Abert's Squirrel (*Sciurus aberti*) Monitoring and Habitat Analysis on Carson National Forest, New Mexico, 2004

A Final Contract 43-83A7-4-0038 Completion Report

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9 December 2004

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Executive Summary

Purpose

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

Method

- 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 31 monitoring plots were established in ponderosa pine stands across the six Carson National Forest districts.
- 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.
- Habitat data were collected on 10 random 32.8 x 57.4 ft (10 x17.5 m) belt transects within each monitoring plot. Habitat variables included: slope, aspect, canopy cover, litter depth, ground cover (of forbs, grasses, litter, bare, and other), woody understory species and cover, number, size and species of each tree, number and size of snags, and number and size of cut stumps.

Results

- Abert's squirrel density estimates ranged from 0 to 0.01 per acre with an overall mean of 0.0048 (ca one squirrel per 500 acres).
- Abert's squirrel density in 2004 was significantly lower than in 2003.
- Only about half (52%) of the plots exhibited recent sign of Abert's squirrel occupancy.
- Most plots (90 %) exhibited evidence of Abert's squirrel occurrence in the past.
- Density of 12- 16 inch DBH ponderosa pine was the most important habitat variable influencing squirrel density. However, other important variables included 16- 20 inch DBH ponderosa pine, < 4 inch DBH ponderosa pine, and understory cover.

Discussion and Conclusions

- Compared to previous density estimates of Abert's squirrel in high quality habitats in other geographic locations, Abert's squirrel densities observed on Carson National Forest in 2004 were extremely low (e.g., one squirrel per 500 acres compared to one squirrel per 6 acres).
- Based on data collected in adjacent states, Abert's squirrel densities crashed in 2002 with continued declines into 2003 and 2004. The regional decline in Abert's squirrel densities is thought to be due to drought conditions that may reduce availability of important foods (i.e., ponderosa pine cones and hypogeous fungi).
- 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

- Annual over-winter spring feeding sign monitoring of Abert's squirrel should continue long-term.
- Annual over-winter spring feeding sign monitoring should include all or a consistent subset of plots sampled during 2003 in all subsequent monitoring strategies.
- In order to preserve the comparability of year-to-year samples, subsequent monitoring methodology should be consistent with those used in 2003 and 2004.
- Additional studies should be initiated that are designed to assess the impacts of specific forest management strategies on Abert's squirrel populations.
- More plots should be monitored in order to increase representation of forest conditions and increase sample size.
- A study to monitor ponderosa pine seed, acorn, and hypogeous fungi production should be conducted in conjunction with Abert's squirrel monitoring.
- As much as feasible, maintain consistency in field crewmembers to reduce inter-annual and other 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.
- To avoid weather related problems (i.e., snow), monitoring should be delayed (e.g., early May to Mid June) relative to the timing recommended for Arizona (i.e., mid March to late May).

Background

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 will also occur below the ponderosa pine zone in the upper edge of pinyon (*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 usually 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 nests 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 squirrel eat the seeds, inner bark, terminal buds, twigs, and flowers of ponderosa pine in addition to other foods such as mushrooms, fungi, pinyon pine, acorns, carrion, and cones raided from red squirrel middens (Flyger and Gates 1982). There is seasonal variation in food habits. During summer and early fall, hypogeous fungi associated with ponderosa pine constitute a major part of the diet (Rasmussen et al. 1975). During winter apical buds and inner bark (i.e., phloem) of ponderosa pine are the major food. 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 variation is both temporal and spatial (Bailey 1931).

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 program is required in order to track population changes and to assess the impacts of forest management practices on this species. Further, during 2003 it was found that available stand characteristics maintained by Carson National Forest were not useful in predicting Abert's squirrel occurrence or abundance. Consequently, the main purpose of this study was to provide a second year of monitoring for this species on the Carson National Forest and to initiate habitat studies. 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 habitat characteristics, and to provide a second year of data for a long-term monitoring program.

Methods

Feeding sign

The technique for monitoring Abert's squirrel was previously developed by the Arizona Game and Fish Department (Dodd no date, Dodd et al. 1998, Dodd personal communication). This monitoring technique provides an indirect population index based on sign consisting of the remains of over-winter feeding activity. This has been demonstrated to be a reliable, consistent, efficient, and cost-effective technique (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). Feeding sign made by Abert's squirrel can easily be confused with sign made by red squirrel, porcupine (*Erethizon dorsatum*), other small mammals, 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 was not immediately possible. Consequently, several steps were taken to insure that all field crewmembers were able to accurately identify all feeding sign types. Prior to initiating fieldwork, crewmembers 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 crewmembers were highly confident in their ability to accurately distinguish the different types of feeding sign.

Field methods

Feeding Sign Plots.—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. In 2003 administrative delays had resulted in field data collected later than this time frame. Consequently, during 2004 a concerted effort was made to conduct the study during the mid-March to late May period.

The establishment of an Abert's squirrel monitoring plot in each of 24 ponderosa pine forest stands was deemed adequate for establishing base-line estimates of Abert's squirrel densities on Carson National 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 were selected from this suite based primarily on logistical considerations. These considerations included distributing plots among the six Forest Districts, accessibility, and drive time. 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. The sampling design followed that 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 (= 1,521 square inches) 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 plot.

The latitude-longitude coordinate of the starting point (a grid 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 (= 10.8 square feet) 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 determined 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. During 2003, a total of 31 monitoring plots were established (7 more than required by Carson National Forest). The sampling effort in 2004 included a repeat of all plots monitored during 2003, with the exception of one. Plot 54 on the Camino Real District was not repeated because that site was predominantly pinyon-juniper woodland rather than ponderosa pine. A new site (El Pato) in a nearby stand of ponderosa pine was monitored in its stead during 2004.

Habitat.—The collection of habitat data was based on a modification of protocols developed by J. Frey in 2003 for assessing red squirrel habitat on Carson National Forest. 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 x 17.5 m) and was positioned in the 57 ft (17.5 m) interval between adjacent feeding sign sample quadrates. Each belt transect sampled a 0.043 acre (0.017 ha) area. Slope and aspect of the surrounding terrain were visually estimated. At each end of the belt transect, a densitometer was used to assess canopy cover in the four cardinal directions and a ruler was used to measure litter depth. The observer slowly walked the transect recording the species and DBH size range of each tree, snag, and cut stump at least 50% within the belt. All trees were placed into seven 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 two size classes including < 8 in (= 20 cm) and > 8 in (= 20 cm) DBH. All tree, snag, and stump densities are reported as the mean number within an 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, and other. Percent cover classes included 0-5, 5-25, 25-50, 50-75, 75-95, and 95-100%. Using the same percent cover classes, understory cover of woody shrubs and saplings < 39 in (= 1 m) tall were visually estimated. Dominant understory species were recorded.

Data analysis

The incidence of feeding sign encountered on monitoring plots 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 relationships between relative abundance of spring feeding sign and the absolute 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.

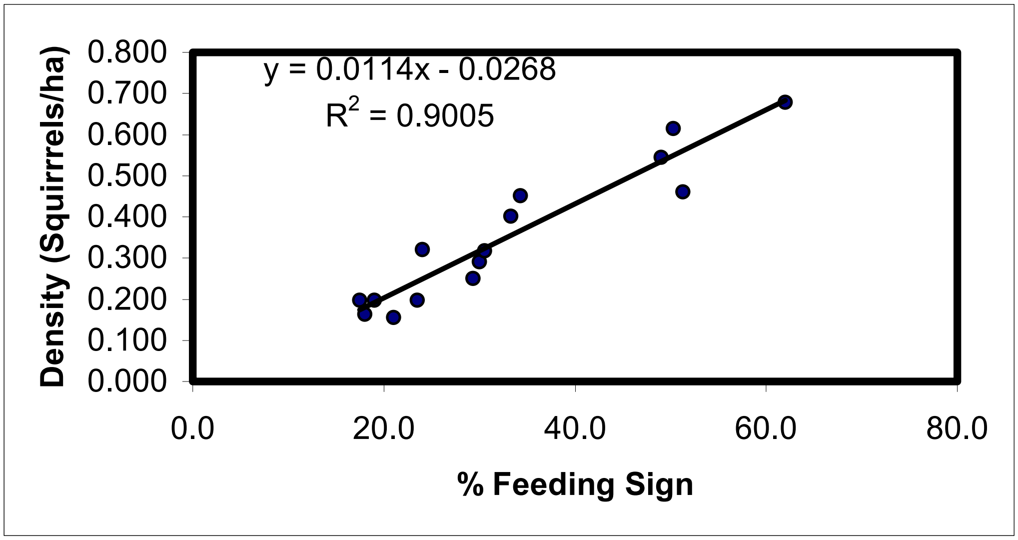

Figure 1. *Regression model between percentage feeding sign and Abert's squirrel density developed by Norris Dodd in Arizona.*

All variables were checked for normality using a one-sample Kolmogorov-Smirnov test. All variables other than elevation, slope, litter depth, ground covers, and understory were non-normal. Thus, where possible, nonparametric tests were performed for non-normal variables. Wilcoxon signed ranks tests were used to test for differences in the percent feeding sign and calculated densities between years. Simple correlations were assessed between Abert's squirrel density estimates and each independent variable. Stepwise multiple regression was used to assess the significance of each independent variable for predicting Abert's squirrel density. A principal components analysis was used to examine the relationship of habitat variables at each site. Based on all available evidence, stands were classified as Abert's squirrel present or absent. Univariate Kolmogorov-Smirnov tests were used to test whether each variable significantly differed in stands where squirrels were present versus stands where squirrels were absent. Discriminant function analysis was used to develop statistical models for red squirrel presence or absence in a stand. This model was used to statistically classify stands as either red squirrel present or red squirrel absent.

Results

Occurrence and density.—Abert's squirrel monitoring occurred between 20 April and 23 May 2004, during the timeframe recommended by Dodd et al. (1998). However, several snowstorms during the early part of the sampling period resulted in significant delays, increased costs, and other logistical problems. Consequently, a later timing (e.g., early May – mid June) of monitoring as occurred during 2003 may be justified in future studies on Carson National Forest relative to guidelines provided for Arizona. An assessment of effort and logistics associated with the monitoring is presented in Appendix 1.

A total of 31 monitoring plots (7 more than required) was sampled across the six Forest Districts (Appendix 1). These included 4 in Camino Real District, 1 in Canjilon District, 13 in El Rito District, 4 in Jicarilla District, 2 in Questa District, and 7 in Tres Piedras District. Fresh Abert's squirrel feeding sign was found in at least one of the 256 1 m^2 sampling quadrants on 15 (48.4 %) of the 31 monitoring plots. However, probable sign of Abert's squirrel (cobbed Douglas fir cone; but possibly resulting from chipmunks) was also found on 1 additional plot. Thus, a total of 16 (51.6 %) of the monitoring plots had evidence of recent or current Abert's squirrel occupancy. This was not significant different as compared with the 58% of plots with sign in 2003 ($X^2 = 0.617$, d.f. = 1, $P = 0.601$). However, most plots (90.3 %) exhibited evidence of Abert's squirrel occurrence at some time in the past.

Abert's squirrel density estimates on each plot ranged from 0 to 0.01 per hectare (0 - 0.004 per acre). A little more than half of the plots (51.6%) had a density estimate of zero (Appendix 2). The 90 % prediction intervals around the density estimates for each plot formed a single overlapping group, which indicates that density estimates were not significantly different across all monitoring plots. The average observed density across all plots was 0.0048 squirrels per hectare (0.002 per acre; ca 1 squirrel per 500 acres). In comparing the 30 sites that were repeated during 2003 and 2004, there was a significantly lower ($P = 0.000$) percentage of feeding sign; and density of squirrels in 2004 (Table 1). The significantly higher density during 2003 was due to several sites with a relatively high frequency of feeding sign (Figure 2).

Table 1. *Comparison of the mean percentage feeding sign and the estimated density on 30 monitoring plots replicated between 2003 and 2004 on Carson National Forest.*

	2003	**2004**	***Z***	***P***
Feeding sign percentage				
mean	0.57297	0.25797	-6.780	0.000
SE	0.39003	0.10258		
Density (squirrels/ha)				
mean	0.00500	0.00467	-6.792	0.000
SE	0.00178	0.00093		

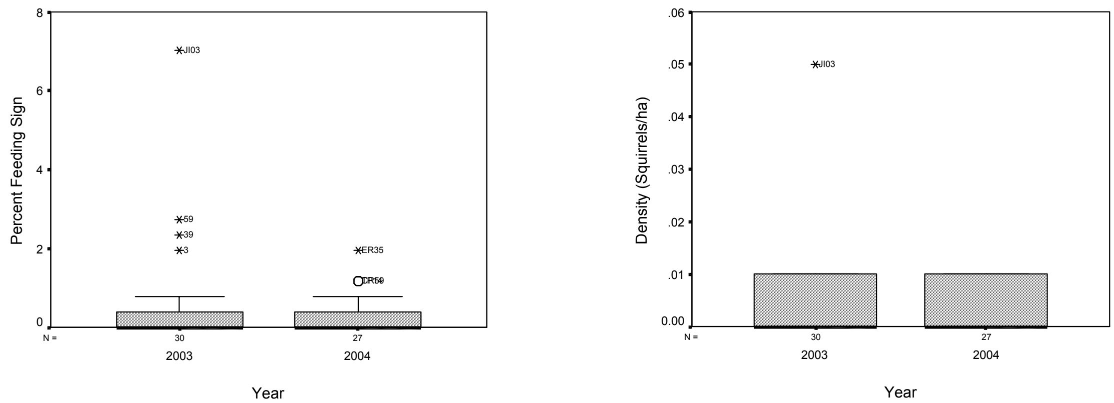

Figure 2. *Percent feeding sign and density of Abert's squirrels on replicated monitoring plots during 2003 and 2004. Black bars represent medians, boxes represent quartiles, circles represent outliers, and asterisks represent extremes.*

***Habitat.*—**Abert's squirrel density exhibited a significant positive correlation with 12-16 inch DBH ponderosa pine (r_s = 0.513; *P* = 0.003; Figure 3A), 16-20 inch ponderosa pine (r_s = 0.454; *P* = 0.010; Figure 3B), and < 4 inch DBH ponderosa pine (r_s = 0.418; *P* = 0.019). In contrast, Abert's squirrel density exhibited a significant negative correlation with understory density (r_s = -0.408; *P* = 0.023) and nearly so for slope (r_s = -0.341; *P* = 0.060).

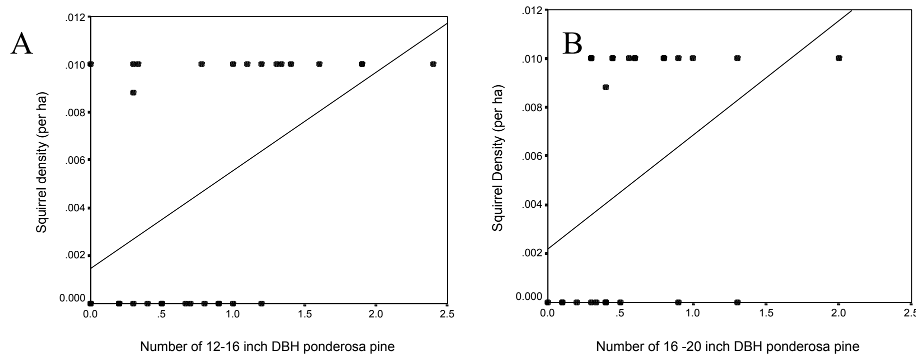

Figure 3. *Significant (P ≤ 0.01) correlations between Abert's squirrel density with A) 12-16 inch DBH ponderosa pine and b) 16-20 inch DBH ponderosa pine.*

A stepwise multiple regression produced three highly significant models (Table 2). The r^2 change between each model was significant. The single best predictor of Abert's squirrel density was 12-16 inch DBH ponderosa pine. Additional variables with positive coefficients that improved the model included < 4 inch DBH ponderosa pine and 8-12 inch DBH ponderosa pine.

Table 2. *Statistics for significant (P < 0.001) models produced through stepwise multiple regression of all independent variables against Abert's squirrel density on Carson National Forest in July 2004. All coefficients are significant (P < 0.05).*

Model	r	ANOVA F	Variable[1]	Coefficient	SE
1	0.500	9.684	constant	0.0014	0.001
			PP 12-16	0.0041	0.001
2	0.637	9.577	constant	-0.0005	0.001
			PP 12-16	0.0040	0.001
			PP < 4	0.0010	0.000
3	0.729	10.237	constant	0.0010	0.001
			PP 12-16	0.0044	0.001
			PP < 4	0.0013	0.000
			PP 8-12	-0.0033	0.001

[1]Abbreviation is ponderosa pine (PP); numbers are DBH size classes.

A principal components analysis resulted in the extraction of 13 components, which together accounted for 88.5 % of the variance. The first two components accounted for 27.9 % of the variance in habitat. On PC 1 variables with high positive loadings (> 6.0) included the density of 12-16 inch DBH Douglas fir, 20-24 inch DBH Douglas fir, 12-16 inch DBH white fir, 20-24 inch DBH white fir, total number of trees, slope, and density of < 4 inch DBH Gambel's oak. No variables had high negative loadings on PC 1. In contrast, high positive loadings on PC 2 included < 4 DBH pinyon, 4-8 DBH pinyon, 8-12 DBH pinyon, < 4 juniper, and 4-8 juniper. There were no variables with high negative loadings on PC2. The only detectable pattern on a scatter plot of PC1 and PC 2, was that squirrel density tended to be zero with higher positive scores on PC 1 (greater densities of Douglas fir, white fir, oaks, and total trees, and steeper slopes; Figure 3).

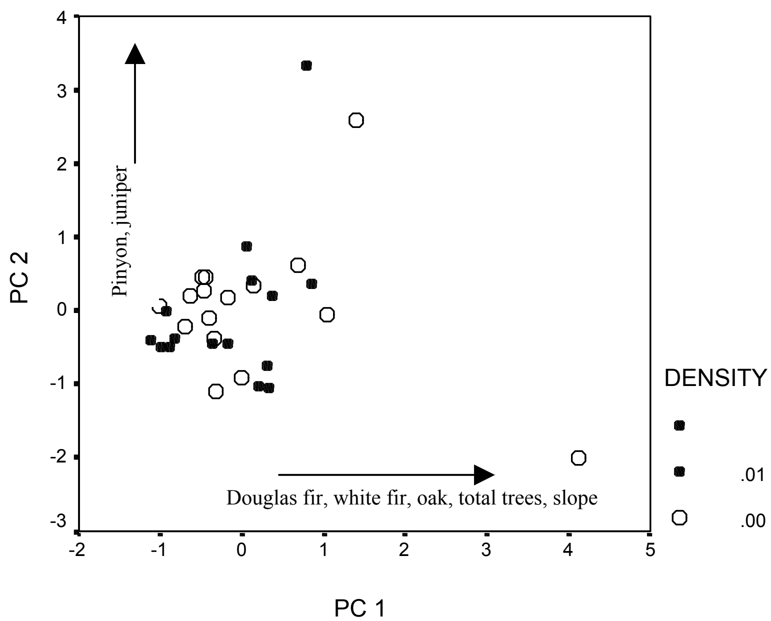

Figure 3. *Scatter plot of habitat characteristics on principal components 1 and 2 for 31 Abert's squirrel monitoring plots sampled in 2004 on Carson National Forest.*

Stands where Abert's squirrel were present or absent in 2004 significantly differed in the density of < 4 inch ponderosa pine (Z = 1.490; P = 0.024). However, a discriminant function analysis revealed that there was no significant multivariate difference (P = 0.069) in habitats where Abert's squirrels were present or absent during 2004.

Discussion

Abert's squirrel densities based on over-winter feeding sign observed on Carson National Forest in 2004 were extremely low (mean of one squirrel per 200 ha [ca 1 squirrel per 500 acres]). Densities in high quality, uncut forests can exceed 1 squirrel per 2.4 ha (= 1 per 5.9 acre; Brown 1984) and a local high density in excess of one squirrel per 0.8 ha (1 per 2.0 acre) has been reported (Keith 1965). More typical levels are one squirrel per every 8 to 16 hectares (ca 1 per 20 to 40 acres; Brown 1984). For example, Dodd et al. (1998) found that Abert's squirrel densities in north-central Arizona during 1996-1997 ranged from one squirrel per 1 to 20 hectares (= one per 2.5 to 49.4 acres). Thus, densities observed during June 2004 on Carson National Forest were substantially lower than typical. Further, although the mean density of squirrels on replicated plots was similar in 2004 (0.0047/ha) as compared with 2003 (0.0050/ ha), a reduction in the variance in density during 2004 (i.e., plots had an estimated density of either 0 or 0.01) resulted in an overall significantly lower density in 2004.

Information on regional patterns of Abert's squirrel densities is available from similar monitoring studies in adjacent Southwest states. 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 seven 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). Thus, Abert's squirrel densities on Carson National Forest (i.e., 0.005 squirrels/ha) were twice as low in compared to similar data collected in Utah during 2003. In 2003 (Frey 2003) it was speculated that one reason for the difference in density between the Utah and New Mexico was due to the late timing of the sampling. Given that similar low densities were found on Carson National Forest during 2004 when sampling occurred earlier in the spring, other factors likely contribute to the regional differences. At least two other Abert's squirrel monitoring studies occurred during 2004. One was a continuing study to evaluate the effects of ponderosa pine restoration in northern Arizona. In 2004 they found densities ranging from 0.01 – 0.30 squirrels/ha with a mean of 0.12 squirrels/ha on 5 control plots (Wightman et al 2004). Even densities on treated plots (i.e., 0.01 squirrels/ha), which had been thinned, burned, and reseeded, were twice as high as on Carson National Forest (Wightman and Yarborough 2004). Densities on Carson National Forest are most similar to densities found on the San Juan National Forest in southern Colorado. In this forest, densities ranged from about 0-0.16 with a mean of 0.044 squirrels/ha in 2003 and 0-011 with a mean of 0.008/ha in 2004 (Randy Ghormley personal communication). The similarity of densities between Carson and San Juan national forests may reflect regional differences in habitat conditions, management, or other factors.

One reason for the extremely low densities on Carson National Forest in 2003 and 2004 was likely due to recent 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. An extended La Niña occurred from late 1999 to 2001 (Sevilleta LTER 2003). The Palmer drought severity index for the north-central mountains region of New Mexico indicates that, in general, drought conditions have existed in the region since late 1999 (NCDC 2003). Recent analyses have suggested that 2002 was the driest year in the Southwest over the past 1,400 years (Tom Sweatnam, in lit).

Drought probably impacts Abert's squirrels primarily through reductions in the 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 zero 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). In addition to drought, intensive, widespread thinning is thought to adversely impact Abert's squirrels (Dodd et al. 1998). It remains unknown to what extent habitat conditions and management actions on Carson National Forest have contributed to the low Abert's squirrel densities.

Abert's squirrel habitat relations have been fairly well studied in the Southwest. Due to the small sample size (N = 31) and extremely low squirrel densities, results of the habitat analyses in this study should be considered preliminary and not the basis for immediate management decisions. Based on previous studies, variation in habitat characteristics is known to influence Abert's squirrel densities. This habitat variation generally relates to the structure of the ponderosa pine forest in terms of nest site selection and food production. Both criteria are likely most optimally met in uncut climax ponderosa pine forests and in managed stands with similar structure. For example, Dodd et al. (1998) found that interlocking canopies was associated with squirrel recruitment while basal area of all trees was associated with squirrel fitness. 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 this model, habitat quality was a positive function of increasing density and size of trees. A similar relationship was found in this study with squirrel density correlated with density of 12-20 DBH ponderosa pine. Optimum habitats have interlocking canopies of large trees on productive sites. Such forests provide escape routes, nest sites and maximum food. For example, during this study there was a significant negative relationship between understory density (especially Gambel's oak) and squirrel density. Dense understory may influence escape behavior. Further, old, large diameter trees (over 60 to 100 years old) produce a maximum number of Ponderosa pine seeds. Poor seed production can result from logging that results in younger and typically denser trees or from fire suppression that prevents nutrient cycling. 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). Because pole sized blackjack ponderosa pine tend to be associated with truffles while mature yellow-pine ponderosa tend to be associated with the greatest cone production, States et al. (1988) suggested that habitat should consist of a combination of tree age classes, with groupings, size, and density that provide all habitat components. During this study there was a positive correlation between squirrel density and density of < 4 DBH ponderosa pine. Additional data is needed to substantiate this trend.

Based on the observation of old feeding sign on the monitoring sites, it is clear that during previous years Abert's squirrel had a greater distribution and abundance than observed in 2003 and 2004. However, squirrel density in previous years cannot be assessed. Thus, it remains unknown the extent to which the extremely low densities are a result of climate related factors or to habitat conditions on Carson National Forest. As summarized above, many aspects of forest habitat may impact squirrel distribution and abundance. Other studies have found that Abert's squirrels are less numerous than they were at the turn of the 20th Century (Keith 1965). It has been suggested that this decline has been primarily the result of logging which has altered the structure and function of ponderosa pine forests (e.g., Keith 1965). Proper forest management can create and improve Abert's squirrel habitat (Dodd et al. 1998). Continued monitoring and additional studies of 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 second year of monitoring for Abert's squirrel densities across a broad spectrum of ponderosa pine forest stands on Carson National Forest. Squirrel densities were found to be extremely low in comparison with most other regions and times. While it is likely that drought conditions are at least partially responsible for these densities, it remains unknown to what extent general habitat conditions and management actions on the forest have contributed to the low densities. Widespread, intensive thinning is thought to be especially adverse for Abert's squirrel populations. Habitat relationships initiated during this study revealed a positive relationship between squirrel density with both small and large diameter ponderosa pine as well as a negative relationship with understory cover. Additional habitat studies are needed to better understand the relationships between habitat, management, and Abert's squirrel biology.

Recommendations

1) Annual over-winter spring feeding sign monitoring of Abert's squirrel should continue long-term.

2) Annual over-winter spring feeding sign monitoring should include all or a consistent subset of plots sampled during 2003 in all subsequent monitoring strategies.

3) In order to preserve the comparability of year-to-year samples, subsequent monitoring methodology should be consistent with those used in 2003 and 2004.

4) Additional studies should be initiated that are designed to assess the impacts of specific forest management strategies on Abert's squirrel populations.

5) More plots should be monitored in order to increase representation of forest conditions and increase sample size.

6) A study to monitor ponderosa pine seed, acorn, and hypogeous fungi production should be conducted in conjunction with Abert's squirrel monitoring.

7) As much as feasible, maintain consistency in field crewmembers to reduce inter-annual and other biases.

8) 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.

Acknowledgements

Thanks are due to Deanna Williams and Chirre Keckler for facilitating this project and to Jeffery Muehleck for GIS support. Special thanks are due to Norris Dodd for providing valuable information. Thanks are extended to the primary field crewmembers, Andrew Hope, Ryan Besser and Geoff Banzhof for their hard work. Aaron Sims was especially helpful with careful data entry.

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Appendix 1

Monitoring Effort and Logistics

Three primary field crewmembers (26 person days; mean 1.4 people per day) were able to train and sample 31 monitoring plots (7 more than required) in 19 days, not including travel to and from Carson National Forest. The number of plots completed per day ranged from 1 to 4 with an average of 1.6 plots completed per day. This was less than the rate of completion in 2003 due to the addition of habitat data collection. Norris Dodd has recommended a rate of 2 plots per day a 2-person crew (not including habitat data). Thus, the efficiency in the study was high despite long travel distances to new monitoring areas, delays due to inclement weather (i.e., snow), and new crewmembers.   The high rate of efficiency was possible because the field crew was physically fit, they worked long hours, they camped near monitoring sites, and typically worked alone. In future monitoring it is recommended that the number of field crewmembers be increase to allow them to work in pairs. While this will decrease efficiency, it will increase safety and data collection accuracy.

Appendix II. Location and density estimates for Abert's squirrel monitoring plots on Carson National Forest in 2004. Note: District was incorrectly reported for some stands in the 2003 report.

			NE Plot Corner						
Date	District	SiteNo.	Zone	Easting	Northing	Elevation	Bearing	Density	90% Prediction Interval
20-Apr-04	Camino Real	SA 55	13S	450278	4009371	2732	130	0	0 -0.09
20-Apr-04	Camino Real	SA 59	13S	430040	3991180	2539	170	0.01	0.01 - 0.10
21-Apr-04	Camino Real	SA 56	13S	443990	4005753	2544	135	0.01	0.01 - 0.10
22-Apr-04	Tres Piedres	SA 30	13S	412727	4048948	2669	220	0	0 -0.09
22-Apr-04	Tres Piedres	SA 31	13S	41253	4047992	2510	140	0	0 -0.09
22-Apr-04	Tres Piedres	SA 32	13S	410958	4046777	2566	225	0.01	0.01 - 0.10
22-Apr-04	Tres Piedres	SA 39	13S	410702	4045455	2530	250	0.01	0.01 - 0.11
27-Apr-04	Tres Piedres	SA 13	13S	411183	4059645	2552	140	0	0 -0.09
27-Apr-04	Tres Piedras	SA 14	13S	410299	4058840	2584	170	0.01	0.01 - 0.10
28-Apr-04	El Rito	SA 25	13S	412264	4052271	2531	290	0	0 -0.09
28-Apr-04	Tres Piedres	SA 22	13S	409501	4052593	2677	160	0	0 -0.09
28-Apr-04	El Rito	SA 34	13S	400598	4048165	2730	160	0	0 -0.09
28-Apr-04	El Rito	SA 28	13S	400532	4049072	2731	310	0	0 -0.09
29-Apr-04	El Rito	SA 38	13S	395023	4045895	2471	280	0.01	0.01 - 0.10
29-Apr-04	El Rito	SA 35	13S	395335	4047575	2445	260	0.01	0.01 - 0.11
2-May-04	Camino Real	El Pato	13S	426085	3993090	2406	135	0.01	0.01 - 0.12
8-May-04	El Rito	SA 44	13S	389033	4033016	2672	260	0.01	0.01 - 0.10
9-May-04	El Rito	SA 49	13S	385695	4025457	2546	210	0	0 -0.09
9-May-04	El Rito	SA 52	13S	383674	4023474	2490	150	0	0 -0.09
10-May-04	Canjilon	SA 45	13S	376080	4029303	2501	290	0.01	0.01 - 0.10
11-May-04	El Rito	SA 50	13S	383147	4025372	2613	270	0	0 -0.09
12-May-04	Jicarilla	SA 09	13S	299723	4074182	2267	146	0	0 -0.09
13-May-04	Jicarilla	SA 08	13S	298768	4075406	2349		0	0 -0.09
13-May-04	Jicarilla	SA 02	13S	293567	4096396	2202	180	0	0 -0.09
14-May-04	Jicarilla	SA 03	13S	294861	4095390	2262	180	0	0 -0.09
15-May-04	Tres Piedres	SA 03	13S	399461	4086654	2784	230	0.01	0.01 - 0.10
16-May-04	Tres Piedres	SA 04	13S	399821	4085576	2740	90	0	0 -0.09
17-May-04	Tres Piedres	SA 05	13S	403381	4081874	2742	220	0.01	0.01 - 0.10
22-May-04	Questa	SA 07	13S	487984	4071439	2543	270	0.01	0.01 - 0.10
23-May-04	Questsa	SA 08	13S	489449	40681978	2546	340	0.01	0.01 - 0.10
16-17 May-04	Tres Piedres	SA 06	13S	402310	4080712	2715	300	0.01	0.01 - 0.10