colorado	medium stocked, all-age stand	moist (+5)	33.3	mark-recapture	Farentinos 1972
1971	Black Forest, east-central Colorado	unknown	normal (0)	2.0	unknown	Ramey 1973
	Boulder County, north-central Colorado	medium stocked, all-age stand	moist (+4)	30.6	mark-recapture	Farentinos 1972
1996-1997	western Mogollon Plateau, north-central Arizona	7 study sites	drought (-5) to moist (+1)	16.0	mark-recapture	Dodd 1998
1998	Mt Trumbull, northern Arizona	2 treatment	moist (+3)	14.7	feeding sign	Dodd 1998
	Mt Trumbull, northern Arizona	1 control stand	moist (+3)	23.6	feeding sign	Dodd 1998
	Camp Navajo, Arizona	2 treatment	moist (+3)	17.2	feeding sign	Dodd 1998
	Camp Navajo, Arizona	1 control stand	moist (+3)	9.0	feeding sign	Dodd 1998
1999-2002	Coconino NF, north-central Arizona	12 high quality plots	drought	42	feeding sign	Dodd et al. 2006
	Coconino NF, north-central Arizona	13 low quality stands	drought	16	feeding sign	Dodd et al. 2006
2001	southeast Utah	7 study sites	drought (-2)	14.0	feeding sign	N. Dodd pers. comm.
2002	southeast Utah	7 study sites	drought (-6)	4.0	feeding sign	N. Dodd pers. comm.
2003	**Carson NF, northern New Mexico**	**31 random stands**	**drought (-5)**	**0.5**	**feeding sign**	**current study**
	southeast Utah	7 study sites	drought (-4)	1.0	feeding sign	N. Dodd pers. comm.
	San Juan NF, southwest Colorado	unknown	drought (-5)	4.4	feeding sign	R. Ghormley pers. comm.
2004	**Carson NF, northern New Mexico**	**31 random stands**	**drought (-3) to moist (+1)**	**0.5**	**feeding sign**	**current study**
	San Juan NF, southwest Colorado	27 plots in optimal habitat	drought (-4)	0.8	feeding sign	R. Ghormley pers. comm.
	Mt Trumbull, northern Arizona	3 thinned, burned, reseeded	drought (-3)	1.0	feeding sign	Wightman et al 2004
	Mt Trumbull, northern Arizona	3 control stands	drought (-3)	12.0	feeding sign	Wightman et al 2004
2005	**Carson NF, northern New Mexico**	**31 random stands**	**moist (+4)**	**1.0**	**feeding sign**	**current study**
	Apache-Sitgreaves NF east-central Arizona	6 control stands	moist (+5)	9.0	feeding sign	R. Rugg pers. comm.
	Apache-Sitgreaves NF east-central Arizona	13 goshawk treatment	moist (+5)	11.0	feeding sign	R. Rugg pers. comm.
	Apache-Sitgreaves NF east-central Arizona	6 pre-settlement treatment	moist (+5)	15.0	feeding sign	R. Rugg pers. comm.
2006	**Carson NF, northern New Mexico**	**37 random stands**		**2.0**	**feeding sign**	**current study**

drought conditions began in 2000 and extended into the beginning of 2004, with the most widespread and severe drought conditions in 2002 and 2003. In contrast with previous years, moisture was high during 2005 and again during summer 2006. Thus, the increased density of Abert's squirrel on Carson National Forest during these years probably was due to increased moisture.

Table 4. *Palmer drought severity indices during May periods between 1999-2006 for the southwest region within the range of Abert's squirrel as well as the north-central New Mexico region, which includes most of Carson National Forest.*

Year	Southwest Region	Carson NF
1999	moderate drought to extremely moist	moderately moist
2000	extreme drought to moderately moist	moderate drought
2001	extreme drought to very moist	mid-range
2002	severe drought to extreme drought	extreme drought
2003	extreme drought to mid-range	severe drought
2004	extreme drought to moderately moist	moderate drought
2005	moderate drought to extremely moist	very moist

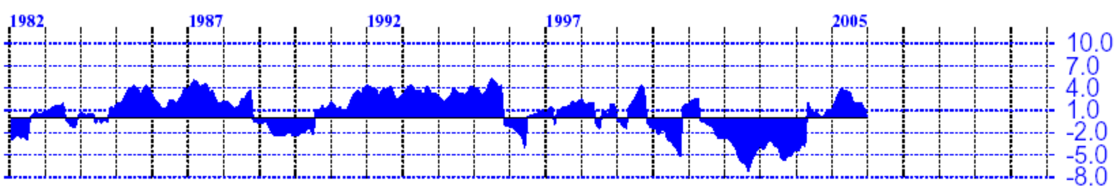

Figure 7. *Monthly Palmer Drought Severity Index for New Mexico region 2, which includes Carson National Forest. An index of 0 = normal precipitation, -2 = moderate drought, -3 = severe drought, and –4 extreme drought. Data are from the National Climate Date Center.*

Drought probably impacts Abert's squirrels primarily through reductions in availability of ponderosa pine cones and hypogeous fungi. Both of these food resources are important in determining Abert's squirrel distribution and abundance (e.g., States et al. 1988). Dodd et al. (1998) thought that drought conditions affected availability of these food resources. The number of cones produced by a particular tree is influenced by its size, age, health, and location (Larson and Schubert 1970 cited in Brown 1984). Ponderosa pine cone crop production exhibits an annual fluctuation with good cone crops typically every 3 to 4 years in the Southwest (Schubert 1974). Overall seed production may be near 0 in some years (e.g., Pearson 1950 as cited in Keith 1965, Rasmussen et al. 1975). The cycle is known to vary with climate but is not reliably periodic (Keyes 2000).

Locally low squirrel densities

Although some studies have reported low Abert's squirrel densities within the range observed for Carson National Forest, densities of Abert's squirrel on Carson National Forest generally were much lower than in other studies conducted at the same time in adjacent states (Table 3). There may be several reasons for this pattern. Two important reasons relate to the relationship between vegetation zones and Abert's squirrel density. In the Southwest, ponderosa pine forests occur in a narrow elevational zone, with its best development typically between 7,544 and 8,692 feet elevation (= 2,300 - 2,650 m; Brown 1994). Ecologically, ponderosa pine forest generally occurs in a mid-elevation zone between the lower, more arid, piñon-juniper woodland zone and below the cooler, more mesic, mixed conifer forest zone. Habitat analyses in this study revealed that Abert's squirrel densities were lower at the lower piñon-juniper ecotone and higher at the upper mixed conifer forest ecotone. This pattern likely reflects a moisture gradient, and hence a productivity gradient, that exist largely due to natural topographic features. Thus, inclusion of stands at the piñon-juniper ecotone will result in relatively low squirrel densities and a low overall mean squirrel density for the forest. The influence of vegetation zone on mean squirrel density is exemplified by inclusion of the 6 new Valle Vidal plots. These plots were at the upper edge of the ponderosa pine zone where Abert's squirrel densities are relatively high. Consequently, the overall mean squirrel density for the forest doubled when these few high-density plots were averaged with the remaining 31 plots.

Related to the influence of vegetation zones, the first potential reason for the relatively low Abert's squirrel densities found on Carson National Forest may be a consequence of the random selection of forest stands. Stands varied in geography, topography, ecology, and management conditions, and included stands at the unproductive piñon-juniper ecotone. There was no attempt to select ponderosa pine stands for their potential to harbor high Abert's squirrel populations. In other studies, especially those designed to examine Abert's squirrel biology or response to specific forest treatments, the location of study areas may not have be random (e.g., Keith 1965). Such studies would be more likely to utilize better developed ponderosa pine stands with the potential for higher Abert's squirrel densities in order to insure adequate sample sizes. Importantly, data presented herein clearly indicate that Abert's squirrel distribution and density is lower at the piñon-juniper ecotone. Thus, inclusion of these sites in this studies results in a lowering of the mean squirrel density for the forest.

Secondly, the relatively low Abert's squirrel densities on Carson National Forest might be attributable to spatial variation in topography and geographic variation in forest community structure. The potential for ponderosa pine forest development varies geographically throughout the Southwest. Large expanses of quality ponderosa pine forest habitat may be best developed in regions, such as the Mogollon Plateau, that have large areas of relatively flat terrain at optimal elevations. In contrast, much of Carson National Forest consists of rugged mountains with steep terrain that function to compress the 7,500 to 8,700 foot contour into a relatively narrow band around the sides of mountains. This zonal compression puts Abert's squirrel populations in relatively close proximity to the arid piñon-juniper woodland zone, which they avoid (see habitat results), and in relatively close proximity to mixed conifer forest, which is occupied by the aggressive and competitively dominant red squirrel (*Tamiasciurus hudsonicus*). Consequently, in areas of high topographic relief, Abert's squirrel populations may be relatively more constrained by factors such as area of available habitat, climate, and competition.

Further, ponderosa pine forest ecosystems may vary in structure and function on geographic scales. For example, Gambel oak, which is a common dominant plant in ponderosa pine forests, exhibits a trend towards a tree growth form in Arizona (which is positively associated with Abert's squirrel density) and a shrub growth form in northern New Mexico and Colorado (which is negatively associated with Abert's squirrel density). Other aspects of the ponderosa pine forest ecosystem may also vary geographically across the range of Abert's squirrel, which may result in natural variation in ability of the forest ecosystem to support Abert's squirrel populations. Habitat conditions for Abert's squirrels may be best expressed on the Mogollon Plateau, which may account for the comparatively high squirrel densities in Arizona, where most studies on the species have been conducted.

Third, climate conditions vary both temporally and spatially. Thus, during a period of time when Carson National Forest is experiencing drought, other areas within the range of Abert's squirrel may be experiencing periods of high moisture (Table 4). Thus, squirrel populations in different geographic regions may be influenced by different local climate and weather patterns.

Fourth, only the inner bark of specific individual ponderosa pine trees with specific genetically controlled chemical traits are used for food by Abert's squirrels (Snyder 1992). The distribution and abundance of suitable target trees within a stand may vary and there is evidence for temporal variation whereby specific target trees are not necessarily consumed each year (Keith 1965, Snyder 1993). Further, Snyder and Linhart (1998) found that the chemical traits of target trees varied geographically such that different Abert's squirrel subspecies were associated with distinct chemical makeup of different associated races of ponderosa pine. Little is known about how spatial and temporal variation in ponderosa pine chemistry might influence Abert's squirrel populations. However, this remains a possible factor in explaining the relatively low Abert's squirrel densities on Carson National Forest.

A final and important potential explanation for the relatively low Abert's squirrel densities on Carson National Forest is past forest management (no active forest management has occurred on any of the plots during this study). Various types of forest management can influence Abert's squirrel densities, especially fire suppression, livestock grazing, thinning, and timber harvesting, (Noss et al. 2006, Prather et al. 2006). In considering effects of management actions, it is important to consider both the temporal and spatial scale of the action. Current forest conditions generally are a product of both current or recent management as well as a deeper history of many decades of fire suppression, livestock grazing, and timber harvesting. On Carson National Forest, current stand conditions are primarily the result of activities that occurred more than 20 years ago, including intensive logging that occurred at the turn of the 20th century. Such management effects are then overlaid on a template of the natural forest potential at a particular site, which is itself determined by topography, climate, soils, and other factors.

Management activities can effect squirrel populations through alterations to either the local or landscape structure of ponderosa pine forest ecosystems (Dodd et al. 2006, Prather et al. 2006). Abert's squirrels depend on ponderosa pines for food production, nest sites, and aboveground travel. Because high cone production is associated with mature yellow pines (i.e., > 60-100 years old; Larson and Schubert 1970) and high truffle production is associated with pole-sized blackjack pine (States 1985), optimal habitat contains both age classes of trees in a density and grouping that also provides for cover, nesting and travel (States et al. 1988). These habitat needs likely are most optimally met in uncut climax ponderosa pine forests and in managed stands with similar structure on productive sites. For example, Dodd et al. (2006) defined high quality Abert's squirrel habitat as unlogged with multiple age classes of trees, a large component of large trees (i.e., 50+ trees/ha with > 18 inch DBH), high basal area (i.e., > 35 m/ha), high canopy closure (i.e., > 50%), and interlocking canopies.

Results of this study indicated that higher Abert's squirrel densities were associated with higher densities of medium and large diameter ponderosa pine, especially at the more productive mixed-conifer ecotone. These results are consistent with previous findings from other geographic areas. For example, Patton (1984; Patton et al. 1985) developed a simple model to predict Abert's squirrel densities based on habitat quality of uneven-aged ponderosa pine stands. In that model, habitat quality was a positive function of increasing density and size of trees. Dodd et al. (1998, 2003) found that at the patch-level squirrel recruitment was associated with interlocking canopy trees and dietary fungi, squirrel fitness was associated with tree basal area, squirrel density was associated with dietary fungal diversity, and squirrel over-winter survival was associated with short duration of snow cover and dietary fungal diversity. More recently (Dodd et al. 2006), Abert's squirrel population parameters were shown to be associated with both patch and landscape level variables. At the patch level density was associated with basal area of trees, recruitment was associated with interlocking trees, and survival was inversely associated with density of saplings; while at the landscape level all three demographic parameters were associated with the proportion of high quality habitat (Dodd et al. 2006). Prather et al. (2006) subsequently developed multiscale models of squirrel density based on tree basal area and canopy closure.

Ponderosa pine forests are a fire-adapted ecosystem. Prior to European settlement, these forests were dominated by widely spaced, fire-tolerant mature trees with a grassy understory; frequent low-intensity fires maintained this system by burning fire-intolerant saplings and other species (Fule et al. 1997, Moore et al. 1999). However, as a consequence of fire suppression coupled with the historical harvesting of large diameter trees, current forests are typically dominated by dense stands of smaller diameter trees, which are more susceptible to stand-replacing fires, insect pests, and drought (Noss et al. 2006). Fire suppression may also prevent nutrient cycling, which can affect many aspects of the forest ecosystem including pine seed production. Belsky and Blumenthal (1997) also implicated livestock grazing as an important source of forest alteration by reduction in herbaceous groundcover that can inhibit conifer recruitment and by reduction in fine fuels that can carry low-intensity fires. Given that Abert's squirrels rely on multiple aspects of the ponderosa pine forest ecosystem, such ubiquitous influences on the structure and function of these forests are likely to have adversely impacted Abert's squirrels across their range.

Timber harvesting has been implicated as detrimental to Abert's squirrel populations at the patch scale (e.g., Keith 1965, Pederson et al. 1987, Patton 1984, Patton et al. 1985, Dodd et al. 2003). Logging can reduce many of the habitat features required by Abert's squirrels including canopy closure, interlocking trees, and density of large trees. Poor seed production can result from logging that results in a younger stand. Similarly, logging can reduce canopy closure and tree basal area, which can result in a decrease in hypogeous fungi production (States and Gaud 1997). This is especially important because truffle production has been shown to be more consistent than production of other foods (States et al. 1988).

In Carson National Forest one important negative influence on Abert's squirrel density was the frequent presence of dense understory of the shrub-form of Gambel oak. Dense oak understory may influence Abert's squirrel foraging and escape behavior. Mature, tree-from Gambel oak have been identified as important components of Abert's squirrel habitat in Arizona (Brown 1984). However, large diameter tree-form Gambel oak have not been recorded on Abert's squirrel monitoring plots on Carson National Forest, which may reflect a general geographic trend in growth form. Regardless, dense oak understory may be a response to past management actions. Gambel oak sprouts readily following disturbance including tree cutting, chaining, and fire (Tiedemann et al. 1987). Successional Gambel oak thickets can persist even after ponderosa pine stands have matured (Dick-Peddie 1993). Creation of new canopy openings will result in dense shrub canopies in a few years (Dick-Peddie 1993).

Given the recognition that the health of contemporary ponderosa pine forests has declined and due to the increased risk of stand-replacing forest fires, there has been increasing interest and effort towards the restoration of these ecosystems and the prevention of catastrophic forest fires, especially at the urban interface. Further, proper forest management can create and improve Abert's squirrel habitat (Patton, 1984, Dodd et al. 1998). However, restoration typically advocates aggressive thinning (i.e., cutting of smaller diameter trees), which can result in sudden and dramatic changes in forest structure depending on the prescription (Covington et al 1997, Allen et al. 2002).

Most studies have concluded that intensive widespread thinning will negatively impact Abert's squirrel populations. For example, in an unpublished study to evaluate the effects of ponderosa pine restoration in the Mount Trumbull area of northern Arizona during 2004, squirrel densities were very low (ca 0.01 squirrels/ha) on treated plots that had been thinned, burned, and reseeded in comparison with 5 control plots (mean = 0.12 squirrels/ha; Wightman and Yarborough 2004). Dodd et al. (1998, 2003) found that in unlogged high quality habitat Abert's squirrels maintained stable densities of resident squirrels and consistent juvenile recruitment. However, there is very little of this habitat left and most stands are of moderate age. In contrast, in intensively thinned low quality habitat Abert's squirrels used the habitat only seasonally by nonresidents from adjacent high quality habitats and these squirrels exhibited poor juvenile recruitment. Dodd et al. (2003) concluded that intensive thinning may adversely effect diversity and abundance of fungi, which is used as an important food resource by Abert's squirrel, as well as having an adverse effect on other important habitat requirements such as interlocking canopy trees. In an expanded study that also included landscape level variables, Dodd et al. (2006) found that Abert's squirrel density, recruitment, and survival were better on high quality plots. Further, they recommended that management for Abert's squirrel consist of maintaining high quality habitat as mesoreserves at or above a 24-42 % threshold, and management of matrix habitats surrounding the mesoreserves for appropriate patch level habitat conditions. Further, because squirrel recruitment and survival in high quality habitats was inversely related to density of sapling trees, they recommended using thinning-from-below prescriptions (i.e., thinning the VSS 2 tree component [< 5 inch DBH]) within the mesoreserves. Similarly, in a spatial modeling effort to predict the effects of proposed thinning on Abert's squirrels, Prather et al (2006) recommended maintaining areas of high basal area, retaining large overstory trees, and leaving large patches (> 160 ha) of habitat with high canopy closure (> 40%).

Although most studies have found negative impacts of intensive thinning on Abert's squirrel, there have been relatively few studies and there have been some conflicting results. For example, during an unpublished study in 2005 on the Apache-Sitgreaves National Forest in east-central Arizona, Abert's squirrel density was lowest on 6 control plots (mean = 0.09/ha, range = 0.01 – 0.019), was higher on 13 plots that had been treated to meet guidelines for goshawk habitat management (mean = 0.11, range = 0.00 – 0.36), and was highest on 6 plots that had been treated to restore pre-settlement conditions (mean = 0.15, range 0.01 – 0.32;Raymound Rugg personal communication). Given the range of existing ponderosa pine forest conditions, it is unlikely that any single prescription will be appropriate for all situations. Recommendations from existing studies should be considered when assessing potential impacts of restoration or fuels-reduction treatments. Further, given the natural geographic variation in ponderosa pine forests, additional research is needed to directly assess effects of different treatments on squirrel populations.

The relative importance of the various natural and management factors to the low Abert's squirrel densities found on Carson National Forest is unknown. However, based on accumulated data from the Carson National Forest Abert's squirrel monitoring program, evidence indicates that Abert's squirrel densities on the forest vary according natural ecological site conditions such as vegetation zone. In particular, inclusion of plots in low quality habitat at the piñon-juniper ecotone results in a reduction in the overall mean squirrel density reported for the forest. However, additional studies are needed to better understand geographic variation in natural forest ecosystem structure and function as it relates to Abert's squirrel density and the influence of historical and current management. Importantly, the management history of each stand remains unknown and that history has not been incorporated into analyses. More information is needed on the history of each stand before conclusions can be drawn. Consequently, it remains unknown the extent to which the low densities of Abert's squirrels on Carson National Forest are a result of sampling biases, climate variation, topographic variation, or past management. Continued monitoring and additional studies on this species should resolve this problem.

CONCLUSIONS

Abert's squirrels are particularly sensitive to habitat changes in climax ponderosa pine ecosystems. Few species are as tightly linked to forest structure and function. As such, the use of this species as a management indicator species on the Carson National Forest is well founded. This study provided a fourth year of monitoring for Abert's squirrel densities across a broad spectrum of ponderosa pine forest stands on Carson National Forest. Although Abert's squirrel density on the forest was the highest yet recorded during 2006, densities continued to be low in comparison with other studies in adjacent states conducted at the same time. While it is likely that drought conditions during the early 2000's have been at least partially responsible for the low squirrel densities observed during 2003-2006, it remains unknown to what extent other natural factors or management actions have contributed to the low densities. Lower densities of Abert's squirrel were associated with the lower, arid piñon-juniper woodland ecotone, especially stands with dense oak shrub understory. Higher Abert's squirrel densities were associated with ponderosa pine forest stands at the more mesic and productive upper mixed coniferous forest ecotone. These stands were characterized by higher densities of medium and large diameter ponderosa pines. Additional studies are needed to better understand the relationships between habitat, management, and Abert's squirrel biology.

RECOMMENDATIONS

Continued monitoring

- Annual over-winter spring feeding sign monitoring of Abert's squirrel should continue long-term using methodology consistent with those used in 2003 - 2006.
- Annual over-winter spring feeding sign monitoring should include all or a consistent subset of plots sampled during 2003 - 2006 in all subsequent monitoring strategies.
- More plots should be monitored in order to increase representation of forest conditions and increase sample size.
- As much as feasible, maintain consistency in field crewmembers to reduce observer biases.
- Data should be collected by teams of two rather than by single individuals. This will increase safety and will help reduce sampling bias and data recording errors.

Additional study

- Forest Service stand exams should be completed at each monitoring plot. Stand exams would provide detailed data about habitat conditions in terms more relevant to forestry management. Such data would allow for more detailed analyses on the influence of forest conditions on Abert's squirrel densities and would allow for an analysis of relationships between stand exam variables and data collected during habitat monitoring.
- Management history of all monitoring plots should be determined and included in analyses. These data would help assess causal relationships between management history and current habitat conditions and squirrel densities. Such information would be particularly helpful in identifying relationships between timber harvesting, thinning, and fire events with squirrel distribution and abundance.
- Additional studies should be initiated that are designed to assess the impacts of specific forest management strategies on Abert's squirrel populations.
- Studies to monitor ponderosa pine seed, acorn, and hypogeous fungi production should be conducted in conjunction with Abert's squirrel monitoring.

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Appendix I. *Density Abert's squirrel on 31 monitoring plots located on Carson National Forest, 2003-2006.*

		Location				2003		2004		2005		2006	
District	**Stand No.**	Easting	Northing	Elevation	Bearing	Density	90% Prediction Interval	Density	90% Prediction Interval	Density	90% Prediction Interval	Density	90% Prediction Interval
Camino Real	El Pato	426085	3993090	2406	135	-	-	0.01	0.01 - 0.12	0.01	0.01 - 0.11	0	0 - 0.09
Jicarilla	J 02	293567	4096396	2202	180	0	0 - 0.09	0	0 - 0.09	0	0 - 0.09	0.01	0.01 - 0.10
Jicarilla	J 03	294861	4095390	2262	180	0.05	0.01 - 0.16	0	0 - 0.09	0.01	0.01 - 0.10	0	0 - 0.09
Jicarilla	J 08	298768	4075406	2349		0	0 - 0.09	0	0 - 0.09	0	0 - 0.09	0	0 - 0.09
Jicarilla	J 09	299723	4074182	2267	146	0	0 - 0.09	0	0 - 0.09	0	0 - 0.09	0	0 - 0.09
Tres Piedres	SA 03	399461	4086654	2784	230	0.01	0.01 - 0.11	0.01	0.01 - 0.10	0.01	0.01 - 0.10	0.01	0.01 - 0.10
Tres Piedres	SA 04	399821	4085576	2740	90	0.01	0.01 - 0.10	0	0 - 0.09	0.01	0.01 - 0.10	0	0 - 0.09
Tres Piedres	SA 05	403381	4081874	2742	220	0.01	0.01 - 0.10	0.01	0.01 - 0.10	0	0 - 0.09	0	0 - 0.09
Tres Piedres	SA 06	402310	4080712	2715	300	0.01	0.01 - 0.10	0.01	0.01 - 0.10	0.01	0.01 - 0.10	0	0 - 0.09
Questa	SA 07	487984	4071439	2543	270	0.01	0.01 - 0.10	0.01	0.01 - 0.10	0.07	0.01 - 0.17	0.03	0.01 - 0.14
Questa	SA 08	488950	4068425	2546	340	0	0 - 0.09	0.01	0.01 - 0.10	0.01	0.01 - 0.12	0.03	0.01 -0 .14
Tres Piedres	SA 13	411183	4059645	2552	140	0	0 - 0.09	0	0 - 0.09	0	0 - 0.09	0	0 - 0.09
Tres Piedras	SA 14	410299	4058840	2584	170	0.01	0.01 - 0.10	0.01	0.01 - 0.10	0.01	0.01 - 0.10	0	0 - 0.09
Tres Piedres	SA 22	409501	4052593	2677	160	0	0 - 0.09	0	0 - 0.09	0.01	0.01 - 0.10	0.01	0.01 - 0.10
Tres Piedres	SA 25	412264	4052271	2531	290	0	0 - 0.09	0	0 - 0.09	0	0 - 0.09	0.01	0.01 - 0.10
El Rito	SA 28	400532	4049072	2731	310	0	0 - 0.09	0	0 - 0.09	0.01	0.01 - 0.10	0.01	0.01 - 0.10
Tres Piedres	SA 30	412727	4048948	2669	220	0	0 - 0.09	0	0 - 0.09	0.01	0.01 - 0.10	0	0 - 0.09
Tres Piedres	SA 31	412930	4047697	2510	140	0.01	0.01 - 0.10	0	0 - 0.09	0.01	0.01 - 0.10	0.01	0.01 - 0.11
Tres Piedres	SA 32	410958	4046777	2566	225	0	0 - 0.09	0.01	0.01 - 0.10	0.01	0.01 - 0.10	0.01	0.01 - 0.10
El Rito	SA 34	400598	4048165	2730	160	0	0 - 0.09	0	0 - 0.09	0.01	0.01 - 0.10	0	0 - 0.09
El Rito	SA 35	395335	4047575	2445	260	0	0 - 0.09	0.01	0.01 - 0.11	0.03	0.01 - 0.14	0.06	0.01 - 0.17
El Rito	SA 38	395023	4045895	2471	280	0	0 - 0.09	0.01	0.01 - 0.10	0.01	0.01 - 0.13	0.01	0.01 - 0.12
Tres Piedres	SA 39	410702	4045455	2530	250	0.01	0.01 - 0.11	0.01	0.01 - 0.11	0.01	0.01 - 0.10	0.01	0.01 - 0.11
El Rito	SA 44	389033	4033016	2672	260	0.01	0.01 - 0.10	0.01	0.01 - 0.10	0.01	0.01 - 0.10	0.01	0.01 - 0.12
Canjilon	SA 45	376080	4029303	2501	290	0	0 - 0.09	0.01	0.01 - 0.10	0.01	0.01 - 0.12	0.02	0.01 - 0.13
El Rito	SA 49	385695	4025457	2546	210	0	0 - 0.09	0	0 - 0.09	0	0 - 0.09	0.01	0.01 - 0.10
El Rito	SA 50	383147	4025372	2613	270	0	0 - 0.09	0	0 - 0.09	0	0 - 0.09	0.01	0.01 - 0.10
El Rito	SA 52	383674	4023474	2490	150	0	0 - 0.09	0	0 - 0.09	0	0 - 0.09	0.01	0.01 - 0.10
Camino Real	SA 55	450278	4009371	2732	130	0	0 - 0.09	0	0 - 0.09	0.01	0.01 - 011	0.01	0.01 - 0.11
Camino Real	SA 56	443990	4005753	2544	135	0	0 - 0.09	0.01	0.01 - 0.10	0.01	0.01 - 011	0.05	0.01 - 0.16
Camino Real	SA 59	430040	3991180	2539	170	0.01	0.01 - 0.12	0.01	0.01 - 0.10	0.01	0.01 - 0.13	0.03	0.01 - 0.14

Appendix II. *Density Abert's squirrel on 6 monitoring plots on the Valle Vidal Unit, Carson National Forest, 2006.*

		Location					2006	
District	**Stand No.**	zone	Easting	Northing	Elevation	Bearing	Density	90% Prediction Interval
Questa	V2	13S	491696	4072055	2528	140	0.07	0.01-0.17
Questa	V3	13S	485356	4066831	2626	180	0.05	0.01-0.16
Questa	V5	13S	487631	4066703	2541	279	0.09	0.01-0.19
Questa	V6	13S	491115	4066652	2483	140	0.01	0.01-0.12
Questa	V7	13S	494565	4070996	2552	180	0.09	0.01-0.19
Questa	V10	13S	487747	4063389	2604	180	0.08	0.01-0.18