



Integrated Upland Vegetation and Soils Monitoring for Bandelier National Monument

2010 Summary Report

Natural Resource Data Series NPS/SCPN/NRDS—2013/509



ON THE COVER

Integrated upland monitoring in Bandelier National Monument
Photography by Jim DeCoster/NPS

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1 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 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 tree dieback, soil erosion, changes in fire regimes, and invasion by nonnative species.

A secondary consideration in monitoring the pinyon-juniper woodlands is the extensive restoration project the park has been recently undertaking. The objectives for this restoration were 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 SCPN integrated upland monitoring project began its work at BAND with the installation of 15 plots in the Mesa Top Pinyon-Juniper ecological site in areas that had not yet been thinned. One of these 2008 plots was later eliminated from analysis. In 2009 and 2010 an additional 31 plots were installed. Of these 31 plots, 17 were located in areas that had been thinned at the time of sampling, and 14 plots were located in areas that had not yet been thinned. The 17 already thinned plots were sampled after different periods of time since thinning: 9 were sampled within one year of the treatment, 6 were sampled between 1 and 2 years following the thinning treatment, and 2 were sampled more than 2 years after the thinning treatment. Of the 28 plots that were not thinned at the time of sampling, 13 have been subsequently thinned. Each plot was only sampled once between 2008 and 2010. Some of the plots also were burned in the Las Conchas fire in 2011.

The goal of our initial monitoring efforts is to establish permanent plots throughout the ecological site and to describe the baseline conditions of vegetation and soils. That goal has proven challenging at BAND, where restoration thinning, drought-related pinyon mortality, and wildfires have occurred during our first years of monitoring. In this report we provide data summaries by restoration treatment (thinned, unthinned), as well as for all plots within the ecological site. At this point, we are uncertain whether it will be necessary to separately track thinned and unthinned plots. In making this decision we will consider sample size and whether the 2 groups of plots are changing in similar ways.

2 Methods

2.1 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 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. Park staff requested that we use this liberal interpretation of which soil types to include in our sampling frame in order to maximize its extent, at the cost of greater heterogeneity in vegetation and soil and higher variation in the data. For the sake of simplicity, we refer to the area represented by the sampling frame we created as the Mesa Top Pinyon-Juniper ecological site, even though it does not technically correspond to existing NRCS ecological site categories. To

create the sampling frame, we modified the map of the ecological site in GIS (Geographic Information System) by removing 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 2 hour hike to the plot from headquarters, park roads, or Base Camp (in the backcountry, located on Capulin Creek)(see Appendix A of DeCoster et al. 2012).

We generated a set of spatially distributed sampling points 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 sensitive resources. The integrated upland crew visited the points in consecutive order and conducted an ecological site assessment, rejecting sites that deviated substantially from the ecological site, had a slope greater than 20%, or contained a major disturbance. They rejected 14 points: 6 points required over 2 hours hiking time to access, 3 points were within 50 m of an established hiking trail, one point contained a large archeological site with altered vegetation, and 2 points were determined to be outside the range of variability for the ecological site. One plot that was established in 2008 was since determined to be outside the range of acceptable variation for the ecological site. We have not included this plot in the analysis of this report.

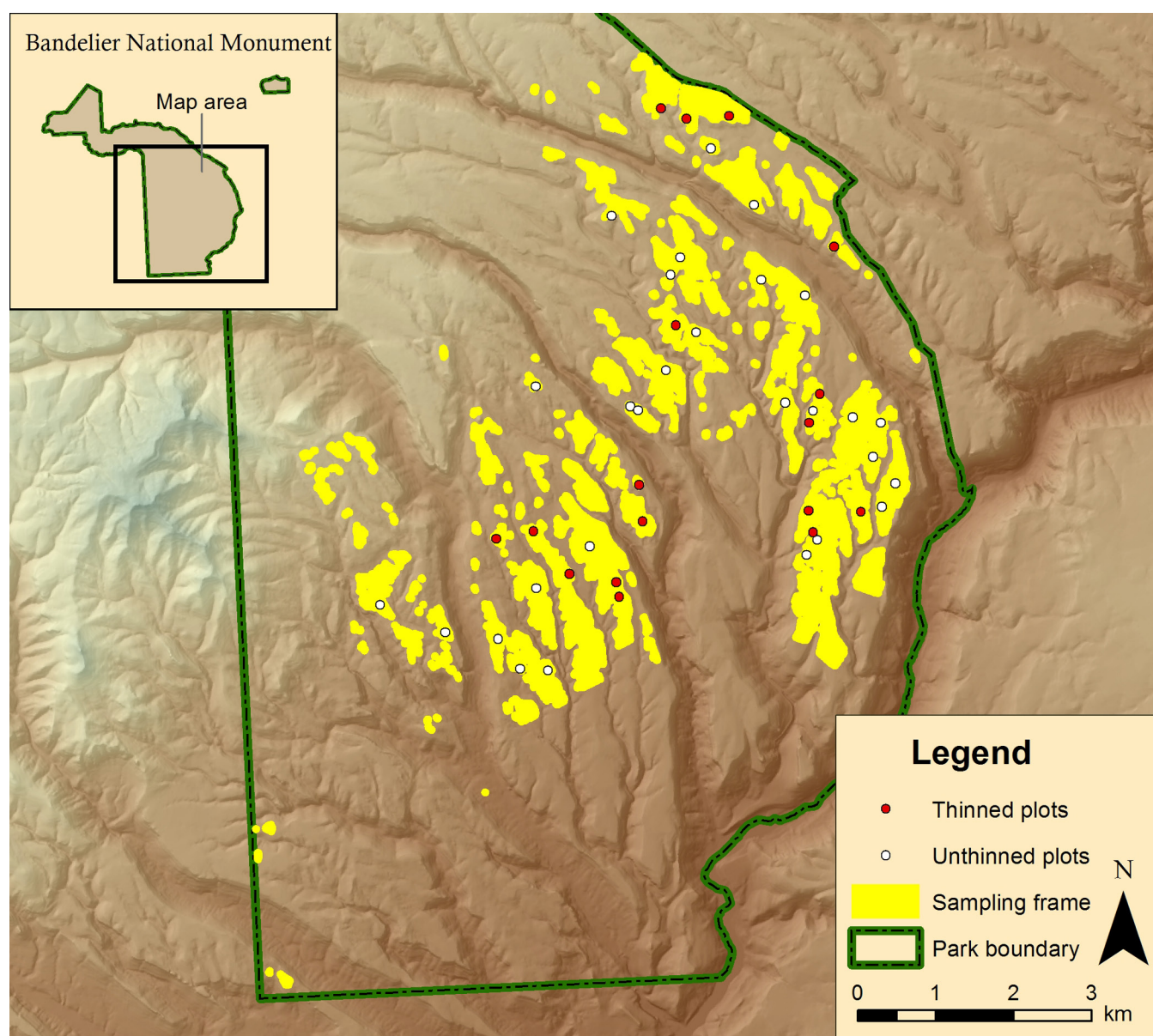


Figure 1. Sampling frame of the Mesa Top Pinyon-Juniper ecological site at BAND showing the 45 established plots, 17 of which were thinned and 28 of which were not thinned at the time of establishment.

2.2 Field methods

Integrated upland monitoring plots are 0.50 ha in size, measuring 71 × 71 m, and consist of 3 parallel 50 m transects spaced 25 m apart. We collected data for shrub and herbaceous species composition, soil cover and stability, tree seedling density and tree canopy on all 3 transects within each plot. We also collected overstory tree and sapling data in subplots located between 2 of the transects. In all years, data was collected in September. In 2009, some data were also collected in late August.

2.2.1 Shrub and herbaceous vegetation

We sampled shrub and herbaceous vegetation within 5 sets of nested quadrats at 10 m intervals along each transect. The largest quadrat size was 10 m² (2 × 5 m), with 4 smaller quadrats nested inside (0.01 m², 0.1 m², 1 m², 5 m²). We recorded the presence of each herbaceous and shrub species within each nested sub-quadrat. We estimated the percent cover of each species in the 10 m² quadrat and assigned it to 1 of 12 cover classes (e.g., 2%–5%, 5%–10%, etc.). We also estimated the percent cover for functional groups (e.g., perennial grasses, forbs, shrubs) in the 10 m² quadrats and recorded the cover class.

2.2.2 Overstory trees, saplings, and seedlings

We measured overstory trees (≥15 cm diameter) in a 20 × 50 m (0.1 ha) plot located between 2 of the transects. We measured all *Juniperus monosperma* (one-seed juniper) at root crown, using a meter stick in 2 perpendicular directions, excluding the horizontal and diagonal branches. *Juniperus deppeana* (alligator juniper) was measured using a diameter tape at root crown. All pines were measured with a diameter tape at breast height. In plots that were thinned prior to sampling, we measured the diameter of root crown of the cut stumps of the juniper trees. (Living individuals of pine were not thinned). Within this overstory tree plot, we tallied saplings (≥2.5 and <15 cm) by size class and species in a smaller, 10 × 25 m plot (0.25 ha). We tallied seedlings by size class and species in the fifteen 10 m² quadrats along the 3 transects. Inadvertently, seedling data were not collected in 2008.

In 2008 we measured tree canopy closure using a spherical densiometer. In 2009 we changed our methods to measure tree canopy cover in pinyon-juniper woodlands using line intercept methods. Plots sampled in 2009 and 2010 were sampled using line intercept methods. We felt that this was a more accurate representation of the canopy than the canopy closure method.

2.2.3 Soil stability and hydrologic function

We estimated the percent cover of soil surface features in the 1 m² quadrats along the transects, and recorded the cover in 1 of 12 cover classes. We measured basal gaps as the length of bare soil between plant bases along each transect. We also conducted a soil aggregate stability test using 18 soil samples per plot collected along the transects. For these we noted whether there was vegetation cover over the sample point.

2.3 Data summary

In this report, we summarize data from the 45 plots at the ecological site level, as well as by treatment group: thinned versus unthinned. The sample unit for summary and analysis is the plot; hence, we summarized data at the level of the plot. For most metrics, we then calculated the mean and standard deviation from the plot means for each treatment group (thinned and unthinned), and also for the ecological site from the plot means.

2.3.1 Species cover and frequency

For herbaceous and shrub vegetation, percent cover was estimated for each species from the cover class midpoints, e.g., 7.5% for cover class 5%–10%. For each treatment group, mean cover was calculated for each plot, and the mean and standard deviation were calculated for the treatment group and for all plots in the ecological site from the plot means. Mean cover was calculated in the same way for all plots in the ecological site. Mean cover and standard deviation of functional groups and soil surface features were calculated in a similar fashion. Species frequency was calculated for quadrats (mean percentage of 10 m² quadrats per plot where the species occurred) and for plots (percentage of plots where the species occurred).

2.3.2 Species diversity

Four diversity measures (Magurran 1988) were calculated for herbaceous and shrub species for each treatment group and for all plots combined. We calculated these metrics first for all species and then for native species only:

(1) Species richness (S) is the number of species at a given spatial scale. This 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:

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

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:

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

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

$$S_e / (S_p - 1)$$

where S_e is the total number of species found in the ecological site (or treatment group), and S_p is the mean number of species found per plot.

For plot richness, Shannon diversity, and evenness, the mean was calculated for each plot, and the mean and standard deviation were then calculated for the treatment groups and the ecological site. Ecological site richness and beta diversity were calculated for each treatment group and for all plots in the ecological site.

2.3.3 Trees

Tree basal area (the total area of the tree cross-sections) for living trees and snags, was calculated for each overstory tree species in terms of m^2/ha . Mean diameter of living overstory trees was also calculated for each species. Tree density was calculated for all species and all size classes for overstory living trees and snags, saplings and seedlings in terms of stems/ha. These metrics were calculated for each plot, and the mean and standard deviation were then calculated for the treatment groups and for the ecological site. Canopy cover was calculated by first deriving the mean value for each plot, and then the mean and standard deviation were calculated for the treatment group and all plots of the ecological site. The canopy cover and seedling data were only calculated for 31 plots (17 thinned plots and 14 unthinned plots), as we did not collect these data in 2008. We are not reporting the canopy closure data for the 14 plots established in 2008.

2.3.4 Basal gaps

We calculated 5 metrics from the basal gap data: median basal gap size, percentage of transects comprised by gaps and plant bases, percentage of transects comprised by each gap size class, and total number of gaps. The mean for each metric was calculated for each plot, and then the mean and standard deviation were calculated for each treatment group and all plots in the ecological site.

2.3.5 Soil stability

We calculated the mean soil aggregate stability index for each plot and then calculated the mean and standard deviation for each treatment group and for all plots in the ecological site. This index ranges between 1 and 6, where 1 indicates low aggregate stability and 6 indicates high aggregate stability. We also grouped the samples by

those with and those without vegetative cover for the analysis. Sampling points located on thick litter and duff were given a rating of 6. Samples were not collected on points located on thick deposits of pumice.

3 Results

3.1 Herbaceous and shrub vegetation

For herbaceous and shrub data, we report the metrics for all plots (the ecological site mean), and then compare differences between the thinned and unthinned plots.

Perennial grasses and shrubs co-dominated the Mesa Top Pinyon-Juniper ecological site. Mean total live foliar cover was 14.434%, mean foliar cover of perennial grass was 5.346%, and mean foliar cover of shrubs was 5.090% (table 1 and fig. 2). There was also a moderate forb component to the vegetation, with a mean foliar cover of 2.732%. Mean foliar cover of cacti/succulents was 0.766%. The mean cover of standing dead herbaceous vegetation was a minor component, at 1.588%. Standing dead woody vegetation and annual grasses had mean covers of less than 1%.

Table 1. Foliar cover of functional groups for unthinned plots, thinned plots, and all plots in the Mesa Top Pinyon-Juniper ecological site at BAND.

Functional groups	Unthinned plots		Thinned plots		All plots	
	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Total live foliar cover	13.381	6.241	16.169	3.661	14.434	5.536
Perennial grasses	5.054	3.734	5.827	3.741	5.346	3.713
Annual grasses	0.595	1.484	0.132	0.297	0.420	1.198
Forbs	2.402	2.087	3.276	2.126	2.732	2.121
Shrubs	4.367	3.575	6.280	4.481	5.090	4.003
Cacti/succulents	0.700	1.042	0.876	1.390	0.766	1.173
Standing dead herbaceous	1.509	0.875	1.720	1.261	1.588	1.029
Standing dead woody	0.677	0.613	0.995	0.857	0.797	0.722

Note: The live functional groups do not add up to the total live foliar cover because the calculations were made from cover class midpoints, the components may overlap, and the estimations have observer error.

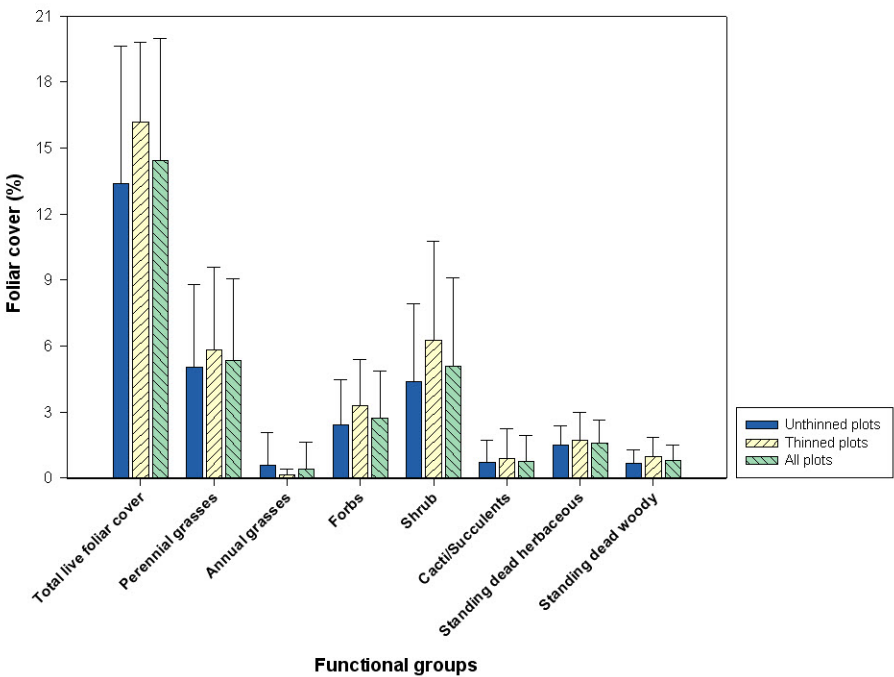


Figure 2. Mean percent foliar cover of functional groups for unthinned plots, thinned plots, and all plots in the Mesa Top Pinyon-Juniper ecological site at BAND. Error bars represent one standard deviation.

There were differences between the thinned and unthinned plots. The thinned plots had greater total live foliar cover than the unthinned plots. Correspondingly, most functional groups, had higher foliar cover in the thinned plots, particularly forbs and shrubs. However, the large standard deviations indicate large among-plot variability, and suggest that these differences may not be ecologically important.

We examine species-level data for the most abundant herbs and shrubs in Figure 3 (foliar cover) and Table 2 (foliar cover and frequency). The dominant perennial grasses across the ecological site were *Bouteloua gracilis* (blue grama), *Elymus elymoides* (squirreltail), and *Poa fendleriana* (muttongrass). Common shrubs included *Gutierrezia sarothrae* (broom snakeweed), *Quercus* spp. (oaks), *Cercocarpus montanus* (birchleaf mountain mahogany), *Rhus trilobata* (skunkbush sumac), and *Fallugia paradoxa* (Apache plume). The dominant cacti/succulent was *Opuntia* (prickly pear), which we did not classify to species. Common forbs included the nonnative *Verbascum thapsus* (common mullein), and 3 species of *Artemisia*: *A. campestris* (field sagewort), *A. carruthii* (Carruth's sagewort), and *A. dracunculus* (false tarragon). The most abundant annual grass was *Bromus tectorum* (cheatgrass), which is nonnative.

Species abundances were fairly similar between the thinned and unthinned plots. The thinned plots had somewhat higher mean foliar cover of *Bouteloua gracilis*, *Gutierrezia sarothrae*, *Cercocarpus montanus*, and *Rhus trilobata*, while the unthinned plots had higher mean foliar cover of *Elymus elymoides* and *Quercus* spp. Quadrat and plot frequencies between the 2 treatment groups were very similar for most species. The exceptions were that in the thinned plots *Rhus trilobata* and *Artemisia campestris* had somewhat higher frequencies, *Quercus* spp. had higher plot frequency, and *Artemisia drancunculus* had lower frequency. Standard deviations were moderately large, indicating large among-plot variability.

A total of 11 nonnative species were encountered in the plots. As mentioned, *Bromus tectorum* and *Verbascum thapsus* were abundant. Both occurred in 64.44% of the plots, and in 19–20% of the quadrats. Three additional species occurred in 20–40% of the plots in low abundance: *Portulaca oleracea* (little hogweed), *Tragopogon dubius* (yellow salsify), and *Lactuca serriola* (prickly lettuce). The remaining 6 nonnative species only occurred in 1 or 2 plots in low abundance (see table 2). *Bromus tectorum* and *Portulaca oleracea* had higher mean foliar covers and high frequencies in the unthinned plots, while *Verbascum thapsus* had high mean foliar cover and high frequencies in the thinned plots. Appendix A lists all species found in all plots, along with common names, families, mean foliar cover and plot frequencies by treatment group and for the ecological site.

Figure 3. Mean percent foliar cover of the 8 most abundant shrub and herbaceous species for all plots compared with the values for unthinned plots and thinned plots in the Mesa Top Pinyon-Juniper ecological site at BAND. Error bars represent one standard deviation.

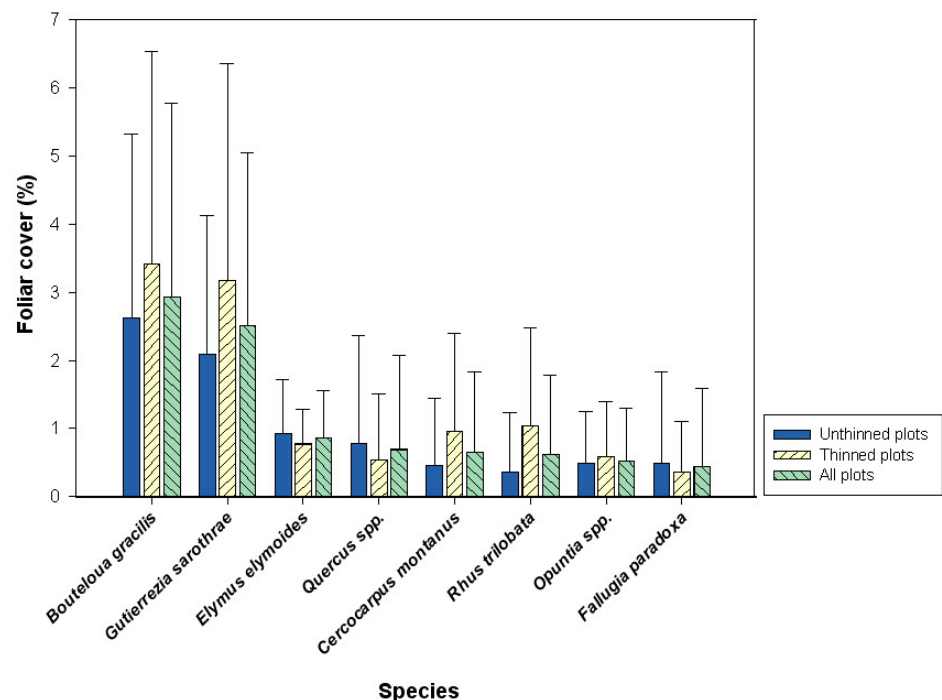


Table 2. Mean foliar cover and standard deviation, and mean quadrat and plot frequencies of the 15 most abundant shrub and herbaceous species for all plots (ecological mean) compared with the values for unthinned and thinned plots in the Mesa Top Pinyon-Juniper ecological site at BAND. Nonnative species are included from all plots.

Species	Unthinned plots				Thinned plots				All plots			
	Foliar cover (%)	SD	Quadrat frequency (%)	Plot frequency (%)	Foliar cover (%)	SD	Quadrat frequency (%)	Plot frequency (%)	Foliar cover (%)	SD	Quadrat frequency (%)	Plot frequency (%)
<i>Bouteloua gracilis</i>	2.629	2.696	73.33	100.00	3.409	3.123	74.12	94.12	2.924	2.856	73.63	97.78
<i>Gutierrezia sarothrae</i>	2.096	2.033	59.52	92.86	3.174	3.182	56.08	94.12	2.503	2.549	58.22	93.33
<i>Elymus elymoides</i>	0.924	0.787	74.29	100.00	0.774	0.503	72.55	100.00	0.867	0.691	73.63	100.00
<i>Quercus</i> spp.	0.787	1.581	12.38	50.00	0.540	0.967	12.55	82.35	0.693	1.374	12.44	62.22
<i>Cercocarpus montanus</i>	0.462	0.986	14.29	46.43	0.953	1.439	19.61	52.94	0.647	1.187	16.30	48.89
<i>Rhus trilobata</i>	0.368	0.872	10.95	67.86	1.044	1.436	15.29	82.35	0.623	1.152	12.59	73.33
<i>Opuntia</i> spp.	0.491	0.754	38.57	89.29	0.584	0.818	39.61	76.47	0.526	0.771	38.96	84.44
<i>Fallugia paradoxa</i>	0.492	1.340	10.95	39.29	0.365	0.740	11.76	52.94	0.444	1.142	11.26	44.44
<i>Bromus tectorum</i> ^a	0.598	1.495	20.71	60.71	0.116	0.280	18.82	70.59	0.416	1.207	20.00	64.44
<i>Artemisia campestris</i>	0.114	0.234	19.76	46.43	0.765	0.810	57.25	88.24	0.360	0.611	33.93	62.22
<i>Poa fendleriana</i>	0.373	0.589	26.90	82.14	0.322	0.394	23.14	70.59	0.354	0.520	25.48	77.78
<i>Verbascum thapsus</i> ^a	0.243	0.430	17.14	57.14	0.355	0.481	22.35	76.47	0.285	0.448	19.11	64.44
<i>Artemisia carruthii</i>	0.294	0.932	12.86	28.57	0.223	0.534	11.37	29.41	0.267	0.798	12.30	28.89
<i>Artemisia dracunculus</i>	0.330	1.099	28.33	50.00	0.064	0.250	2.35	11.76	0.229	0.884	18.52	35.56
<i>Piptatherum micranthum</i>	0.205	0.531	12.86	57.14	0.127	0.179	10.20	82.35	0.176	0.431	11.85	66.67
<i>Portulaca oleracea</i> ^a	0.015	0.029	5.95	39.29	0.001	0.005	0.39	5.88	0.009	0.024	3.85	26.67
<i>Tragopogon dubius</i> ^a	0.008	0.016	6.19	39.29	0.010	0.029	5.88	35.29	0.008	0.021	6.07	37.78
<i>Lactuca serriola</i> ^a	0.007	0.018	4.52	21.43	0.005	0.014	5.10	23.53	0.007	0.016	4.74	22.22
<i>Salsola tragus</i> ^a	0.003	0.013	0.48	3.57	0.003	0.012	0.39	5.88	0.003	0.013	0.44	4.44
<i>Bromus japonicus</i> ^a	0	0	0	0	0.003	0.014	1.18	5.88	0.001	0.008	0.44	2.22
<i>Melilotus officinalis</i> ^a	0	0	0	0	0.003	0.012	0.39	5.88	0.001	0.007	0.15	2.22
<i>Erodium cicutarium</i> ^a	0.001	0.008	0.48	3.57	0	0	0	0	0.001	0.006	0.30	2.22
<i>Sisymbrium altissimum</i> ^a	0.001	0.004	0.24	3.57	<0.001	0.001	0.39	5.88	0.001	0.003	0.30	4.44
<i>Taraxacum officinale</i> ^a	<0.001	0.001	0.24	3.57	0	0	0	0	<0.001	<0.001	0.15	2.22

Note: Species are arranged in descending order by the mean cover of all plots.

^aNonnative species.

The diversity metrics demonstrate a pattern of moderately high species diversity on the scale of the plot and high species diversity on the scale of the ecological site (table 3). On the scale of the plot, mean richness was 33.9 species. Shannon diversity (which takes into account relative abundance of species and generally ranges between 1.5 and 3.5) was 2.184, and evenness (the degree to which all species are of equal abundance, ranging from 0 to 1) was 0.624. On the scale of the ecological site, richness was 159, and beta diversity (a measure of within-site heterogeneity, generally ranging between 1 and 5) was 4.838. This suggests that while diversity was moderate at the local level, there were large differences in species composition among the plots due to heterogeneity across the ecological site. When the metrics were recalculated using only native species, they generally decreased, with the exception of beta diversity for the unthinned plots and all plots. The species diversity metrics were similar when compared between thinned and unthinned plots. Ecological site richness and beta diversity were lower for the the thinned plots than for all plots.

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

	Unthinned plots		Thinned plots		All plots	
	Mean	SD	Mean	SD	Mean	SD
All species						
Plot						
Plot richness	34.0	8.1	33.6	6.5	33.9	7.5
Shannon diversity	2.178	0.382	2.194	0.510	2.184	0.429
Evenness	0.623	0.106	0.625	0.132	0.624	0.115
Ecological site						
Ecological site richness	144		121		159	
Beta diversity	4.359		3.713		4.838	
Native species						
Plot						
Plot richness	31.7	6.5	31.2	5.5	31.5	6.1
Shannon diversity	2.132	0.368	2.137	0.488	2.134	0.412
Evenness	0.621	0.108	0.622	0.131	0.622	0.116
Ecological site						
Ecological site richness	135		112		148	
Beta diversity	4.395		3.704		4.847	

3.2 Trees

For tree data, we report the unthinned data as a representation of the pre-treatment baseline. The changes associated with the thinning treatment can be inferred by the differences between the treatment groups, and also by data from cut trees. Data from all plots (both thinned and unthinned) represent mean values for the ecological site. However, this state was transitory, as 13 out of 28 of the unthinned plots were subsequently thinned.

3.2.1 Baseline conditions from unthinned plots

The tree layer of the Mesa Top Pinyon-Juniper ecological site was dominated by *Juniperus monosperma*, with a low abundance of *Pinus edulis* (twoneedle pinyon), *Pinus ponderosa* (ponderosa pine), and *Juniperus deppeana* (table 4, fig. 4). In the unthinned plots, both density and basal area of the *Juniperus monosperma* live overstory were far higher than other trees, at 15.18 m²/ha and 166.8 stems/ha, respectively. The other 3 species in unthinned plots were sparse. The density of *Pinus ponderosa* was 1.1 stems/ha; the other 2 species had densities

Table 4. Mean density, mean basal area, and mean diameter of trees for unthinned plots, thinned plots, and all plots in the Mesa Top Pinyon-Juniper ecological site at BAND.

Metric	Species	Unthinned plots	Thinned plots	All plots
Seedling ^a density (stems/ha)	<i>Juniperus deppeana</i>	0	0	0
	<i>Juniperus monosperma</i>	214.3	152.9	180.6
	<i>Pinus edulis</i>	181.0	102.0	137.6
	<i>Pinus ponderosa</i>	0	0	0
	All species	395.3	254.9	318.2
Sapling ^a density (stems/ha)	<i>Juniperus deppeana</i>	0	0	0
	<i>Juniperus monosperma</i>	128.6	21.2	88.0
	<i>Pinus edulis</i>	21.4	16.5	19.6
	<i>Pinus ponderosa</i>	0	0	0
	All species	150.0	37.7	107.6
Overstory ^a density (stems/ha)	<i>Juniperus deppeana</i>	0.4	0	0.2
	<i>Juniperus monosperma</i>	166.8	94.7	139.6
	<i>Pinus edulis</i>	0.4	0	0.2
	<i>Pinus ponderosa</i>	1.1	0	0.7
	All species	168.6	94.7	140.7
Snag ^a density (stems/ha)	<i>Juniperus deppeana</i>	0.4	0	0.2
	<i>Juniperus monosperma</i>	23.9	14.1	20.2
	<i>Pinus edulis</i>	11.4	14.1	12.4
	<i>Pinus ponderosa</i>	1.4	0	0.9
	All species	37.1	28.2	33.7
Overstory basal area (m ² /ha)	<i>Juniperus deppeana</i>	0.10	0	0.06
	<i>Juniperus monosperma</i>	15.18	18.21	16.33
	<i>Pinus edulis</i>	0.01	0	<0.01
	<i>Pinus ponderosa</i>	0.11	0	0.07
	All species	15.40	18.21	16.46
Snag basal area (m ² /ha)	<i>Juniperus deppeana</i>	0.12	0	0.08
	<i>Juniperus monosperma</i>	2.06	1.73	1.93
	<i>Pinus edulis</i>	0.40	0.57	0.47
	<i>Pinus ponderosa</i>	0.12	0	0.07
	All species	2.70	2.30	2.55
Cut basal area (m ² /ha)	<i>Juniperus deppeana</i>	0	0	0
	<i>Juniperus monosperma</i>	0	5.54	2.09
	<i>Pinus edulis</i>	0	0.24	0.09
	<i>Pinus ponderosa</i>	0	0	0
	All species	0	5.78	2.18
Mean overstory diameter ^b (cm)	<i>Juniperus deppeana</i>	60.0	0	60.0
	<i>Juniperus monosperma</i>	32.7	46.1	37.7
	<i>Pinus edulis</i>	15.0	0	15.0
	<i>Pinus ponderosa</i>	34.7	0	34.7
	All species	32.8	46.1	37.6

Note: Values in the "All species" rows represent all 4 species combined. "All species" density and basal area metrics are the sum of the individual species mean values. "All species" overstory diameter is the mean diameter across all tree species.

^aSize classes: seedlings are <2.5 cm diameter, saplings are 2.5 to <15 cm diameter, overstory trees are ≥15 cm diameter; snags are standing dead stems ≥15 cm diameter. Seedling data were not collected in 2008 so these data are calculated from 14 unthinned plots and 17 thinned plots.

^bMean tree diameter is provided as DBH for *Pinus* spp. and as DRC for *Juniperus* spp.

of 0.4 stems/ha. The live overstory basal areas of *Pinus ponderosa* and *Juniperus deppeana* in the unthinned plots were similar, at 0.11 and 0.10 m²/ha, respectively. The overstory basal area for *Pinus edulis* was much less, at 0.01 m²/ha.

While *Juniperus monosperma* had a greater basal area and density of snags (standing dead overstory trees) than any of the other 3 trees in the unthinned plots, the density and basal area of *Pinus edulis* snags were more than an order of magnitude greater than for live *Pinus edulis* in the unthinned plots.

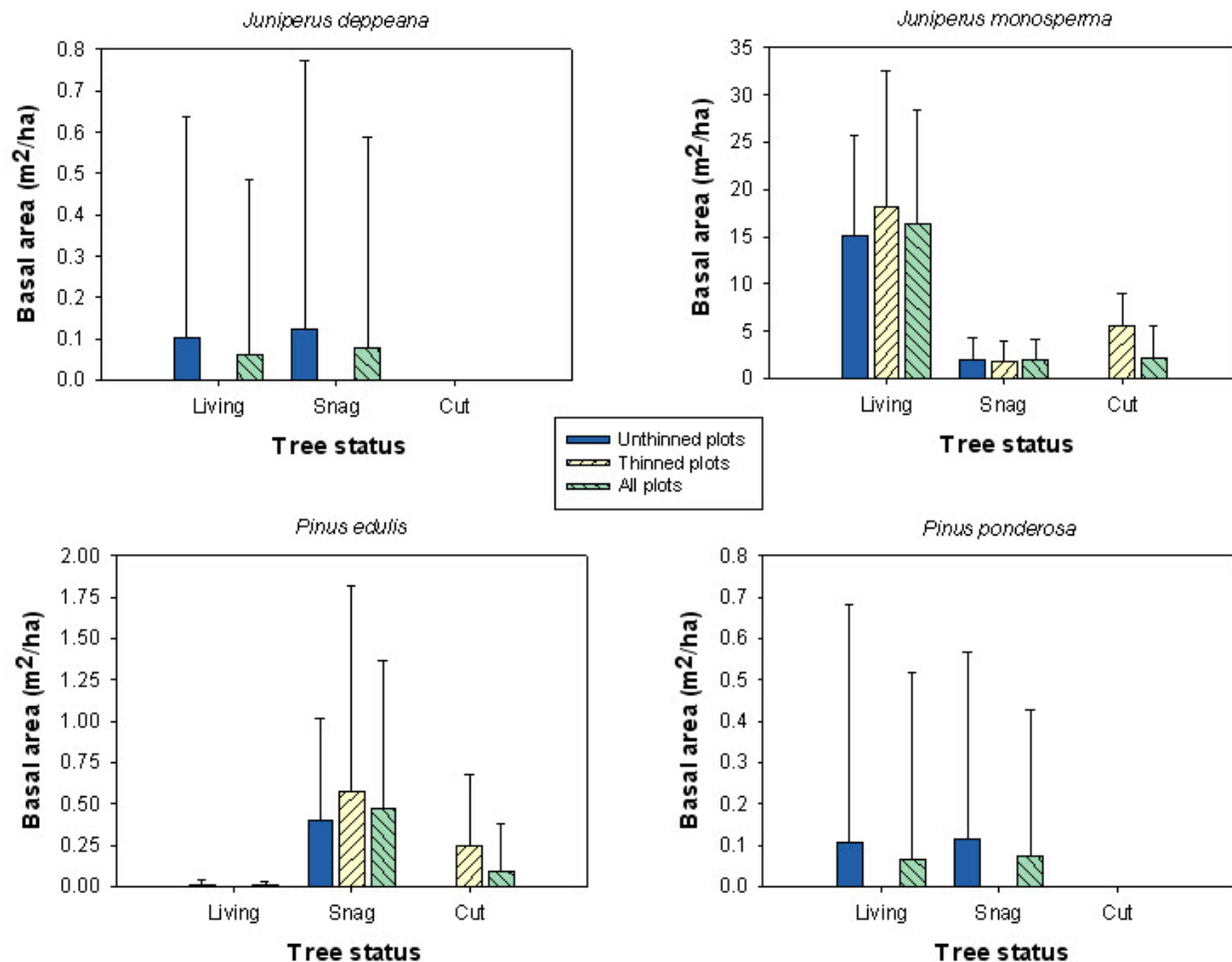


Figure 4. Mean basal area for living trees, snags, and cut trees by species in unthinned plots, thinned plots, and all plots in the Mesa Top Pinyon-Juniper ecological site. Error bars represent 1 standard deviation. Note that the y axis scales vary.

3.2.2 Comparison of thinned and unthinned plots

The thinned and the unthinned plots differed somewhat in composition. There were no individuals of *Pinus ponderosa* or *Juniperus deppeana*, and no living individuals of *Pinus edulis*, in the thinned plots. While there were some cut stumps of *Pinus edulis* measured in the thinned plots (basal area of 0.24 m²/ha), these were likely snags that were cut.

The results of the thinning treatment can be seen in the difference in tree density of the plots that were thinned and the plots that were not thinned. The thinned plots had a lower density of *Juniperus monosperma* living overstory than the unthinned plots: 94.7 stems/ha versus 166.8 stems/ha. Overstory basal area of this species was similar among plot groups, though slightly higher in the thinned plots: 18.21 m²/ha versus 15.18 m²/ha. The size distribution for this species shows that the smallest 2 size classes had lower densities in the thinned plots, apparently as a direct result of the thinning (fig. 5). The thinned plots had higher densities in the 3 largest

size classes. The thinned plots therefore, had a much greater basal area than the unthinned plots, as a result of having a greater number of large trees. Based on the measurement of the cut stumps, the basal area of *Juniperus monosperma* was reduced by 5.54 m²/ha in the thinned plots. The standard deviations for most tree metrics were large, indicating large among plot variation.

The sapling and seedling layers for both thinned and unthinned plots were comprised of *Juniperus monosperma* and *Pinus edulis* (figs. 6 and 7). Sapling density of *Juniperus monosperma* was 128.6 stems/ha in the unthinned plots, and 21.2 stems/ha in the thinned plots, suggesting that many saplings were removed by the thinning treatment. In the unthinned plots, there was a positive relationship between size class and sapling density: the largest size class had the highest density and the smallest size class had the lowest. In the thinned plots, sapling densities in the 3 size classes were similar. The sapling density of *Pinus edulis* was slightly lower in thinned plots compared with unthinned plots, at 16.5 stems/ha and 21.4 stems/ha, respectively.

Juniperus monosperma had only slightly higher seedling density than *Pinus edulis*: 214.3 stems/ha versus 181.0 stems/ha, respectively, in unthinned plots. Both species had slightly lower seedling densities in the thinned plots across all size classes. Standard deviations for seedling and sapling metrics were moderately large, indicating large among-plot variability.

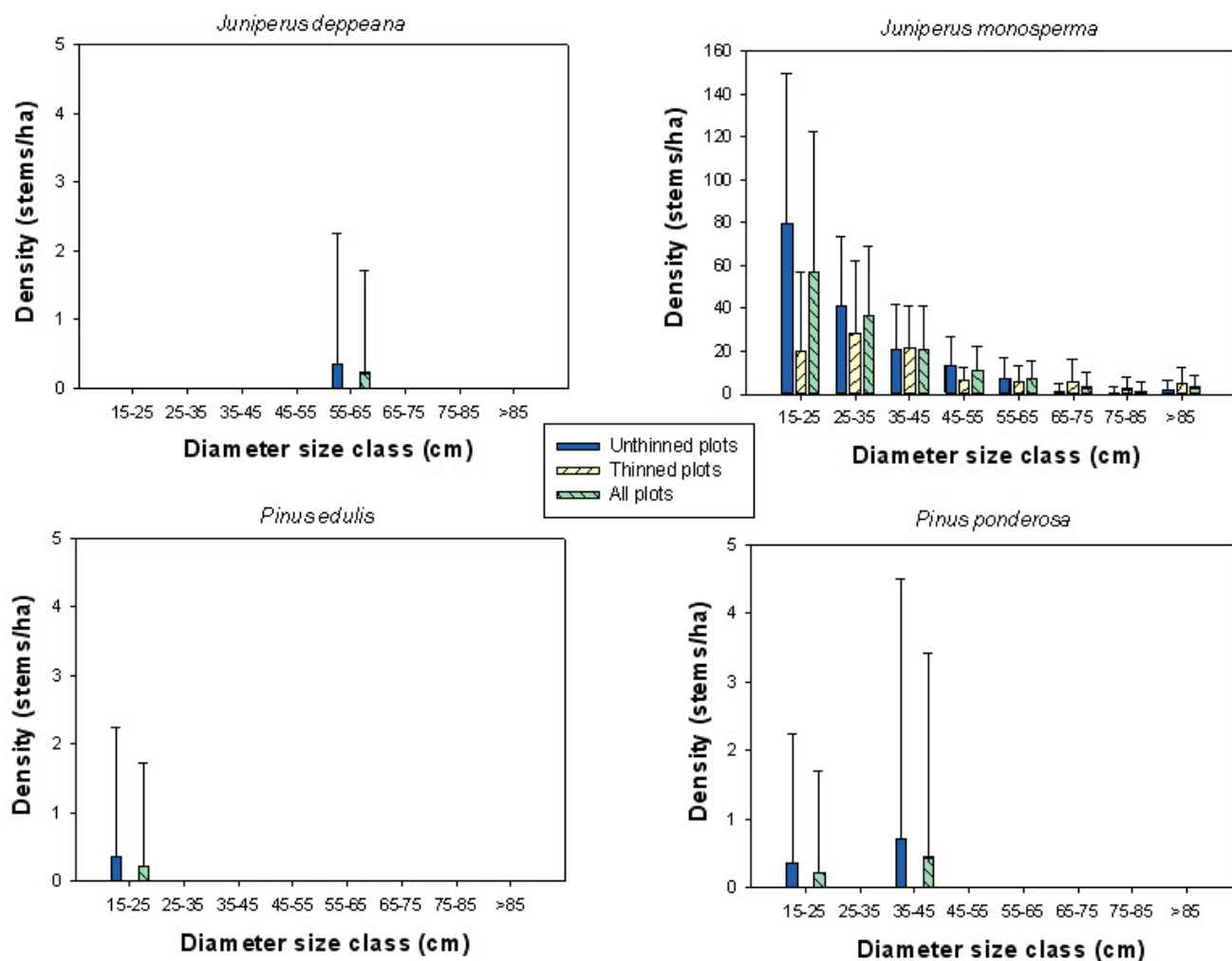


Figure 5. Size structure of living overstory trees by species for unthinned plots, thinned plots, and all plots in the Mesa Top Pinyon-Juniper ecological site at BAND. Error bars represent 1 standard deviation. Note that the scale of the y-axis for the graph of *Juniperus monosperma* differs from the scale for the other 3 species.

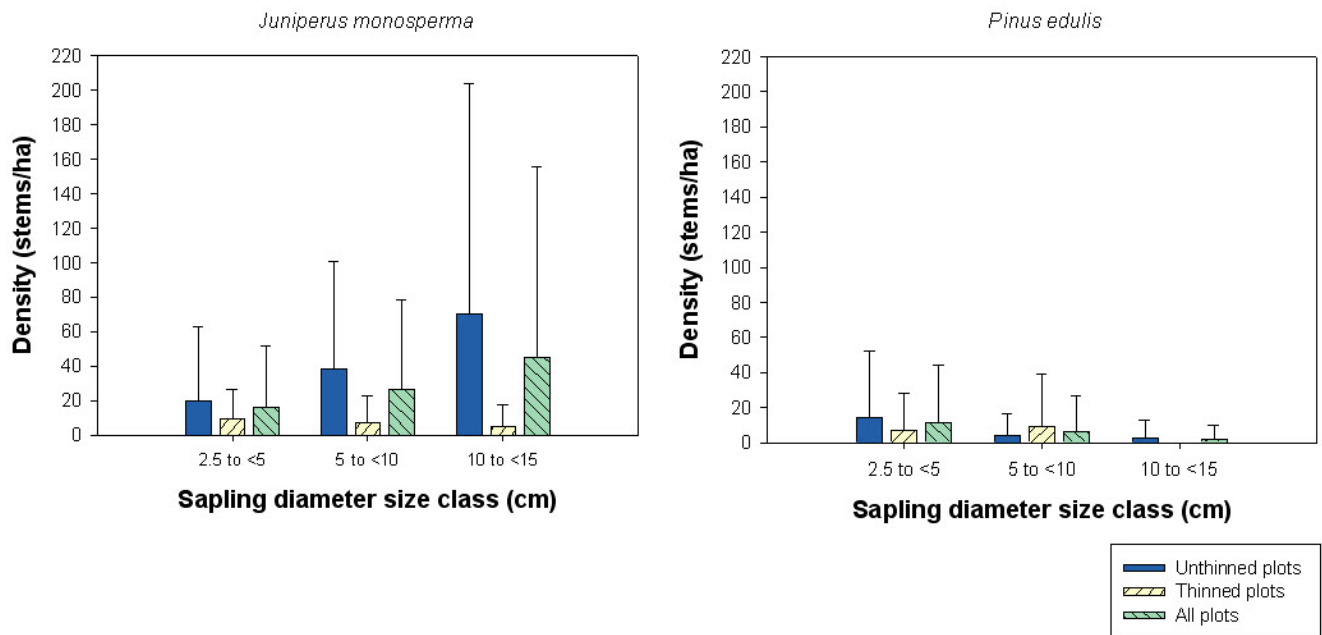


Figure 6. Mean density of saplings in different diameter classes by species for unthinned plots, thinned plots, and all plots in the Mesa Top Pinyon-Juniper ecological site at BAND. Error bars represent 1 standard deviation. (There were no saplings of *Juniperus deppeana* or *Pinus ponderosa* in any of the plots.)

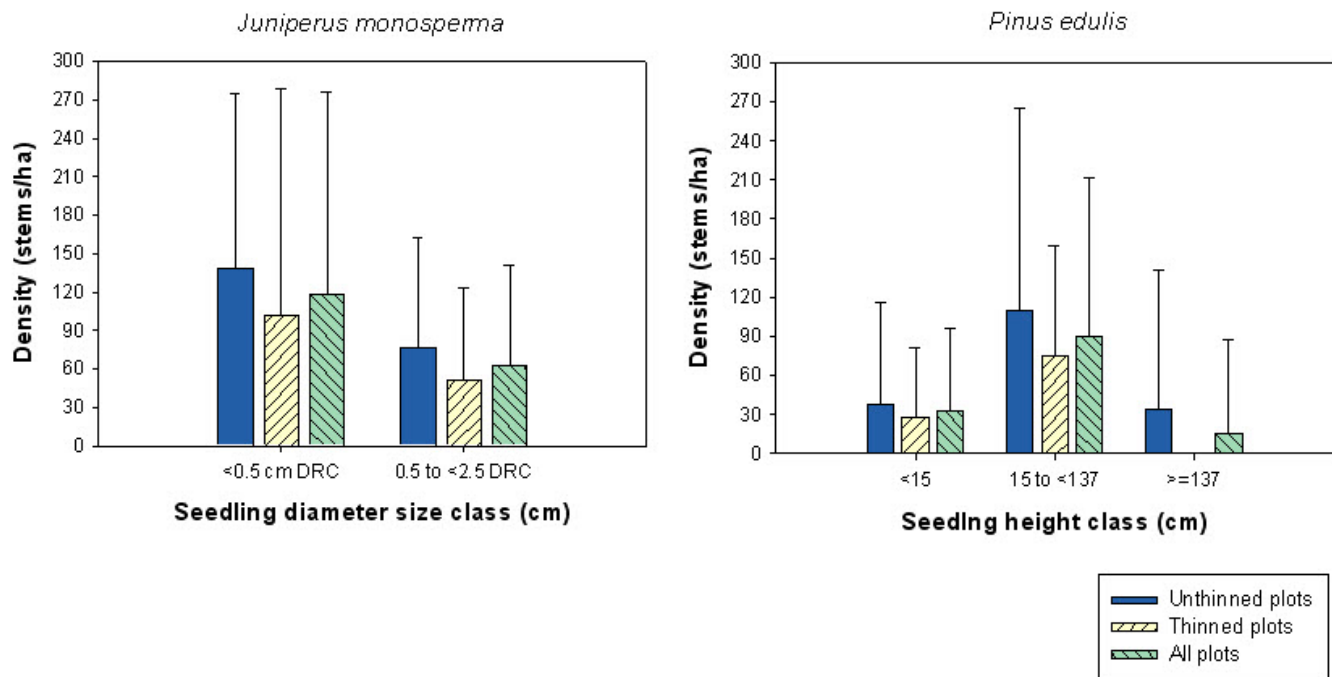


Figure 7. Mean density of tree seedlings in different size classes by species for unthinned plots, thinned plots, and all plots in the Mesa Top Pinyon-Juniper ecological site at BAND. Error bars represent 1 standard deviation. The seedling category includes all trees <2.5 cm in diameter (*Pinus edulis* was measured at breast height and *Juniperus monosperma* was measured at root crown.) There were no seedlings of *Juniperus deppeana* or *Pinus ponderosa*. Seedling data were not collected in 2008, so these data are derived from 14 unthinned plots and 17 thinned plots collected in 2009 and 2010.

The overall size structure of overstory trees and saplings demonstrates interesting patterns (fig. 8). In the unthinned plots, the structure shows a unimodal curve, with the mode being the 15–25 cm size class. The thinned plots, on the other hand, showed a much more even size class distribution, most likely the result of the thinning treatment. The resulting curve of thinned and unthinned plots combined is a unimodal curve with a much lower mode.

Mean canopy cover of the unthinned plots was 16.9% (fig. 9). While the canopy cover was lower in the thinned plots, 11.3%, the difference was smaller than expected.

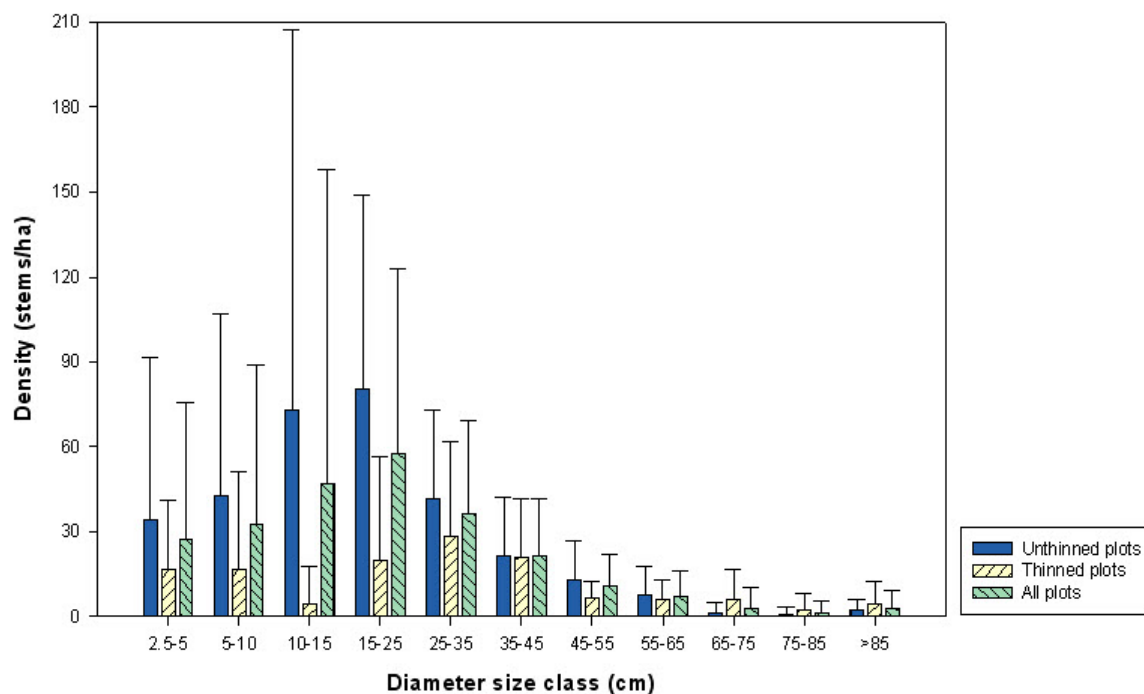


Figure 8. Size structure of living overstory trees and saplings for unthinned plots, thinned plots, and all plots in the Mesa Top Pinyon-Juniper ecological site at BAND. Error bars represent 1 standard deviation.

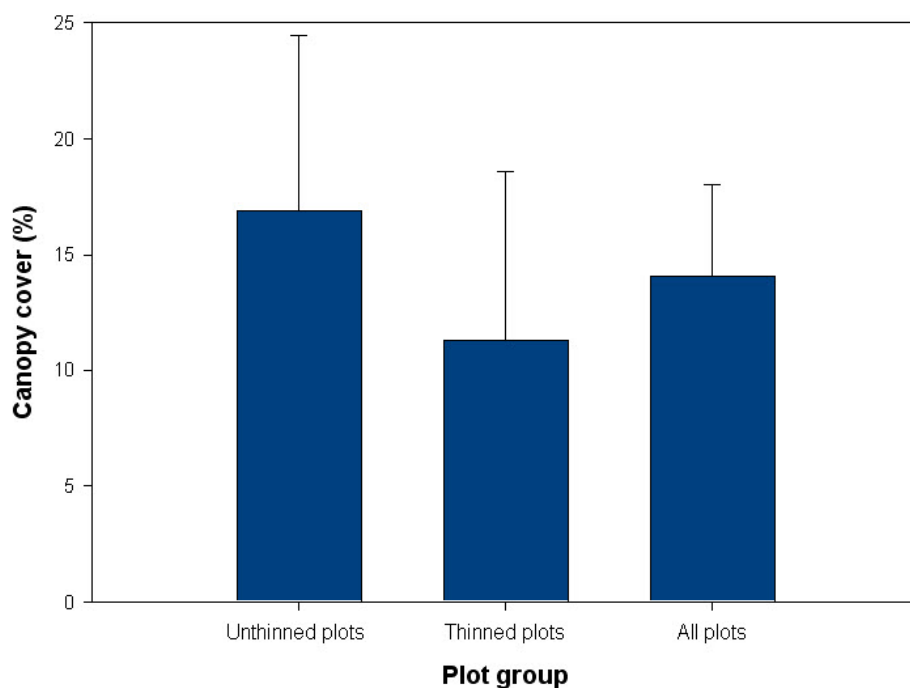


Figure 9. Mean percent canopy cover for unthinned plots, thinned plots, and all plots in the Mesa Top Pinyon-Juniper ecological site at BAND. Error bars indicate 1 standard deviation. Canopy cover data were not collected in 2008, so these data are derived from 14 unthinned plots and 17 thinned plots collected in 2009 and 2010.

3.3 Soil stability and hydrologic function

We measured the amount of soil surface potentially subject to erosion in 2 ways; cover estimates of soil surface features in quadrats and measurements of basal gaps along transects. We report the metrics for the ecological site, i.e., all plots, and compare the 2 treatment groups.

The soil surface feature data demonstrate that duff/litter and fine gravel (mostly pumice) co-dominated the soil surface, with mean covers of 34.052% and 33.007%, respectively (table 5 and fig. 10). The mean cover of undifferentiated crust was 14.394%, and the mean cover of bare soil was 4.867%. The remaining features had less than 3% cover. Cyanobacteria, moss and lichen each had mean covers of less than 1%. While there were substantial amounts of undifferentiated crust and bare soil, the large cover of duff/litter, in addition to the moderate amount of live and dead plant bases, cyanobacteria, moss lichen and stone/bedrock, impart greater resistance to soil erosion. The extent to which fine gravel protects against soil erosion is unclear. The fine gravel component in this ecological site is largely comprised of pumice, which can be easily transported by surface water sheetflow, and may provide little or no protection.

Soil surface features for the unthinned and thinned plots had similar mean cover values. Cyanobacteria had greater cover in the unthinned plots compared to the thinned plots, with 1.098% mean cover versus 0.191% mean cover. This may be the result of trampling during the thinning treatment. Higher cover of woody debris would be expected in the thinned plots as a result of the cutting and spreading of cut trees from the thinning treatment, however the mean cover of woody debris was only slightly higher in the thinned plots than the unthinned plots. Standard deviations were moderately high, indicating high among-plot variability.

The basal gap data showed a large amount of exposed soil surface between plant bases. Basal gaps greater than 100 cm comprised 79.3% of the transects (table 6 and fig. 11). The median gap size was 85.5 cm. The size distributions of basal gaps in thinned and unthinned plots were quite similar.

Table 5. Cover of soil surface features for unthinned plots, thinned plots, and all plots in the Mesa Top Pinyon-Juniper ecological site at BAND.

Soil surface feature	Unthinned plots		Thinned plots		All plots	
	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Live plant base	2.670	2.333	2.809	1.640	2.722	2.079
Dead woody base	0.268	0.351	0.385	0.471	0.312	0.400
Dead herbaceous base	0.891	0.644	0.876	0.600	0.886	0.621
Bare soil	4.615	4.720	5.283	7.096	4.867	5.664
Duff/litter ^a	33.770	12.252	34.516	13.518	34.052	12.598
Undifferentiated crust	13.614	9.756	15.679	11.742	14.394	10.468
Moss	0.173	0.447	0.098	0.260	0.145	0.386
Lichen	0.002	0.006	0.017	0.048	0.008	0.030
Cyanobacteria ^b	1.098	2.193	0.191	0.398	0.755	1.790
Fine gravel (0.2 to <2 cm)	33.796	17.740	31.707	20.170	33.007	18.496
Coarse gravel (2 to <7.5 cm)	2.032	1.954	1.938	2.367	1.997	2.093
Cobble (7.5 to <25 cm)	1.091	1.765	0.736	0.919	0.957	1.500
Stone, bedrock (>25 cm)	1.804	2.756	2.271	4.557	1.980	3.502
Woody debris	2.237	1.995	2.585	1.148	2.368	1.717

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

Soil aggregate stability ratings indicated moderate stability (table 7). The ratings range from 1 to 6, with 1 indicating low stability and 6 indicating high stability. The mean rating of all samples was 3.78. Samples collected under vegetative cover had higher ratings than samples collected where there was no vegetative cover. Stability ratings for the thinned plots were somewhat higher than for the unthinned plots, although the standard deviations were moderately high. In general, the relatively high soil stability ratings for all the plots are in part a result of the large amount of duff/litter cover. Since we apply the highest rating to areas of deep litter, the mean soil stability rating would be much lower if we had omitted these samples from the analysis. The higher ratings for the samples under vegetative cover is also partially explained by the fact that duff/litter is concentrated under juniper canopy.

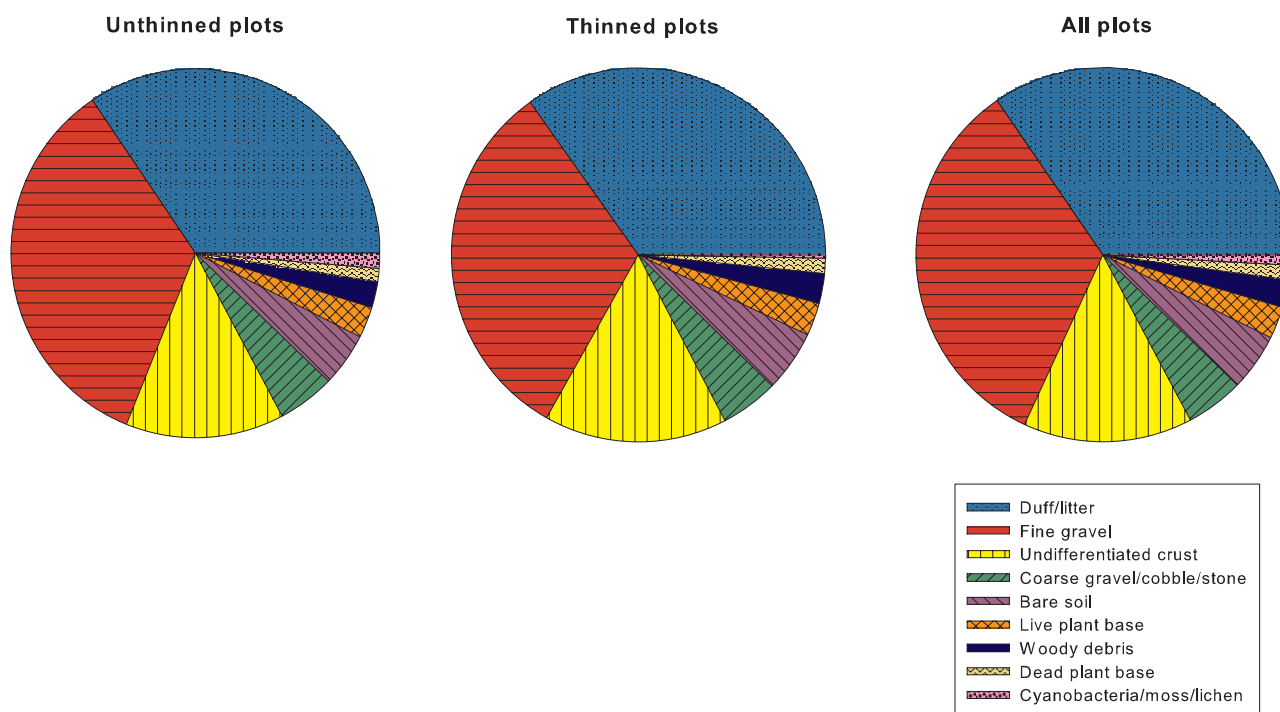


Figure 10. Mean percent cover of soil surface features for unthinned plots, thinned plots, and all plots in the Mesa Top Pinyon-Juniper ecological site at BAND.

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

Metric	Unthinned plots		Thinned plots		All plots	
	Mean	SD	Mean	SD	Mean	SD
Number of gaps	112.7	47.5	106.1	53.7	110.2	49.4
Median gap size (cm)	82.2	63.8	91.0	50.4	85.5	58.7
Percentage of transect in gaps	95.6	2.5	95.4	2.9	95.5	2.6
Percentage of transect in gaps 0-19 cm	1.8	1.3	1.7	1.6	1.8	1.4
Percentage of transect in gaps 20-49 cm	4.9	3.1	4.7	3.6	4.8	3.2
Percentage of transect in gaps 50-99 cm	9.7	5.5	9.3	6.0	9.5	5.6
Percentage of transect in gaps ≥100 cm	79.1	11.3	79.7	13.2	79.3	11.9
Percentage of transect in plant bases	4.2	2.2	4.4	2.7	4.3	2.4

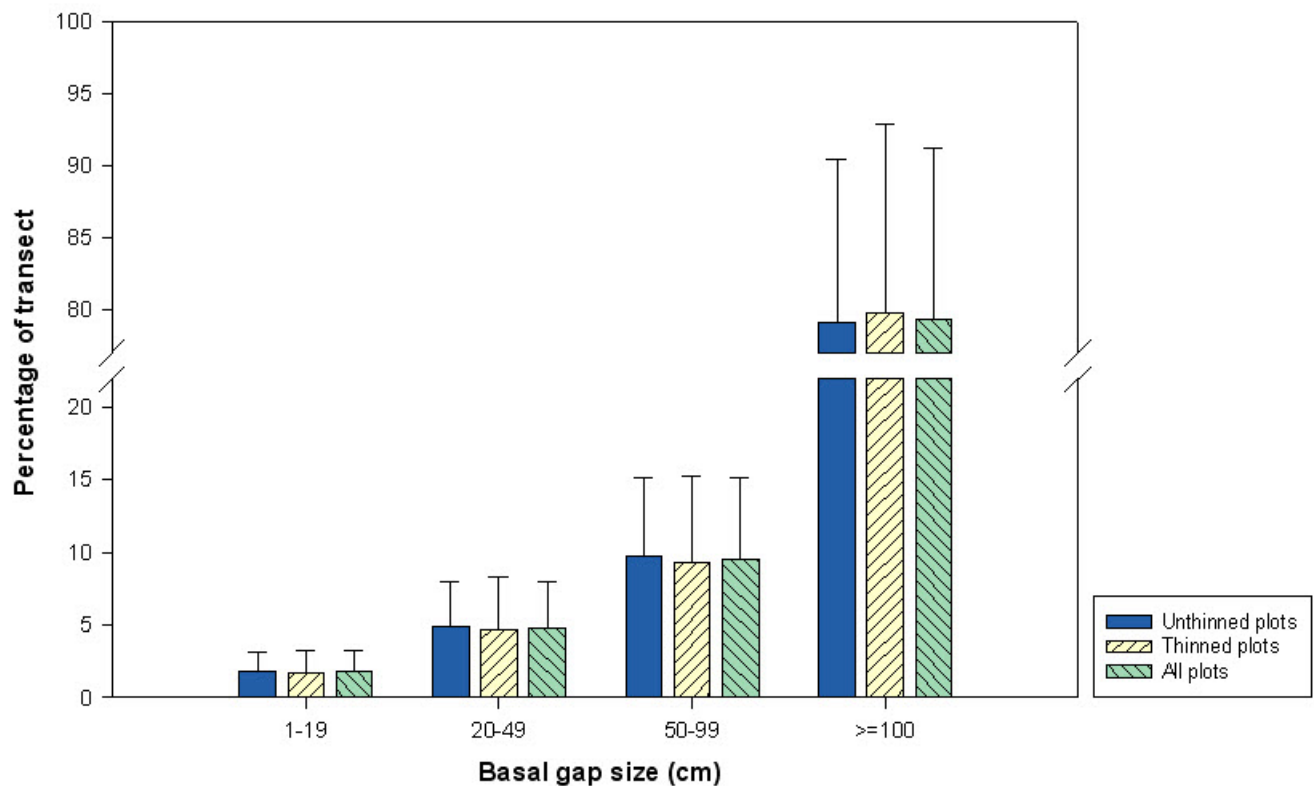


Figure 11. Mean percentage of transect in different gap size classes for unthinned plots, thinned plots, and all plots in the Mesa Top Pinyon-Juniper ecological site at BAND. Error bars represent 1 standard deviation.

Table 7. Soil stability rating for all samples, and for samples with and without vegetative cover, in unthinned, thinned, and all plots in the Mesa Top Pinyon-Juniper ecological site at BAND.

	Unthinned plots		Thinned plots		All plots	
	Mean	SD	Mean	SD	Mean	SD
All samples	3.71	1.11	3.90	0.84	3.78	1.01
Samples under vegetative cover	4.07	1.25	4.36	1.00	4.18	1.16
Samples not under vegetative cover	3.20	1.27	3.35	0.79	3.26	1.10

Note: Ratings ranged from 1–6, with 1 being the lowest stability and 6 being the highest.

3.4 Western Regional Climate Center precipitation data

Precipitation records for Los Alamos, NM, are available from the Western Regional Climate Center (2013). Figure 12 shows the total monthly precipitation for each of the 3 years of monitoring described in this report, compared with the long term average precipitation by month for the period 1933–2010.

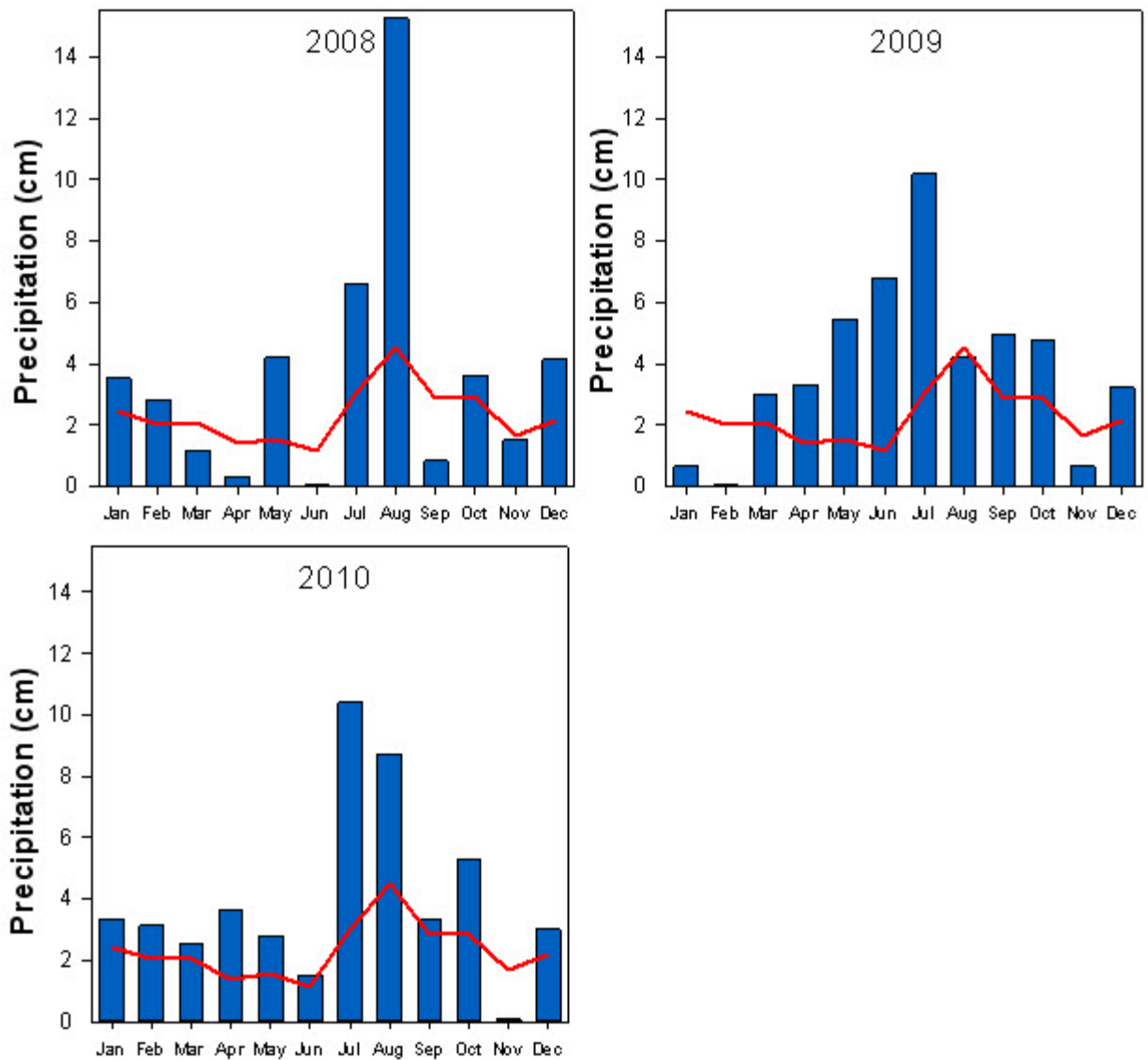


Figure 12. Total monthly precipitation for the 3 years of sampling. The red line represents the long term average precipitation for the Los Alamos (295084) weather station for the period 1933–2010, collected by the Western Regional Climate Center.

4 Discussion

4.1 Baseline conditions

This report provides the baseline data for the Mesa Top Pinyon-Juniper ecological site at BAND, representing data from the 45 plots established between 2008 and 2010. Unfortunately, we were not able to establish all plots before thinning treatments began, nor were we able to sample plots over multiple years to understand the interannual variability of key metrics.

The baseline conditions for this ecological site describe a woodland characterized by an herbaceous and shrub layer co-dominated by perennial grasses and shrubs, with a moderate forb and cacti component. Dominant perennial grasses include *Bouteloua gracilis* and *Elymus elymoides*; dominant shrubs include *Gutierrezia sarothrae*, *Quercus* spp., and *Cercocarpus montanus*; dominant forbs include *Verbascum thapsus* and *Artemisia* spp. We encountered 11 nonnative species in the plots, of which *Bromus tectorum* and *Verbascum thapsus* were abundant. Species diversity was moderate on the scale of the plot, and high on the scale of the ecological site. This was, in part, a result of the wide range of soil types included in our sampling frame.

The tree layer was dominated by *Juniperus monosperma*. *Pinus edulis*, *Pinus ponderosa*, and *Juniperus deppeana* were sparse in the overstory. Snags of *Pinus edulis* were abundant, a result of the recent die-off. *Pinus edulis* and *Juniperus monosperma* were both well represented in the sapling and seedling layers.

The soil surface is characterized by large unvegetated areas that are potentially susceptible to erosion. This erosion potential is offset by large areas covered by duff/litter, in addition to areas covered by biological soil crusts (cyanobacteria, moss and lichen) and exposed stones.

4.2 Thinning treatments

Our long-term monitoring objectives are to track changes in vegetation composition and structure, along with soil stability and hydrologic function, through time in the Mesa Top Pinyon-Juniper ecological site for both thinned and unthinned areas. Ideally, we would have completed our baseline sampling before the commencement of the restoration thinning treatments. While the overstory tree layer of the thinned plots was reconstructed by measuring cut stumps, the impact of the thinning on the sapling and seedlings could only be inferred by comparing these layers in the thinned and unthinned plots. Moreover, it is likely that the shrub and herbaceous layer responded to the removal of the tree overstory, particularly for the plots that were sampled more than one year after the thinning treatments. The differences between the thinned and unthinned plots may be the result of 3 factors: direct impacts of thinning, indirect impacts of thinning, and spatial differences in the vegetation and soils between the plot groups.

Before examining the effects of the thinning, the spatial differences between the thinned and unthinned areas should be assessed. Vegetation and soils will inevitably be different between plots due to spatial heterogeneity in soil nutrients, soil texture, water availability, microclimates, and human and natural disturbance, irrespective of treatment area. Moreover, the treatments were not undertaken in a spatially random fashion across the landscape. The treatments avoided areas of shallow, nutrient-poor soils with woodlands that were less productive (lower biomass). This may explain the higher basal area of living junipers in the thinned plots compared to the unthinned plots, even after thinning reduced the basal area by over 5 m²/ha. It may also explain why the difference in canopy cover between the 2 plots groups was not greater. Another difference was that *Pinus ponderosa* and *Juniperus deppeana* occurred only in the unthinned areas. These species occurred in more open, savanna-like areas and may not have occurred in the areas targeted for the restoration treatments.

Only the tree layer was directly affected by the thinning treatments. The lower densities of the smaller overstory size classes and the lower densities of saplings in the thinned plots are undoubtedly a direct result of the thinning. Less canopy cover in the thinned plots is also a direct effect. By measuring cut stumps, we determined that a mean basal of 5.54 m²/ha was removed through the thinning. It is therefore surprising that the mean basal area of living trees was higher in the thinned plots. As suggested above, this may have been a result of higher productivity

in the sites targeted for thinning.

The primary indirect effect of the thinning was the response of the herbaceous and shrub vegetation. Increased light, water and available nutrients may have caused increased growth of vegetation following the thinning treatments, particularly for plots sampled more than one year after the thinning. The thinned plots had higher mean foliar cover for most functional groups and a number of dominant species. While it is possible that differences in the treatment groups could have been a result of disproportionate application of thinning to productive areas, as was suggested above, they could also partially be the direct result of thinning. We will continue tracking these plots to see if this slight pattern of higher shrub and herbaceous cover in thinned plots becomes more pronounced through time.

4.3 Revisit design

Now that we have completed our baseline monitoring of this ecological site, we will begin to implement long term monitoring according to our revisit design, that is, the temporal plan for revisiting plots through time. Our power analysis indicates that 45 plots should provide a large enough sample size to detect trends in key metrics. Before implementing our revisit design, we will examine the data collected in 2012 for the plots burned in the Las Conchas fire and determine whether any plots should be temporarily removed from our sampling design.

We will then begin resampling the plots using a type of revisit design called a “panel design”. Between the extremes of monitoring the same set of plots with every revisit, and monitoring a new set of plots with each revisit, there are designs that provide some balance between high revisit frequency and increasing the total number of plots visited. In these “panel designs” a panel is the group of plots that will always be sampled together. Our general revisit design balances the allocation of effort between addressing temporal (year to year) variability and spatial variability within the ecological site. We will split the plots in the Mesa Top Pinyon-Juniper ecological site into 3 panels, and sample 2 of the panels every other year (table 8).

Table 8. The panel design we are currently planning to use for the revisit design at BAND. “X” represents the number of plots in a panel.

Panel	Year											
	1	2	3	4	5	6	7	8	9	10	11	12
1	X				X		X				X	
2	X		X				X		X			
3			X		X				X		X	
Sum/yr	2X	0	2X	0	2X	0	2X	0	2X	0	2X	0

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Appendix A: Complete species list for plots sampled in the Mesa Top Pinyon-Juniper ecological site at BAND.

Table A1. Herbaceous and shrub species with mean foliar cover and mean plot frequency in thinned plots, unthinned plots, and all plots in the Mesa Top Pinyon-Juniper ecological site at BAND, 2008–2010.

Species	Common name	Family	Thinned plots			Unthinned plots			All plots	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Plot frequency (%)
<i>Achnatherum hymenoides</i>	Indian ricegrass	Poaceae	0	0	0.001	0	5.88	<0.001	2.22	2.22
<i>Agoseris glauca</i>	pale agoseris	Asteraceae	0.001	3.57	0	0	0	0.001	2.22	2.22
<i>Amaranthus</i> spp.	pigweed	Amaranthaceae	0.006	17.86	<0.001	<0.001	5.88	0.004	13.33	13.33
<i>Amaranthus retroflexus</i>	redroot pigweed	Amaranthaceae	0.018	17.86	0.002	0.002	17.65	0.012	17.78	17.78
<i>Antennaria parvifolia</i>	small leaf pussytoes	Asteraceae	0.001	3.57	0	0	0	<0.001	2.22	2.22
<i>Arabis</i> spp.	rockcress	Brassicaceae	0.001	14.29	0.002	0.002	35.29	0.001	22.22	22.22
<i>Aristida arizonica</i>	Arizona threeawn	Poaceae	0.008	3.57	0	0	0	0.005	2.22	2.22
<i>Aristida purpurea</i>	Fendler's threeawn	Poaceae	0.053	60.71	0.042	0.042	35.29	0.049	51.11	51.11
<i>Artemisia campestris</i>	field sagewort	Asteraceae	0.114	46.43	0.765	0.765	88.24	0.360	62.22	62.22
<i>Artemisia carruthii</i>	Carruth's sagewort	Asteraceae	0.294	28.57	0.223	0.223	29.41	0.267	28.89	28.89
<i>Artemisia dracunculus</i>	false tarragon	Asteraceae	0.330	50.00	0.064	0.064	11.76	0.229	35.56	35.56
<i>Artemisia frigida</i>	fringed sagebrush	Asteraceae	0	0	0.008	0.008	17.65	0.003	6.67	6.67
<i>Artemisia ludoviciana</i>	white sagewort	Asteraceae	0.173	57.14	0.050	0.050	41.18	0.127	51.11	51.11
<i>Astragalus</i> spp.	milkvetch	Fabaceae	<0.001	3.57	<0.001	<0.001	5.88	<0.001	4.44	4.44
<i>Atriplex canescens</i>	fourwing saltbush	Chenopodiaceae	0	0	0.100	0.100	5.88	0.038	2.22	2.22
<i>Bahia dissecta</i>	ragleaf bahia	Asteraceae	0.143	92.86	0.100	0.100	100.00	0.127	95.56	95.56
<i>Blepharoneuron tricholepis</i>	pine dropseed	Poaceae	0.008	3.57	0	0	0	0.005	2.22	2.22
<i>Bouteloua curtipendula</i>	sideoats grama	Poaceae	0.002	7.14	<0.001	<0.001	5.88	0.001	6.67	6.67
<i>Bouteloua eriopoda</i>	black grama	Poaceae	0.004	7.14	0.230	0.230	17.65	0.090	11.11	11.11
<i>Bouteloua gracilis</i>	blue grama	Poaceae	2.629	100.00	3.409	3.409	94.12	2.924	97.78	97.78
<i>Brickellia</i> spp.	brickellbush	Asteraceae	<0.001	3.57	0.032	0.032	11.76	0.012	6.67	6.67
<i>Brickellia brachyphylla</i>	plumed brickellbush	Asteraceae	0	0	0.003	0.003	5.88	0.001	2.22	2.22
<i>Brickellia californica</i>	California brickellbush	Asteraceae	0.001	3.57	0.005	0.005	11.76	0.002	6.67	6.67
<i>Brickellia eupatorioides</i>	false boneset	Asteraceae	0.013	14.29	0.024	0.024	11.76	0.017	13.33	13.33
<i>Brickelliastrum fendleri</i>	Fendler's brickellbush	Asteraceae	0.003	3.57	0.006	0.006	5.88	0.004	4.44	4.44
<i>Bromus japonicus</i> ^a	Japanese brome	Poaceae	0	0	0.003	0.003	5.88	0.001	2.22	2.22

Table A1 (continued)

Species	Common name	Family	Thinned plots		Unthinned plots		All plots	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Bromus tectorum</i> ^a	cheatgrass	Poaceae	0.598	60.71	0.116	70.59	0.416	64.44
<i>Carex</i> spp.	sedge	Cyperaceae	<0.001	3.57	0.001	11.76	0.001	6.67
<i>Castilleja integra</i>	wholeleaf Indian paintbrush	Scrophulariaceae	0.002	7.14	0	0	0.001	4.44
<i>Cercocarpus montanus</i>	birchleaf mountain mahogany	Rosaceae	0.462	46.43	0.953	52.94	0.647	48.89
<i>Chaetopappa ericoides</i>	rose heath	Asteraceae	0.002	7.14	0	0	0.001	4.44
<i>Chamaesyce</i> spp. Group A	annual sandmats	Euphorbiaceae	0.033	64.29	0.085	70.59	0.053	66.67
<i>Chamaesyce</i> spp. Group B	annual sandmats	Euphorbiaceae	0.056	75.00	0.021	47.06	0.043	64.44
<i>Chamaesyce fendleri</i>	Fendler's sandmat	Euphorbiaceae	0.021	39.29	0.034	52.94	0.026	44.44
<i>Chenopodium</i> spp.	goosefoot	Chenopodiaceae	0.001	17.86	0.014	58.82	0.006	33.33
<i>Chenopodium fremontii</i>	Fremont's goosefoot	Chenopodiaceae	0.006	25.00	0.016	29.41	0.010	26.67
<i>Chenopodium graveolens</i>	fetid goosefoot	Chenopodiaceae	0.006	32.14	0.002	23.53	0.004	28.89
<i>Chenopodium incanum</i>	mealy goosefoot	Chenopodiaceae	0.011	28.57	0.001	11.76	0.007	22.22
<i>Chenopodium leptophyllum</i>	narrowleaf goosefoot	Chenopodiaceae	0.081	71.43	0.045	35.29	0.067	57.78
<i>Cirsium</i> spp.	thistle	Asteraceae	0.003	7.14	0	0	0.002	4.44
<i>Cirsium neomexicanum</i>	New Mexico thistle	Asteraceae	0.003	3.57	0.003	5.88	0.003	4.44
<i>Conyza canadensis</i>	Canadian horseweed	Asteraceae	0.001	10.71	0.005	23.53	0.002	15.56
<i>Cordylanthus wrightii</i>	Wright's bird's beak	Scrophulariaceae	0.030	32.14	0.055	29.41	0.040	31.11
<i>Croton texensis</i>	Texas croton	Euphorbiaceae	0.086	35.71	0.126	47.06	0.101	40.00
<i>Cryptantha cinerea</i>	James' cryptantha	Boraginaceae	0.016	64.29	0.019	82.35	0.017	71.11
<i>Cyperus fendlerianus</i>	Fendler's flatsedge	Cyperaceae	<0.001	7.14	0	0	<0.001	4.44
<i>Dalea candida</i>	white prairieclover	Fabaceae	0.007	28.57	0.005	11.76	0.006	22.22
<i>Dalea polygonoides</i>	six-weeks prairie-clover	Fabaceae	<0.001	3.57	0	0	<0.001	2.22
<i>Descurainia</i> spp.	tansymustard	Brassicaceae	<0.001	3.57	0.001	5.88	<0.001	4.44
<i>Descurainia pinnata</i>	western tansymustard	Brassicaceae	0	0	0.001	5.88	<0.001	2.22
<i>Drymaria molluginea</i>	slimleaf drymary	Caryophyllaceae	0.001	14.29	0	0	0.001	8.89
<i>Echinocereus</i> spp.	hedgehog cactus	Cactaceae	0.002	10.71	0.001	5.88	0.002	8.89
<i>Elymus elymoides</i>	squirreltail	Poaceae	0.924	100.00	0.774	100.00	0.867	100.00
<i>Ericameria nauseosa</i>	rubber rabbitbrush	Asteraceae	0.031	10.71	0.001	5.88	0.020	8.89
<i>Erigeron</i> spp.	fleabane	Asteraceae	0	0	<0.001	5.88	<0.001	2.22
<i>Erigeron divergens</i>	spreading fleabane	Asteraceae	0.021	60.71	0.037	64.71	0.027	62.22

Table A1 (continued)

Species	Common name	Family	Thinned plots		Unthinned plots		All plots	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Erigeron flagellaris</i>	trailing fleabane	Asteraceae	0.097	28.57	0.004	11.76	0.062	22.22
<i>Eriogonum alatum</i>	winged buckwheat	Polygonaceae	0.001	3.57	0	0	<0.001	2.22
<i>Eriogonum cernuum</i>	nodding buckwheat	Polygonaceae	0	0	0.006	11.76	0.002	4.44
<i>Eriogonum jamesii</i>	James' buckwheat	Polygonaceae	0.033	35.71	0.021	29.41	0.029	33.33
<i>Eriogonum polycladon</i>	sorrel buckwheat	Polygonaceae	0.001	7.14	<0.001	5.88	0.001	6.67
<i>Eriogonum racemosum</i>	redroot buckwheat	Polygonaceae	0.001	3.57	0	0	0.001	2.22
<i>Erodium cicutarium</i> ^a	stork's bill	Geraniaceae	0.001	3.57	0	0	0.001	2.22
<i>Erysimum capitatum</i>	sanddune wallflower	Brassicaceae	0.003	35.71	0.006	23.53	0.004	31.11
<i>Fallugia paradoxa</i>	Apache plume	Rosaceae	0.492	39.29	0.365	52.94	0.444	44.44
<i>Forestiera pubescens</i>	New Mexico olive	Oleaceae	0.004	3.57	0.124	11.76	0.049	6.67
<i>Gaura coccinea</i>	scarlet beeblossom	Onagraceae	0	0	0.001	5.88	<0.001	2.22
<i>Geranium caespitosum</i>	piney-woods geranium	Geraniaceae	0.035	10.71	0	0	0.022	6.67
<i>Gutierrezia sarothrae</i>	broom snakeweed	Asteraceae	2.096	92.86	3.174	94.12	2.503	93.33
<i>Hedeoma drummondii</i>	Drummond's false pennyroyal	Lamiaceae	0.001	7.14	<0.001	5.88	0.001	6.67
<i>Helianthus annuus</i>	common sunflower	Asteraceae	0.100	42.86	0.027	41.18	0.072	42.22
<i>Heliomeris multiflora</i>	showy goldeneye	Asteraceae	0.006	14.29	0.014	11.76	0.009	13.33
<i>Hesperostipa comata</i>	needle and thread	Poaceae	0.009	7.14	0.010	11.76	0.009	8.89
<i>Heterotheca villosa</i>	hairy false goldenaster	Asteraceae	0.117	57.14	0.077	35.29	0.102	48.89
<i>Hymenopappus filifolius</i>	fineleaf hymenopappus	Asteraceae	0.005	32.14	0.036	35.29	0.017	33.33
<i>Hymenoxys richardsonii</i>	Colorado rubberweed	Asteraceae	0.028	25.00	0.034	29.41	0.031	26.67
<i>Ipomopsis aggregata</i>	scarlet gilia	Polemoniaceae	0.011	39.29	0.012	23.53	0.012	33.33
<i>Ipomopsis longiflora</i>	whiteflower ipomopsis	Polemoniaceae	0.005	35.71	0.017	41.18	0.010	37.78
<i>Koeleria macrantha</i>	prairie junegrass	Poaceae	0.103	28.57	0.030	23.53	0.076	26.67
<i>Lactuca seriola</i> ^a	prickly lettuce	Asteraceae	0.007	21.43	0.005	23.53	0.007	22.22
<i>Lappula occidentalis</i>	flatspine stickseed	Boraginaceae	0.014	28.57	0.017	41.18	0.015	33.33
<i>Liatis punctata</i>	dotted blazing star	Asteraceae	0.001	7.14	0.002	5.88	0.001	6.67
<i>Linum lewisii</i>	prairie flax	Linaceae	0.001	7.14	0	0	0.001	4.44
<i>Linum neomexicanum</i>	New Mexico yellow flax	Linaceae	0.001	7.14	0.004	17.65	0.002	11.11
<i>Lithospermum incisum</i>	narrowleaf gromwell	Boraginaceae	<0.001	7.14	0.001	5.88	0.001	6.67
<i>Lotus wrightii</i>	Wright's deerweetch	Fabaceae	0.044	75.00	0.131	88.24	0.077	80.00

Table A1 (continued)

Species	Common name	Family	Thinned plots		Unthinned plots		All plots	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Lupinus kingii</i>	King's lupine	Fabaceae	0.005	21.43	0.013	17.65	0.008	20.00
<i>Lycurus setosus</i>	bristly wolfstail	Poaceae	0.013	21.43	0.037	17.65	0.022	20.00
<i>Machaeranthera bigelovii</i>	Bigelow's tansy-aster	Asteraceae	0.036	28.57	0.025	23.53	0.032	26.67
<i>Machaeranthera canescens</i>	hoary tansyaster	Asteraceae	0.001	3.57	0	0	<0.001	2.22
<i>Machaeranthera gracilis</i>	slender goldenweed	Asteraceae	0.002	10.71	0.001	5.88	0.001	8.89
<i>Mahonia repens</i>	creeping barberry	Berberidaceae	<0.001	3.57	0	0	<0.001	2.22
<i>Mellilotus officinalis</i> ^a	yellow sweetclover	Fabaceae	0	0	0.003	5.88	0.001	2.22
<i>Menodora scabra</i>	rough menodora	Oleaceae	0	0	0.025	5.88	0.009	2.22
<i>Mentzelia albicaulis</i>	whitestem blazingstar	Loasaceae	<0.001	3.57	0	0	<0.001	2.22
<i>Mentzelia multiflora</i>	Adonis blazingstar	Loasaceae	0.086	53.57	0.074	47.06	0.081	51.11
<i>Mentzelia springeri</i>	Santa Fe blazingstar	Loasaceae	0.017	7.14	0.004	5.88	0.012	6.67
<i>Mirabilis linearis</i>	narrowleaf four o'clock	Nyctaginaceae	0.001	10.71	0.001	5.88	0.001	8.89
<i>Mirabilis multiflora</i>	Colorado four o'clock	Nyctaginaceae	0.003	10.71	0.037	41.18	0.016	22.22
<i>Mirabilis oxybaphoides</i>	smooth spreading four o'clock	Nyctaginaceae	0.010	25.00	<0.001	11.76	0.006	20.00
<i>Monroa squarrosa</i>	false buffalograss	Poaceae	<0.001	3.57	0	0	<0.001	2.22
<i>Muhlenbergia minutissima</i>	annual muhly	Poaceae	0.001	7.14	0	0	0.001	4.44
<i>Muhlenbergia montana</i>	mountain muhly	Poaceae	0.057	35.71	0.104	23.53	0.075	31.11
<i>Muhlenbergia wrightii</i>	spike muhly	Poaceae	0.003	3.57	0.001	5.88	0.002	4.44
<i>Nama dichotomum</i>	wishbone fiddleleaf	Hydrophyllaceae	0.001	7.14	0.001	17.65	0.001	11.11
<i>Oenothera caespitosa</i>	tufted evening-primrose	Onagraceae	0.001	10.71	0.001	11.76	0.001	11.11
<i>Opuntia</i> spp.	prickly pear	Cactaceae	0.491	89.29	0.584	76.47	0.526	84.44
<i>Opuntia imbricata</i>	tree cholla	Cactaceae	0.073	21.43	0.127	35.29	0.093	26.67
<i>Orobanche</i> sp.	broomrape	Orobanchaceae	0.001	3.57	0	0	<0.001	2.22
<i>Orthocarpus purpureoalbus</i>	purple owllover	Scrophulariaceae	0.002	14.29	<0.001	5.88	0.001	11.11
<i>Oxalis violacea</i>	violet woodsorrel	Oxalidaceae	0	0	<0.001	5.88	<0.001	2.22
<i>Penstemon</i> spp.	penstemon	Scrophulariaceae	0.014	28.57	0.006	35.29	0.011	31.11
<i>Penstemon barbatus</i>	beardlip penstemon	Scrophulariaceae	0.001	7.14	0	0	0.001	4.44
<i>Phacelia</i> spp.	scorpionweed	Hydrophyllaceae	0.001	3.57	0	0	<0.001	2.22
<i>Physalis hederifolia</i>	ivyleaf groundcherry	Solanaceae	0.004	28.57	0.015	35.29	0.008	31.11
<i>Piptatherum micranthum</i>	littleseed ricegrass	Poaceae	0.205	57.14	0.127	82.35	0.176	66.67

Table A1 (continued)

Species	Common name	Family	Thinned plots		Unthinned plots		All plots	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Plantago patagonica</i>	woolly plantain	Plantaginaceae	<0.001	7.14	<0.001	5.88	<0.001	6.67
<i>Pleuraphis jamesii</i>	James' galleta	Poaceae	0.016	17.86	0.122	35.29	0.056	24.44
<i>Poa fendleriana</i>	muttongrass	Poaceae	0.373	82.14	0.322	70.59	0.354	77.78
<i>Polanisia dodecandra</i>	redwhisker clammyweed	Capparaceae	<0.001	3.57	0.005	11.76	0.002	6.67
<i>Polygonum douglasii</i>	Douglas' knotweed	Polygonaceae	0.001	7.14	0.001	11.76	0.001	8.89
<i>Portulaca oleracea</i> ^a	little hogweed	Portulacaceae	0.015	39.29	0.001	5.88	0.009	26.67
<i>Ptelea trifoliata</i>	common hoptree	Rutaceae	0.004	3.57	0	0	0.002	2.22
<i>Quercus</i> spp.	oak	Fagaceae	0.787	50.00	0.540	82.35	0.693	62.22
<i>Rhus trilobata</i>	skunkbush sumac	Anacardiaceae	0.368	67.86	1.044	82.35	0.623	73.33
<i>Salsola tragus</i> ^a	prickly Russian thistle	Chenopodiaceae	0.003	3.57	0.003	5.88	0.003	4.44
<i>Schizachyrium scoparium</i>	little bluestem	Poaceae	0.082	39.29	0.099	35.29	0.089	37.78
<i>Schoenocrambe linearifolia</i>	slimleaf plains mustard	Brassicaceae	0.002	21.43	<0.001	5.88	0.001	15.56
<i>Sclerocactus papyracanthus</i>	paperspine fishhook cactus	Cactaceae	<0.001	7.14	0.003	23.53	0.001	13.33
<i>Senecio eremophilus</i>	desert groundsel	Asteraceae	<0.001	3.57	0	0	<0.001	2.22
<i>Senecio flaccidus</i>	threadleaf ragwort	Asteraceae	0.016	17.86	0.065	41.18	0.034	26.67
<i>Senecio spartioides</i>	broomlike ragwort	Asteraceae	0.022	39.29	0.029	29.41	0.025	35.56
<i>Sisymbrium altissimum</i> ^a	tumblemustard	Brassicaceae	0.001	3.57	<0.001	5.88	0.001	4.44
<i>Solanum triflorum</i>	cutleaf nightshade	Solanaceae	0	0	0.003	5.88	0.001	2.22
<i>Solidago</i> sp.	goldenrod	Asteraceae	0.002	3.57	0	0	0.001	2.22
<i>Sphaeralcea</i> spp.	globemallow	Malvaceae	0.001	3.57	0.001	5.88	0.001	4.44
<i>Sporobolus contractus</i>	spike dropseed	Poaceae	0.003	3.57	0	0	0.002	2.22
<i>Sporobolus cryptandrus</i>	sand dropseed	Poaceae	0.063	71.43	0.023	35.29	0.048	57.78
<i>Stephanomeria pauciflora</i>	brownplume wirelettuce	Asteraceae	0.001	14.29	0.005	17.65	0.003	15.56
<i>Taraxacum officinale</i> ^a	common dandelion	Asteraceae	<0.001	3.57	0	0	<0.001	2.22
<i>Tetrameuris ivesiana</i>	Ives' fournerved daisy	Asteraceae	0.010	17.86	0	0	0.006	11.11
<i>Thelesperma filifolium</i>	stiff greenthread	Asteraceae	0.021	25.00	<0.001	5.88	0.013	17.78
<i>Townsendia eximia</i>	tall Townsend daisy	Asteraceae	0.007	7.14	0.003	17.65	0.005	11.11
<i>Tragopogon dubius</i> ^a	yellow salsify	Asteraceae	0.008	39.29	0.010	35.29	0.008	37.78
<i>Verbascum thapsus</i> ^a	common mullein	Scrophulariaceae	0.243	57.14	0.355	76.47	0.285	64.44
<i>Vicia americana</i>	American vetch	Fabaceae	0	0	<0.001	5.88	<0.001	2.22

Table A1 (continued)

Species	Common name	Family	Thinned plots			Unthinned plots			All plots		
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Foliar cover (%)	Plot frequency (%)	Plot frequency (%)
<i>Vulpia octoflora</i>	sixweeks fescue	Poaceae	<0.001	10.71	0.001	0.001	17.65	0.001	0.001	13.33	13.33
<i>Yucca angustissima</i>	narrowleaf yucca	Agavaceae	0.022	17.86	0	0	0	0.013	0.013	11.11	11.11
<i>Yucca baccata</i>	banana yucca	Agavaceae	0.123	28.57	0.147	0.147	23.53	0.132	0.132	26.67	26.67
unknown BAND20080907_1			0.012	14.29	0	0	0	0.007	0.007	8.89	8.89
unknown BAND20080921_1			0.001	3.57	0	0	0	<0.001	<0.001	2.22	2.22
unknown BAND20090822_1			0.001	3.57	0.001	0.001	11.76	0.001	0.001	6.67	6.67
unknown BAND20090822_2			<0.001	3.57	0	0	0	<0.001	<0.001	2.22	2.22
unknown BAND20090824_1			0	0	0.001	0.001	5.88	<0.001	<0.001	2.22	2.22
unknown BAND20090825_1			<0.001	3.57	0	0	0	<0.001	<0.001	2.22	2.22
unknown BAND20090825_2			<0.001	3.57	0	0	0	<0.001	<0.001	2.22	2.22
unknown BAND20090904_1			<0.001	3.57	0	0	0	<0.001	<0.001	2.22	2.22
unknown BAND20090906_1			<0.001	3.57	0	0	0	<0.001	<0.001	2.22	2.22
unknown BAND20090921_1			<0.001	3.57	0	0	0	<0.001	<0.001	2.22	2.22

Note: Annual species of *Chamaesyce* spp. were placed into 2 groups based on morphological characteristics.

^aNonnative species.

Table A2. Tree species with mean basal area and plot frequency for unthinned plots, thinned plots, and all plots in the Mesa Top Pinyon-Juniper ecological site at BAND, 2008-2010.

Species	Common name	Family	Unthinned plots			Thinned plots			All plots		
			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	Basal area (m ² /ha) ^a	Plot frequency (%) ^b	Plot frequency (%) ^b
<i>Juniperus deppeana</i>	alligator juniper	Cupressaceae	0.10	3.57	0	0	0.06	2.22	0.06	2.22	2.22
<i>Juniperus monosperma</i>	one-seed juniper	Cupressaceae	15.18	96.43	18.21	100.00	16.33	97.78	16.33	97.78	97.78
<i>Pinus edulis</i>	twoneedle pinyon	Pinaceae	0.01	53.57	0	58.82	<0.01	55.56	<0.01	55.56	55.56
<i>Pinus ponderosa</i>	ponderosa pine	Pinaceae	0.11	3.57	0	0	0.07	2.22	0.07	2.22	2.22

^aBasal area measures only overstory trees.

^bPlot frequency includes overstory trees, saplings, and seedlings.