



Integrated Upland Vegetation and Soils Monitoring for Bandelier National Monument

2008 Summary Report, revised January 2011

Natural Resource Data Series NPS/SCPN/NRDS—2011/158



ON THE COVER

Mesa Top Pinyon Juniper woodlands at Bandelier National Monument.
Photograph by: Eric Vasquez

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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 2008 field crew consisted of Jessica Erickson, Anna Lowell, and Eric Vasquez.

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Introduction and Background

The National Park Service Inventory and Monitoring (I&M) Program was designed to determine the current status and monitor long-term trends in the condition of park natural resources, providing park managers with a strong scientific foundation for making decisions and working with other agencies and the public for the protection of park ecosystems. The Southern Colorado Plateau Network (SCPN) is monitoring vegetation and soils as overall indicators of upland ecosystem integrity (Thomas et al. 2006).

At Bandelier National Monument (BAND), SCPN and park staff selected the Mesa Top Pinyon-Juniper ecological site to monitor for vegetation and soils. Ecological sites are landscape divisions based on soil survey data with characteristic soils, hydrology, plant communities, and disturbance regimes and responses (Butler et al. 2003). The Mesa Top Pinyon-Juniper ecosystem encompasses large portions of the monument, and it faces a number of threats, including climate change, pinyon dieback, soil erosion, and invasion by nonnative species. The site is currently undergoing extensive restoration through the selected thinning of mature junipers.

In 2008 the Integrated Upland Monitoring program of SCPN began upland monitoring at BAND. In this report, we document monitoring activities in the 2008 field season and summarize the data that were collected.

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 US Natural Resources Conservation Service (NRCS) to create their sampling frames. Although a recent soil survey update was completed for the monument (Sandoval County, New Mexico; Bandelier Soil Survey Update; 2000), the ecological site data was not updated. Rather than use old ecological site descriptions to create a sampling frame, SCPN developed their own version of the Mesa Top Pinyon-Juniper ecological site by identifying soil map units in the park that are dominated by pinyon-juniper woodlands. The targeted soil types demonstrated large variation, 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 that 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 with Geographic Information System (GIS) technology 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 archaeological sites and other sensitive resources. Before establishing a plot, the Integrated Upland crew conducted an ecological site assessment for each sampling point, and they rejected the site if it (1) did not fall within the ecological site, (2) had a slope exceeding 20%, or (3) contained a major disturbance. They rejected six points: three points were within 50 m of a trail,

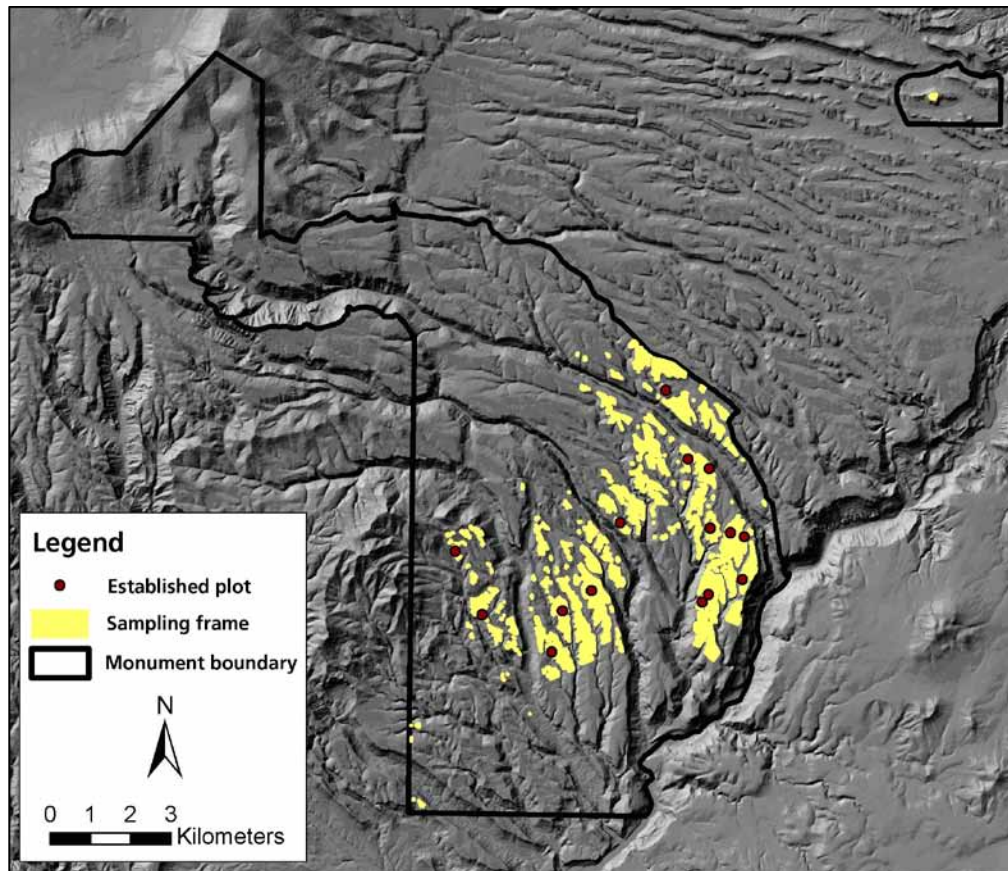


Figure 1. Sampling frame of the Mesa Top Pinyon-Juniper ecological site with the 15 plots established in 2008.

three points required over two hours hiking time to access the point, and one site contained more than 20% rock outcrop (another ecological site).

Field methods

The SCPN Upland Monitoring crew began monitoring at BAND in 2008 with the establishment of 15 plots in the Mesa Top Pinyon-Juniper ecological site. The crew installed the plots in July and September, and they collected data from the plots in September. Plots are 0.50 ha in size, measuring 71 m x 71 m. Shrub and herbaceous vegetation data and soil data were collected on three 50 m transects, spaced 25 meters apart, within each plot. Overstory tree and sapling data were collected in nested subplots located between two of the transects. Field methodology is described in detail in the SCPN Integrated Upland Protocol (DeCoster et al., in review).

Shrub and herbaceous vegetation

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

Overstory trees and saplings

Overstory trees, defined as having a diameter greater than or equal to 15 cm, were measured within a 20 x 50 m (0.1 ha) subplot between two of the transects. Due to their multi-stemmed growth form, diameter at root crown (drc) was used to measure the size of *Juniperus* spp. (juniper species). For all other species, diameter at breast height (dbh) was used. For each individual tree, species, diameter, and status (live or dead) was recorded. Saplings (≥ 2.5 and < 15 cm diameter) were sampled in a 10 m x 20 m subplot and then tallied by species and size class. Tree seedlings were sampled in the 10 m² quadrats in conjunction with the herbaceous/shrub data, and then tallied by species and size class. Unfortunately, there were some inconsistencies in the way that seedling data were collected, so it will not be reported. Canopy closure was measured with a hemispherical densitometer one meter away from each of the quadrats.

Soil stability and hydrologic function

The crew measured the amount of bare soil by recording the length of each basal gap (the space between plant bases) along each transect. A soil aggregate stability test was conducted using 18 soil samples collected at random points along the transects. Soil samples were not collected under deep pumice or deep litter and duff. When litter/duff was encountered, the point was given a score of 6 (maximum stability). When pumice was encountered, the point was skipped. Percent cover of ground surface features was estimated in the 1 m² quadrats in conjunction with the shrub and herbaceous data and recorded as one of 12 cover classes.

Data summary

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

For herbaceous and shrub vegetation, cover was calculated for each species from the cover class mid-points, e.g. using 7.5% for cover class 5-10%. The mean cover was calculated for each plot, and the mean, standard deviation (SD), and range of cover (range between the minimum and maximum of measured foliar covers, only including those plots where the species occurs) were calculated for the ecological site. Species frequency was calculated for quadrats (mean percentage of quadrats per plot where the species occurs) and for plots (percentage of plots where the species occurs). Mean cover and SD of functional groups and surface features were calculated in a similar fashion.

We calculated four diversity measures for herbaceous and shrub species (Magurran 1988)—first for all species in a site and then for native species only.

(1) Species richness (S) is the number of species at a given spatial scale, and it was calculated at all spatial scales (i.e. for each nested quadrat size, for the plot, and for 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 (diversity among plots):

$$S_e / (S_p - 1)$$

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 calculated tree basal area (the total cross-sectional area of the trees) for each overstory tree species in terms of m^2/ha . Tree density was calculated for all species and size classes for overstory, sapling, and seedling layers in terms of stems/ha. Mean diameter of overstory trees was also calculated by species. Density and basal area were calculated for snags (standing dead overstory trees) by species. Mean canopy closure was calculated for each plot, and then the mean canopy closure and SD were calculated for the ecological site.

We made five calculations for the basal gaps data: (1) median basal gap size, (2) percentage of transects comprised by gaps, (3) percentage of transects comprised by gaps ≥ 50 cm, (4) number of gaps by size class, and (5) total number of gaps. Mean and SD were calculated for each metric.

The mean soil aggregate stability index was calculated along with the standard deviation. 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 those without vegetative cover.

Results

Shrub and herbaceous vegetation

A mixture of shrubs, grasses, and forbs co-dominated the herbaceous and shrub vegetation of the BAND Mesa Top Pinyon-Juniper ecological site. Table 1 lists the 15 most abundant species. The shrub *Gutierrezia sarothrae* (broom snakeweed) and the grass *Bouteloua gracilis* (blue grama) had the greatest covers, at 2.044% and 1.913%, respectively. Other abundant shrubs included *Rhus trilobata* (skunkbush sumac), *Artemisia ludoviciana* (white sagebrush), and *Quercus* spp. (oak). Other abundant grasses include *Elymus elymoides* (squirreltail), *Poa fendleriana* (muttongrass), and *Bromus tectorum* (cheatgrass). Common forbs included *Artemisia dracunculoides* (false tarragon), *Erigeron flagellaris* (trailing fleabane), *Verbascum thapsus* (common mullein), *Bahia dissecta* (ragleaf bahia), and *Helianthus annuus* (common sunflower). Common succulents included *Opuntia* spp. (prickly pear) and *Opuntia whipplei* (Whipple's cholla). Species composition was variable among plots: many species had wide ranges in their foliar covers, standard deviations that exceeded their means, and/or low quadrat and plot frequencies. For example, *Erigeron flagellaris* only occurred in three plots, but in one plot its cover was 3.870%. Appendix A lists all the species, along with their common names, families, mean foliar cover, and plot frequencies.

Six nonnative species were found in the plots (table 1). The annual grass *Bromus tectorum* occurred in over half of the plots, with a maximum cover value of 4.690%, although its mean cover was much lower, 0.376%. *Verbascum thapsus* also occurred in over half of the plots, with a mean cover of 0.246% and a maximum cover of 1.073%. *Portulaca oleracea* (little hogweed), *Lactuca serriola* (prickly lettuce), *Sisymbrium altissimum* (tumble mustard), and *Tragopogon dubius* (yellow salsify) were less frequent, and sparse where they occurred.

Table 1. Foliar cover and frequency of the fifteen most abundant shrub and herbaceous species and all nonnative species.

Species	Foliar cover (%)			Frequency (%)	
	Mean	SD	Range	Quadrat	Plot
<i>Gutierrezia sarothrae</i>	2.044	1.778	0.040 - 4.520	57.78	93.33
<i>Bouteloua gracilis</i>	1.913	1.524	0.100 - 5.320	74.67	100.00
<i>Elymus elymoides</i>	0.910	0.894	0.033 - 2.797	69.78	100.00
<i>Artemisia dracuncululus</i>	0.609	1.466	0.003 - 5.817	52.44	86.67
<i>Poa fendleriana</i>	0.452	0.752	0.020 - 2.833	29.78	93.33
<i>Rhus trilobata</i>	0.408	0.930	0.003 - 3.433	9.33	60.00
<i>Bromus tectorum</i> ^a	0.376	1.207	0.003 - 4.690	14.67	53.33
<i>Quercus</i> spp.	0.333	0.820	0.007 - 3.033	9.78	40.00
<i>Artemisia ludoviciana</i>	0.269	0.734	0.020 - 2.893	17.78	66.67
<i>Opuntia</i> spp.	0.266	0.382	0.003 - 1.227	35.11	86.67
<i>Erigeron flagellaris</i>	0.263	0.998	0.020 - 3.870	8.00	20.00
<i>Verbascum thapsus</i> ^a	0.246	0.422	0.003 - 1.073	13.78	53.33
<i>Bahia dissecta</i>	0.176	0.126	0.023 - 0.470	60.44	93.33
<i>Helianthus annuus</i>	0.127	0.205	0.107 - 0.690	17.33	40.00
<i>Opuntia whipplei</i>	0.117	0.251	0.467 - 0.773	3.56	20.00
<i>Portulaca oleracea</i> ^a	0.012	0.018	0.003 - 0.053	8.89	40.00
<i>Lactuca serriola</i> ^a	0.007	0.019	0.047 - 0.060	3.56	13.33
<i>Tragopogon dubius</i> ^a	0.006	0.015	0.003 - 0.050	4.44	33.33
<i>Sisymbrium altissimum</i> ^a	0.001	0.005	0.020 - 0.020	0.44	6.67

Note: The ranges only include plots where the species occurs. (Many species do not occur in every plot of an ecological site; for these species, we did not include the plots with 0% cover in the range).

^a Nonnative species.

Cover estimates by functional groups confirm the co-dominance of perennial grass, shrubs, and forbs in the plots (table 2). Total vegetative cover was 11.72%, the mean cover of perennial grass was 4.30%, the mean cover of shrubs was 3.17%, and the mean cover of forbs was 2.43%. Cacti/succulents and annual grass comprised less than 1%. While standard deviations were generally smaller than the means, the large ranges indicate high variability among the plots. Cover of standing dead herbaceous was 1.42% while cover of standing dead woody was 0.57%.

All the diversity indices indicate moderately high diversity at both the plot and ecological site levels. We recorded a total of 108 species in this ecological site, with a mean species richness of 33.5 species per plot (table 3). Shannon diversity was 2.196. Values generally fall between 1.5 and 3.5 (Margalef 1972). Evenness was 0.630. The Evenness Index is bounded by 0 and 1, where a value of 1 indicates that all species are of equal abundance. Beta diversity was 3.326. High values (greater than 5) indicate large differences among plots, whereas low values (less than 1) indicate similar composition (McCune and Grace 2002). When these indices were recalculated using only native species, most were lowered slightly except beta diversity, which was slightly raised (table 3). The species area curve (fig. 2) illustrates how species richness accumulated with increased area. The concave shape of the curve indicates low diversity at finer spatial scales, which is typical of woodlands and shrublands of the

Table 2. Foliar cover of functional groups at Bandelier National Monument.

Functional group	Foliar cover (%)		
	Mean	SD	Range
Total live vegetation	11.72	5.45	4.33 - 23.33
Perennial grass	4.30	2.83	0.90 - 9.65
Annual grass	0.38	1.21	0.00 - 4.69
Forbs	2.43	2.42	0.51 - 9.20
Shrubs, dwarf shrubs	3.17	2.42	0.02 - 7.92
Cacti, succulents	0.48	0.62	0.00 - 1.81
Standing dead herbaceous	1.42	0.72	0.39 - 3.00
Standing dead woody	0.57	0.54	0.00 - 2.16

Note: Components of total live vegetation are not strictly additive due to the fact that calculations are made from cover class midpoints, the various components may overlap, and estimations were made independently.

Table 3. Species diversity metrics for all species and for native species only.

Metric	Mean	SD	Range
All species			
Plot			
Plot richness	33.5	7.0	22 – 46
Shannon diversity	2.196	0.331	
Evenness	0.630	0.089	
Ecological site			
Ecological site richness	108		
Beta diversity	3.326		
Native species			
Plot			
Plot richness	31.3	5.6	22 – 41
Shannon diversity	2.155	0.329	
Evenness	0.629	0.095	
Ecological site			
Ecological site richness	102		
Beta diversity	3.363		

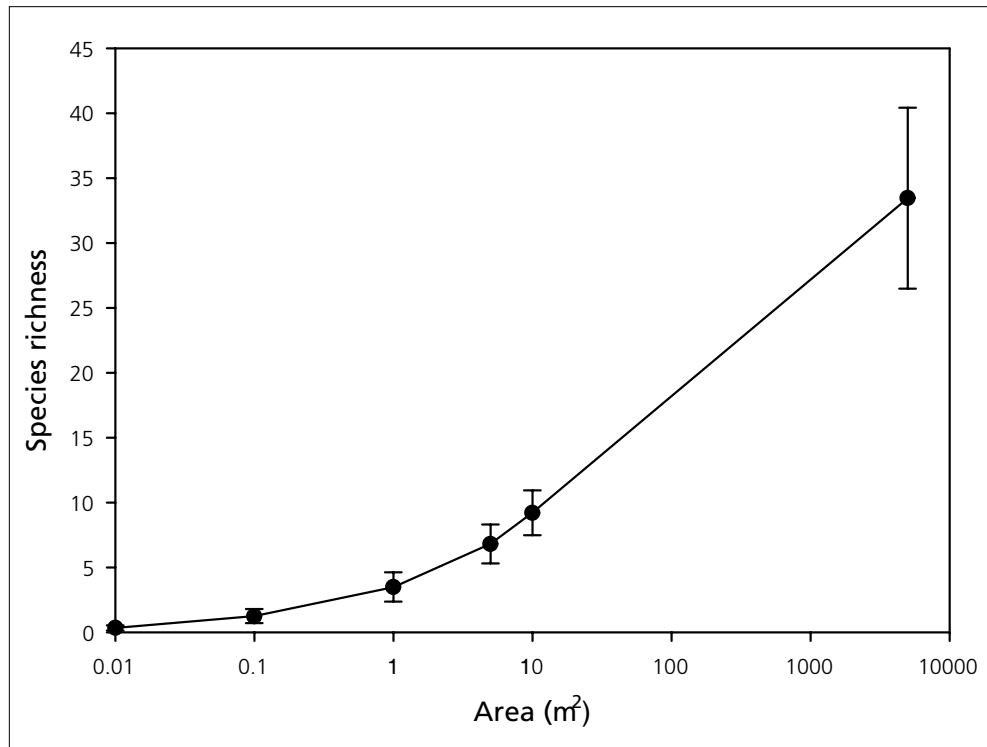


Figure 2. Species-area curve, with species richness at six spatial scales. Estimates are based on 10 plots with 15 quadrats each. The point at 5000 m² represents plot species richness. Error bars represent one standard deviation.

region.

Trees

Figures 3 and 4 and table 4 show the relative abundance of overstory trees by species and size class in terms of density and basal area. There were four tree species found in the plots: *Juniperus monosperma* (oneseed juniper), *Juniperus deppeana* (alligator juniper), *Pinus edulis* (two-needle pinyon), and *Pinus ponderosa* (ponderosa pine). *Juniperus monosperma* was the dominant tree species with an overstory basal area of 13.59 m²/ha and an overstory density of 156.7 stems/ha. *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 (1 stem in 15 plots). *Pinus ponderosa* and *Juniperus deppeana* each occurred in only one plot each. *Juniperus deppeana* occurred on a plot that is not on a mesa top, but rather on a southeast-facing slope below Boundary Peak. *Pinus ponderosa* occurred infrequently throughout the sampling frame, and three individuals occurred in one plot just east of Alamo Canyon. The standard deviations of basal areas were moderately high, indicating variability among plots (fig. 3).

The density and basal area of *Pinus edulis* snags greatly exceeded the density and basal area of the live trees (fig 3). There were 24.0 stems/ha with a basal area of 0.86 m²/ha. The snag density and basal area of *Juniperus deppeana* were also relatively high compared with live density and basal area. The size structure of *Juniperus monosperma* indicates that most individuals occurred in the smaller size classes, and progressively fewer occurred as diameter class increased (fig. 4). It is difficult to make generalizations about the size structure of the other species because the sample size was too small.

Sapling densities provide insight into the structure and dynamics of the forest. Sapling densities

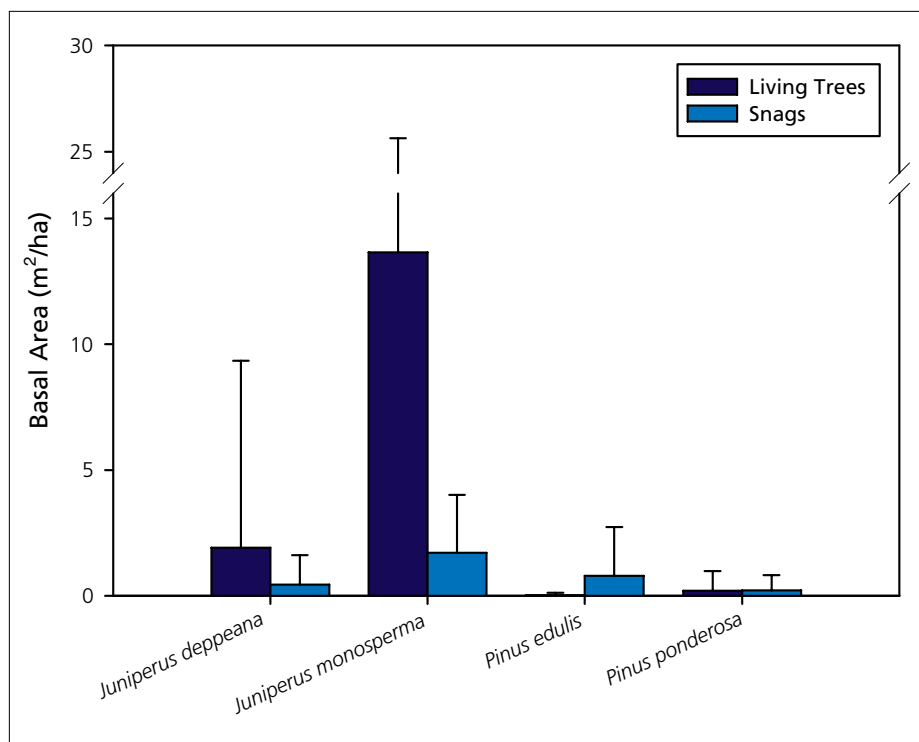


Figure 3. Basal area of living trees and snags by species. Error bars represent one standard deviation.

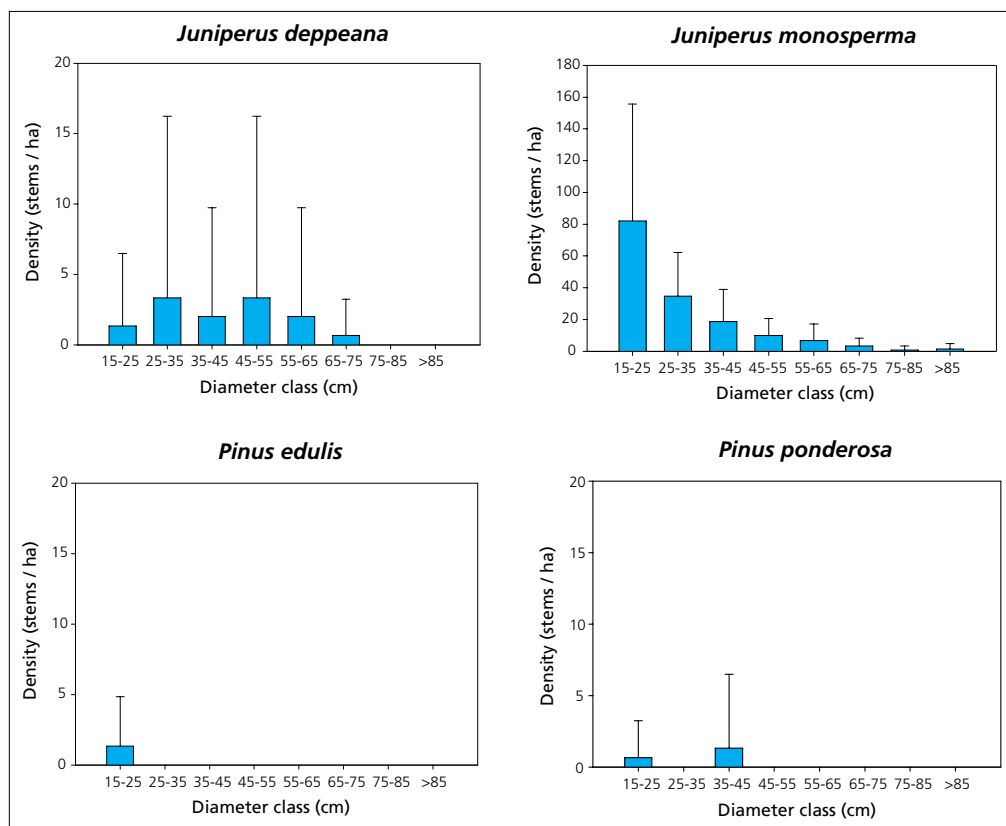


Figure 4. Size structure of the overstory tree species. Error bars represent one standard deviation. Note that the scale for *Juniperus monosperma* is different from the other species.

were moderately low. *Juniperus monosperma* had the highest densities in the largest two size classes, while *Pinus edulis* had the highest density in the smallest size class (table 4 and fig. 5). There were no saplings of *Pinus ponderosa*. Large standard deviations indicate high variability in sapling densities among plots. Figure 6 shows the density of both overstory and sapling size classes. The overstory size classes indicate a typical decline in density with increasing tree diameter, but the sapling size classes do not conform to this trend, showing lower densities than would be expected.

Measurements of canopy closure showed a plot mean of 19.9% with a standard deviation of 8.4.

Soil stability and hydrologic function

Table 4. Density and basal area of trees by species and size class.

Species	Sapling (stems/ha)	Overstory density (stems/ha)	Snag density (stems/ha)	Overstory basal area (m ² /ha)	Snag basal area (m ² /ha)	Mean diameter ^a (cm)
<i>Juniperus deppeana</i>	10.7	12.7	4.7	1.92	0.45	41.6
<i>Juniperus monosperma</i>	144.0	156.7	24.0	13.59	1.74	29.5
<i>Pinus edulis</i>	50.7	0.7	24.0	0.01	0.86	15.0
<i>Pinus ponderosa</i>	0	2.0	2.7	0.20	0.22	34.7
Total	205.3	172.0	55.3	15.72	3.25	29.6

Note: Saplings are 2.5-14.9 cm in diameter, and overstory trees are ≥15 cm in diameter.

^a Diameter at root crown was used for *Juniperus* spp. and diameter at breast height was used for *Pinus* spp.

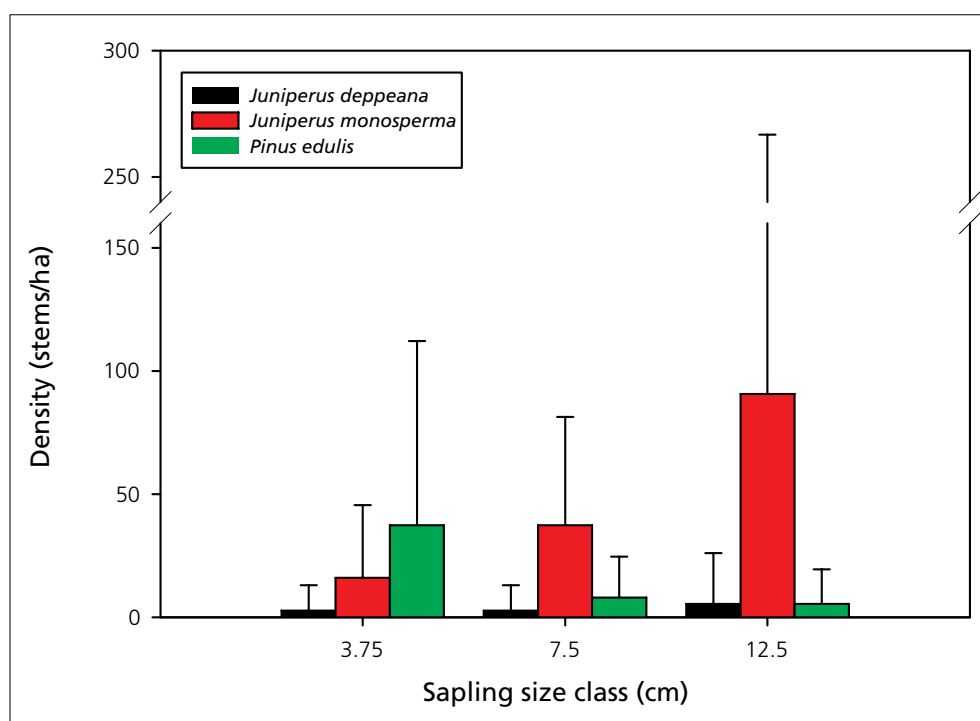


Figure 5. Mean sapling density by size class. Error bars represent one standard deviation.

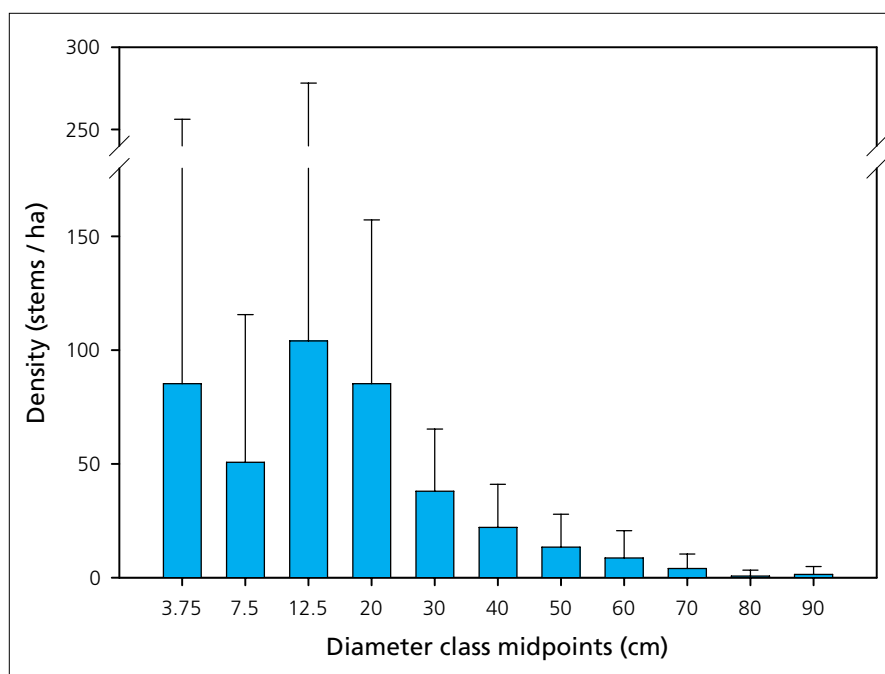


Figure 6. Size structure of the overstory trees and saplings. Error bars represent one standard deviation.

The crew monitored the amount of exposed soil in two ways: cover estimates of ground surface features in quadrats and measurements of basal gaps along transects. The cover of ground surface features (table 5) showed that the dominant surface features were fine gravel (33.19%), duff and litter (32.55%), and undifferentiated crust (14.11%). Fine gravel was primarily volcanic pumice, which had

Table 5. Cover of ground surface features at Bandelier National Monument.

Surface feature	Percent cover		
	Mean	SD	Range
Live plant base	3.32	2.95	1.11 - 12.70
Dead woody base	0.99	0.63	0.24 - 2.71
Dead herbaceous base	0.23	0.28	0.00 - 0.88
Bare soil	4.24	4.37	0.05 - 15.17
Duff and litter	32.55	12.08	13.33 - 55.72
Undifferentiated crust	14.11	9.29	4.10 - 33.30
Moss	0.25	0.59	0.00 - 1.96
Lichen	0.01	0.01	0.00 - 0.05
Cyanobacteria	0.69	1.72	0.00 - 5.63
Fine gravel (0.2 cm - 2cm)	33.19	18.51	0.74 - 61.77
Coarse gravel (2cm – 7.5 cm)	2.24	2.01	0.32 - 6.52
Cobble (7.5 cm – 25 cm)	1.98	3.72	0.00 - 14.25
Stone, bedrock (>25 cm)	2.40	3.21	0.00 - 9.43
Woody debris	2.08	1.61	0.47 - 5.45

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

high variability among plots, with a range of 0.74% to 61.77%. Cover of live plant base, woody debris, bare soil, and larger rock components comprised between 1% and 5% of the ground surface. Cover of dead herbaceous and woody bases and biological soil crusts (i.e. moss, lichen, and cyanobacteria) comprised less than 1% each. Variability of the surface features was generally moderate.

Basal gap data (table 6) showed that the median gap size was 67.5 cm and that 95.6 % of the total transect length was composed of gap; consequently 4.4% of the transect length intersected plant bases. (Note the similarity between the amount of live and dead plant base in the basal gap data and surface feature data). When only gaps greater than 50 cm were considered in the percentage of transect in gap, the figure only dropped from 95.6% to 87.8%. These large gaps are the areas most susceptible to erosion. The size distribution of gaps (fig. 7) demonstrates a fairly even distribution.

Soil aggregate stability provides a measurement of the erodibility of the soil (table 7). The mean rat-

Table 6. Number of basal gaps, mean gap size and percentage of total transect length comprised by gaps.

Metric	Mean	(SD)
Gap number	125.2	(48.2)
Median gap size (cm)	67.5	(38.5)
Percent of transect in gaps	95.6	(2.3)
Percent of transect in gaps $\geq$ 50 cm	87.8	(6.3)

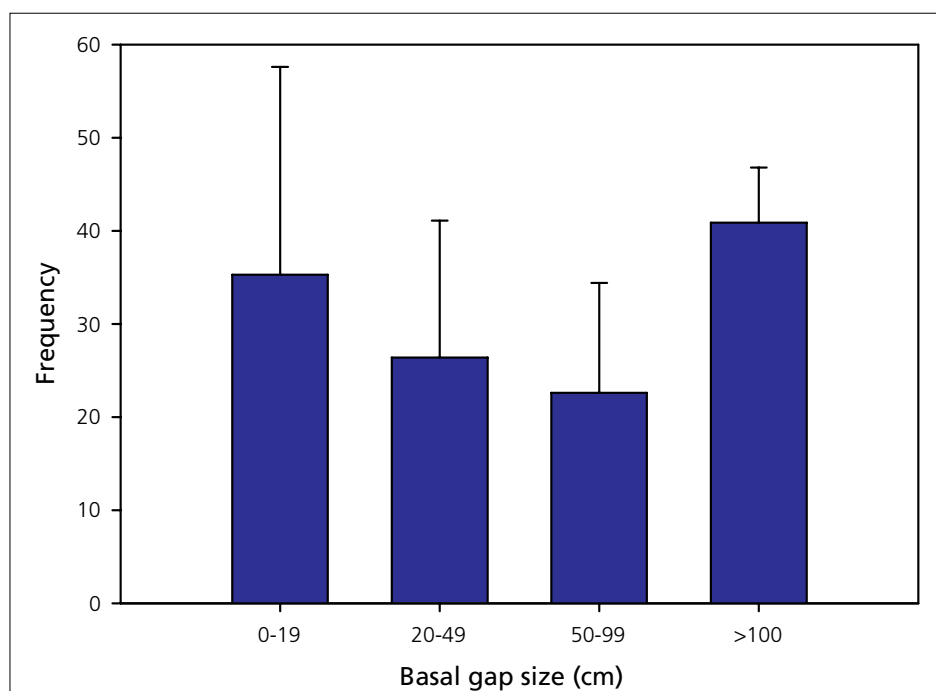


Figure 7. Frequency distribution of basal gap sizes. Error bars indicate one standard deviation.

ing was 4.00, indicating moderately high stability. Soil occurring under vegetative cover had a slightly higher aggregate stability rating than the bare soil without cover: 4.35 compared to 3.60.

Table 7. Soil stability rating for samples with and without vegetative cover.

Metric	Mean	(SD)
With vegetative cover	4.35	(0.96)
Without vegetative cover	3.60	(0.99)
All samples	4.00	(0.68)

Note: A rating of 1 is the lowest stability, and a rating of 6 is the highest stability.

Discussion

These data represent the first year baseline for sampling at the Mesa Top Pinyon-Juniper ecological site of BAND. The data indicate that a moderately diverse mixture of grasses, shrubs, and succulents comprise the vegetation cover (fig. 8). Common shrubs included *Gutierrezia sarothrae* and *Rhus trilobata*; common grasses included *Bouteloua gracilis*, *Elymus elymoides*, and *Poa fendleriana*; common forbs included *Artemisia dracuncululus*, *Erigeron flagellaris*, *Verbascum thapsus* and *Bahia dissecta*; and common succulents included *Opuntia* spp. and *Opuntia whipplei*. While we found six nonnative species in the plots, *Bromus tectorum* and *Verbascum thapsus* were the only abundant ones. This site had moderately high species diversity, both on the scale of the plot and on the scale of the landscape.

The tree data show that *Juniperus monosperma* was the dominant overstory tree, while *Juniperus deppeana*, *Pinus edulis*, and *Pinus ponderosa* had low abundance. The majority of *Pinus edulis* stems were snags, likely a result of the recent drought. *Juniperus deppeana* also had a relatively high number of snags. This was probably the result of the 1996 Dome fire. The sapling layer had lower than expected densities, but there was moderate representation of *Pinus edulis* in the understory, suggesting that regeneration may eventually be compensate for its recent mortality.

Soil aggregate stability and the amount of exposed soil are measurements that quantify the potential of the site for soil erosion. Even though the gap data shows extensive areas occupied by large basal gaps, the potential for soil erosion is buffered by a combination of the high cover of duff and litter and the moderately high soil aggregate stability.

We plan to continue to install plots annually so that we can get a reasonable baseline before the restoration treatments have been completed. We will conduct power analysis on key metrics to determine the final number of plots necessary to detect change in the key metrics. 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.



Figure 8. Photopoints from various plots showing the diversity of vegetation and groundcover. (A) “Typical” woodland with moderately dense *Juniperus monosperma*. (B) Herbaceous layer dominated by *Bouteloua gracilis*, (C) Pumice soils with *Verbascum thapsus*. (D) Open woodland dominated by *Gutierrezia sarothrae*. (E) Soil surface with biological soil crust. (F) *Juniperus deppeana* woodland with a herbaceous layer of *Erigeron flagellaris*.

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Appendix A

Complete species list with foliar cover and frequency values for herbaceous and shrub species and with overstory basal area and frequency for tree species. Annual *Chamaesyce* spp. that were not identifiable in the field to species were placed in one of two groups.

Shrub and herbaceous species				
Species	Common name	Family	Foliar cover (%)	Plot frequency (%)
<i>Allium cernuum</i>	nodding onion	Liliaceae	0.000	6.67
<i>Amaranthus</i> sp.	pigweed	Amaranthaceae	0.012	33.33
<i>Antennaria parvifolia</i>	small leaf pussytoes	Asteraceae	0.001	6.67
<i>Aristida purpurea</i>	Fendler's threeawn	Poaceae	0.026	66.67
<i>Artemisia dracunculus</i>	false tarragon	Asteraceae	0.609	86.67
<i>Artemisia frigida</i>	fringed sagebrush	Asteraceae	0.001	6.67
<i>Artemisia ludoviciana</i>	white sagewort	Asteraceae	0.269	66.67
<i>Astragalus</i> sp.	milkvetch	Fabaceae	<0.001	6.67
<i>Bahia dissecta</i>	ragleaf bahia	Asteraceae	0.176	93.33
<i>Blepharoneuron tricholepis</i>	pine dropseed	Poaceae	0.001	6.67
<i>Bouteloua curtipendula</i>	sideoats grama	Poaceae	0.018	13.33
<i>Bouteloua eriopoda</i>	black grama	Poaceae	0.008	13.33
<i>Bouteloua gracilis</i>	blue grama	Poaceae	1.913	100.00
<i>Brickellia eupatorioides</i>	false boneset	Asteraceae	0.008	6.67
<i>Bromus tectorum</i> ^a	cheatgrass	Poaceae	0.376	53.33
<i>Castilleja</i> sp.	Indian paintbrush	Scrophulariaceae	0.001	6.67
<i>Cercocarpus montanus</i>	birchleaf mountain mahogany	Rosaceae	0.111	46.67
<i>Chaetopappa ericoides</i>	rose heath	Asteraceae	0.003	13.33
<i>Chamaesyce</i> spp. Group A	annual sandmats	Euphorbiaceae	0.043	86.67
<i>Chamaesyce</i> spp. Group B	annual sandmats	Euphorbiaceae	0.045	80.00
<i>Chamaesyce fendleri</i>	Fendler's sandmat	Euphorbiaceae	0.008	33.33
<i>Chenopodium fremontii</i>	Fremont's goosefoot	Chenopodiaceae	0.010	33.33
<i>Chenopodium graveolens</i>	fetid goosefoot	Chenopodiaceae	0.010	46.67
<i>Chenopodium incanum</i>	mealy goosefoot	Chenopodiaceae	0.019	46.67
<i>Chenopodium leptophyllum</i>	narrowleaf goosefoot	Chenopodiaceae	0.113	93.33
<i>Cirsium</i> sp.	thistle	Asteraceae	0.006	20.00
<i>Conyza canadensis</i>	Canadian horseweed	Asteraceae	0.000	6.67
<i>Cordylanthus wrightii</i>	Wright's bird's beak	Scrophulariaceae	0.052	40.00
<i>Croton texensis</i>	Texas croton	Euphorbiaceae	0.043	26.67
<i>Cryptantha cinerea</i>	James' cryptantha	Boraginaceae	0.015	80.00
<i>Cyperus fendlerianus</i>	Fendler's flatsedge	Cyperaceae	0.074	13.33
<i>Dalea candida</i>	white prairieclover	Fabaceae	0.003	6.67
<i>Dalea polygonoides</i>	six-weeks prairie-clover	Fabaceae	0.001	6.67

Appendix A, continued.

<i>Drymaria molluginea</i>	slimleaf drymary	Caryophyllaceae	0.001	20.00
<i>Echinocereus</i> sp.	hedgehog cactus	Cactaceae	<0.001	13.33
<i>Elymus elymoides</i>	squirreltail	Poaceae	0.910	100.00
<i>Ericameria nauseosa</i>	rubber rabbitbrush	Asteraceae	<0.001	13.33
<i>Erigeron divergens</i>	spreading fleabane	Asteraceae	0.016	73.33
<i>Erigeron flagellaris</i>	trailing fleabane	Asteraceae	0.263	20.00
<i>Eriogonum alatum</i>	winged buckwheat	Polygonaceae	0.001	6.67
<i>Eriogonum jamesii</i>	James' buckwheat	Polygonaceae	0.025	40.00
<i>Eriogonum racemosum</i>	redroot buckwheat	Polygonaceae	0.007	13.33
<i>Erysimum capitatum</i>	sanddune wallflower	Brassicaceae	0.002	33.33
<i>Fallugia paradoxa</i>	Apache plume	Rosaceae	0.114	26.67
<i>Geranium caespitosum</i>	piney-woods geranium	Geraniaceae	0.003	6.67
<i>Gutierrezia sarothrae</i>	broom snakeweed	Asteraceae	2.044	93.33
<i>Hedeoma drummondii</i>	Drummond's false pennyroyal	Lamiaceae	0.001	6.67
<i>Helianthus annuus</i>	common sunflower	Asteraceae	0.127	40.00
<i>Heliomeris multiflora</i>	showy goldeneye	Asteraceae	0.022	13.33
<i>Hesperostipa comata</i>	needle and thread	Poaceae	0.001	6.67
<i>Heterotheca villosa</i>	hairy false goldenaster	Asteraceae	0.094	53.33
<i>Hymenopappus filifolius</i>	fineleaf hymenopappus	Asteraceae	0.002	20.00
<i>Hymenoxys richardsonii</i>	Colorado rubberweed	Asteraceae	0.018	20.00
<i>Ipomopsis aggregata</i>	scarlet gilia	Polemoniaceae	0.007	33.33
<i>Ipomopsis longiflora</i>	whiteflower ipomopsis	Polemoniaceae	0.008	40.00
<i>Koeleria macrantha</i>	prairie junegrass	Poaceae	0.100	20.00
<i>Lactuca serriola</i> ^a	prickly lettuce	Asteraceae	0.007	13.33
<i>Lappula occidentalis</i>	flatspine stickseed	Boraginaceae	0.002	6.67
<i>Lotus wrightii</i>	Wright's deervetch	Fabaceae	0.045	80.00
<i>Lupinus kingii</i>	King's lupine	Fabaceae	0.008	20.00
<i>Lycurus setosus</i>	bristly wolfstail	Poaceae	0.006	20.00
<i>Machaeranthera bigelovii</i>	tansy aster	Asteraceae	0.061	26.67
<i>Machaeranthera canescens</i>	hoary tansyaster	Asteraceae	0.003	6.67
<i>Machaeranthera gracilis</i>	slender goldenweed	Asteraceae	0.001	6.67
<i>Mahonia repens</i>	creeping barberry	Berberidaceae	<0.001	6.67
<i>Mentzelia multiflora</i>	Adonis blazingstar	Loasaceae	0.095	60.00
<i>Mirabilis multiflora</i>	Colorado four o'clock	Nyctaginaceae	0.003	6.67
<i>Mirabilis oxybaphoides</i>	smooth spreading four o'clock	Nyctaginaceae	0.018	33.33
<i>Monroa squarrosa</i>	false buffalograss	Poaceae	<0.001	6.67
<i>Muhlenbergia minutissima</i>	annual muhly	Poaceae	0.002	13.33
<i>Muhlenbergia montana</i>	mountain muhly	Poaceae	0.029	33.33
<i>Oenothera caespitosa</i>	tufted evening-primrose	Onagraceae	0.001	13.33
<i>Opuntia</i> spp.	prickly pear	Cactaceae	0.266	86.67
<i>Opuntia whipplei</i>	Whipple's cholla	Cactaceae	0.117	20.00

Appendix A, continued.

<i>Orobancha</i> sp.	clustered broomrape	Orobanchaceae	0.001	6.67
<i>Orthocarpus purpureoalbus</i>	purple owllover	Scrophulariaceae	0.003	20.00
<i>Penstemon</i> sp.	penstemon	Scrophulariaceae	0.006	26.67
<i>Penstemon barbatus</i>	beardlip penstemon	Scrophulariaceae	0.002	6.67
<i>Phacelia</i> sp.	scorpionweed	Hydrophyllaceae	0.001	6.67
<i>Physalis hederifolia</i>	ivyleaf groundcherry	Solanaceae	0.005	40.00
<i>Piptatherum micranthum</i>	littleseed ricegrass	Poaceae	0.112	46.67
<i>Pleuraphis jamesii</i>	James' galleta	Poaceae	0.010	13.33
<i>Poa fendleriana</i>	muttongrass	Poaceae	0.452	93.33
<i>Polygonum douglasii</i>	Douglas' knotweed	Polygonaceae	0.006	13.33
<i>Portulaca oleracea</i> ^a	little hogweed	Portulacaceae	0.012	53.33
<i>Quercus</i> sp.	oak	Fagaceae	0.333	40.00
<i>Rhus trilobata</i>	skunkbush sumac	Anacardiaceae	0.408	60.00
<i>Schizachyrium scoparium</i>	little bluestem	Poaceae	0.069	33.33
<i>Schoenocrambe linearifolia</i>	slimleaf plains mustard	Brassicaceae	0.002	26.67
<i>Senecio flaccidus</i>	threadleaf ragwort	Asteraceae	0.001	6.67
<i>Senecio spartioides</i>	broomlike ragwort	Asteraceae	0.033	66.67
<i>Sisymbrium altissimum</i> ^a	tumblemustard	Brassicaceae	0.001	6.67
<i>Solidago</i> sp.	goldenrod	Asteraceae	0.003	6.67
<i>Sphaeralcea</i> sp.	globemallow	Malvaceae	0.001	6.67
<i>Sporobolus contractus</i>	spike dropseed	Poaceae	0.005	6.67
<i>Sporobolus cryptandrus</i>	sand dropseed	Poaceae	0.025	73.33
<i>Stephanomeria pauciflora</i>	brownplume wirelettuce	Asteraceae	<0.001	13.33
<i>Tetaneuris ivesiana</i>	Ives' fournerved daisy	Asteraceae	0.007	13.33
<i>Thelesperma filifolium</i>	stiff greenthread	Asteraceae	0.009	20.00
<i>Townsendia eximia</i>	tall Townsend daisy	Asteraceae	0.006	6.67
<i>Tragopogon dubius</i> ^a	yellow salsify	Asteraceae	0.006	33.33
<i>Verbascum thapsus</i> ^a	common mullein	Scrophulariaceae	0.246	53.33
<i>Yucca angustissima</i>	narrowleaf yucca	Agavaceae	0.025	26.67
<i>Yucca baccata</i>	banana yucca	Agavaceae	0.071	33.33
Unknown 2008Sep07-1			0.023	33.33
Unknown 2008Sep07-2			<0.001	6.67
Unknown 2008SEP09-1			<0.001	6.67
Unknown 2008Sep21-1			0.001	6.67

^a Nonnative species

^b Species found in the plots that are not included on the park's species list

Tree species

Appendix A, continued.

Species	Common name	Family	Basal area (m ² /ha)	Plot frequency (%)
<i>Juniperus monosperma</i>	one-seed juniper	Cupressaceae	13.65	93.33
<i>Pinus ponderosa</i>	ponderosa pine	Pinaceae	0.20	6.67