



Integrated Upland Vegetation and Soils Monitoring for Bandelier National Monument

2009 Summary Report

Natural Resource Data Series NPS/SCPN/NRDS—2011/168



ON THE COVER

Mesa Top Pinyon-Juniper ecological site at Bandelier National Monument

Photograph by: Jim DeCoster

Integrated Upland Vegetation and Soils Monitoring for Bandelier National Monument

2009 Summary Report

Natural Resource Data Series NPS/SCPN/NRDS—2011/168

James K. DeCoster
Megan C. Swan

National Park Service
Southern Colorado Plateau Network
Northern Arizona University
P.O. Box 5765
Flagstaff, AZ 86011-5765

June 2011

U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Fort Collins, Colorado

The National Park Service, Natural Resource Program Center publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

Funding for the SCPN upland field crew was provided to Northern Arizona University by the National Park Service through Colorado Plateau CESU Agreement H1200040002 (Tasks NAU-285/289).

This report is available from the Southern Colorado Plateau Network (<http://science.nature.nps.gov/im/units/scpn/>) and the Natural Resource Publications Management Web site (<http://www.nature.nps.gov/publications/nrpm/>) on the Internet.

The corresponding author and project manager for this project is Jim DeCoster (jim_decoster@nps.gov). Megan Swan is the botanist and crew leader for the project. Other contributions were made by the SCPN staff. The 2009 field crew consisted of Teresa DeKoker, Lara Dickson, Hillary Hudson, and Steve Till.

Please cite this publication as:

DeCoster, J. K., and M. C. Swan. 2011. Integrated upland vegetation and soils monitoring for Bandelier National Monument 2009 summary report. Natural Resource Data Series NPS/SCPN/NRDS—2011/168. National Park Service, Fort Collins, Colorado.

Introduction and Background

The National Park Service Inventory and Monitoring (I&M) Program was designed to determine the status and monitor the conditions of park natural resources, providing park managers with a strong scientific foundation that informs resource management decisions. The Southern Colorado Plateau Network (SCPN) is monitoring vegetation and soils as overall indicators of upland ecosystem integrity (Thomas et al. 2006).

SCPN and park staff selected the Mesa Top Pinyon-Juniper ecological site for long-term monitoring of upland vegetation and soils at Bandelier National Monument (BAND). An ecological site is a landscape division with characteristic soils, hydrology, plant communities, and disturbance regimes and responses, and its classification is based on soil survey data (Butler et al. 2003). The Mesa Top Pinyon-Juniper ecological site encompasses a large portion of the monument, and it faces a number of threats, including climate change, pinyon dieback, soil erosion, and invasion by nonnative species.

The pinyon-juniper woodlands have been undergoing extensive restoration through the selective thinning of mature junipers. The objectives for this restoration are 1) to reduce the density of junipers to reflect historical conditions, 2) to increase the herbaceous/shrub cover to reduce soil erosion so as to protect archeological sites and ecosystem functions, and 3) to restore historical fire regimes. Restoration thinning was conducted on the majority of the area occupied by the Mesa Top Pinyon-Juniper ecological site between 2007 and 2010.

In 2008 the Integrated Upland Monitoring program of SCPN began monitoring upland sites at BAND with the installation of 15 plots in the Mesa Top Pinyon-Juniper ecological site in areas that had not been thinned. In 2009 an additional 25 plots were installed. Fourteen plots were located in areas that had been thinned, and 11 plots were located in areas that had not been thinned. Some of the unthinned plots have subsequently been thinned. In this report, we document monitoring activities in the 2009 field season and compare these data with the data collected in 2008.

Methods

Sampling frame

The sampling frame is the area from which sites are randomly selected, and hence the area to which statistical inferences can be made. SCPN generally uses ecological sites developed by the U.S. Natural Resources Conservation Service (NRCS) to create their sampling frames. Although a recent soil survey update was completed for the monument (Hibner 2000), ecological site data was not updated. Rather than use old ecological site descriptions to create a sampling frame, we developed a version of the Mesa Top Pinyon-Juniper ecological site by identifying soil map units in the park that were dominated by pinyon-juniper woodlands. The targeted soil types had more variability than we typically include within the same sampling frame, and they may include more than one NRCS ecological site. However, park staff requested that we use this liberal interpretation in order to maximize the extent of the sampling frame at the expense of encompassing greater heterogeneity and higher variation in vegetation and soil. For the sake of simplicity, the area represented by the sampling frame we created will be referred to as Mesa Top Pinyon-Juniper ecological site.

To create the sampling frame, we modified the map of the ecological site in GIS (Geographic Information System) by removing the roads, areas where the slopes exceeded 20%, and other vegetation plots and study areas (fig. 1). The sampling frame was further modified by removing areas that required more than a two hour hike to the plot from headquarters, park roads, or Base Camp (see

Appendix A of DeCoster et al., in review). A set of spatially distributed sampling points was generated using the Generalized Random-Tessellation Stratified (GRTS) design (Stevens and Olsen 2004). Park staff reviewed the sampling points and had the opportunity to reject points that landed too close to archeological sites and other sensitive resources. Before establishing a plot, the integrated upland crew conducted an ecological site assessment for each sampling point, and rejected the site if it (1) did not possess the characteristics of the ecological site, (2) had a slope exceeding 20%, or (3) contained a major disturbance. They rejected thirteen points: six points required over two hours

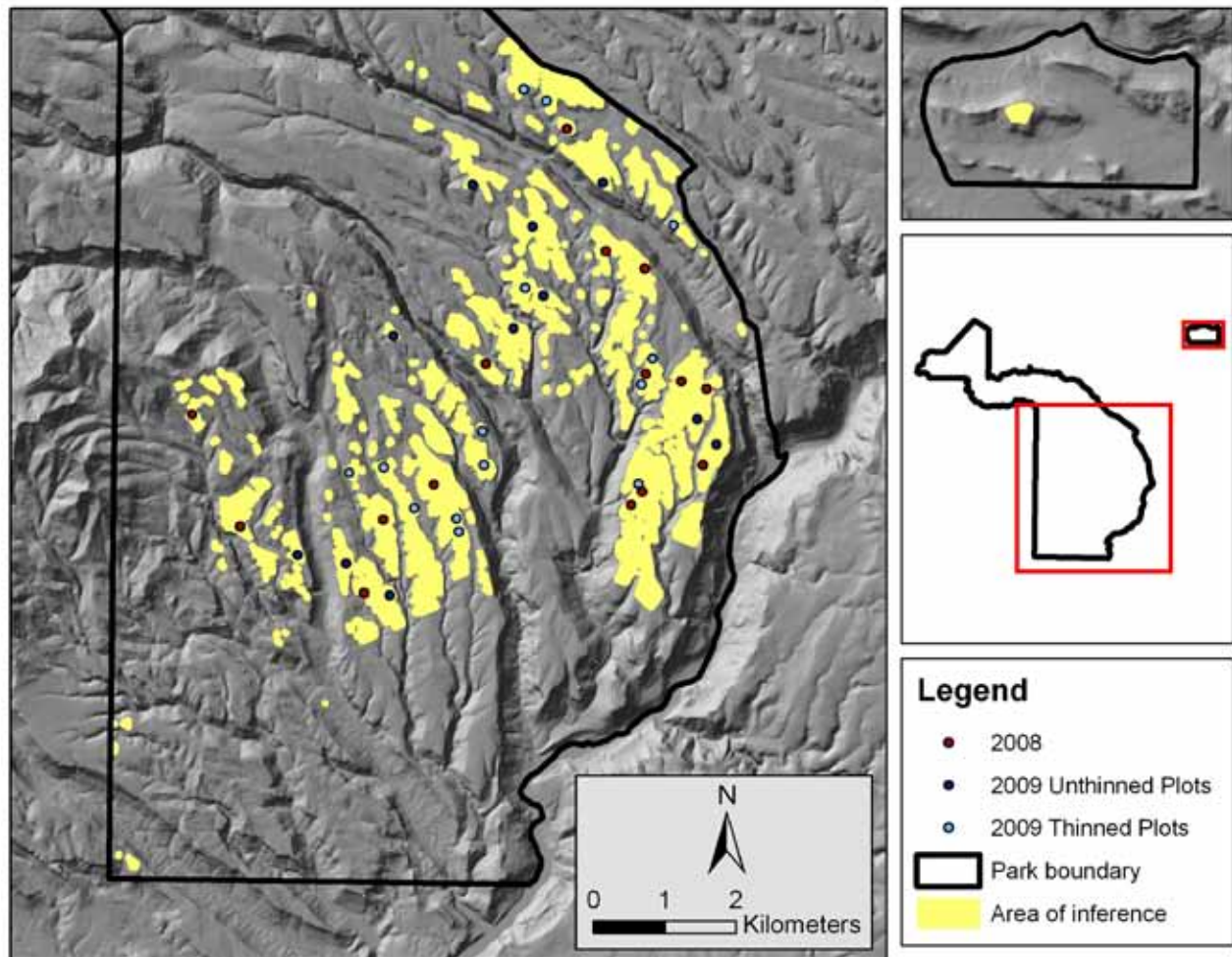


Figure 1. Sampling frame of Mesa Top Pinyon-Juniper ecological site at BAND with the 15 plots established in 2008 and the 25 established in 2009

hiking time to access the point, two points were within 50 m of a trail, one point contained a large archeological site with altered vegetation, one point was within 100 meters of another plot, one point fell next to an elk enclosure, and two points were comprised of other ecological sites.

Field methods

In 2008, the SCPN upland monitoring crew installed 15 plots, and in 2009 they installed 25 plots. The plots were 0.50 ha in size, measuring 71 × 71 m. Shrub, herbaceous, tree seedling, and soil data were collected on three 50 m transects, spaced 25 meters apart within each plot. Tree data were collected in a 20 × 50 m subplot located between two of the transects. In 2008 the crew collected data

from the plots in September; in 2009 they collected data in late August and September. Field methodology is provided in detail in the SCPN Integrated Upland Protocol (DeCoster et al. in review).

Shrub and herbaceous vegetation

The crew sampled shrub and herbaceous vegetation within five sets of nested quadrats at 10 m intervals along each transect. The largest quadrat size was 10 m² (2 × 5 m), with four smaller quadrats nested inside (0.01 m², 0.1 m², 1 m², 5 m²). For each nested sub-quadrat we recorded the presence of individual vascular species. For each 10 m² quadrat we estimated percent foliar cover for herbaceous and shrub species and recorded it as one of 12 cover classes (e.g., 2%–5%, 5%–10%, etc.). We also estimated the percent foliar cover for functional groups (e.g., perennial grasses, forbs, shrubs) in the 10 m² quadrats, and recorded the cover class for each.

Overstory trees, saplings, and seedlings

We measured overstory trees, defined as having a diameter greater than or equal to 15 cm, within a 20 × 50 m (0.1 ha) subplot between two of the transects. Due to their multi-stemmed growth form, *Juniperus* spp. were measured using diameter at root crown (DRC). All other species were measured in diameter at breast height (DBH). We recorded the species, diameter, and status (live or dead) for each individual tree. Saplings (≥2.5 and <15 cm diameter) were sampled in a 10 × 20 m subplot and then tallied by species and size class. Tree seedlings (<2.5 cm diameter) were sampled in the 10 m² quadrats, in conjunction with the herbaceous/shrub data, and then tallied by species and size class. Size classes of *Juniperus* spp. seedlings were based on DRC, while size classes of other species were based on height. Unfortunately, because of some inconsistencies in the way that seedling data were collected in 2008, these data will not be reported.

Due to inherent problems associated with measuring multi-stemmed individuals of *Juniperus* spp., the crew also measured the tree canopy. In 2008 we used hemispherical densiometers to measure canopy closure at each quadrat. In 2009 we changed our methodology and measured tree canopy cover using line-intercept methods along the three transects. Canopy closure refers to the proportion of the hemisphere of sky obscured by vegetation when viewed from a single point; canopy cover measures the proportion of the forest floor covered by the vertical projection of tree crowns (Jennings et al. 1999). We felt canopy cover would provide more repeatable and less variable measurements.

Soil stability and hydrologic function

To measure the amount of bare soil, the crew recorded the length of basal gaps (the space between plant bases) along each transect. Percent cover of soil surface features (duff/litter, woody debris, gravel, biological soil crusts, bare soil, etc.) was estimated in the 1 m² quadrats in conjunction with shrub and herbaceous data, and recorded in one of 12 cover classes. A soil aggregate stability test was conducted using 18 soil samples collected at random points along the transects. Locations with deep pumice were not measured.

Data summary

The sample unit for summary and analysis is the plot; hence, we summarized data at the level of the plot. In order to calculate summary statistics for the ecological site, we calculated means and standard deviations from the plot means.

For herbaceous and shrub vegetation, we calculated

- Species frequency for the 10 m² quadrats (mean percentage of quadrats per plot where the species occurs), and for plots (percentage of plots where the species occurs).
- Cover for each species from the cover class midpoints, (e.g., using 7.5% for cover class 5%–10%). The mean cover was calculated for each plot, and the mean and standard deviation (SD) were calculated for the ecological site from the plot means.
- Mean cover and SD of functional groups.

We also calculated four diversity measures for herbaceous and shrub species, first for all species and then for native species only (Magurran 1988).

(1) Species richness (S) is the number of species at a given spatial scale, and it was calculated at the level of the plot and at the level of the ecological site.

(2) The Shannon Diversity Index (H') provides a measure of species diversity that takes into account the relative abundance of each species:

$$H' = - \sum_{i=1}^n p_i \ln p_i$$

where p_i is the abundance of each species.

(3) Species evenness (E) is a measure of the degree to which all species are equal in abundance:

$$E = H' / \ln(S)$$

(4) Beta diversity (β_w) is a measure of within-ecological site heterogeneity (diversity among plots):

$$\beta_w = S_e / (S_p - 1)$$

where S_e is the total number of species found in the ecological site, and S_p is the mean number of species found per plot.

We also calculated

- tree basal area (the total cross-sectional area of the trees) for each overstory tree species in terms of m²/ha
- tree density for all species and size classes for overstory, sapling, and seedling layers in terms of stems/ha
- mean diameter of overstory trees by species
- mean canopy cover

The mean soil aggregate stability index and its standard deviation were calculated. This index ranges between 1 and 6, where 1 indicates low aggregate stability and 6 indicates high aggregate stability. The index was also calculated separately for samples with vegetative cover and for samples without vegetative cover.

We calculated mean and SD for the following basal gap measures:

- median basal gap size
- percentage of transects comprised by gaps and plant bases
- percentage of transects comprised by each of four basal gap size classes
- total number of gaps

Mean cover and SD of soil surface features were also calculated.

Data summaries present the 2008 (unthinned) data and the thinned and unthinned data of 2009.

Results

Shrub and herbaceous vegetation

The vegetation of the Mesa Top Pinyon-Juniper ecological site at BAND is dominated by shrubs and perennial grasses, with less cover of forbs, cacti/succulents and annual grasses (table 1 and fig. 2). Total foliar cover ranged from 11.72% to 16.88% in the three sets of plots (2008 unthinned, 2009 thinned and 2009 unthinned). Shrub cover ranged from 3.17% to 7.32%, perennial grass cover ranged from 4.30% to 6.46%, and forb cover ranged from 2.09% to 2.78%. Cover of annual grasses and cacti/succulents comprised less than 1%. Total foliar cover was lowest in 2008, as was cover of perennial grasses and shrubs.

Table 1. Mean foliar cover of functional groups for 2008 (unthinned) and 2009 (thinned and unthinned) plots in the Mesa Top Pinyon-Juniper ecological site at BAND

Functional Groups	Foliar Cover (%)					
	2008 Unthinned		2009 Thinned		2009 Unthinned	
	Mean	SD	Mean	SD	Mean	SD
Perennial grasses	4.30	2.83	5.90	3.78	6.46	4.70
Annual grasses	0.38	1.21	0.07	0.13	0.12	0.23
Forbs	2.43	2.42	2.78	1.88	2.09	1.29
Shrubs	3.17	2.42	7.32	4.23	6.00	4.45
Cacti and succulents	0.48	0.62	1.02	1.49	1.12	1.43
Total live foliar cover	11.72	5.45	16.88	2.92	15.36	6.45
Standing dead herbaceous	1.42	0.72	1.43	0.58	1.64	0.95
Standing dead woody	0.57	0.54	1.07	0.91	0.92	0.68

Dominant grasses included *Bouteloua gracilis* (blue grama), *Elymus elymoides* (squirreltail) and *Poa fendleriana* (muttongrass); dominant shrubs included *Gutierrezia sarothrae* (broom snakeweed), *Quercus* spp. (oak), *Cercocarpus montanus* (birchleaf mountain mahogany) and *Rhus trilobata* (skunkbush sumac) (table 2 and fig. 3). Many species had similar cover among the three sets of plots, while the cover of others were substantially different. For example, *Gutierrezia sarothrae* had the greatest cover in the 2009 thinned plots; *Quercus* spp. and *Rhus trilobata* had the greatest cover in the 2009 unthinned plots; the cover of *Bouteloua gracilis* was lowest in the 2008 plots. Quadrat and

Figure 2. Mean foliar cover of all functional groups in 2008 (unthinned) and 2009 (thinned and unthinned) plots in the Mesa Top Pinyon-Juniper ecological site at BAND. Error bars represent one standard deviation.

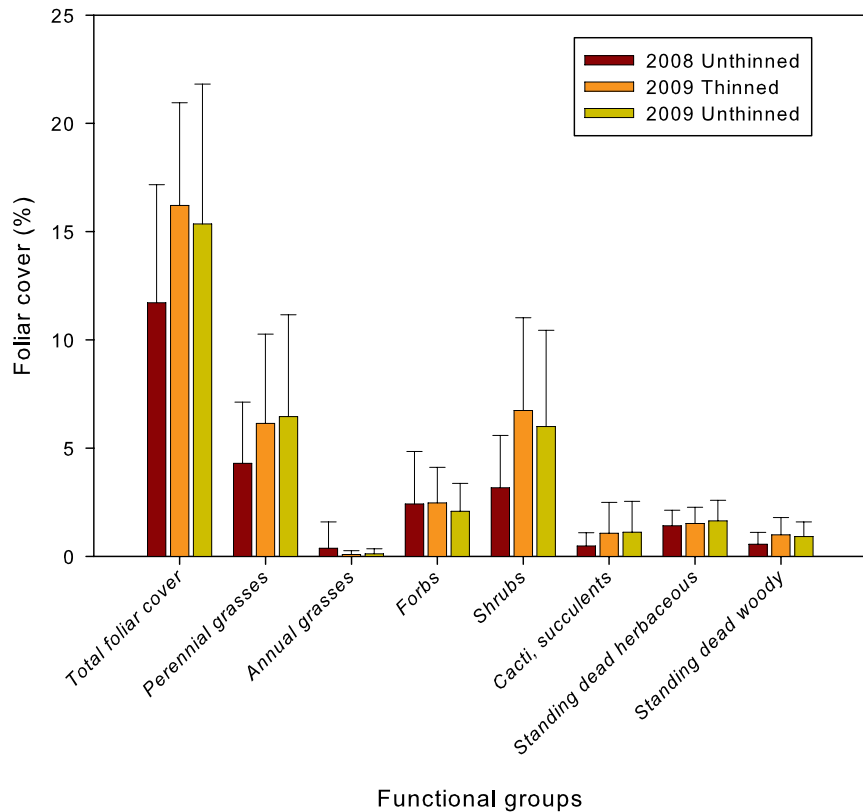


Figure 3. Mean foliar cover of abundant shrub and herbaceous species in 2008 (unthinned) and 2009 (thinned and unthinned) plots in the Mesa Top Pinyon-Juniper ecological site at BAND. Species with foliar cover greater than 0.85% in any one of the three groups are included. Error bars represent one standard deviation.

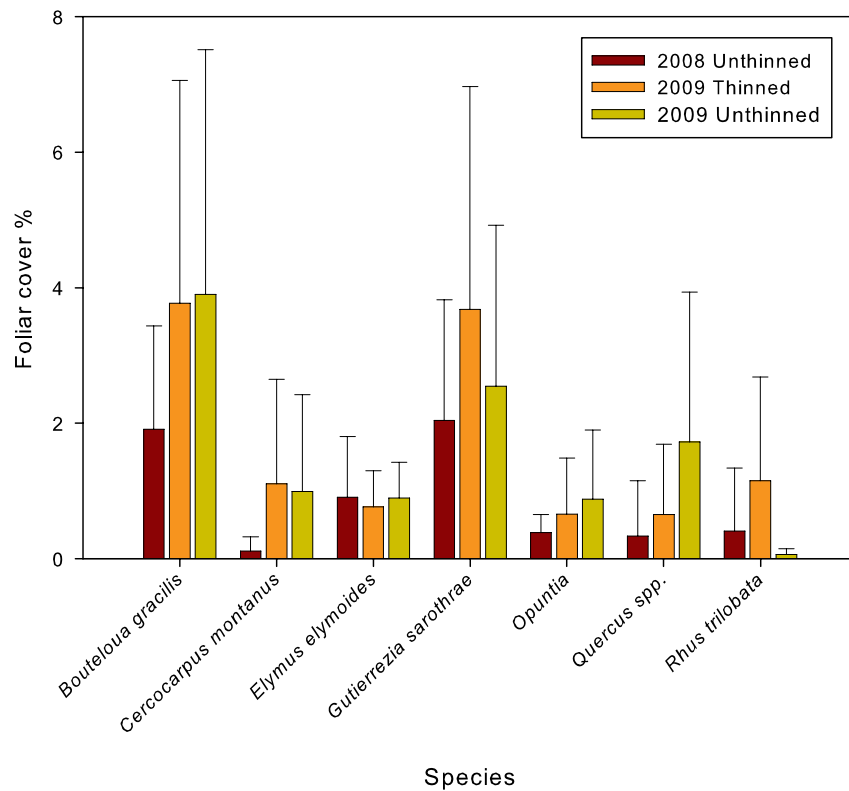


Table 2. Foliar cover and frequency of the most abundant vascular species and all nonnative species in 2008 (unthinned) and 2009 (thinned and unthinned) plots in the Mesa Top Pinyon-Juniper ecological site at BAND

Species	2008 Unthinned					2009 Thinned					2009 Unthinned				
	Mean cover (%)	SD	Quad freq	Plot freq	Mean cover (%)	SD	Quad-freq	Plot-freq	Mean cover (%)	SD	Quad freq	Plot freq	Mean cover (%)	SD	Quad freq
<i>Gutierrezia sarothrae</i>	2.044	1.778	57.78	93.33	3.677	3.288	60.95	100.00	2.545	2.374	72.12	100.00	2.545	2.374	72.12
<i>Bouteloua gracilis</i>	1.913	1.524	74.67	100.00	3.770	3.290	76.67	100.00	3.899	3.614	81.21	100.00	3.899	3.614	81.21
<i>Elymus elymoides</i>	0.910	0.894	69.78	100.00	0.766	0.533	70.48	100.00	0.900	0.525	79.39	100.00	0.900	0.525	79.39
<i>Artemisia dracunculoides</i>	0.609	1.466	52.44	86.67	0.004	0.013	0.48	7.14	0.009	0.03	0.61	9.09	0.009	0.03	0.61
<i>Poa fendleriana</i>	0.452	0.752	29.78	93.33	0.347	0.419	25.71	71.43	0.585	0.808	31.52	72.73	0.585	0.808	31.52
<i>Rhus trilobata</i>	0.408	0.930	9.33	60.00	1.152	1.531	16.19	85.71	0.064	0.082	7.88	63.64	0.064	0.082	7.88
<i>Bromus tectorum</i> ^a	0.376	1.207	14.67	53.33	0.054	0.105	16.19	71.43	0.120	0.234	15.15	63.64	0.120	0.234	15.15
<i>Quercus</i> spp.	0.333	0.820	9.78	40.00	0.650	1.038	13.33	85.71	1.722	2.215	22.42	72.73	1.722	2.215	22.42
<i>Opuntia</i> spp.	0.269	0.384	34.22	86.67	0.658	0.828	41.90	85.71	0.880	1.022	49.70	100.00	0.880	1.022	49.70
<i>Verbascum thapsus</i> ^a	0.246	0.422	13.78	53.33	0.345	0.517	20.00	71.43	0.194	0.488	11.52	45.45	0.194	0.488	11.52
<i>Fallugia paradoxa</i>	0.114	0.368	4.89	26.67	0.439	0.800	13.81	57.14	0.508	0.950	14.55	45.45	0.508	0.950	14.55
<i>Cercocarpus montanus</i>	0.111	0.213	12.00	46.67	1.107	1.543	22.38	57.14	0.991	1.428	20.61	54.55	0.991	1.428	20.61
<i>Yucca baccata</i>	0.071	0.167	3.56	33.33	0.172	0.468	7.14	21.43	0.218	0.453	9.09	36.36	0.218	0.453	9.09
<i>Portulaca oleracea</i> ^a	0.012	0.018	8.89	40.00	0.001	0.005	0.48	7.14	0.011	0.030	1.82	18.18	0.011	0.030	1.82
<i>Lactuca serriola</i> ^a	0.007	0.019	3.56	13.33	0.004	0.012	3.33	21.43	0.001	0.002	1.82	18.18	0.001	0.002	1.82
<i>Tragopogon dubius</i> ^a	0.006	0.015	4.44	33.33	0.011	0.032	5.24	35.71	0.004	0.010	4.85	36.36	0.004	0.010	4.85
<i>Sisymbrium altissimum</i> ^a	0.001	0.005	0.44	6.67	<0.001	0.001	0.48	7.14	0.000	0.000	0.00	0.00	0.000	0.000	0.00
<i>Artemisia campestris</i>	0	0	0	0	0.825	0.869	57.62	92.86	0.262	0.324	38.18	90.91	0.262	0.324	38.18
<i>Salsola tragus</i> ^a	0	0	0	0	0.004	0.013	0.48	7.14	0.006	0.021	1.21	9.09	0.006	0.021	1.21
<i>Taraxacum officinale</i> ^a	0	0	0	0	0	0	0	0	<0.001	0.001	0.61	9.09	<0.001	0.001	0.61
<i>Erodium cicutarium</i> ^a	0	0	0	0	0	0	0	0	0.004	0.012	1.21	9.09	0.004	0.012	1.21

Note: Species are arranged in descending order by 2008 mean cover values. Native species with foliar cover greater than 0.5% in any one of the three groups are included, in addition to all nonnative species. In 2008 there was some confusion in distinguishing the species of *Artemisia*.

^aNonnative species.

plot frequencies of the more abundant species did not reveal substantial differences among the three sets of plots, but there were substantial differences among the plots for the less abundant species. For example, there were 17 species that occurred in the 2008 plots but not the 2009 plots, 10 species that occurred in the 2009 thinned plots but not in the unthinned plots, and 9 species that occurred in the 2009 unthinned plots but not the other plots (excluding unknowns). Appendix A lists all species, along with common names, families, mean foliar covers, and plot frequencies by year.

We found nine nonnative species in the plots across all plot groups. *Bromus tectorum* (cheatgrass) and *Verbascum thapsus* (common mullein) were the most abundant nonnative species. The cover of both species was low ($< 0.4\%$), but plot frequency ranged from 53.33% to 71.43% and from 20.00% to 53.33%, respectively. The other seven species had mean covers of less than 0.10%, and most had plot frequencies of less than 30%. Four species occurred in only one or two of the plots. Three species were found in the 2009 plots, but were not found in the 2008 plots: *Salsola tragus* (prickly Russian thistle), *Erodium cicutarium* (stork's bill), *Taraxacum officinale* (common dandelion).

On the scale of the plot, the diversity indices were similar for the three sets of plots. Mean species richness ranged from 32.1 to 33.5 (table 3). Shannon diversity (which takes into account relative species abundance, and generally ranges between 1.5 and 3.5) ranged between 2.089 and 2.196. Evenness (the degree to which all species are of equal abundance, ranging from 0 to 1 [Margalef 1972]) ranged from 0.599 to 0.630. On the scale of the ecological site, species richness ranged from 98 to 101. Beta diversity (a measure of within-site heterogeneity, generally ranging between 1 and 5 [McCune and Grace 2002]) ranged from 3.296 to 3.409. In all instances, the diversity indices were highest for the 2008 plots, except beta diversity which was highest for the 2009 unthinned plots. When these indices were recalculated using only native species, they did not change substantially.

Table 3. Species diversity metrics for all species, and for native species only, in 2008 (unthinned) and 2009 (thinned and unthinned) plots in the Mesa Top Pinyon-Juniper ecological site at BAND

	2008 Unthinned		2009 Thinned		2009 Unthinned	
	Mean	SD	Mean	SD	Mean	SD
All species						
Plot						
Plot richness	33.5	7.0	32.9	6.3	32.1	8.6
Shannon diversity	2.197	0.330	2.089	0.499	2.118	0.485
Evenness	0.630	0.089	0.599	0.131	0.617	0.138
Ecological site						
Ecological site richness	107		106		106	
Beta diversity	3.296		3.327		3.409	
Native species						
Plot						
Plot richness	31.3	5.6	30.6	5.5	30.0	6.8
Shannon diversity	2.156	0.329	2.038	0.481	2.077	0.457
Evenness	0.630	0.095	0.596	0.131	0.616	0.136
Ecological site						
Ecological site richness	101		99		98	
Beta diversity	3.330		3.340		3.379	

Trees

Figures 4 and 5 and table 4 show the relative abundance of overstory trees by species and size class in terms of density and basal area.

Juniperus monosperma (oneseed juniper) was the dominant overstory tree in all three sets of plots. Its overstory density in both of the unthinned sets of plots was similar: 156.7 stems/ha in the 2008 and 177.3 stems/ha in 2009. However, its basal area was much lower in the 2008 than in the 2009 unthinned plots: 13.59 m²/ha in 2008 and 17.85 m²/ha in 2009.

Juniperus deppeana (alligator juniper), *Pinus edulis* (two-needle pinyon), and *Pinus ponderosa* (ponderosa pine) were of low abundance in all three sets of plots. *Pinus edulis* was sparse in the overstory with a basal area of 0.01 m²/ha and an overstory density of 0.7 stems/ha in the 2008 plots (1 individual in 15 plots). There were no overstory individuals in the 2009 plots. *Pinus ponderosa* occurred in only one of the 2008 plots. *Juniperus deppeana* was the dominant tree in one of the 2008 plots, and only one individual occurred in one of the 2009 unthinned plots.

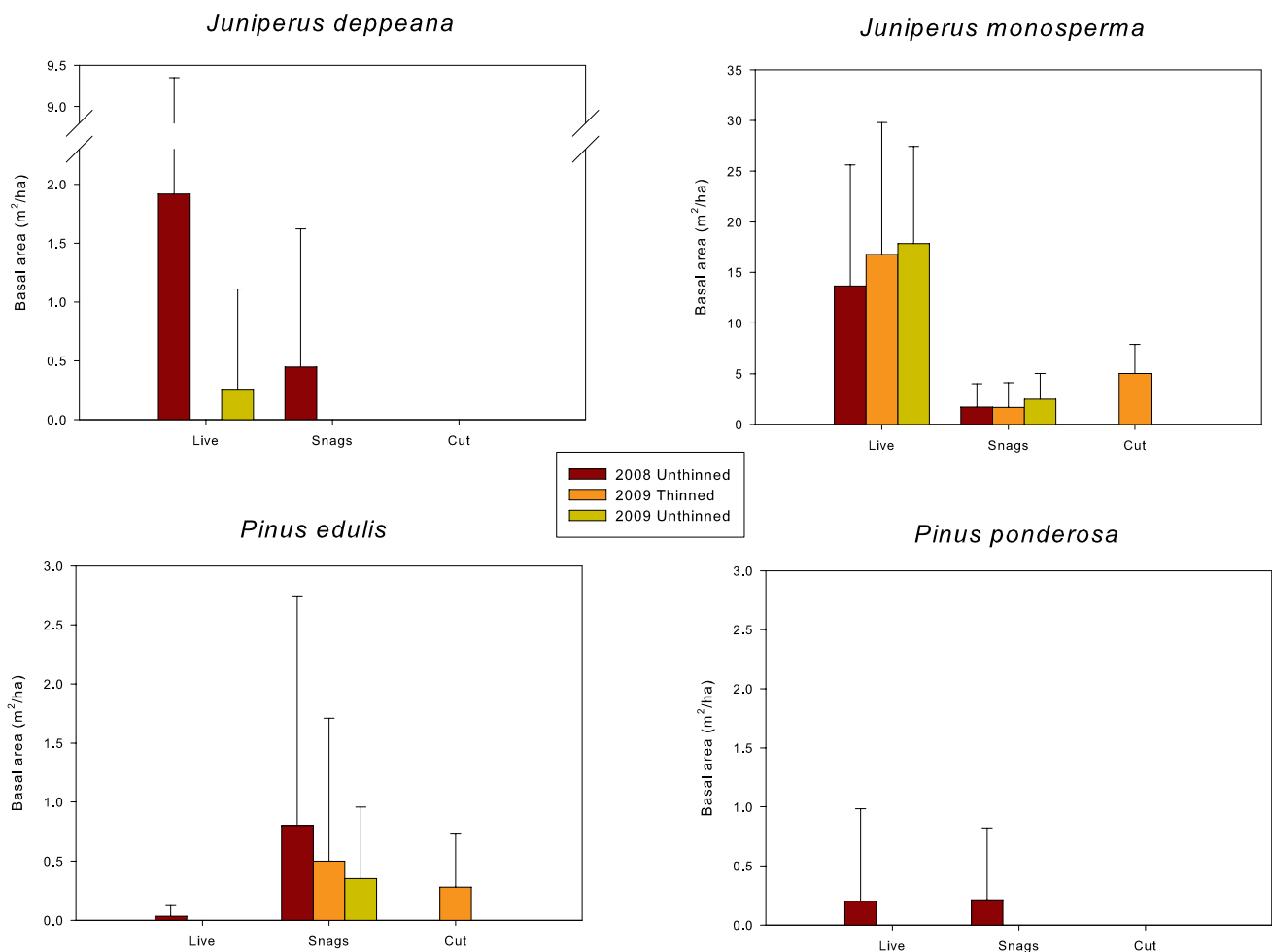


Figure 4. Mean basal area for living trees, snags, and cut trees in 2008 (unthinned) and 2009 (thinned and unthinned) plots in the Mesa Top Pinyon-Juniper ecological site at BAND, by species. Note that the scale of the graph of *Juniperus monosperma* differs from the other three.

Table 4. Mean density, basal area, and diameter of trees in 2008 (unthinned) and 2009 (thinned and unthinned) plots in the Mesa Top Pinyon-Juniper ecological site at BAND, by species and size class^a

Metric	Plot Group	<i>Juniperus deppeana</i>	<i>Juniperus monosperma</i>	<i>Pinus edulis</i>	<i>Pinus ponderosa</i>	Total
Seedling density ^b (stems/ha)						
	2009 Thinned	0	171.4	104.8	0	276.2
	2009 Unthinned	0	248.5	218.2	0	466.7
Sapling density (stems/ha)						
	2008 Unthinned	10.7	144.0	50.7	0	205.3
	2009 Thinned	0	20.0	20.0	0	40.0
	2009 Unthinned	0	127.3	10.9	0	138.2
Overstory density (stems/ha)						
	2008 Unthinned	12.7	156.7	0.7	2.0	172.0
	2009 Thinned	0	94.3	0	0	94.3
	2009 Unthinned	0.9	177.3	0	0	178.2
	2009 Cut	0	96.4	7.8	0	0
Snag density (stems/ha)						
	2008 Unthinned	4.7	24.0	24.0	2.7	55.3
	2009 Thinned	0	12.1	12.9	0	25.0
	2009 Unthinned	0	24.5	10.9	0	35.5
Overstory basal area (m ² /ha)						
	2008 Unthinned	1.92	13.59	0.01	0.20	15.72
	2009 Thinned	0	16.78	0	0	16.78
	2009 Unthinned	0.26	17.85	0	0	18.11
	2009 Cut	0	5.00	0.28	0	5.28
Snag basal area (m ² /ha)						
	2008 Unthinned	0.45	1.74	0.86	0.22	3.25
	2009 Thinned	0	1.67	0.50	0	2.17
	2009 Unthinned	0	2.47	0.35	0	2.82
Overstory diameter ^c (cm)						
	2008 Unthinned	41.6	29.5	15.0	34.7	29.6
	2009 Thinned	0	45.6	0	0	45.6
	2009 Unthinned	60	38.8	0	0	38.9

^aSize classes: seedlings are <2.5 cm diameter, saplings are 2.5–14.9 cm diameter, overstory trees are ≥15 cm diameter, and snags are standing dead stems ≥15 cm diameter.

^bSeedlings were not consistently measured in 2008, and hence are not shown here.

^cMean diameter of trees is provided as DBH for *Pinus* spp. and as DRC for *Juniperus* spp. Total values reflect the mean diameter, not the cumulative total, as for basal area and density above.

The snag density and basal area of *Pinus edulis* greatly exceeded the density and basal area of the live trees in the 2008 plots (fig. 4). Snag density and basal area of *Juniperus monosperma* were higher than *P. edulis*, but much lower than the living stems of *J. monosperma*.

The objective of the thinning treatment was to reduce the density of small stems of *Juniperus monosperma*. This was evident in its lower density in the 2009 thinned plots compared to the 2009 unthinned plots: 94.3 stems/ha compared with 177.3 stems/ha, respectively. The basal area of the 2009 thinned plots was only somewhat lower than the 2009 unthinned plots: 16.78 m²/ha compared to 17.85 m²/ha. We measured the diameter of cut stumps in the thinned plots: their density was 96.4 stems/ha, and their basal area was 5.00 m²/ha. Basal area of *J. monosperma* was reduced by 23% and its density was reduced by 50% by the thinning treatment. Cut overstory stems of *Pinus edulis* were also present in the 2009 thinned plots, but these were likely to be individuals that were dead at the time of the thinning, as the thinning prescription was to cut only individuals of *J. monosperma*.

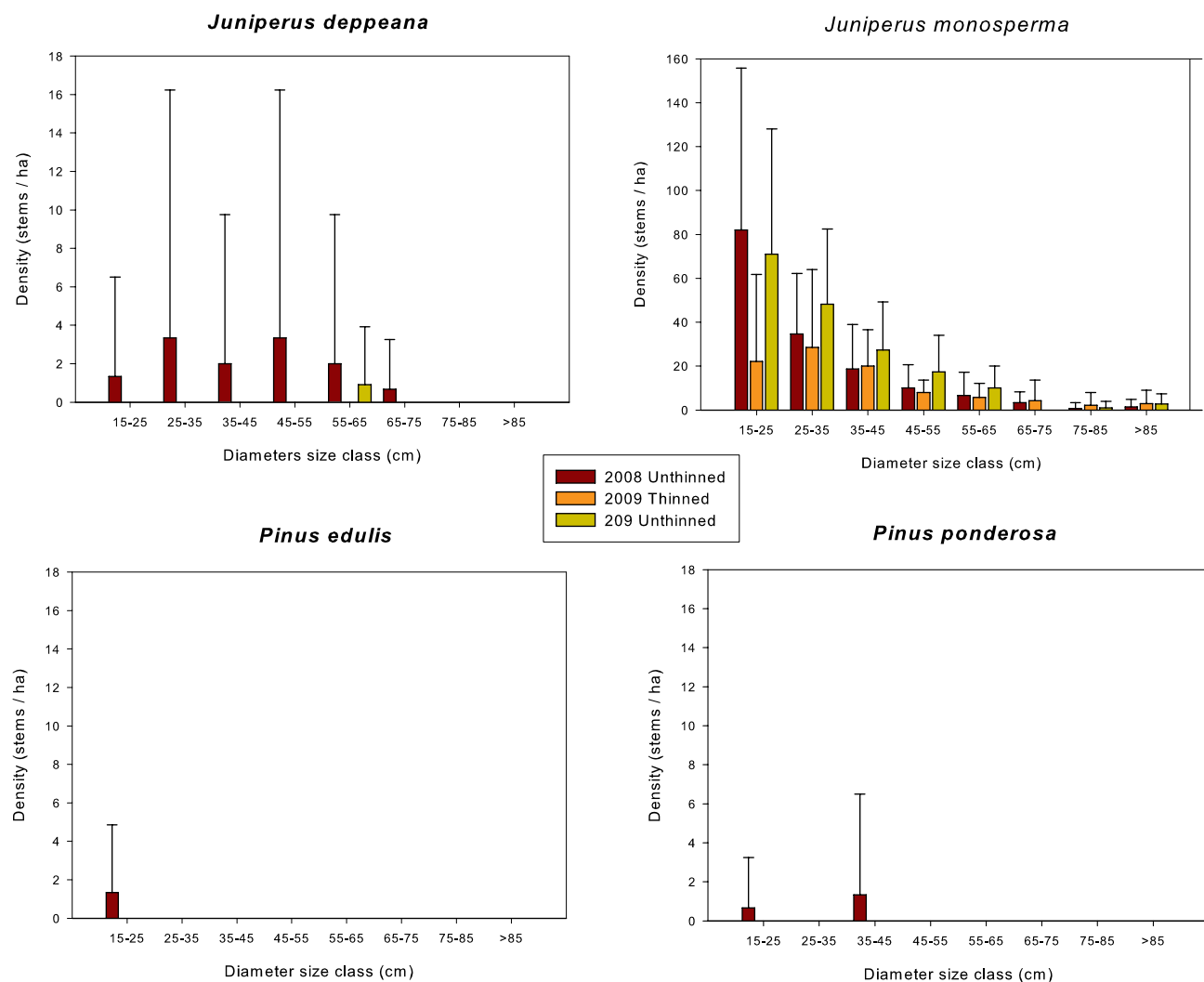


Figure 5. Size structure of overstory tree species in 2008 (unthinned) and 2009 (thinned and unthinned) plots in the Mesa Top Pinyon-Juniper ecological site at BAND. Error bars represent 1 standard deviation. Note that the scale of the graph of *Juniperus monosperma* differs from the other three.

In both the 2008 and 2009 unthinned plots, most *Juniperus monosperma* individuals were of the smaller diameter classes and progressively fewer occurred in the larger diameter classes (fig. 5). As expected, the size structure of the 2009 thinned plots demonstrates a much lower density in the smallest overstory size class (15–25 cm), and a slightly lower density in the second lowest size class (35–45 cm). It is difficult to make generalizations about the size structure of the other species due to the small sample sizes.

Sapling and seedling densities provide insight into the structure and dynamics of the forest. Saplings of *Juniperus monosperma*, *Pinus edulis*, and *Juniperus deppeana* occurred in all three sapling size classes in the 2008 plots, with *Juniperus monosperma* having the highest densities in the two largest size classes, and *Pinus edulis* having the highest density in the smallest size class (fig. 6). In the 2009 unthinned plots, the sapling size classes of *Juniperus monosperma* were more evenly distributed, but the total sapling density was comparable to the 2008 density: 144.0 stems/ha in 2008 and 127.3 stems/ha in 2009. In the 2009 thinned plots, *Juniperus monosperma* sapling density was much lower, 20.0 stems/ha (table 4). In both the 2009 thinned and unthinned plots, *Pinus edulis* only occurred in the

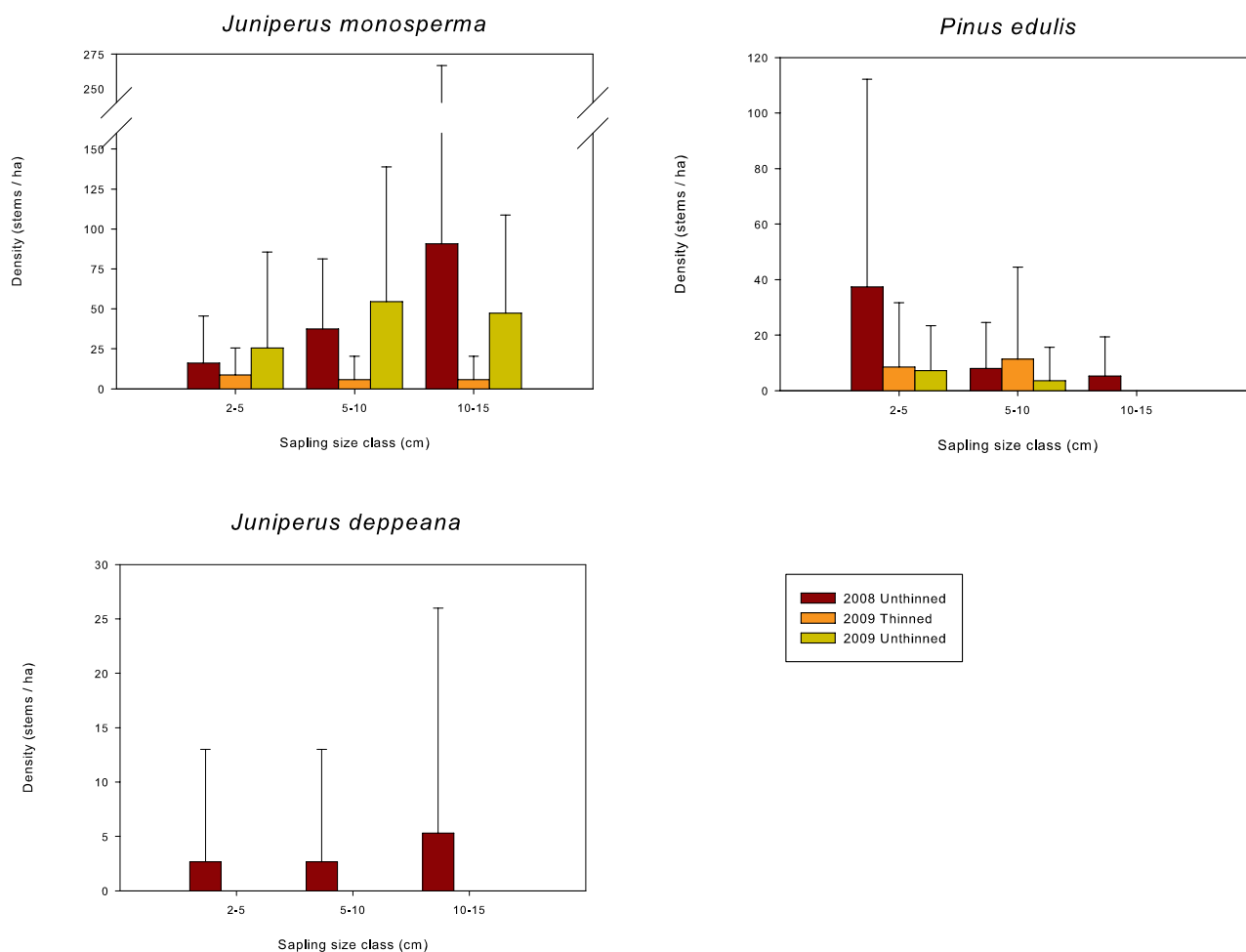


Figure 6. Mean density of saplings in different diameter size classes in 2008 (unthinned) and 2009 (thinned and unthinned) plots in the Mesa Top Pinyon-Juniper ecological site at BAND. Error bars represent 1 standard deviation. Note that the scales of the three graphs differ.

smaller two size classes in low densities. No *Juniperus deppeana* saplings occurred in any of the 2009 plots. Large standard deviations in the figures indicate high variability in sapling densities among plots.

Seedling data was not collected consistently in 2008, so only data from 2009 is presented (table 4 and fig. 7). Only *Juniperus monosperma* and *Pinus edulis* were represented in the seedling layer; both occurred in moderately low densities. There were no *P. edulis* seedlings of the largest size class in the thinned plots. Densities for both species were lower in the thinned plots than in the unthinned plots. Large standard deviations indicate high variability in seedling densities among plots.

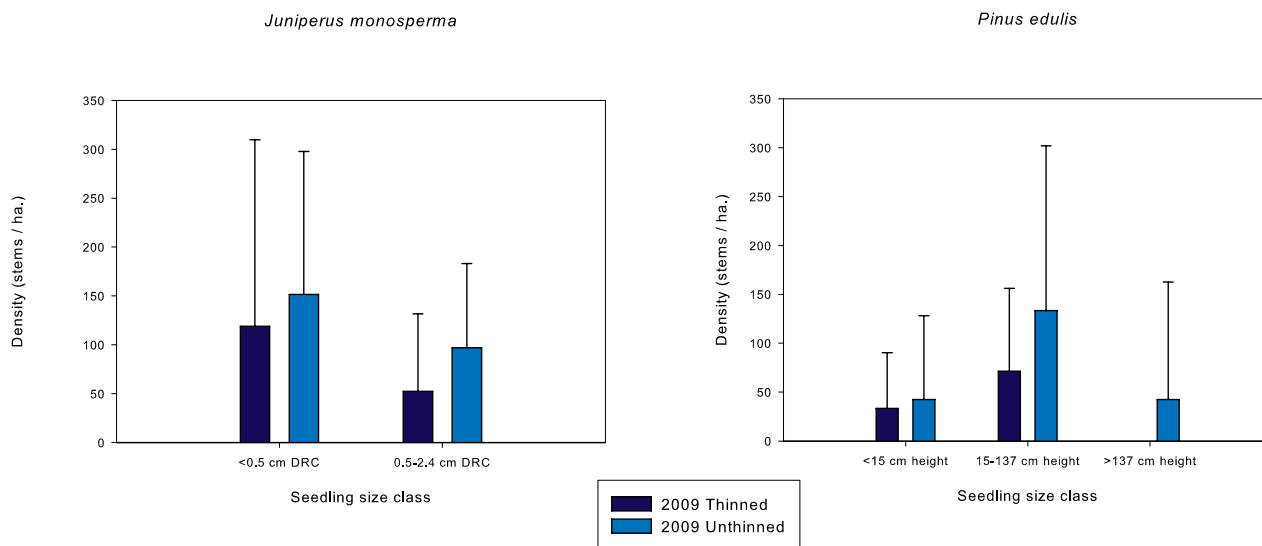


Figure 7. Mean density of seedlings in different size classes in 2009 (thinned and unthinned) plots in the Mesa Top Pinyon-Juniper ecological site at BAND. Error bars represent 1 standard deviation. Seedlings were not consistently measured in 2008, hence are not shown here. Note that seedling size classes differ for the two species because of the difference in how the two species were measured, however, all seedlings were defined as those with stems <2.5 cm diameter.

Figure 8 shows the density of both overstory and sapling trees by diameter size class for all species combined. Tree density in the overstory size classes for the 2008 plots demonstrates a typical decline with increasing tree diameter. Density in the two sapling size classes does not conform to this trend, being lower than expected. This flattening of the curve is more pronounced in the 2009 thinned and unthinned plots. In the 2009 unthinned plots, the 15–25 cm size class has the highest density. The size class distribution in the 2009 thinned plots is fairly flat, showing lower tree densities than both the 2008 plots and the 2009 unthinned plots in all size classes but the largest three.

Figure 9 shows canopy cover results for 2009, since the 2008 collection of canopy closure (the proportion of the hemisphere of sky obscured by vegetation when viewed from a single point) was abandoned in favor of collecting canopy cover (the proportion of the forest floor covered by the vertical projection of tree crowns) in 2009. Mean canopy cover was 17.6% in the 2009 unthinned plots and 11.5% in the 2009 thinned plots.

Soil stability and hydrologic function

The crew monitored the amount of exposed soil in two ways: 1) cover estimates of soil surface fea-

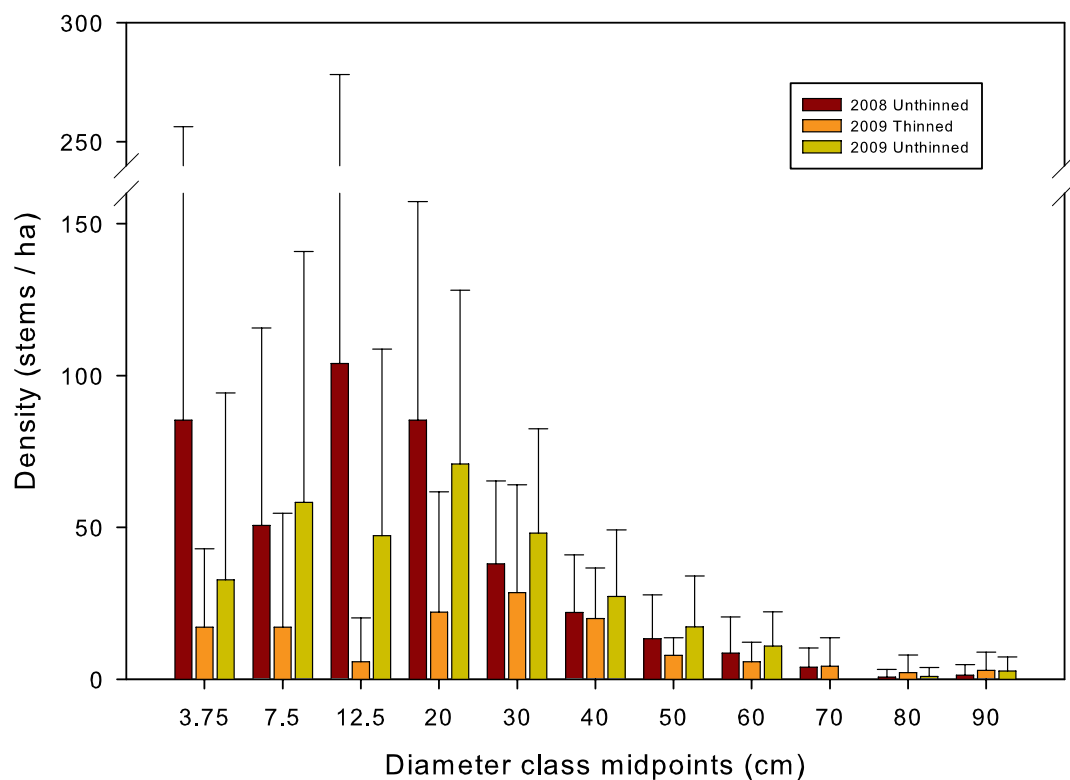


Figure 8. Size structure of overstory trees and saplings in 2008 (unthinned) and 2009 (thinned and unthinned) plots in the Mesa Top Pinyon-Juniper ecological site at BAND. Error bars represent 1 standard deviation.

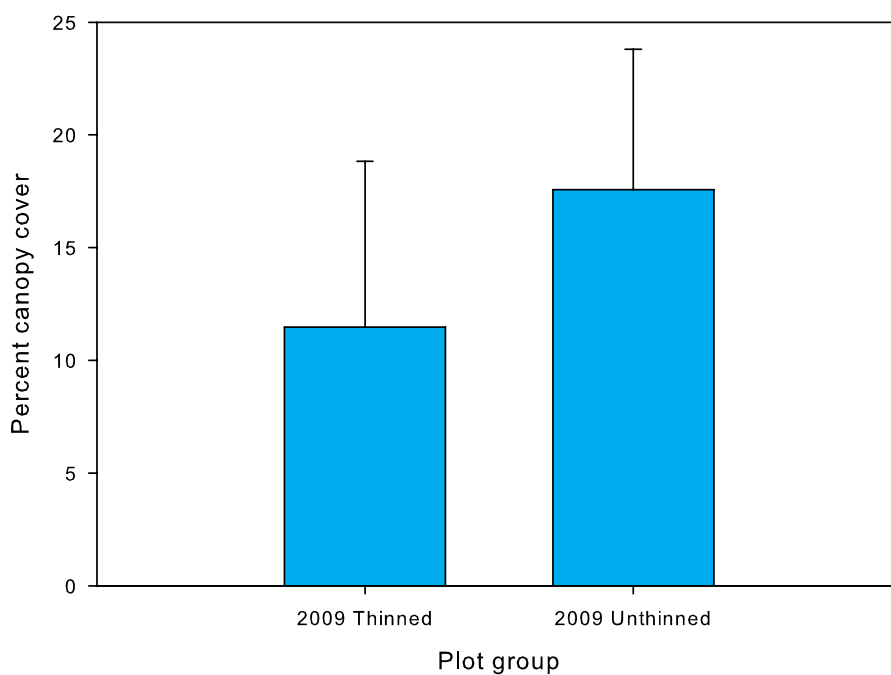


Figure 9. Mean canopy cover comparing 2009 thinned and unthinned plots in the Mesa Top Pinyon-Juniper ecological site at BAND. Error bars indicate 1 standard deviation.

tures in quadrats and 2) measurements of basal gaps along transects. The most abundant soil surface features across all plot groups were duff/litter (32.55%–37.60%), fine gravel (30.73%–33.19%) and undifferentiated crust (13.97%–16.49%) (table 5 and fig. 10). There were small differences in surface features among the three sets of plots. The basal gap data in table 6 and figure 11 indicate that gaps greater than 100 cm occupied 76.9%–81.0% of the transects. While there were noticeable differences in the number of basal gaps and the mean basal gap size between the 2008 and 2009 plots, the percentage of transect occupied by the different basal gap sizes was not substantially different.

Table 5. Mean cover of soil surface features in 2008 (thinned) and 2009 (thinned and unthinned) plots in the Mesa Top Pinyon-Juniper ecological site at BAND

Surface feature	2008 Unthinned		2009 Thinned		2009 Unthinned	
	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Live plant base	3.32	3.00	3.06	1.58	2.49	1.51
Dead woody base	0.23	0.28	0.38	0.49	0.32	0.45
Dead herbaceous base	0.99	0.64	0.83	0.56	0.78	0.62
Bare soil	4.24	4.37	4.47	7.43	2.70	2.59
Duff and litter	32.55	12.08	34.89	13.46	37.60	14.34
Undifferentiated crust	14.11	9.29	16.49	12.18	13.97	10.72
Moss	0.25	0.59	0.12	0.28	0.13	0.18
Lichen	0.01	0.01	0.02	0.05	0.00	0.01
Cyanobacteria	0.69	1.72	0.23	0.43	1.86	2.77
Fine gravel (0.2–2 cm)	33.19	18.51	31.86	17.48	30.73	19.21
Coarse gravel (2–7.5 cm)	2.24	2.01	2.01	2.59	2.21	2.48
Cobble (7.5–25 cm)	1.98	3.72	0.61	0.70	1.25	2.22
Stone, bedrock (>25 cm)	2.40	3.21	1.50	2.43	1.69	3.01
Woody debris	2.08	1.61	2.26	0.86	2.29	2.59

Note: The surface feature components do not add up to 100% because the calculations were made from cover class midpoints, and the estimations have observer error.

Table 6. Number of basal gaps, median gap size, and percentage of transect in different gap size classes in 2008 (unthinned) and in 2009 (thinned and unthinned) plots in the Mesa Top Pinyon-Juniper ecological site at BAND

Metric	2008 Unthinned		2009 Thinned		2009 Unthinned	
	Mean	SD	Mean	SD	Mean	SD
Number of gaps	125.2	48.2	99.0	50.9	106.6	48.4
Median gap size (cm)	67.5	38.5	95.5	52.6	78.0	41.4
Percent of transect in gaps 0–19 cm	2.1	4.2	1.5	1.5	1.8	1.5
Percent of transect in gaps 20–49 cm	5.7	3.0	4.4	3.7	4.3	3.4
Percent of transect in gaps 50–99 cm	10.9	5.9	8.4	5.5	8.8	4.6
Percent of transect in gaps ≥100 cm	76.9	11.5	81.0	13.0	80.3	11.6
Percent of transect in gaps	95.5	2.3	95.3	3.0	95.3	2.6
Percent of transect in plant bases	4.5	2.3	4.7	3.0	4.7	2.6

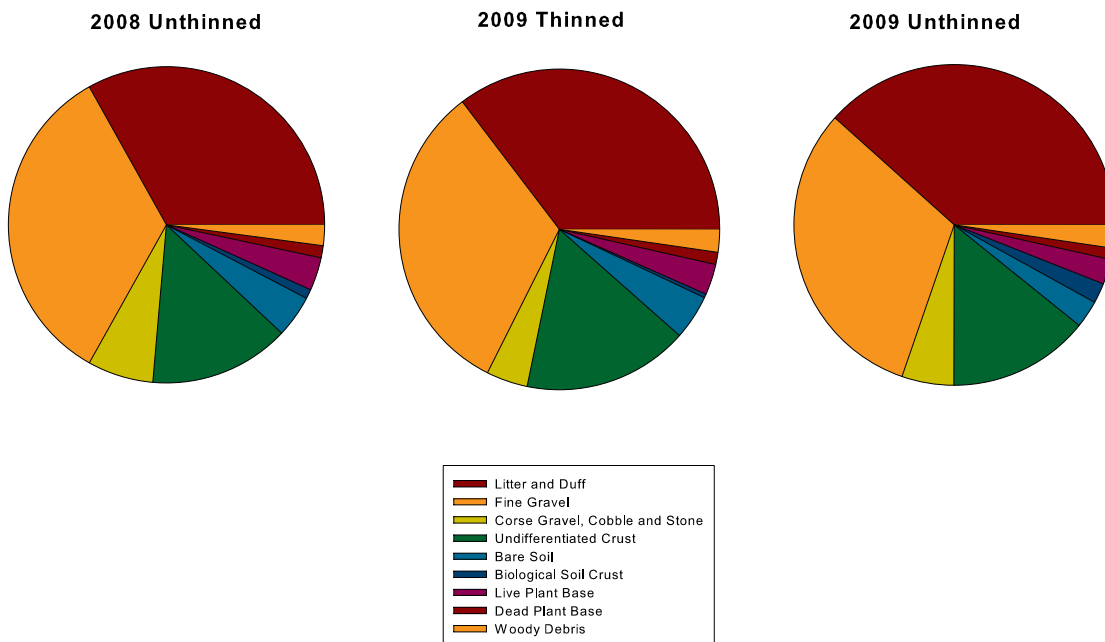


Figure 10. Mean cover of soil surface features for 2008 (unthinned) and 2009 (thinned and unthinned) plots in the Mesa Top Pinyon-Juniper ecological site at BAND

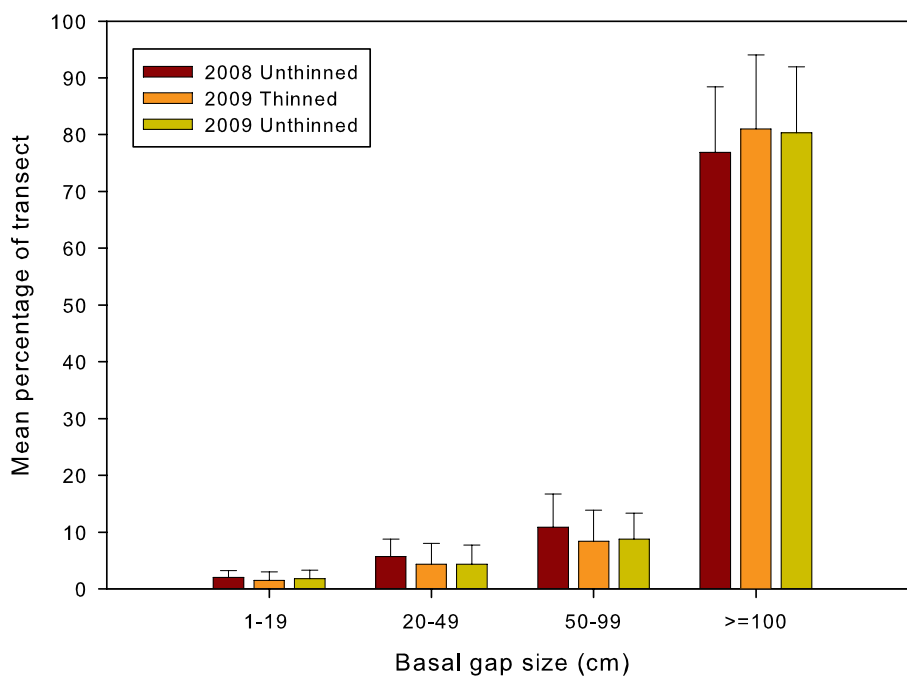


Figure 11. Mean percentage of transect in different gap sizes in 2008 (unthinned) and 2009 (thinned and unthinned) plots in the Mesa Top Pinyon-Juniper ecological site at BAND. Error bars represent 1 standard deviation.

The mean soil stability rating ranged between 3.28 and 4.00, which is moderate (table 7). Soil under vegetative cover invariably had a higher rating than soil without vegetative cover. The 2009 thinned plot values were intermediate between the 2008 and 2009 unthinned plot values.

Table 7. Mean soil stability rating by cover in 2008 (unthinned) and 2009 (thinned and unthinned) plots in the Mesa Top Pinyon-Juniper ecological site at BAND

	Soil Stability Rating					
	2008 Unthinned		2009 Thinned		2009 Unthinned	
	Rating ^a	SD	Rating ^a	SD	Rating ^a	SD
Cover	4.35	0.96	4.21	0.93	3.64	1.40
No cover	3.60	0.99	3.30	0.75	2.86	1.43
Total	4.00	0.68	3.76	0.74	3.28	1.16

Note: We measured up to 18 points per plot in each of the 3 plot groups. However, because this is a soil surface measurement, locations with deep pumice were not measured, resulting in fewer than 18 points in some plots.

^aRatings ranged from 1-6, with 1 being the lowest stability and 6 being the highest.

Discussion

The data collected in 2009 augment the data collected in 2008 to provide a more complete representation of the vegetation of the Mesa Top Pinyon-Juniper ecological site at BAND. Compositional differences among the three plot groups most likely reflect spatial variability within the ecological site.

The shrub/herbaceous data indicate a diverse mixture of grasses, shrubs, and succulents. Common shrubs included *Gutierrezia sarothrae*, *Quercus* spp., *Cercocarpus montanus* and *Rhus trilobata*; common grasses included *Bouteloua gracilis*, *Elymus elymoides*, and *Poa fendleriana*; common forbs included *Artemisia* spp. and *Verbascum thapsus*. Foliar cover and cover of perennial grasses and shrubs were lower in 2008 than in the 2009 thinned and unthinned plots. The cover and frequencies of the dominant species varied among the three sets of plots. Species diversity was generally higher in the 2008 plots than in either set of the 2009 plots. This may have been an artifact of the slightly larger sample size for the 2008 plots. Of the nine nonnative species found in the plots, two were abundant: *Bromus tectorum* and *Verbascum thapsus*. *Bromus tectorum* was most abundant in the 2008 plots and *Verbascum thapsus* was most abundant in the 2009 thinned plots. It is possible that there could have been some immediate post-thinning response in the herbaceous and shrub layers. Most of the differences, however, were likely due to random spatial variation.

The overstory trees were dominated by *Juniperus monosperma*, with *Pinus edulis*, *Juniperus deppeana* and *Pinus ponderosa* in low abundance. The effect of the mechanical thinning was evident when comparing the overstory tree data of the thinned and unthinned plots of 2009. The thinned plots had a much lower density of *Juniperus monosperma*, and slightly lower basal area. This was expected as the thinning was directed at the smaller stems, which would produce a much larger effect on density than it would on basal areas. The effect of the thinning was also seen in the size class distribution, which showed a reduced density in the smaller size classes in the thinned plots, and a reduction in canopy cover. The sapling and seedling layers were composed of *Juniperus monosperma* and *Pinus edulis*, in moderately low densities, although saplings of *Juniperus deppeana* also occurred in low abundance in the 2008 plots. The 2009 thinned plots showed lower densities of *Juniperus monosperma* saplings. The seedling densities of thinned plots were also lower than those of unthinned plots.

With respect to soil attributes, the 2009 data was similar to the 2008 data. The soil surface features were dominated by duff/litter, undifferentiated crust and fine gravel (pumice). The basal gap data showed a predominance of gaps over 100 cm. The soil aggregate stability showed moderate values, indicating that the soils are not overly susceptible to erosion. The large amount of bare ground is undoubtedly moderated by the large amount of litter. The largest differences between the thinned and unthinned plots were seen in the soil aggregate stability data; the 2009 thinned data had higher values than the 2009 unthinned plots, but the 2008 plots had even higher values.

In summary, the primary differences between the thinned and unthinned plots were in the trees. The thinned plots showed lower densities of *Juniperus monosperma*. This was particularly evident in the saplings and smaller overstory size classes. The thinned plots also showed lower seedling densities of both *J. monosperma* and *Pinus edulis*, and lower canopy cover as well. The soil attributes of the thinned and unthinned plots showed little difference. While functional group cover was similar among the three sets of the plots, some of the species' cover and frequency values differed.

We plan to install an additional six plots in 2010. We will conduct power analysis on key metrics to determine the final number of plots necessary to detect a reasonable level of change. We are currently estimating that we will need approximately 45 plots. A temporal sampling design will then be implemented, where a certain number of plots will be visited each year.

Literature Cited

- Butler, L. D., J. B. Cooper, R. H. Johnson, A. J. Norman, G. L. Peacock, P. L. Shaver, and K. E. Spaeth. 2003. National range and pasture handbook. U.S. Department of Agriculture, National Resources Conservation Service, Grazing Lands Technology Institute, Fort Worth, Texas.
- DeCoster, J. K., C. L. Lauver, M. E. Miller, J. R. Norris, A. E. C. Snyder, M. C. Swan, L. P. Thomas, and D. L. Witwicki. Integrated upland monitoring protocol for the Southern Colorado Plateau Network. Natural Resource Technical Report, National Park Service, Fort Collins, CO, *in review*.
- Hibner, Charles D. 2000. Special project soil survey of Bandelier National Monument. U.S. Department of Agriculture, National Resources Conservation Service, Santa Fe Soil Survey Office, Santa Fe, N.M.. Interim report.
- Jennings, S. B., N. D. Brown, and D. Sheil. 1999. Assessing forest canopies and understory illumination: canopy closure, canopy cover and other measures. *Forestry* 72(1): 59–73.
- Magurran, A. E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, NJ.
- Margalef, R. 1972. Homage to Evelyn Hutchinson, or why there is an upper limit to diversity. *Transactions of the Connecticut Academy of Arts and Sciences* 44: 211–35.
- McCune, B. and J. B. Grace. 2002. Analysis of ecological communities. MjM Software Design. Gleneden Beach, Oregon.
- Stevens, D. L. and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. *Journal of the American Statistical Association* 99: 262–278.
- Thomas, L. P., M. N. Hendrie (editor), C. L. Lauver, S. A. Monroe, N. J. Tancreto, S. L. Garman, and M. E. Miller. 2006. Vital signs monitoring plan for the Southern Colorado Plateau Network. Natural Resource Report NPS/SCPN/NRR-2006/002. National Park Service, Fort Collins, CO.

Appendix

Complete species list from all plots in 2008 and 2009

Table A1. Shrub and herbaceous species, with foliar cover and plot frequency

Species	Common name	Family	2008 Unthinned		2009 Thinned		2009 Unthinned	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Achnatherum hymenoides</i>	Indian ricegrass	Poaceae	0	0	0.001	7.14	0	0
<i>Allium cernuum</i>	nodding onion	Liliaceae	<0.001	6.67	0	0	0	0
<i>Amaranthus</i> sp.	pigweed	Amaranthaceae	0.012	33.33	<0.001	7.14	0	0
<i>Amaranthus retroflexus</i>	redroot pigweed	Amaranthaceae	0	0	0.002	14.29	0.014	18.18
<i>Antennaria parvifolia</i>	small leaf pussytoes	Asteraceae	0.001	6.67	0	0	0	0
<i>Arabis</i> sp.	rockcress	Asteraceae	0	0	0.001	21.43	0.001	9.09
<i>Arabis fendleri</i>	Fendler's rockcress	Brassicaceae	0	0	0.002	21.43	0.001	18.18
<i>Aristida purpurea</i>	Fendler's threeawn	Poaceae	0.026	66.67	0.046	35.71	0.076	45.45
<i>Artemisia campestris</i>	field sagewort	Asteraceae	0	0	0.825	92.86	0.262	90.91
<i>Artemisia carruthii</i>	Carruth's sagewort	Asteraceae	0	0	0.166	28.57	0.375	63.64
<i>Artemisia dracunculus</i>	false tarragon	Asteraceae	0.609	86.67	0.004	7.14	0.009	9.09
<i>Artemisia frigida</i>	fringed sagebrush	Asteraceae	0.001	6.67	0.010	21.43	0	0
<i>Artemisia ludoviciana</i>	white sagewort	Asteraceae	0.269	66.67	0.027	35.71	0.052	45.45
<i>Astragalus</i> sp.	milkvetch	Fabaceae	<0.001	6.67	0	0	0	0
<i>Bahia dissecta</i>	ragleaf bahia	Asteraceae	0.176	93.33	0.096	100.00	0.096	90.91
<i>Blepharoneuron tricholepis</i>	pine dropseed	Poaceae	0.001	6.67	0	0	0.021	9.09
<i>Bouteloua curtipendula</i>	sideoats grama	Poaceae	0.018	13.33	0	0	0.002	9.09
<i>Bouteloua eriopoda</i>	black grama	Poaceae	0.008	13.33	0.065	14.29	0	0
<i>Bouteloua gracilis</i>	blue grama	Poaceae	1.913	100.00	3.770	100.00	3.899	100.00
<i>Brickellia</i> sp.	brickellbush	Asteraceae	0	0	0.039	14.29	<0.001	9.09
<i>Brickellia brachyphylla</i>	plumed brickellbush	Asteraceae	0	0	0.004	7.14	0	0
<i>Brickellia californica</i>	California brickellbush	Asteraceae	0	0	0.006	14.29	0	0
<i>Brickellia eupatorioides</i>	false boneset	Asteraceae	0.008	6.67	0.021	7.14	0	0
<i>Brickellia fendleri</i>	Fendler's brickellbush	Asteraceae	0	0	0.007	7.14	0.007	9.09
<i>Bromus tectorum</i> ^a	cheatgrass	Poaceae	0.376	53.33	0.054	71.43	0.120	63.64

Table A1 continued

Species	Common name	Family	2008 Unthinned			2009 Thinned			2009 Unthinned		
			Foliar cover (%)	Plot frequency (%)		Foliar cover (%)	Plot frequency (%)		Foliar cover (%)	Plot frequency (%)	
<i>Carex</i> sp.	sedge	Cyperaceae	0	0		0.002	14.29		< 0.001	9.09	
<i>Castilleja</i> sp.	Indian paintbrush	Scrophulariaceae	0.001	6.67		0	0		0	0	
<i>Castilleja integra</i>	wholeleaf Indian paintbrush	Scrophulariaceae	0	0		0	0		0.002	9.09	
<i>Cercocarpus montanus</i>	birchleaf mountain mahogany	Rosaceae	0.111	46.67		1.107	57.14		0.991	54.55	
<i>Chaetopappa ericoides</i>	rose heath	Asteraceae	0.003	13.33		0	0		0	0	
<i>Chamaesyce</i> spp. Group A ^b	annual sandmats	Euphorbiaceae	0.043	86.67		0.103	85.71		0.026	45.45	
<i>Chamaesyce</i> spp. Group B ^b	annual sandmats	Euphorbiaceae	0.045	80.00		0.025	57.14		0.030	54.55	
<i>Chamaesyce fendleri</i>	Fendler's sandmat	Euphorbiaceae	0.008	33.33		0.018	42.86		0.036	27.27	
<i>Chenopodium</i> sp.	goosefoot	Chenopodiaceae	0	0		0.017	71.43		0.002	45.45	
<i>Chenopodium fremontii</i>	Fremont's goosefoot	Chenopodiaceae	0.010	33.33		0.015	21.43		0	0	
<i>Chenopodium graveolens</i>	fetid goosefoot	Chenopodiaceae	0.010	46.67		0.003	28.57		0.001	18.18	
<i>Chenopodium incanum</i>	mealy goosefoot	Chenopodiaceae	0.019	46.67		0.001	14.29		0.004	18.18	
<i>Chenopodium leptophyllum</i>	narrowleaf goosefoot	Chenopodiaceae	0.113	93.33		0.003	21.43		0.010	36.36	
<i>Cirsium neomexicanum</i>	New Mexico thistle	Asteraceae	0.006	20.00		0.004	7.14		0	0	
<i>Conyza canadensis</i>	Canadian horseweed	Asteraceae	<0.001	6.67		0.002	21.43		< 0.001	9.09	
<i>Cordylanthus wrightii</i>	Wright's bird's beak	Scrophulariaceae	0.052	40.00		0.040	28.57		0.002	18.18	
<i>Croton texensis</i>	Texas croton	Euphorbiaceae	0.043	26.67		0.153	57.14		0.076	27.27	
<i>Cryptantha cinerea</i>	James' cryptantha	Boraginaceae	0.015	80.00		0.021	85.71		0.005	36.36	
<i>Cyperus fendlerianus</i>	Fendler's flatsedge	Cyperaceae	0.074	13.33		0	0		0	0	
<i>Dalea candida</i>	white prairieclover	Fabaceae	0.003	13.33		0.006	14.29		0.010	36.36	
<i>Dalea polygonoides</i>	six-weeks prairie-clover	Fabaceae	0.001	6.67		0	0		0	0	
<i>Descurainia pinnata</i>	western tansymustard	Brassicaceae	0	0		0.001	7.14		0	0	
<i>Drymaria molluginea</i>	slimleaf drymary	Caryophyllaceae	0.001	20.00		< 0.001	9.09		< 0.001	9.09	
<i>Echinocereus</i> spp.	hedgehog cactus	Cactaceae	<0.001	13.33		0.005	18.18		0.005	18.18	
<i>Elymus elymoides</i>	squirreltail	Poaceae	0.910	100.00		0.766	100.00		0.900	100.00	

^bAnnual species of *Chamaesyce* spp. were placed into 2 groups based on morphological characteristics.

Table A1 continued

Species	Common name	Family	2008 Unthinned		2009 Thinned		2009 Unthinned	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Ericameria nauseosa</i>	rubber rabbitbrush	Asteraceae	<0.001	13.33	0	0	0	0
<i>Erigeron</i> sp.	fleabane	Asteraceae	0	0	<0.001	7.14	0	0
<i>Erigeron divergens</i>	spreading fleabane	Asteraceae	0.016	73.33	0.040	64.29	0.028	54.55
<i>Erigeron flagellaris</i>	trailing fleabane	Asteraceae	0.263	20.00	0.005	14.29	0.237	45.45
<i>Eriogonum alatum</i>	winged buckwheat	Polygonaceae	0.001	6.67	0	0	0	0
<i>Eriogonum jamesii</i>	James' buckwheat	Polygonaceae	0.025	40.00	0.012	21.43	0.051	36.36
<i>Eriogonum polycladon</i>	sorrel buckwheat	Polygonaceae	0	0	0	0	0.002	9.09
<i>Eriogonum racemosum</i>	redroot buckwheat	Polygonaceae	0.007	13.33	0	0	0	0
<i>Erodium cicutarium</i> ^a	stork's bill	Geraniaceae	0	0	0	0	0.004	9.09
<i>Erysimum capitatum</i>	sanddune wallflower	Brassicaceae	0.002	33.33	0.004	21.43	0.003	18.18
<i>Fallugia paradoxa</i>	Apache plume	Rosaceae	0.114	26.67	0.439	57.14	0.508	45.45
<i>Forestiera pubescens</i>	New Mexico olive	Oleaceae	0	0	0.150	14.29	<0.001	9.09
<i>Gaura coccinea</i>	scarlet beeblossom	Onagraceae	0	0	0.001	7.14	0	0
<i>Geranium caespitosum</i>	piney-woods geranium	Geraniaceae	0.003	6.67	0	0	0	0
<i>Gutierrezia sarothrae</i>	broom snakeweed	Asteraceae	2.044	93.33	3.677	100.00	2.545	100.00
<i>Hedeoma drummondii</i>	Drummond's false penny-royal	Lamiaceae	0.001	6.67	<0.001	7.14	<0.001	9.09
<i>Helianthus annuus</i>	common sunflower	Asteraceae	0.127	40.00	0.024	42.86	0.037	36.36
<i>Heliomeris multiflora</i>	showy goldeneye	Asteraceae	0.022	13.33	0.016	14.29	<0.001	9.09
<i>Hesperostipa comata</i>	needle and thread	Poaceae	0.001	6.67	0.009	7.14	0.021	9.09
<i>Heterotheca villosa</i>	hairy false goldenaster	Asteraceae	0.094	53.33	0.025	28.57	0.119	45.45
<i>Hymenopappus filifolius</i>	fineleaf hymenopappus	Asteraceae	0.002	20.00	0.040	35.71	0.010	54.55
<i>Hymenoxys richardsonii</i>	Colorado rubberweed	Asteraceae	0.018	20.00	0.023	28.57	0.058	45.45
<i>Ipomopsis aggregata</i>	scarlet gilia	Polemoniaceae	0.007	33.33	0.015	28.57	0.014	27.27
<i>Ipomopsis longiflora</i>	whiteflower ipomopsis	Polemoniaceae	0.008	40.00	0.014	35.71	0.002	27.27
<i>Juncus</i> sp.	rush	Juncaceae	0	0	0	0	<0.001	9.09
<i>Koeleria macrantha</i>	prairie junegrass	Poaceae	0.100	20.00	0.026	21.43	0.102	27.27
<i>Lactuca serriola</i> ^a	prickly lettuce	Asteraceae	0.007	13.33	0.004	21.43	0.001	18.18

Table A1 continued

Species	Common name	Family	2008 Unthinned		2009 Thinned		2009 Unthinned	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Lappula occidentalis</i>	flatspine stickseed	Boraginaceae	0.002	6.67	0.004	28.57	0.025	36.36
<i>Liatis punctata</i>	dotted blazingstar	Asteraceae	0	0	0.002	7.14	0.002	18.18
<i>Linum lewisii</i>	prairie flax	Linaceae	0	0	0	0	0.004	18.18
<i>Linum neomexicanum</i>	New Mexico yellow flax	Linaceae	0	0	0.004	14.29	0.003	9.09
<i>Lithospermum incisum</i>	narrowleaf gromwell	Boraginaceae	0	0	0.001	7.14	0.001	18.18
<i>Lotus wrightii</i>	Wright's deervetch	Fabaceae	0.045	80.00	0.085	85.71	0.046	63.64
<i>Lupinus kingii</i>	King's lupine	Fabaceae	0.008	20.00	0.004	14.29	<0.001	9.09
<i>Lycurus setosus</i>	bristly wolfstail	Poaceae	0.006	20.00	0.006	14.29	0.024	27.27
<i>Machaeranthera bigelovii</i>	Bigelow's tansy-aster	Asteraceae	0.064	33.33	0.006	14.29	<0.001	9.09
<i>Machaeranthera gracilis</i>	slender goldenweed	Asteraceae	0.001	6.67	0	0	0.002	9.09
<i>Mahonia repens</i>	creeping barberry	Berberidaceae	<0.001	6.67	0	0	0	0
<i>Melilotus officinalis</i>	yellow sweetclover	Fabaceae	0	0	0.004	7.14	0	0
<i>Mentzelia multiflora</i>	Adonis blazingstar	Loasaceae	0.095	60.00	0.090	57.14	0.088	45.45
<i>Mirabilis linearis</i>	narrowleaf four o'clock	Nyctaginaceae	0	0	0	0	<0.001	9.09
<i>Mirabilis multiflora</i>	Colorado four o'clock	Nyctaginaceae	0.003	6.67	0.025	35.71	<0.001	9.09
<i>Mirabilis oxybaphoides</i>	smooth spreading four o'clock	Nyctaginaceae	0.018	33.33	<0.001	14.29	0.001	9.09
<i>Monroa squarrosa</i>	false buffalograss	Poaceae	<0.001	6.67	0	0	0	0
<i>Muhlenbergia minutissima</i>	annual muhly	Poaceae	0.002	13.33	0	0	0	0
<i>Muhlenbergia montana</i>	mountain muhly	Poaceae	0.029	33.33	0.068	21.43	0.055	36.36
<i>Muhlenbergia wrightii</i>	spike muhly	Poaceae	0	0	0.001	7.14	0.006	9.09
<i>Nama dichotomum</i>	wishbone fiddleleaf	Hydrophyllaceae	0	0	<0.001	7.14	0	0
<i>Oenothera caespitosa</i>	tufted evening-primrose	Onagraceae	0.001	13.33	0.002	14.29	0	0
<i>Opuntia</i> spp.	prickly pear	Cactaceae	0.269	86.67	0.658	85.71	0.880	100.00
<i>Opuntia imbricata</i>	tree cholla	Cactaceae	0.117	20.00	0.171	42.86	0.025	27.27
<i>Orthocarpus purpureoalbus</i>	purple owllover	Scrophulariaceae	0.003	20.00	<0.001	7.14	0	0
<i>Oxalis violacea</i>	Violet woodsorrel	Oxalidaceae	0	0	<0.001	7.14	0	0
<i>Penstemon</i> sp.	penstemon	Scrophulariaceae	0.006	26.67	0.005	21.43	0.026	36.36

Table A1 continued

Species	Common name	Family	2008 Unthinned		2009 Thinned		2009 Unthinned	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Penstemon barbatus</i>	beardlip penstemon	Scrophulariaceae	0.002	6.67	0.001	9.09	0.001	9.09
<i>Phacelia</i> sp.	scorpionweed	Hydrophyllaceae	0.001	6.67	0	0	0	0
<i>Physalis hederifolia</i>	ivyleaf groundcherry	Solanaceae	0.005	40	0.018	42.86	0.003	18.18
<i>Piptatherum micranthum</i>	littleseed ricegrass	Poaceae	0.112	46.67	0.148	92.86	0.361	72.73
<i>Plantago patagonica</i>	woolly plantain	Plantaginaceae	0	0	< 0.001	7.14	0.001	18.18
<i>Pleuraphis jamesii</i>	James' galleta	Poaceae	0.01	13.33	0.111	35.71	0.028	27.27
<i>Poa fendleriana</i>	muttongrass	Poaceae	0.452	93.33	0.347	71.43	0.585	72.73
<i>Polanisia dodecandra</i>	redwhisker clammyweed	Capparaceae	0	0	0.005	14.29	0.001	9.09
<i>Polygonum douglasii</i>	Douglas' knotweed	Polygonaceae	0.006	13.33	0.001	14.29	0	0
<i>Portulaca oleracea</i> ^a	little hogweed	Portulacaceae	0.012	53.33	0.001	7.14	0.011	18.18
<i>Ptelea trifoliata</i>	common hoptree	Rutaceae	0	0	0	0	0.009	9.09
<i>Quercus</i> spp.	oak	Fagaceae	0.333	40.00	0.650	85.71	1.722	72.73
<i>Rhus trilobata</i>	skunkbush sumac	Anacardiaceae	0.408	60.00	1.152	85.71	0.064	63.64
<i>Salsola tragus</i> ^a	prickly Russian thistle	Chenopodiaceae	0	0	0.004	7.14	0.006	9.09
<i>Schizachyrium scoparium</i>	little bluestem	Poaceae	0.069	33.33	0.050	35.71	0.020	36.36
<i>Schoenocrambe linearifolia</i>	slimleaf plains mustard	Brassicaceae	0.002	26.67	0	0	0.001	18.18
<i>Sclerocactus papyracanthus</i>	paperspine fishhook cactus	Cactaceae	0	0	0.002	21.43	0.001	18.18
<i>Senecio flaccidus</i>	threadleaf ragwort	Asteraceae	0.001	6.67	0.078	50.00	0.039	36.36
<i>Senecio spartioides</i>	broomlike ragwort	Asteraceae	0.033	66.67	0.013	14.29	0	0
<i>Sisymbrium altissimum</i> ^a	tumblemustard	Brassicaceae	0.001	6.67	< 0.001	7.14	0	0
<i>Solidago</i> sp.	goldenrod	Asteraceae	0.003	6.67	0	0	0	0
<i>Sphaeralcea</i> sp.	globemallow	Malvaceae	0.001	6.67	0.002	7.14	0	0
<i>Sporobolus contractus</i>	spike dropseed	Poaceae	0.005	6.67	0	0	0	0
<i>Sporobolus cryptandrus</i>	sand dropseed	Poaceae	0.025	73.33	0.014	28.57	0.078	72.73
<i>Stephanomeria pauciflora</i>	brownplume wirelettuce	Asteraceae	< 0.001	13.33	0.006	21.43	0.002	18.18
<i>Taraxacum officinale</i> ^a	common dandelion	Asteraceae	0	0	0	0	< 0.001	9.09
<i>Tetrameuris ivesiana</i>	ives' fournerved daisy	Asteraceae	0.007	13.33	0	0	0.023	36.36

Table A1 continued

Species	Common name	Family	2008 Unthinned		2009 Thinned		2009 Unthinned	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Thelesperma filifolium</i>	stiff greenthread	Asteraceae	0.009	20.00	< 0.001	7.14	0.041	36.36
<i>Townsendia eximia</i>	tall Townsend daisy	Asteraceae	0.006	6.67	0.002	14.29	0.009	9.09
<i>Tragopogon dubius</i> ^a	yellow salsify	Asteraceae	0.006	33.33	0.011	35.71	0.004	36.36
<i>Verbascum thapsus</i> ^a	common mullein	Scrophulariaceae	0.246	53.33	0.345	71.43	0.194	45.45
<i>Vicia</i> sp.	vetch	Fabaceae	0	0	< 0.001	7.14	0	0
<i>Vulpia octoflora</i>	sixweeks fescue	Poaceae	0	0	0	0	0.001	18.18
<i>Yucca angustissima</i>	narrowleaf yucca	Agavaceae	0.025	26.67	0	0	0.021	9.09
<i>Yucca baccata</i>	banana yucca	Agavaceae	0.071	33.33	0.172	21.43	0.218	36.36
Unknown 2008Sep07-1			0.023	33.33	0	0	0	0
Unknown 2008Sep07-2			< 0.001	6.67	0	0	0	0
Unknown 2008Sep09-1			< 0.001	6.67	0	0	0	0
Unknown 2008Sep21-1			0.001	6.67	0	0	0	0
Unknown 2009Sept21_1			0	0	0	0	< 0.001	9.09
Unknown 2009Aug25_1			0	0	0	0	< 0.001	9.09
Unknown 2009Aug24_1			0	0	0.001	7.14	0	0
Unknown 2009Aug22-2			0	0	0	0	< 0.001	9.09
Unknown 2009Aug22_1			0	0	0.001	14.29	0.002	9.09
Unknown 2009_Sept06_1			0	0	0	0	< 0.001	9.09

^aNonnative species.

Appendix

Complete species list from all plots in 2008 and 2009

Table A2. Tree species, with basal area and plot frequency

Species	Common name	Family	2008 Unthinned		2009 Thinned		2009 Unthinned	
			Basal area (m ² /ha) ^a	Plot frequency (%) ^b	Basal area (m ² /ha) ^a	Plot frequency (%) ^b	Basal area (m ² /ha) ^a	Plot frequency (%) ^b
<i>Juniperus deppeana</i>	alligator juniper	Cupressaceae	1.92	6.67	0	0	0.26	9.09
<i>Juniperus monosperma</i>	one-seed juniper	Cupressaceae	13.65	93.33	16.78	100.00	17.85	100.00
<i>Pinus edulis</i>	two-needle pinyon	Pinaceae	0.03	40.00	0	51.15	0	81.82
<i>Pinus ponderosa</i>	ponderosa pine	Pinaceae	0.20	6.67	0	0	0	0

^aBasal area measures overstory trees.

^bPlot frequency includes both overstory trees and saplings.