



Integrated Upland Vegetation and Soils Monitoring for Wupatki National Monument

2010 Summary Report

Natural Resource Data Series NPS/SCPN/NRDS—2013/515



ON THE COVER

Integrated upland monitoring in Wupatki National Monument
Photography by: Megan Swan/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 Limy Upland and Sandstone Upland ecological sites for long-term monitoring of upland vegetation and soils at Wupatki National Monument (WUPA). 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). These 2 ecological sites comprise large areas of the upland grassland and shrubland ecosystems at WUPA. They face numerous threats, including climate change and invasion by nonnative species.

In 2007, the SCPN integrated upland monitoring project began its work at WUPA with the installation of 10 plots in the Limy Upland ecological site and 10 plots in the Sandstone Upland ecological site. We sampled vegetation in nested quadrats and measured basal gaps annually for 3 years to determine the range of temporal variability for key metrics. In 2010, we established and sampled 20 new plots in each ecological site. The original 10 plots were not resampled. This brings our total for these ecological sites to 30 established plots for each. In this report, we document monitoring activities in the 2010 field season and report these data in the context of the data collected in 2007, 2008 and 2009. The data summarized for these 30 plots in each of these 2 ecological sites represent the baseline for our vegetation and soil monitoring of these sites.

2 Methods

2.1 Sampling frame

We derived our base sampling frame (figs. 1 and 2) from the maps of the Limy Upland and Sandstone Upland ecological sites, which were developed by the U.S. Natural Resources Conservation Service (NRCS) (see appendix A of DeCoster et al. 2012). The sampling frames are the areas from which we randomly select our sites, and hence the areas to which statistical inferences can be made. To make final adjustments to our sampling frames, we modified the maps of the ecological sites using Geographical Information System (GIS) technology by removing areas within 100 m of roads and exceeding 20% slope.

For each ecological site, 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 rejected those points that landed too close to archeological sites and other sensitive resources. The integrated upland crew then 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 an archeological site or major disturbance. We rejected 8 points in the Limy Upland ecological site: 5 points were in proximity to archeological sites, one was outside of the acceptable variation for the ecological site, and 2 were less than 200 meters from an established plot. The crew also rejected 8 points in the Sandstone ecological site: one point was in proximity to an archeological site, 3 points were less than 200 meters from an established plot, 2 points were outside of the acceptable variation for the ecological site, one point was in an area of human disturbance, and one point was too close to a road.

2.2 Field methods

The SCPN integrated upland crew established 10 monitoring plots in each ecological site in 2007, and resampled these plots in 2008 and 2009. In 2010, the crew established 20 additional plots in each ecological site. The plots established in 2007 were not sampled in 2010. We conducted our field work in the latter part of August for all years, except in 2007 when our field work extended into early September.

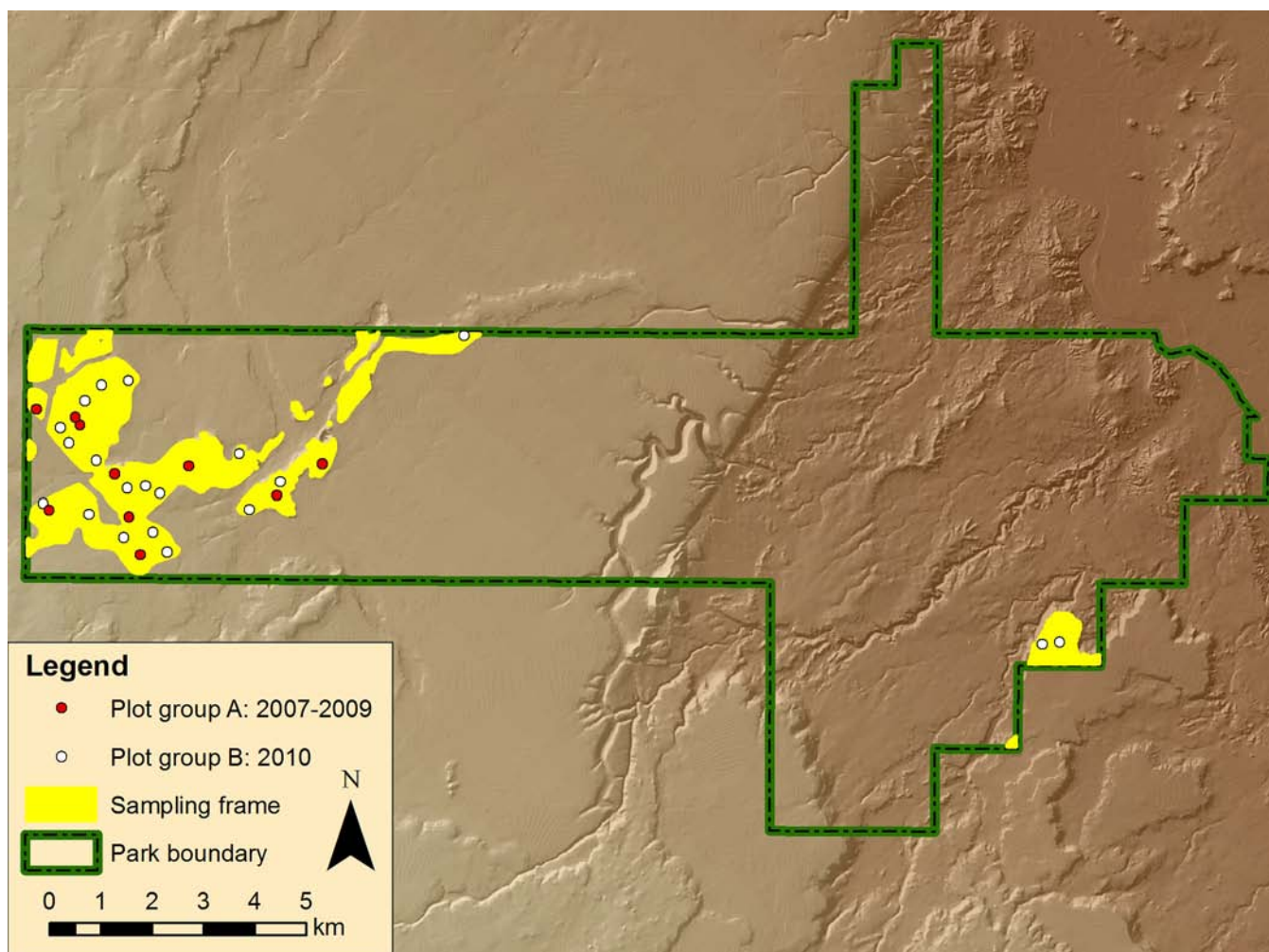


Figure 1. Sampling frame for the Limy Upland and ecological site at WUPA, showing the 10 plots established in 2007, and the 20 plots established in 2010.

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 cover and frequency, functional group cover, soil surface feature cover, and seedling data in quadrats on all 3 transects within each plot. We also collected overstory tree and sapling data in subplots located between 2 of the transects.

We collected all of these data for each sampling of the plots, with the exception of tree data. We refined our tree measurement methods over the first 3 years of sampling. Field methodology is provided in detail in the SCPN integrated upland monitoring protocol (DeCoster et al. 2012).

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 m^2 ($2 \times 5 \text{ m}$), with 4 smaller quadrats nested inside (0.01 m^2 , 0.1 m^2 , 1 m^2 , 5 m^2). 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 m^2 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 m^2 quadrats and recorded the cover class. We collected these data in the initial 10 plots in 2007, 2008 and 2009 in each ecological site, and collected the same set of data for the 20 new plots established in 2010.

2.2.2 Overstory trees, saplings, and seedlings

In 2007 and 2010, we measured overstory trees in a $50 \times 50 \text{ m}$ (0.25 ha) plot located between 2 of the transects.

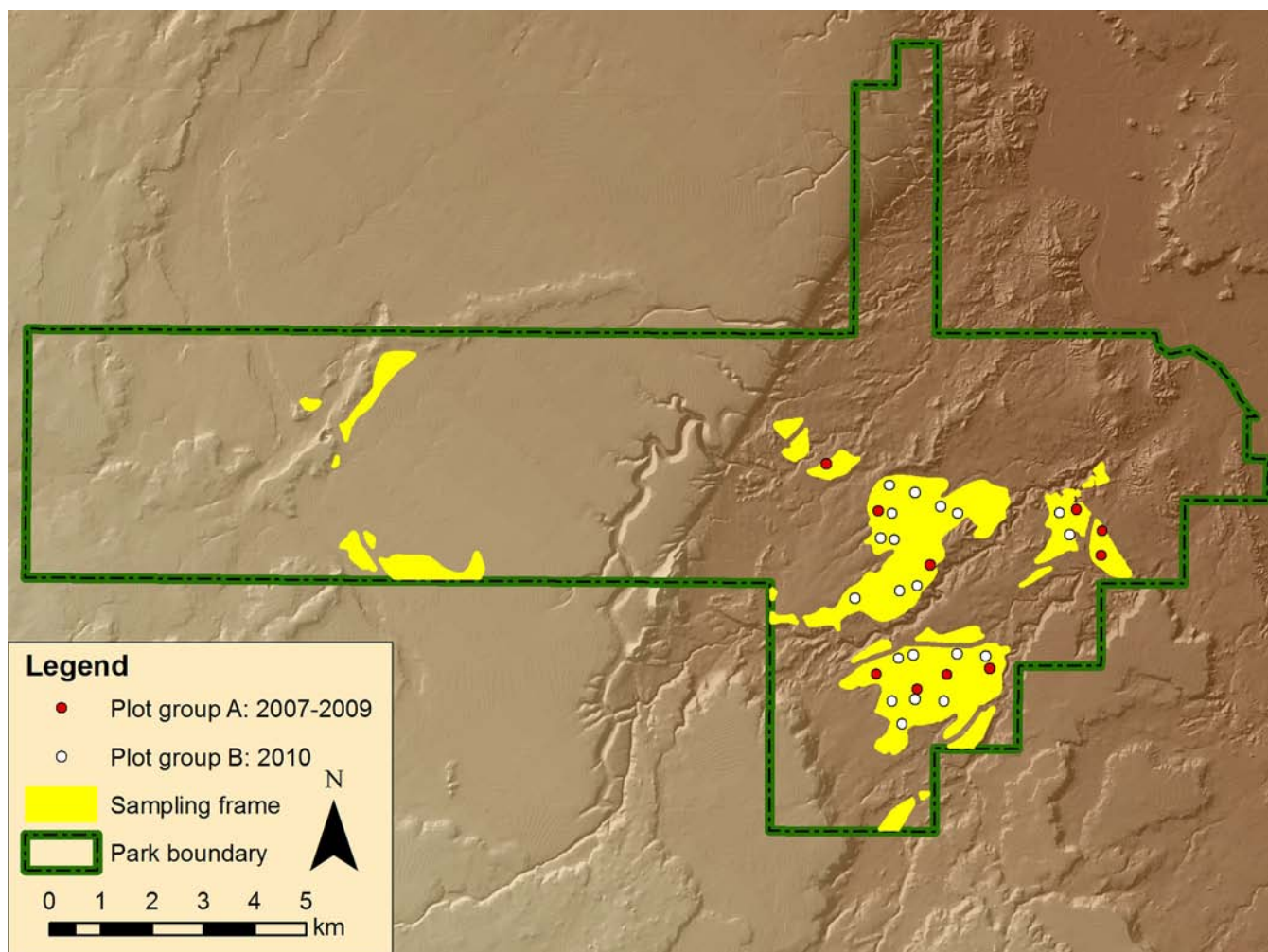


Figure 2. Sampling frame for the Sandstone Upland and ecological site at WUPA, showing the 10 plots established in 2007, and the 20 plots established in 2010.

Within this overstory tree plot, we tallied saplings by size class and species in a smaller, 25×25 m plot. We tallied seedlings by size class and species in the fifteen 10 m^2 quadrats along the 3 transects. After the initial sampling in 2007, we refined our methods, as described below. There were no saplings or seedlings in any of the plots.

In 2007, we measured all trees (only junipers occurred in our plots) using a diameter tape at the root crown. In 2008, we remeasured all overstory junipers using a meter stick in 2 perpendicular directions, excluding the horizontal and diagonal branches. This method does not exaggerate the size of the trees. We repeated this method for trees in the plots established in 2010.

In 2009 we measured tree canopy cover using the line intercept method along transects in the first 10 plots. This new method was used for the plots established in 2010, as well.

2.2.3 Soil surface features

We estimated the percent cover of soil surface features in the 1 m^2 quadrats along the transects, and recorded the cover in 1 of 12 cover classes. We collected soil surface feature data for 3 years in the plots established in 2007 and for one year in the plots established in 2010.

2.3 Data summary

For each ecological site we examine the data for all 30 plots, as these represent the baseline conditions, and report them as the ecological site means. We also compare the data collected in the 20 plots in 2010 to the data

collected in the 10 plots between 2007 and 2009. The 2010 plots are a different sample than the 2007–2009 plots, and it must be stressed that the differences between these 2 plot groups do not represent change over time, but rather indicate differences in composition and structure resulting largely from spatial variation. We refer to these 2 groups of plots as Plot Group A for the plots established in 2007, and Plot Group B for the plots established in 2010.

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 for the plot group from the plot means (ecological site species diversity metrics were the exception). For Plot Group A metrics, where there were 3 years of data, we calculated the mean value and standard deviation for the 10 plots for each year, and then calculated the mean of the means and the mean of the standard deviations for the 3 years. Metrics with 3 years of data include species cover and frequency, functional group cover and soil surface features. For Plot Group B we calculated the mean and standard deviation based on a single year of data. We then combined the plot means for all 30 plots, and calculated the mean and standard deviation, which represents the ecological site mean.

We also combined data for all 30 plots and calculated an ecological site mean. For most metrics, we combined the values from the plots in Plot Group B with the 3 year mean values for the plots from Plot Group A. In this report, we describe data in terms of the ecological site mean, and note differences among the plot groups.

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 year, mean cover was calculated for each plot, and the mean and standard deviation were calculated for the ecological site from the plot means. 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 occurs) and for plots (percentage of plots where the species occurs). For Plot Group A, we calculated the quadrat and plot frequency for each year, and then calculated the 3 year means. We calculated the ecological site mean of these frequencies by using weighted means for Plot Group A and Plot Group B.

2.3.2 Species diversity

Four diversity measures were calculated for herbaceous and shrub species for each year (Magurran 1988), 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, 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 year, and the mean and standard deviation were then calculated for the ecological site for each year. Ecological site richness and beta diversity were calculated for the ecological site for each year.

We also calculated the ecological site mean for all metrics, using data from all 30 plots. For the ecological site richness and beta diversity, we used one year of data from Plot Group A: the year that had the median value for Shannon diversity. The one-year data for these plots were combined with the other 20 plots to calculate these 2 metrics. For the other 3 metrics (plot richness, evenness, Shannon diversity), we took the 3-year mean for each plot in Plot Group A, and combined these with the plot means for the remaining 20 plots, and calculated the mean and standard deviation for all 30 plots in the ecological site.

2.3.3 Trees

Using the 2008 data for Plot Group A, and the 2010 data for Plot Group B, each metric was calculated for each plot, and the mean and standard deviation were then calculated for each plot group and for all plots in each ecological site. Tree basal area (the total area of the tree cross-sections) for living trees and snags was calculated in terms of m^2/ha . Mean diameter of living overstory trees was also calculated for each species. Tree density was calculated for all size classes for overstory living trees and snags in terms of stems/ha. Canopy cover was calculated by first deriving the mean for each plot, and then the mean and standard deviation were calculated for the plot group.

3 Results

We describe results generally for the ecological site mean, i.e., all plots, but specify whenever data come from only one of the plot groups.

3.1 Limy Upland ecological site

3.1.1 Shrub and herbaceous vegetation

Perennial grasses and forbs co-dominated the Limy Upland ecological site (table 1 and fig. 3). The ecological site mean for foliar cover of perennial grasses and forbs for all plots was similar: 9.22% and 10.99%, respectively. The foliar cover of shrubs and cacti/succulents was less than 1%. There was only a trace amount of annual grasses. Standing dead herbaceous vegetation had a mean cover of 4.55%, while standing dead woody vegetation had a mean cover of 0.57%. Plot Group B had greater total live foliar cover and forb cover, and less perennial grass cover, than Plot Group A.

We examine species-level data for the most abundant herbs and shrubs in Figure 4 (foliar cover) and Table 2 (foliar cover and frequency). Based on the ecological site mean values, *Salsola tragus* (prickly Russian thistle) was the species with the greatest foliar cover. Other dominant forbs included *Chenopodium leptophyllum* (narrowleaf goosefoot) and *Chamaesyce* spp. (2 groups of annual sand mats, distinguished by morphological characteristics). Dominant perennial grasses included *Pleuraphis jamesii* (James' galleta), *Bouteloua eriopoda* (black grama), *Hesperostipa neomexicana* (New Mexico needlegrass), *Sporobolus airoides* (alkali sacaton), and *Sporobolus flexuosus* (mesa dropseed). Dominant shrubs included *Ericameria nauseosa* (rubber rabbitbrush) and *Ephedra torreyana* (Torrey's jointfir). Species with high foliar cover tended to have high plot and quadrat frequencies.

While the foliar covers and frequencies were generally similar between the plot groups, *Salsola tragus* was much more abundant in Plot Group B. Several species only occurred in one of the plot groups, the most abundant being *Ephedra torreyana*, which did not occur at all in Plot Group A. Appendix A lists all species that occurred in the ecological site, along with common names, families, mean foliar cover, and plot frequencies by plot group.

We encountered four nonnative species in the plots. *Salsola tragus* was the most abundant species. It had a mean cover of 10.013%, and occurred in 77.56% of the quadrats and 88.89% of all plots. The other 3 nonnative species were *Kochia scoparia* (burning bush), *Portulaca oleracea* (little hogweed), and *Mollugo cerviana* (threadstem carpetweed). They all had low foliar cover and low frequencies.

Table 1. Foliar cover of functional groups for Plot Group A, Plot Group B and the ecological site mean from all plots combined in the Limy Upland ecological site at WUPA.

Functional groups	Plot Group A 2007-2009		Plot Group B 2010		Ecological site	
	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Total live foliar cover	16.07	4.50	23.63	7.73	21.11	7.48
Perennial grasses	12.07	3.63	7.79	6.22	9.22	5.74
Annual grasses	0	0	0	0	0	0
Forbs	2.85	2.11	15.07	12.01	10.99	11.40
Shrubs	0.38	0.40	0.40	0.63	0.40	0.53
Cacti/succulents	0.01	0.02	0.08	0.35	0.06	0.29
Standing dead herbaceous	4.72	1.69	4.47	2.51	4.55	2.14
Standing dead woody	0.47	0.37	0.62	0.66	0.57	0.57

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.

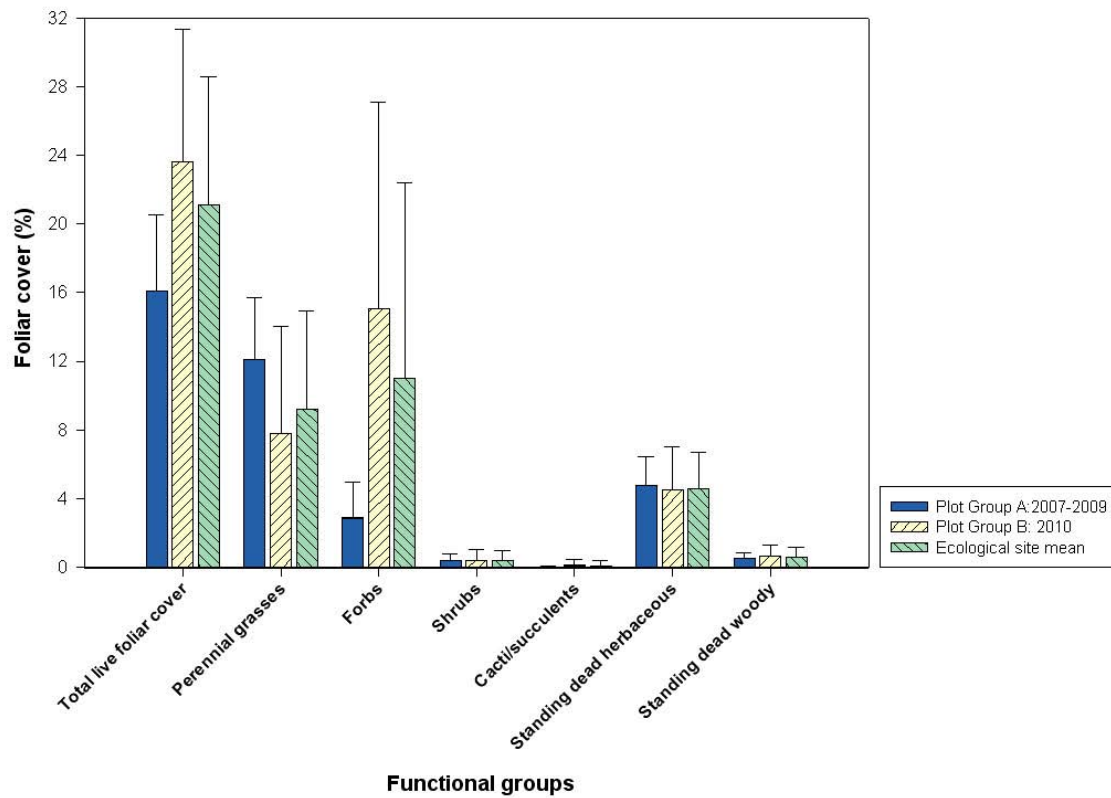


Figure 3. Mean percent foliar cover by functional group for Plot Group A, Plot Group B, and all plots (ecological site mean) in the Limy Upland ecological site at WUPA. Annual grasses occurred in trace amounts and were not graphed.

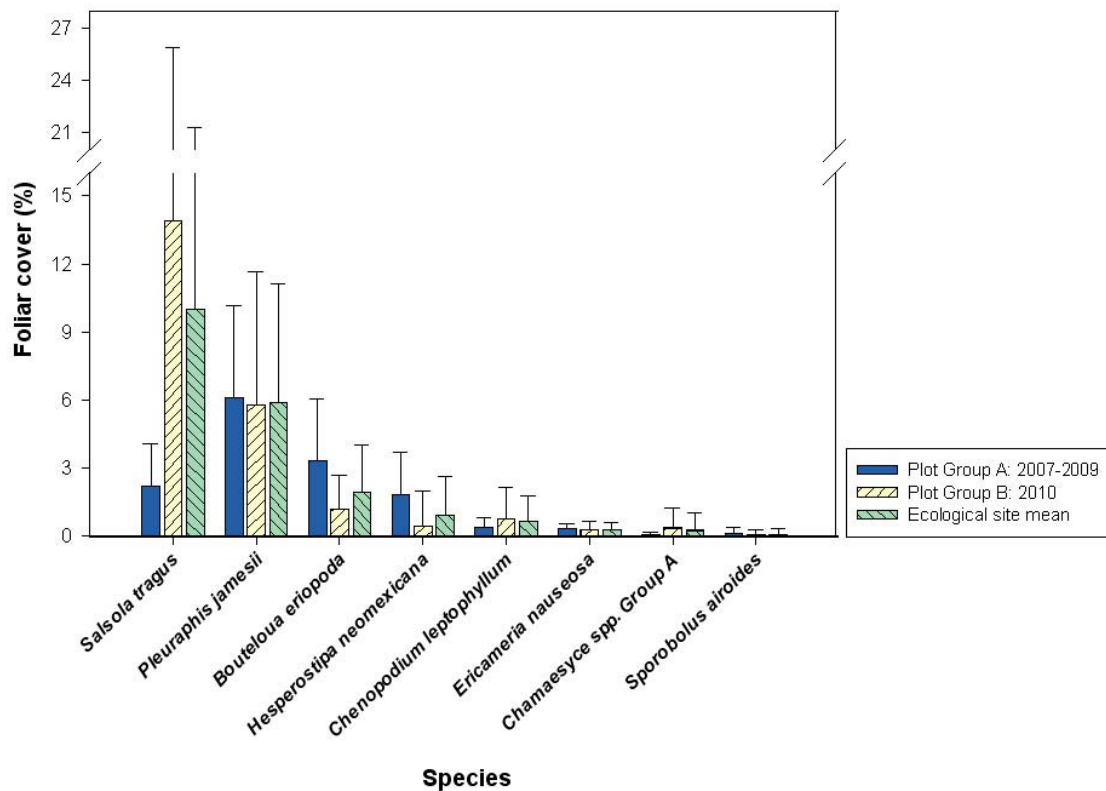


Figure 4. Mean percent foliar cover of the 8 most abundant shrub and herbaceous species for all plots (ecological site mean) compared to mean foliar cover for Plot Group A and Plot Group B in the Limy Upland ecological site at WUPA. Error bars represent one standard deviation.

Table 2. Mean foliar cover and standard deviation, and mean quadrat and plot frequencies of the 15 most abundant shrub and herbaceous species and all nonnative species for all plots (ecological site mean) compared with the values for Plot Group A and Plot Group B in the Limy Upland ecological site at WUPA.

Species	Plot Group A 2007-2009				Plot Group B 2010				Ecological site mean			
	Foliar cover (%)	SD	Quadrat frequency (%)	Plot frequency (%)	Foliar cover (%)	SD	Quadrat frequency (%)	Plot frequency (%)	Foliar cover (%)	SD	Quadrat frequency (%)	Plot frequency (%)
<i>Salsola tragus</i> ^a	2.227	1.832	69.33	86.67	13.906	11.977	81.67	90.00	10.013	11.237	77.56	88.89
<i>Pleuraphis jamesii</i>	6.118	4.062	95.78	100.00	5.790	5.859	93.67	100.00	5.899	5.229	94.37	100.00
<i>Bouteloua eriopoda</i>	3.327	2.701	77.78	100.00	1.223	1.467	55.33	90.00	1.924	2.106	62.81	93.33
<i>Hesperostipa neomexicana</i>	1.848	1.866	74.22	96.67	0.468	1.536	26.33	65.00	0.928	1.731	42.30	75.56
<i>Chenopodium leptophyllum</i>	0.402	0.420	52.00	80.00	0.759	1.399	64.33	85.00	0.640	1.163	60.22	83.33
<i>Ericameria nauseosa</i>	0.320	0.243	26.00	93.33	0.301	0.345	21.33	80.00	0.307	0.307	22.89	84.44
<i>Chamaesyce</i> spp. Group A	0.056	0.113	28.67	76.67	0.371	0.897	36.33	70.00	0.266	0.744	33.78	72.22
<i>Sporobolus airoides</i>	0.115	0.292	3.78	23.33	0.056	0.243	2.33	10.00	0.075	0.256	2.81	14.44
<i>Chamaesyce</i> spp. Group B	0.035	0.047	26.67	63.33	0.080	0.157	41.00	85.00	0.065	0.130	36.22	77.78
<i>Ephedra torreyana</i>	0	0	0	0	0.093	0.414	1.67	5.00	0.062	0.338	1.11	3.33
<i>Sphaeralcea hastulata</i>	0.073	0.130	13.56	43.33	0.042	0.101	8.67	40.00	0.052	0.107	10.30	41.11
<i>Sporobolus flexuosus</i>	0	0	0	0	0.046	0.207	1.67	5.00	0.031	0.169	1.11	3.33
<i>Zinnia grandiflora</i>	0.015	0.028	8.89	43.33	0.039	0.117	5.00	25.00	0.031	0.097	6.30	31.11
<i>Amaranthus</i> sp.	0	0	0	0	0.040	0.126	8.00	25.00	0.027	0.104	5.33	16.67
<i>Achnatherum hymenoides</i>	0	0	0	0	0.037	0.140	3.67	20.00	0.025	0.115	2.44	13.33
<i>Kochia scoparia</i> ^a	0.001	0.002	1.78	16.67	0.007	0.015	5.67	30.00	0.005	0.012	4.37	25.56
<i>Portulaca oleracea</i> ^a	0	0	0	0	0.004	0.016	2.33	5.00	0.002	0.013	1.56	3.33
<i>Mollugo cerviana</i> ^a	0	0	0	0	0.001	0.005	2.67	10.00	0.001	0.004	1.78	6.67

Note: Species are arranged in descending order by the ecological site mean cover. Also, annual species of *Chamaesyce* spp. were placed into 2 groups, A and B, based on morphological characteristics.

^aNonnative species.

In 2010 we corrected the identification for 2 species that had occurred previously in the plots. Plants that we identified as *Gutierrezia sarothrae* before 2010 are now identified as *Gutierrezia microcephala*, and plants that we previously identified as *Hesperostipa comata* are now identified as *Hesperostipa neomexicana*. In both cases, the corrected species predominates. However, the 2 congeneric species may occur in the ecological site and are often not easily distinguished from each other during our sampling period.

The diversity metrics demonstrate a pattern of low diversity on the scale of the plot, with higher levels of diversity on the scale of the ecological site (table 3). On the scale of the plot, mean richness was 13.4 species. Moreover, Shannon diversity (which takes into account relative abundance of species and generally ranges between 1.5 and 3.5) was 1.004, and evenness (the degree to which all species are of equal abundance, ranging from 0 to 1) was 0.390. On the scale of the ecological site, richness was 65, and beta diversity (a measure of within-site heterogeneity, generally ranging between 1 and 5) was 5.228. This suggests that while diversity is low at a local level, there are large differences in species composition among the plots due to heterogeneity across the ecological site.

There were some differences in the diversity among the 2 plot groups. Plot Group B had much lower Shannon diversity and evenness, and higher ecological site richness and beta diversity. The lower values at the smaller scales are likely to be a result of high cover of *Salsola tragus*. The higher values for metrics at the ecological site level may be the result of the larger sample size: 20 plots in Plot Group B compared to 10 plots in Plot Group A.

When we recalculated the metrics using only native species, Shannon diversity, evenness and beta diversity all increased for the ecological site mean. Moreover, the between-plot group differences in Shannon diversity and evenness decreased. This was likely due to the high foliar cover of *Salsola tragus*.

Table 3. Species diversity metrics for all species and for native species only, for Plot Group A, Plot Group B and all plots (ecological site mean) in the Limy Upland ecological site at WUPA.

	Plot Group A 2007-2009		Plot Group B 2010		Ecological site	
	Mean	SD	Mean	SD	Mean	SD
All species						
Plot						
Plot richness	13.4	2.3	13.4	4.3	13.4	3.6
Shannon diversity	1.263	0.287	0.875	0.469	1.004	0.449
Evenness	0.490	0.110	0.340	0.165	0.390	0.162
Ecological site						
Ecological site richness	37.67		59 ^a		65	
Beta diversity	3.031		4.758 ^a		5.228	
Native species						
Plot						
Plot richness	12.4	2.3	12.1	3.7	12.2	3.2
Shannon diversity	1.115	0.245	1.099	0.346	1.105	0.309
Evenness	0.448	0.104	0.444	0.118	0.446	0.110
Ecological site						
Ecological site richness	36		55 ^a		61	
Beta diversity	3.158		4.977 ^a		5.495	

^aThese are not mean values.

3.1.2 Trees

There was only one species of tree in the ecological site: *Juniperus monosperma* (oneseed juniper). Living overstory tree density was sparse, at 7.6 stems/ha, and the basal area was low, at 0.89 m²/ha (table 4 and fig. 5). The large error bars for basal area in Figure 5 indicate large among-plot variation. The mean diameter (taken at root crown) of the trees was 37.6 cm. The density of snags was 0.5 stems/ha, and their basal area was 0.02 m²/ha. Between the 2 plot groups, living overstory tree density and basal area were higher in Plot Group A. There were no individuals in the sapling and seedling layers. The density of trees in different size classes demonstrates a fairly even size structure, with the 25–35 cm class having the highest density (fig. 6). Again, the large error bars indicate large among-plot variation.

Table 4. Mean density, mean basal area, and mean diameter of trees for Plot Group A, Plot Group B, and all plots (ecological site mean) in the Limy Upland ecological site at WUPA. All trees were *Juniperus monosperma*.

	Seedling ^a density (stems/ha)	Sapling ^a density (stems/ha)	Overstory ^a density (stems/ha)	Snag ^a density (stems/ha)	Overstory basal area (m ² /ha)	Snag basal area (m ² /ha)	Mean diameter at root crown (cm)
Plot Group A 2008 ^b	0	0	12.8	0.8	1.57	0.02	44.7
Plot Group B 2010	0	0	5.0	0.4	0.56	0.02	32.0
Ecological site mean	0	0	7.6	0.5	0.89	0.02	37.6

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

^bAll Plot Group A tree measurements are from 2008, when we implemented the revised method of measuring tree diameters.

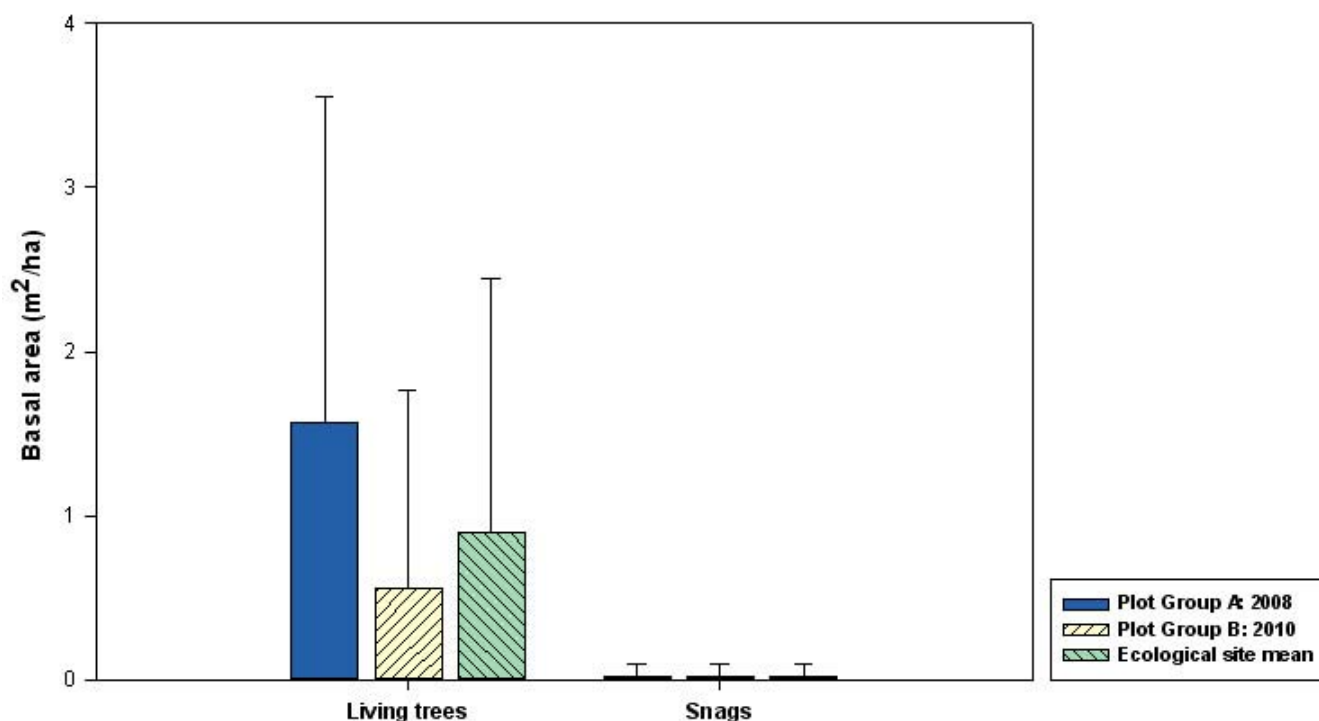


Figure 5. Mean basal area for living trees and snags for Plot Group A, Plot Group B, and all plots (ecological site mean) in the Limy Upland ecological site at WUPA. Error bars represent 1 standard deviation.

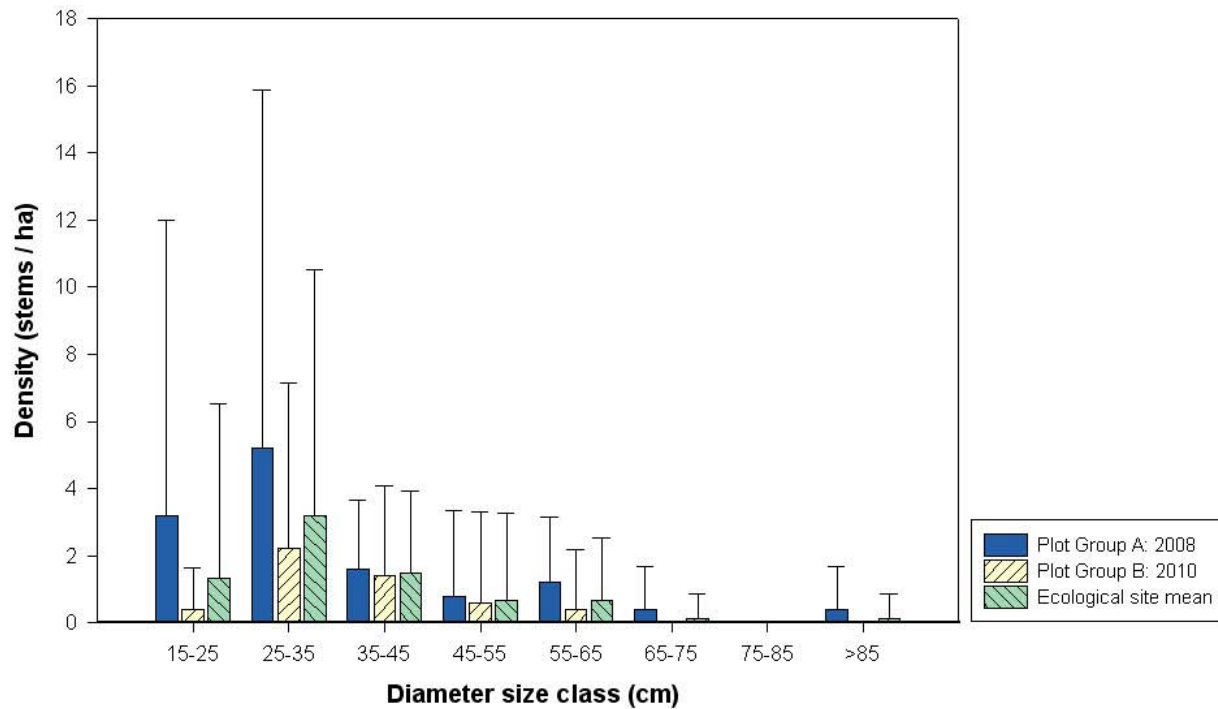


Figure 6. Size structure of living overstory trees for Plot Group A, Plot Group B, and all plots (ecological site mean) in the Limy Upland ecological site at WUPA. Error bars represent 1 standard deviation.

3.1.3 Soil surface features

We measured the amount of soil surface potentially subject to erosion using cover estimates of soil surface features in quadrats. Fine gravel and bare soil co-dominated the soil surface of this ecological site, with 54.08% cover and 24.17% cover, respectively (fig. 7 and table 5). Other important features included coarse gravel, with 8.67% cover, duff/litter, with 5.82% cover, live plant base, with 3.09% cover, and undifferentiated crust, with 2.78% cover. The remainder of the soil surface features had less than 2% cover. There were no biological soil crusts encountered in the plots.

Figure 7. Mean percent cover of soil surface features for Plot Group A, Plot Group B, and all plots (ecological site mean) in the Limy Upland ecological site at WUPA.

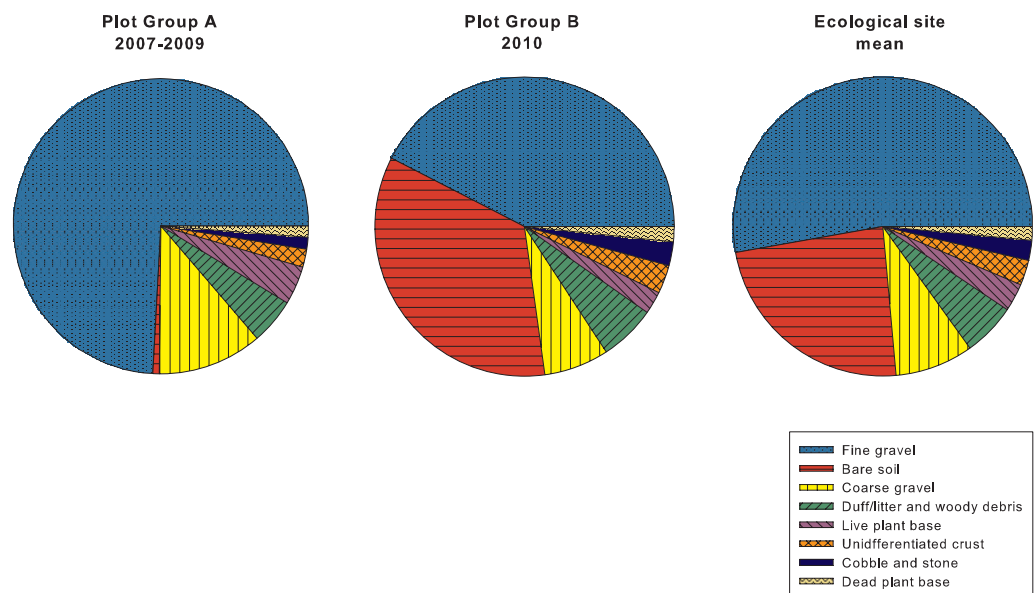


Table 5. Cover of soil surface features for Plot Group A, Plot Group B, and all plots (ecological site mean) in the Limy Upland ecological site at WUPA.

Soil surface feature	Plot Group A 2007–2009		Plot Group B 2010		Ecological site	
	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Live plant base	4.23	1.63	2.53	1.41	3.09	1.53
Dead woody base	0.08	0.12	0.09	0.14	0.09	0.13
Dead herbaceous base	1.13	0.54	1.62	0.92	1.46	0.81
Bare soil	0.70	0.96	35.90	25.29	24.17	26.53
Duff/litter	5.06	2.48	6.21	2.08	5.82	2.08
Undifferentiated crust	1.98	1.31	3.17	2.93	2.78	2.51
Moss	0	0	0	0	0	0
Lichen	0	0	0	0	0	0
Cyanobacteria	0	0	0	0	0	0
Fine gravel (0.2 to <2 cm)	74.48	13.37	43.89	23.26	54.08	24.99
Coarse gravel (2 to <7.5 cm)	11.51	13.70	7.25	9.51	8.67	10.97
Cobble (7.5 to <25 cm)	0.78	0.68	1.65	3.92	1.36	3.22
Stone, bedrock (>25 cm)	0.53	0.77	1.00	2.46	0.84	2.04
Woody debris	<0.01	0.01	0.08	0.27	0.05	0.22

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.

Differences in features between the 2 plot groups were relatively small with the exception of fine gravel and bare soil, and coarse gravel to a lesser extent. These differences are likely attributable to a variation in data collection methods. The 2010 crew interpreted soil particle and rock fragment size classes differently than did crews in earlier years, particularly the cut-off between the particle size of coarse sand (bare soil) and fine gravel.

3.2 Sandstone Upland ecological site

3.2.1 Shrub and herbaceous vegetation

Shrubs and perennial grasses co-dominated the Sandstone Upland ecological site (table 6 and fig. 8). Total live foliar cover was 9.51%, foliar cover of shrubs was 4.66% and foliar cover of perennial grasses was 3.88%. Foliar cover of forbs was low at 0.88%. There were only trace amounts of annual grasses and cacti/succulents. The cover of standing dead woody was substantial, at 2.80%.

The 2 plot groups exhibited some differences. For example, Plot Group B had much higher perennial grass cover: 4.89% compared to 1.86% in Plot Group A. Plot Group B also had higher forb cover and higher total foliar cover.

We examine species-level data for the most abundant herbs and shrubs within all plots and between plot groups in Table 7 (foliar cover and frequency) and Figure 9 (foliar cover). *Pleuraphis jamesii* (James' galleta) was the species with the greatest foliar cover. Other dominant perennial grasses included *Muhlenbergia porteri* (bush muhly), *Sporobolus airoides* (alkali sacaton), and *Bouteloua eriopoda* (black grama). There were numerous species of codominant shrubs: *Ephedra torreyana* (Torrey's jointfir), *Artemisia filifolia* (sand sagebrush), *Fallugia paradoxa* (Apache plume), *Ericameria nauseosa* (rubber rabbitbrush), *Atriplex canescens* (fourwing saltbush), and *Atriplex confertifolia* (shadscale saltbush). Common forbs included *Chamaesyce* spp., *Salsola tragus* (prickly Russian thistle), and *Solanum elaeagnifolium* (silverleaf nightshade).

While there were substantial differences in the foliar cover of the dominant species between the 2 plot groups; the differences in quadrat and plot frequencies were generally not as great. There were, however, a number of species that occurred in only one of the plot groups, the most abundant being *Solanum elaeagnifolium*, which occurred only in Plot Group B.

Table 6. Foliar cover of functional groups for Plot Group A, Plot Group B, and all plots (ecological site mean) in the Sandstone Upland ecological site at WUPA.

Functional groups	Plot Group A 2007-2009		Plot Group B 2010		Ecological site	
	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Total live foliar cover	6.49	3.44	11.02	6.62	9.51	6.07
Perennial grasses	1.86	2.30	4.89	7.81	3.88	6.61
Annual grasses	0	0	0	0	0	0
Forbs	0.42	0.42	1.11	0.73	0.88	0.70
Shrubs	4.06	2.23	4.94	2.59	4.65	2.44
Cacti/succulents	<0.01	<0.01	<0.01	0.02	<0.01	0.01
Standing dead herbaceous	0.88	0.92	1.10	1.04	1.03	0.98
Standing dead woody	2.74	1.21	2.83	1.93	2.80	1.68

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.

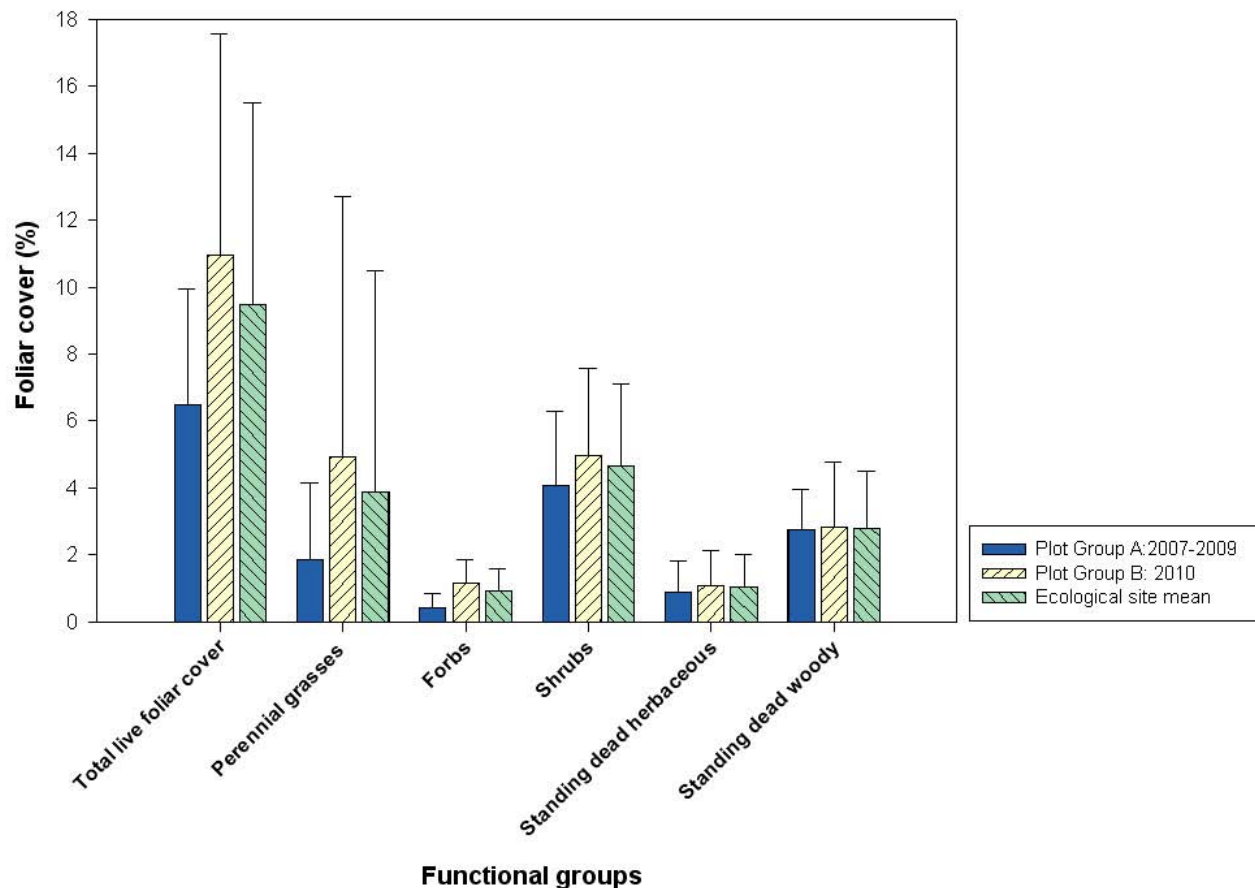


Figure 8. Mean percent foliar cover of functional groups for Plot Group A, Plot Group B, and all plots (ecological site mean) in the Sandstone Upland ecological site at WUPA. Error bars represent one standard deviation.

Table 7. Mean foliar cover and standard deviation, and mean quadrat and plot frequencies of the 15 most abundant shrub and herbaceous species and all nonnative species for all plots (ecological site mean) compared with the values for Plot Group A and Plot Group B in the Sandstone Upland ecological site at WUPA.

Species	Plot Group A 2007–2009				Plot Group B 2010				Ecological site mean			
	Foliar cover (%)	SD	Quadrat frequency (%)	Plot frequency (%)	Foliar cover (%)	SD	Quadrat frequency (%)	Plot frequency (%)	Foliar cover (%)	SD	Quadrat frequency (%)	Plot frequency (%)
<i>Pleuraphis jamesii</i>	1.099	1.784	40.00	70.00	3.718	8.036	60.67	90.00	2.845	6.698	53.78	83.33
<i>Ephedra torreyana</i>	1.332	1.101	40.89	100.00	1.706	1.771	32.67	90.00	1.581	1.558	35.41	93.33
<i>Artemisia filifolia</i>	1.440	1.903	33.78	40.00	1.241	1.652	33.67	55.00	1.307	1.705	33.70	50.00
<i>Fallugia paradoxa</i>	0.575	1.266	12.44	30.00	1.019	2.344	14.67	40.00	0.871	2.034	13.93	36.67
<i>Muhlenbergia porteri</i>	0.425	0.667	29.33	80.00	0.629	1.078	21.67	60.00	0.561	0.947	24.22	66.67
<i>Chamaesyce</i> spp. Group A ^a	0.106	0.121	32.00	66.67	0.600	0.633	87.00	95.00	0.436	0.568	68.67	85.56
<i>Sporobolus airoides</i>	0.053	0.117	2.67	20.00	0.300	0.755	8.00	25.00	0.217	0.626	6.22	23.33
<i>Ericameria nauseosa</i>	0.149	0.190	11.78	63.33	0.249	0.502	11.33	55.00	0.216	0.420	11.48	57.78
<i>Atriplex canescens</i>	0.090	0.122	8.00	56.67	0.275	0.502	15.67	40.00	0.213	0.421	13.11	45.56
<i>Salsola tragus</i> ^b	0.123	0.287	16.67	33.33	0.238	0.446	22.33	50.00	0.200	0.398	20.44	44.44
<i>Atriplex confertifolia</i>	0.181	0.326	16.00	30.00	0.194	0.562	8.67	15.00	0.189	0.489	11.11	20.00
<i>Bouteloua eriopoda</i>	0.148	0.307	10.89	33.33	0.076	0.283	6.33	30.00	0.100	0.286	7.85	31.11
<i>Gutierrezia microcephala</i>	0.118	0.146	16.44	53.33	0.090	0.263	7.67	30.00	0.099	0.227	10.59	37.78
<i>Solanum elaeagnifolium</i>	0	0	0	0	0.050	0.144	4.33	20.00	0.033	0.119	2.89	13.33
<i>Achnatherum hymenoides</i>	0.026	0.048	8.89	50.00	0.037	0.093	9.67	45.00	0.033	0.080	9.41	46.67
<i>Mollugo cerviana</i> ^b	0	0	0	0	0.012	0.052	0.33	5.00	0.008	0.043	0.22	3.33

^aAnnual species of *Chamaesyce* spp. were placed into 2 groups, A and B, based on morphological characteristics.

^bNonnative species.

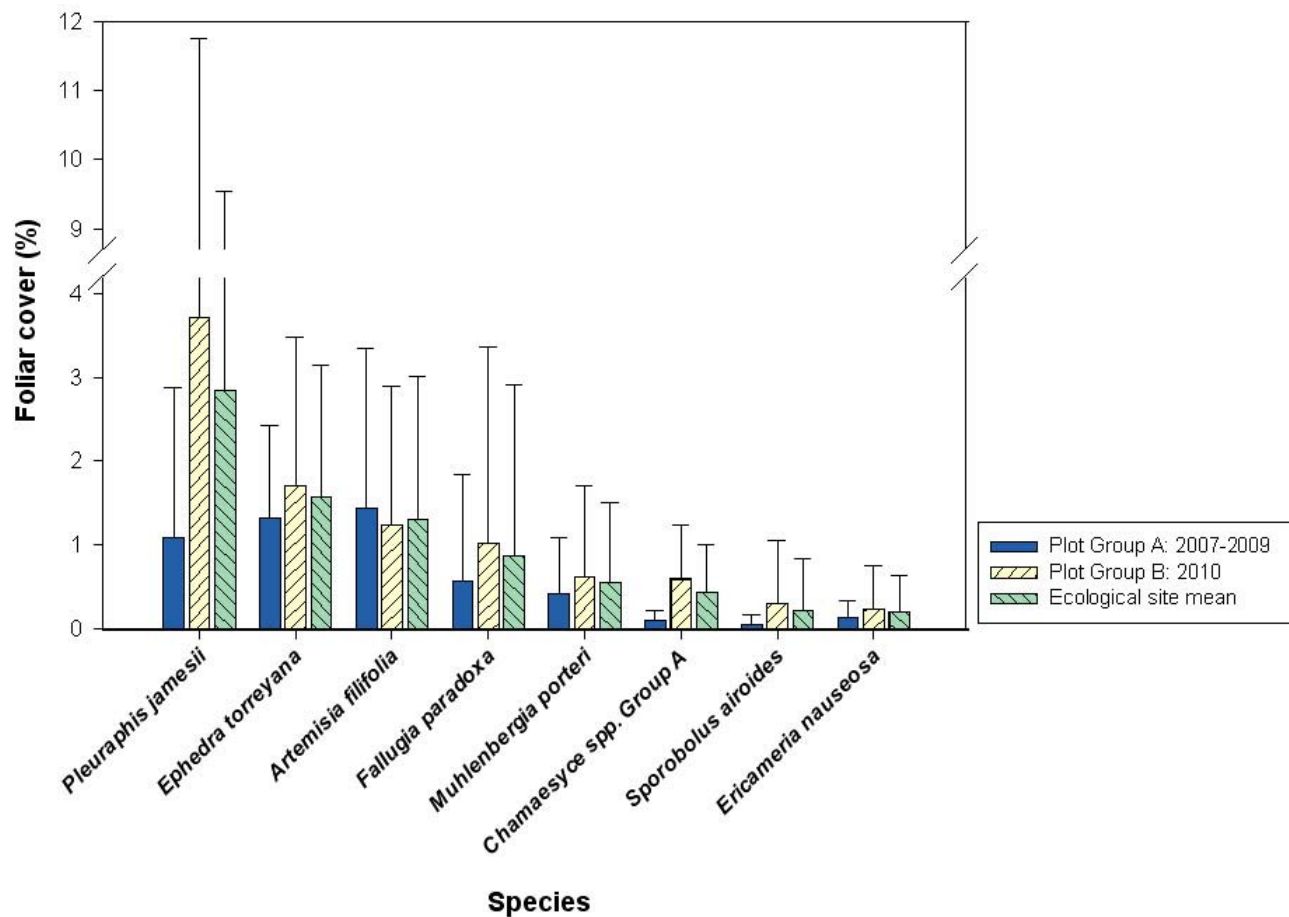


Figure 9. Mean percent foliar cover of the 8 most abundant shrub and herbaceous species for all plots (ecological site mean) compared to mean foliar cover for Plot Group A and Plot Group B in the Sandstone Upland ecological site at WUPA. Error bars represent one standard deviation.

Appendix B lists all species that occur in the ecological site, along with common names, families, mean foliar cover and plot frequencies by plot group.

We encountered 2 nonnative species in the plots. *Salsola tragus* was abundant, though not as abundant as it was in the Limy Upland ecological site. Its cover was 0.200%, and it occurred in 20.44% of the quadrats and 44.44% of the plots. *Mollugo cerviana* (threadstem carpetweed) only occurred in one plot with low cover.

We identified *Panicum obtusum* (vine mesquite) in one plot. This appears to be a new record for the park. In 2010 we corrected the identification for 2 species that had occurred previously in the plots. Plants that we identified as *Gutierrezia sarothrae* before 2010 are now identified as *Gutierrezia microcephala*, and plants that we previously identified as *Hesperostipa comata* are now identified as *Hesperostipa neomexicana*. In both cases, the corrected species predominates. However, the 2 congeneric species may occur in the ecological site and are often not easily distinguished from each other during our sampling period.

The diversity metrics demonstrate a pattern of moderately low diversity on the scale of the plot, with higher levels of diversity on the scale of the ecological site (table 8). On the scale of the plot, mean richness was 13.0. Moreover, Shannon diversity (which takes into account relative abundance of species and generally ranges between 1.5 and 3.5) was 1.479, and evenness (the degree to which all species are of equal abundance, ranging from 0 to 1) was 0.573. On the scale of the ecological site, richness was 60, and beta diversity (a measure of within-site heterogeneity, generally ranging between 1 and 5) was 4.749. This suggests that while diversity was low at a local level, there were large differences in species composition among the plots due to heterogeneity across the ecological site.

Table 8. Species diversity metrics for all species and for native species only for Plot Group A, Plot Group B, and all plots (ecological site mean) in the Sandstone Upland ecological site at WUPA.

	Plot Group A 2007-2009		Plot Group B 2010		Ecological site	
	Mean	SD	Mean	SD	Mean	SD
All species						
Plot						
Plot richness	12.9	3.0	13.1	3.9	13.0	3.5
Shannon diversity	1.463	0.232	1.487	0.620	1.479	0.515
Evenness	0.580	0.070	0.570	0.206	0.573	0.170
Ecological site						
Ecological site richness	34.3		52 ^a		60	
Beta diversity	2.906		4.298 ^a		4.749	
Native species						
Plot						
Plot richness	12.5	3.1	12.6	3.5	12.5	3.2
Shannon diversity	1.439	0.230	1.453	0.593	1.448	0.494
Evenness	0.576	0.062	0.567	0.203	0.570	0.167
Ecological site						
Ecological site richness	33.3		50 ^a		58	
Beta diversity	2.903		4.329 ^a		4.793	

^aThese are not mean values.

The largest differences between the 2 plot groups were found at the scale of the ecological site. Plot Group B had greater richness and beta diversity. This was likely the result of the larger sample size: 20 plots in Plot Group B compared to 10 plots in Plot Group A. When we recalculated the metrics using only native species, all metrics decreased, with the exception of beta diversity, which showed a substantial increase.

3.2.2 Trees

There was only one species of tree in the Sandstone Upland ecological site: *Juniperus monosperma* (oneseed juniper). The living overstory tree density was very sparse, at 0.7 stems/ha, and the basal area was also very low, at 0.13 m²/ha (table 9 and fig. 10). The large error bars indicate large among-plot variation: most plots had no trees, and ones that did only had 1 or 2 individuals. The mean diameter (at root crown) of the trees was 48.6 cm. The density of snags was 0.1 stems/ha, and the basal area was 0.03 m²/ha.

Living overstory tree density and basal area were higher in Plot Group A. There were no individuals in the sapling and seedling layers. The tree structure demonstrates a range of diameter sizes, from 35 to 75 cm (fig. 11).

3.2.3 Soil surface features

We measured the amount of soil surface potentially subject to erosion using cover estimates of soil surface features in quadrats. Fine gravel and bare soil dominated the soil surface in the plots of this ecological site, with 43.95% cover and 33.48% cover, respectively (table 10 and fig. 12). Other common features included duff/litter, with 6.90% cover, coarse gravel, with 4.93% cover, undifferentiated crust, with 4.67% cover, and live plant base, with 1.20%. The remainder of the soil surface features had less than 1% cover. There were trace amounts of cyanobacteria and moss, but no lichen, all of which are components of the biological soil crust.

Table 9. Mean density, mean basal area, and mean diameter at root crown of trees for Plot Group A, Plot Group B, and all plots (ecological site mean) in the Sandstone Upland ecological site at WUPA. All trees are *Juniperus monosperma*.

	Seedling ^a density (stems/ha)	Sapling ^a density (stems/ha)	Overstory ^a density (stems/ha)	Snag ^a density (stems/ha)	Overstory basal area (m ² /ha)	Snag basal area (m ² /ha)	Mean diameter at root crown (cm)
Plot Group A 2008 ^b	0	0	1.2	0.4	0.16	0.08	41.0
Plot Group B 2010	0	0	0.4	0	0.11	0	60.0
Ecological site mean	0	0	0.7	0.1	0.13	0.03	48.6

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

^bAll Plot Group A tree measurements are from 2008, when we implemented the revised method of measuring tree diameters.

Figure 10. Mean basal area for living trees and snags for Plot Group A, Plot Group B, and all plots (ecological site mean) in the Sandstone Upland ecological site at WUPA. Error bars represent 1 standard deviation.

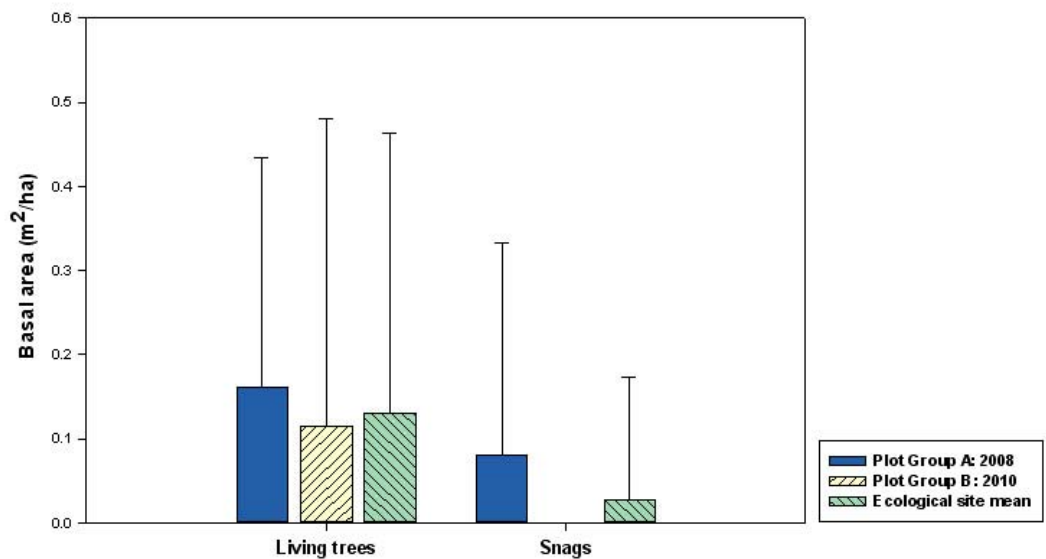
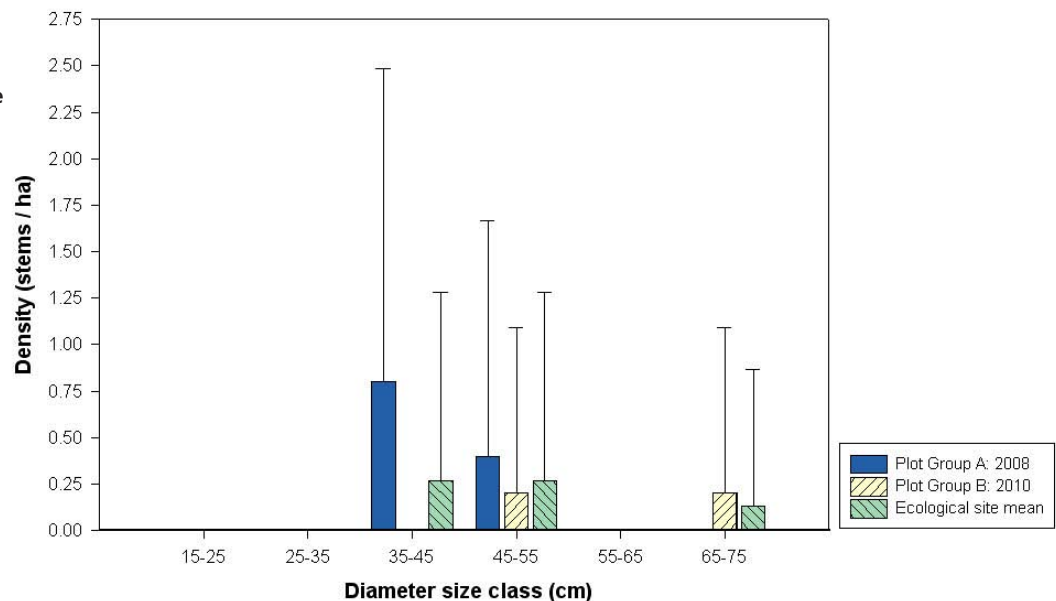


Figure 11. Size structure of living overstory trees for Plot Group A, Plot Group B, and all plots (ecological site mean) in the Sandstone Upland ecological site at WUPA. Error bars represent 1 standard deviation.



Differences in features between the 2 plot groups were relatively small with the exception of fine gravel and bare soil, and coarse gravel to a lesser extent. These differences are likely attributable to a variation in data collection methods. The 2010 crew interpreted soil particle and rock fragment size classes differently than did crews in earlier years, particularly the cut-off between the particle size of coarse sand (bare soil) and fine gravel.

Table 10. Cover of soil surface features for Plot Group A, Plot Group B, and all plots (ecological site mean) in the Sandstone Upland ecological site at WUPA.

Soil surface feature	Plot Group A 2007–2009		Plot Group B 2010		Ecological site	
	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Live plant base	1.17	0.99	1.22	1.03	1.20	0.98
Dead woody base	0.41	0.24	0.28	0.22	0.32	0.22
Dead herbaceous base	0.31	0.35	0.43	0.35	0.39	0.33
Bare soil	2.80	3.03	48.82	29.69	33.48	32.66
Duff/litter	6.88	3.80	6.91	4.86	6.90	4.39
Undifferentiated crust	4.18	4.64	4.92	7.98	4.67	6.93
Moss	0	0	<0.01	<0.01	<0.01	<0.01
Lichen	0	0	0	0	0	0
Cyanobacteria	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fine gravel (0.2 to <2 cm)	69.27	15.93	31.29	29.08	43.95	31.00
Coarse gravel (2 to <7.5 cm)	9.92	11.52	2.43	5.30	4.93	8.43
Cobble (7.5 to <25 cm)	1.44	2.01	0.42	0.82	0.76	1.34
Stone, bedrock (>25 cm)	0.86	1.69	0.04	0.12	0.31	1.01
Woody debris	0.05	0.09	0.20	0.63	0.15	0.51

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.

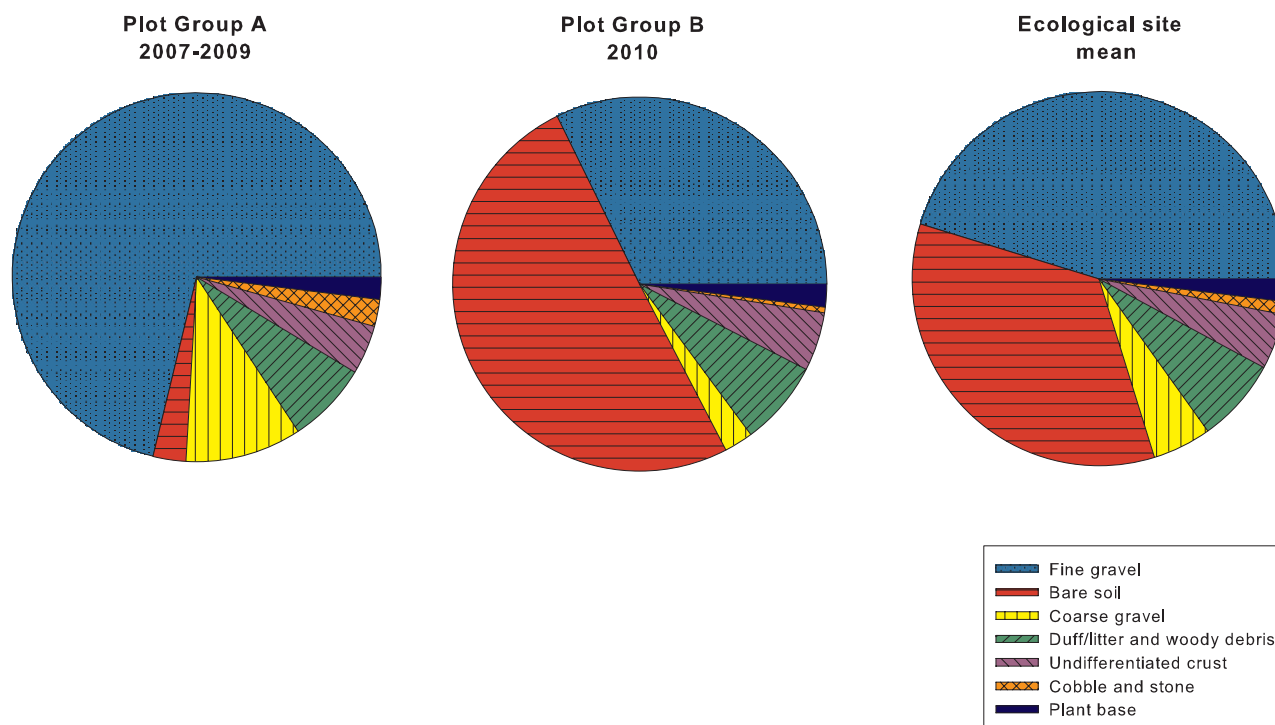


Figure 12. Mean percent cover of soil surface features for Plot Group A, Plot Group B, and all plots (ecological site mean) in the Sandstone Upland ecological site at WUPA.

3.3 Western Regional Climate Center precipitation data

Precipitation records for WUPA are available from the Western Regional Climate Center (2012). Figure 13 shows the total monthly precipitation for each of the 4 years of monitoring described in this report, compared with the long term average precipitation by month for the period 1948–2010.

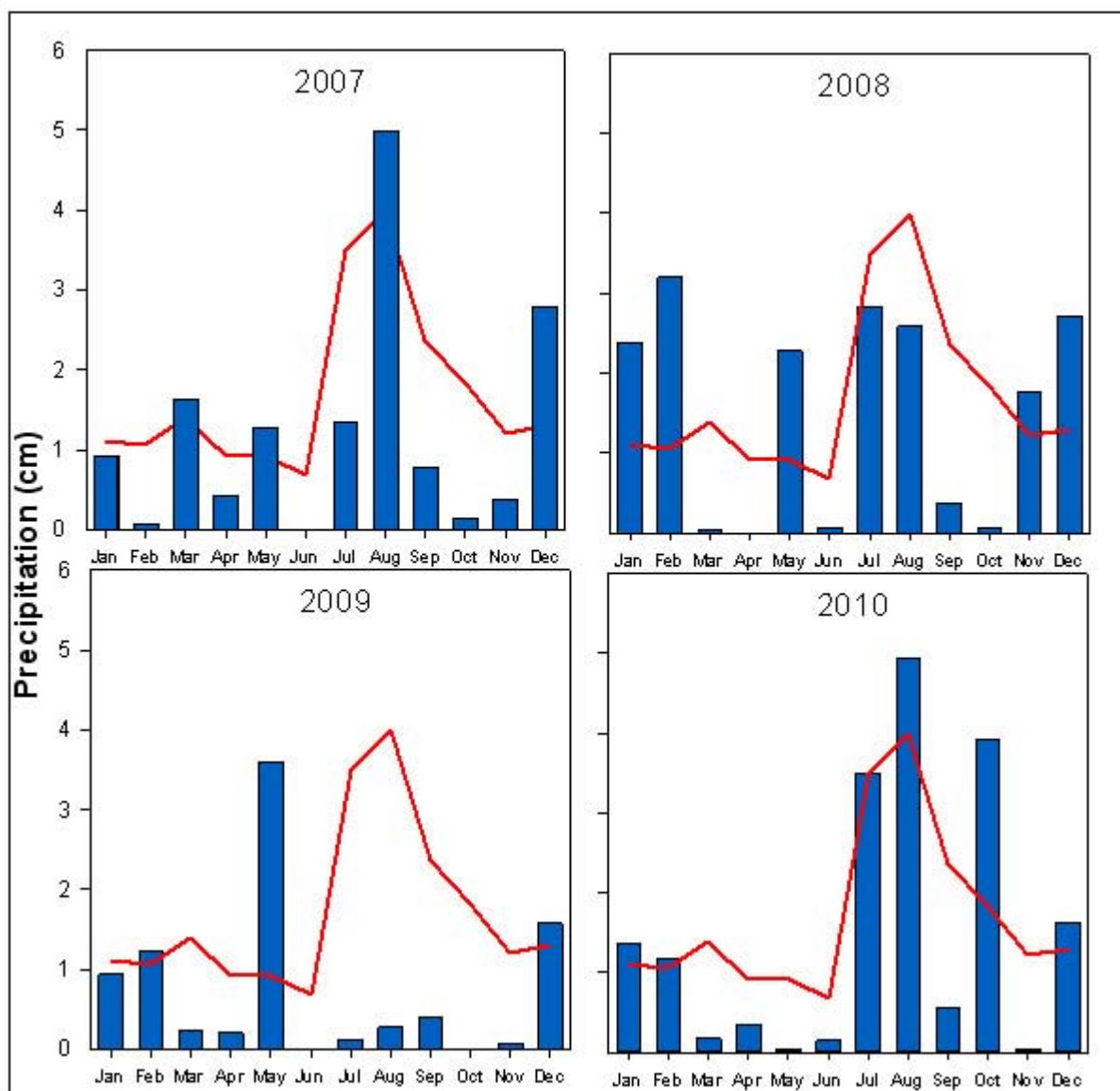


Figure 13. Total monthly precipitation for the 4 years of sampling taken from the Wupatki NM, AZ weather station (29542), collected by the Western Regional Climate Center. The red line represents the mean monthly totals for 1948 through 2010.

4 Discussion

The data presented in this report represent the baseline conditions of the vegetation and soils of these 2 ecological sites at WUPA. The Limy Upland and Sandstone Upland ecological sites represent 2 distinct ecosystems. The Limy Upland ecological site is a grassland, dominated by *Pleuraphis jamesii*, with a large forb component. In contrast, the Sandstone Upland ecological site is a diverse shrubland, co-dominated by a number of shrub species, with a large perennial grass component. The nonnative annual, *Salsola tragus*, is fairly frequent in the Sandstone Upland, but is dominant in the Limy Upland. Both ecological sites have fairly low species diversity at the plot scale (alpha diversity), but have relatively high species diversity at the landscape scale (beta diversity). Scattered individuals of *Juniperus monosperma* occur in both sites, but are more abundant in the Limy Upland ecological site. The lack of seedlings and saplings suggest that juniper recruitment has not occurred for many years.

The soil surface of both sites is dominated by fine and coarse gravel, which is composed of tephra or volcanic cinders. This cover seems to protect the soil from erosion. We have discontinued basal gap and soil stability monitoring protocols in these ecosites, as soil erosion did not appear to be a significant threat to either of these ecological sites.

The 2 plot groups represent different plots in different locations. We would expect minor differences in species composition and soil characteristics between them due to random spatial variation. Due to endogenous and exogenous factors, the species composition and structure and soil characteristics naturally vary. While spatial variability likely accounts for the majority of the differences between the 2 plot groups, additional variation may result from annual climatic variation. Variation in precipitation has been associated with changes in cover and frequency of herbaceous plants, particularly annual species and forbs. Precipitation records for WUPA indicate that 2010 had higher levels of precipitation in July and August than the other years we sampled at WUPA. This may have accounted for slightly higher cover and frequency values for herbaceous species in Plot Group B. These differences in precipitation, however, likely are a minor factor contributing to the differences between the plot groups.

The high abundance of *Salsola tragus* is concerning, particularly in the Limy Upland ecological site. There were 8 plots in Plot Group B where foliar cover of this species exceeded 20% in 2010. Since 2007 we've observed a steady increase in *S. tragus* mean foliar cover in the 10 plots of Plot Group A (0.260% in 2007, 1.422% in 2008, and 4.998% in 2009). While it is premature to interpret these recent results as a long-term trend, if they are considered along with *S. tragus* high invasive potential, there is cause for management concern.

Now that we have completed the baseline for our monitoring of these 2 ecological sites, we will begin to implement long term monitoring according to our revisit design. Our power analysis indicates that sample sizes of 30 plots should provide a large enough sample size to detect trends in key metrics. Before implementing our revisit design, we will compare our current sampling frame to the soil map currently being completed for the park by the NRCS. We will make changes in the sampling frame and possibly establish new plots if warranted.

We will then implement a revisit design using a panel design. Panel designs describe the temporal plan for revisiting monitoring plots through time. Between the extremes of monitoring the same set of plots with every revisit, and monitoring a new set of sites with each revisit, there are designs that provide some balance between repeated visits to individual plots and the total number of sites visited. Our general revisit design is a connected design in both spatial and temporal aspects that balances the allocation of effort between addressing temporal (year to year) variability and spatial variability within the ecological site. We will split the 30 plots in each ecological site into 3 panels, and sample 2 of the panels every other year (table 11). We will alternate years that we sample each ecological site.

Table 11. The panel design we are currently planning to use for the revisit design at WUPA. "X" represents 10 plots in an ecological site, for a total of 30 plots across 3 panels for the ecological site.

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 Limy Upland ecological site at WUPA between 2007 and 2010.

Table A1. Shrub and herbaceous species with mean foliar cover and mean plot frequency for Plot Group A, Plot Group B, and all plots (ecological site mean) in the Limy Upland ecological site at WUPA.

Species	Common name	Family	Plot Group A 2007–2009			Plot Group B 2010			Ecological site mean	
			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	0.037	0.037	20.00	0.025	13.33	13.33
<i>Amaranthus</i> spp.	pigweed	Amaranthaceae	0	0	0.040	0.040	25.00	0.027	16.67	16.67
<i>Aristida havardii</i>	Havard's threeawn	Poaceae	0.012	10.00	0.001	0.001	5.00	0.004	6.67	6.67
<i>Aristida purpurea</i>	Fendler's threeawn	Poaceae	0.018	43.33	0.009	0.009	10.00	0.012	21.11	21.11
<i>Artemisia filifolia</i>	sand sagebrush	Asteraceae	0	0	0.003	0.003	5.00	0.002	3.33	3.33
<i>Astragalus</i> spp.	milkvetch	Fabaceae	<0.001	3.33	0.002	0.002	25.00	0.001	17.78	17.78
<i>Atriplex canescens</i>	fourwing saltbush	Chenopodiaceae	0	0	0.012	0.012	5.00	0.008	3.33	3.33
<i>Bouteloua curtipendula</i>	sideoats grama	Poaceae	0.010	10.00	0.001	0.001	5.00	0.004	6.67	6.67
<i>Bouteloua eriopoda</i>	black grama	Poaceae	3.327	100.00	1.223	1.223	90.00	1.924	93.33	93.33
<i>Bouteloua gracilis</i>	blue grama	Poaceae	0.001	6.67	0	0	0	<0.001	2.22	2.22
<i>Chaetopappa ericoides</i>	rose heath	Asteraceae	0.020	90.00	0.010	0.010	40.00	0.013	56.67	56.67
<i>Chamaesaracha coronopus</i>	greenleaf five eyes	Solanaceae	0	0	0.004	0.004	40.00	0.003	26.67	26.67
<i>Chamaesyce</i> spp. Group A	annual sandmats	Euphorbiaceae	0.056	76.67	0.371	0.371	70.00	0.266	72.22	72.22
<i>Chamaesyce</i> spp. Group B	annual sandmats	Euphorbiaceae	0.035	63.33	0.080	0.080	85.00	0.065	77.78	77.78
<i>Chamaesyce albomarginata</i>	whitemargin sandmat	Euphorbiaceae	<0.001	3.33	0	0	0	<0.001	1.11	1.11
<i>Chamaesyce fendleri</i>	Fendler's sandmat	Euphorbiaceae	0.002	6.67	0.014	0.014	15.00	0.010	12.22	12.22
<i>Chenopodium fremontii</i>	Fremont's goosefoot	Chenopodiaceae	0.005	10.00	0.011	0.011	5.00	0.009	6.67	6.67
<i>Chenopodium leptophyllum</i>	narrowleaf goosefoot	Chenopodiaceae	0.402	80.00	0.759	0.759	85.00	0.640	83.33	83.33
<i>Chrysothamnus depressus</i>	longflower rabbitbrush	Asteraceae	0	0	0.003	0.003	5.00	0.002	3.33	3.33
<i>Cryptantha cinerea</i>	James' cryptantha	Boraginaceae	0	0	<0.001	<0.001	5.00	<0.001	3.33	3.33
<i>Cuscuta</i> sp.	dodder	Cuscutaceae	0.001	3.33	0	0	0	<0.001	1.11	1.11
<i>Elymus elymoides</i>	squirreltail	Poaceae	0.001	3.33	0.001	0.001	5.00	0.001	4.44	4.44
<i>Ephedra torreyana</i>	Torrey's jointfir	Ephedraceae	0	0	0.093	0.093	5.00	0.062	3.33	3.33
<i>Ericameria nauseosa</i>	rubber rabbitbrush	Asteraceae	0.320	93.33	0.301	0.301	80.00	0.307	84.44	84.44
<i>Escobaria vivipara</i>	spinytar	Cactaceae	0	0	<0.001	<0.001	5.00	<0.001	3.33	3.33

Table A1 (continued)

Species	Common name	Family	Plot Group A 2007–2009		Plot Group B 2010		Ecological site mean	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Euphorbia exstipulata</i>	squareseed spurge	Euphorbiaceae	0.002	6.67	0.003	25.00	0.002	18.89
<i>Evolvulus nuttallianus</i>	shaggy dwarf morning-glory	Convolvulaceae	0.009	50.00	0.003	45.00	0.005	46.67
<i>Fallugia paradoxa</i>	Apache plume	Rosaceae	0	0	0.012	5.00	0.008	3.33
<i>Gilia</i> sp.	gilia	Polemoniaceae	<0.001	3.33	0	0	<0.001	1.11
<i>Glandularia gooddingii</i>	southwestern mock vervain	Verbenaceae	0.002	6.67	0	0	0.001	2.22
<i>Gutierrezia microcephala</i>	threadleaf snakeweed	Asteraceae	<0.001	10.00	0.014	10.00	0.009	10.00
<i>Hesperostipa neomexicana</i>	New Mexico needlegrass	Poaceae	1.848	96.67	0.468	65.00	0.928	75.56
<i>Hoffmannseggia drepanocarpa</i>	sicklepod holdback	Fabaceae	0.002	13.33	0.002	20.00	0.002	17.78
<i>Kallstroemia californica</i>	California caltrop	Zygophyllaceae	<0.001	3.33	0	0	<0.001	1.11
<i>Kochia scoparia</i> ^a	Mexican burningbush	Chenopodiaceae	0.001	16.67	0.007	30.00	0.005	25.56
<i>Krascheninnikovia lanata</i>	winterfat	Chenopodiaceae	0.008	10.00	0	0	0.003	3.33
<i>Lithospermum incisum</i>	narrowleaf gromwell	Boraginaceae	0.001	10.00	0.001	5.00	0.001	6.67
<i>Lycium andersonii</i>	wolfberry	Solanaceae	0.003	6.67	0	0	0.001	2.22
<i>Machaeranthera canescens</i>	hoary tansyaster	Asteraceae	<0.001	3.33	<0.001	5.00	<0.001	4.44
<i>Mentzelia albicaulis</i>	whitestem blazingstar	Loasaceae	0	0	<0.001	5.00	<0.001	3.33
<i>Mentzelia multiflora</i>	Adonis blazingstar	Loasaceae	0	0	0.018	50.00	0.012	33.33
<i>Mollugo cerviana</i> ^a	threadstem carpetweed	Molluginaceae	0	0	0.001	10.00	0.001	6.67
<i>Muhlenbergia porteri</i>	bush muhly	Poaceae	0	0	0.031	5.00	0.021	3.33
<i>Opuntia</i> spp.	prickly pear	Cactaceae	0.003	6.67	0.001	10.00	0.002	8.89
<i>Opuntia whipplei</i>	Whipple's cholla	Cactaceae	0.003	16.67	0.003	10.00	0.003	12.22
<i>Physalis hederifolia</i>	ivyleaf groundcherry	Solanaceae	0	0	0.012	10.00	0.008	6.67
<i>Pleuraphis jamesii</i>	James' galleta	Poaceae	6.118	100.00	5.790	100.00	5.899	100.00
<i>Polanisia dodecandra</i>	redwhisker clammyweed	Capparaceae	<0.001	6.67	<0.001	5.00	<0.001	5.56
<i>Pomaria jamesii</i>	James' holdback	Fabaceae	0.001	10.00	0.007	20.00	0.005	16.67
<i>Portulaca oleracea</i> ^a	little hogweed	Portulacaceae	0	0	0.004	5.00	0.002	3.33
<i>Portulaca pilosa</i>	kiss me quick	Portulacaceae	0	0	0.001	5.00	0.001	3.33
<i>Salsola tragus</i> ^a	prickly Russian thistle	Chenopodiaceae	2.227	86.67	13.906	90.00	10.013	88.89
<i>Sanvitalia abertii</i>	Albert's creeping zinnia	Asteraceae	0	0	0.002	5.00	0.001	3.33

Table A1 (continued)

Species	Common name	Family	Plot Group A 2007–2009			Plot Group B 2010			Ecological site mean	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Senecio flaccidus</i>	threadleaf ragwort	Asteraceae	0.012	30.00	0	0	0.004	10.00		
<i>Sphaeralcea</i> spp.	globemallow	Malvaceae	0.006	50.00	0.001	20.00	0.003	30.00		
<i>Sphaeralcea ambigua</i>	apricot globemallow	Malvaceae	0.001	3.33	<0.001	5.00	<0.001	4.44		
<i>Sphaeralcea coccinea</i>	scarlet globemallow	Malvaceae	0	0	<0.001	5.00	<0.001	3.33		
<i>Sphaeralcea hastulata</i>	spear globemallow	Malvaceae	0.073	43.33	0.042	40.00	0.052	41.11		
<i>Sporobolus airoides</i>	alkali sacaton	Poaceae	0.115	23.33	0.056	10.00	0.075	14.44		
<i>Sporobolus cryptandrus</i>	sand dropseed	Poaceae	0.001	6.67	0.003	5.00	0.002	5.56		
<i>Sporobolus flexuosus</i>	mesa dropseed	Poaceae	0	0	0.046	5.00	0.031	3.33		
<i>Stanleya pinnata</i>	desert prince's plume	Brassicaceae	0	0	0.001	5.00	0.001	3.33		
<i>Stephanomeria</i> spp.	wire lettuce	Asteraceae	0.004	26.67	<0.001	5.00	0.001	12.22		
<i>Stephanomeria minor</i>	lesser wirelettuce	Asteraceae	<0.001	3.33	<0.001	5.00	<0.001	4.44		
<i>Stephanomeria pauciflora</i>	brownplume wirelettuce	Asteraceae	0.003	10.00	0.005	25.00	0.004	20.00		
<i>Tiquilia nuttallii</i>	Nuttall's crinklemat	Boraginaceae	0	0	0.001	5.00	<0.001	3.33		
<i>Tragia ramosa</i>	branched noseburn	Euphorbiaceae	0.004	10.00	0.002	5.00	0.003	6.67		
<i>Zinnia grandiflora</i>	Rocky Mountain zinnia	Asteraceae	0.015	43.33	0.039	25.00	0.031	31.11		
unknownWUPA20070829_1			0.002	3.33	0	0	0.001	1.11		
unknownWUPA2007-821_1			<0.001	3.33	0	0	<0.001	1.11		
unknownWUPA20070821_2			<0.001	3.33	0	0	<0.001	1.11		
unknownWUPA20070823_5			<0.001	3.33	0	0	<0.001	1.11		
unknownWUPA20080822_2			<0.001	3.33	0	0	<0.001	1.11		
unknownWUPA20080823_1			<0.001	6.67	0	0	<0.001	2.22		
unknownWUPA20090812_1			<0.001	3.33	0	0	<0.001	1.11		

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 plots sampled in 2008 (Plot Group A), plots sampled in 2010 (Plot Group B), and all plots (ecological site mean), in the Limy Upland ecological site at WUPA.

Species	Common name	Family	Plot Group A 2008		Plot Group B 2010		Ecological site mean	
			Basal area (m ² /ha)	Plot frequency (%)	Basal area (m ² /ha)	Plot frequency (%)	Basal area (m ² /ha)	Plot frequency (%)
<i>Juniperus monosperma</i>	oneseed juniper	Cupressaceae	1.57	70.00	0.56	45.00	0.89	53.33

Appendix B: Complete species list for plots sampled in the Sandstone Upland ecological site at WUPA between 2007 and 2010.

Table B1. Shrub and herbaceous species with mean foliar cover and mean plot frequency for Plot Group A, Plot Group B, and all plots (ecological site mean) in the Sandstone Upland ecological site at WUPA.

Species	Common name	Family	Plot Group A 2007–2009		Plot Group B 2010		Ecological site mean	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Achnatherum hymenoides</i>	Indian ricegrass	Poaceae	0.026	50.00	0.037	45.00	0.033	46.67
<i>Ambrosia acanthicarpa</i>	flatspine burr ragweed	Asteraceae	0	0	0.035	15.00	0.023	10.00
<i>Amsonia</i> sp.	bluestar	Apocynaceae	0	0	0.025	5.00	0.017	3.33
<i>Aristida purpurea</i>	Fendler's threawn	Poaceae	0.017	20.00	0.013	20.00	0.014	20.00
<i>Artemisia filifolia</i>	sand sagebrush	Asteraceae	1.440	40.00	1.241	55.00	1.307	50.00
<i>Astragalus</i> sp.	milkvetch	Fabaceae	0	0	0.004	25.00	0.003	16.67
<i>Atriplex canescens</i>	fourwing saltbush	Chenopodiaceae	0.090	56.67	0.275	40.00	0.213	45.56
<i>Atriplex confertifolia</i>	shadscale saltbush	Chenopodiaceae	0.181	30.00	0.194	15.00	0.189	20.00
<i>Bouteloua eriopoda</i>	black grama	Poaceae	0.148	33.33	0.076	30.00	0.100	31.11
<i>Brickellia oblongifolia</i>	Mohave brickellbush	Asteraceae	0.013	33.33	0	0	0.004	11.11
<i>Chaetopappa ericoides</i>	rose heath	Asteraceae	0.003	16.67	0.001	5.00	0.001	8.89
<i>Chamaesaracha coronopus</i>	greenleaf five eyes	Solanaceae	0.002	20.00	0.005	10.00	0.004	13.33
<i>Chamaesyce</i> spp. Group A	annual sandmats	Euphorbiaceae	0.106	66.67	0.600	95.00	0.436	85.56
<i>Chamaesyce</i> spp. Group B	annual sandmats	Euphorbiaceae	<0.001	3.33	<0.001	5.00	<0.001	4.44
<i>Chamaesyce fendleri</i>	Fendler's sandmat	Euphorbiaceae	0.016	50.00	0.015	50.00	0.016	50.00
<i>Chenopodium leptophyllum</i>	narrowleaf goosefoot	Chenopodiaceae	<0.001	3.33	0	0	<0.001	1.11
<i>Dasyochloa pulchella</i>	low woollygrass	Poaceae	0.017	40.00	0.008	30.00	0.011	33.33
<i>Elymus elymoides</i>	squirreltail	Poaceae	0	0	0.001	5.00	0.001	3.33
<i>Ephedra torreyana</i>	Torrey's jointfir	Ephedraceae	1.332	100.00	1.706	90.00	1.581	93.33
<i>Ephedra viridis</i>	mormon tea	Ephedraceae	0.013	23.33	0.038	15.00	0.029	17.78
<i>Ericameria nauseosa</i>	rubber rabbitbrush	Asteraceae	0.149	63.33	0.249	55.00	0.216	57.78
<i>Eriogonum cernuum</i>	nodding buckwheat	Polygonaceae	0.026	23.33	0.019	10.00	0.022	14.44
<i>Eriogonum corymbosum</i>	crispleaf buckwheat	Polygonaceae	0.014	23.33	0.039	10.00	0.031	14.44
<i>Eriogonum leptoclodon</i>	sand buckwheat	Polygonaceae	0.010	13.33	0	0	0.003	4.44
<i>Euphorbia exstipulata</i>	squareseed spurge	Euphorbiaceae	0	0	<0.001	5.00	<0.001	3.33

Table B1 (continued)

Species	Common name	Family	Plot Group A 2007–2009		Plot Group B 2010		Ecological site mean	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Fallugia paradoxa</i>	Apache plume	Rosaceae	0.575	30.00	1.019	40.00	0.871	36.67
<i>Gilia</i> spp.	gilia	Polemoniaceae	0.005	33.33	0	0	0.002	11.11
<i>Gutierrezia microcephala</i>	threadleaf snakeweed	Asteraceae	0.118	53.33	0.090	30.00	0.099	37.78
<i>Hesperostipa neomexicana</i>	New Mexico needlegrass	Poaceae	<0.001	3.33	<0.001	10.00	<0.001	7.78
<i>Lycium andersonii</i>	water jacket	Solanaceae	0	0	<0.001	5.00	<0.001	3.33
<i>Mentzelia albicaulis</i>	whitestem blazingstar	Loasaceae	0	0	0.048	65.00	0.032	43.33
<i>Mentzelia pumila</i>	dwarf mentzelia	Loasaceae	0.001	3.33	0.010	10.00	0.007	7.78
<i>Mollugo cerviana</i> ^a	threadstem carpetweed	Molluginaceae	0	0	0.012	5.00	0.008	3.33
<i>Muhlenbergia porteri</i>	bush muhly	Poaceae	0.425	80.00	0.629	60.00	0.561	66.67
<i>Opuntia</i> spp.	prickly pear	Cactaceae	0	0	0.004	5.00	0.003	3.33
<i>Opuntia whipplei</i>	Whipple's cholla	Cactaceae	0	0	<0.001	5.00	<0.001	3.33
<i>Panicum obtusum</i>	vine mesquite	Poaceae	0	0	0.012	5.00	0.008	3.33
<i>Phacelia</i> sp.	scorpionweed	Hydrophyllaceae	0	0	<0.001	5.00	<0.001	3.33
<i>Physalis hederifolia</i>	ivyleaf groundcherry	Solanaceae	0	0	<0.001	5.00	<0.001	3.33
<i>Pleuraphis jamesii</i>	James' galleta	Poaceae	1.099	70.00	3.718	90.00	2.845	83.33
<i>Psilostrophe sparsiflora</i>	greenstem paperflower	Asteraceae	0	0	0.014	10.00	0.009	6.67
<i>Salsola tragus</i> ^a	prickly Russian thistle	Chenopodiaceae	0.123	33.33	0.238	50.00	0.200	44.44
<i>Solanum elaeagnifolium</i>	silverleaf nightshade	Solanaceae	0	0	0.050	20.00	0.033	13.33
<i>Sphaeralcea</i> spp.	globemallow	Malvaceae	0.007	26.67	0.034	20.00	0.025	22.22
<i>Sphaeralcea ambigua</i>	apricot globemallow	Malvaceae	0	0	0.003	5.00	0.002	3.33
<i>Sphaeralcea grossulariifolia</i>	gooseberryleaf globemallow	Malvaceae	0.029	26.67	0	0	0.010	8.89
<i>Sphaeralcea hastulata</i>	spear globemallow	Malvaceae	0.033	43.33	0.013	20.00	0.020	27.78
<i>Sphaeralcea parvifolia</i>	smallflower globemallow	Malvaceae	0.011	10.00	0	0	0.004	3.33
<i>Sporobolus airoides</i>	alkali sacaton	Poaceae	0.053	20.00	0.300	25.00	0.217	23.33
<i>Stanleya pinnata</i>	desert prince's plume	Brassicaceae	0	0	0.027	15.00	0.018	10.00
<i>Stephanomeria</i> spp.	wire lettuce	Asteraceae	0.009	43.33	0.004	10.00	0.006	21.11
<i>Stephanomeria minor</i>	lesser wirelettuce	Asteraceae	<0.001	3.33	0.008	20.00	0.005	14.44
<i>Stephanomeria pauciflora</i>	brownplume wirelettuce	Asteraceae	0.001	13.33	0.022	25.00	0.015	21.11

Table B1 (continued)

Species	Common name	Family	Plot Group A 2007–2009			Plot Group B 2010			Ecological site mean	
			Foliar cover (%)	Plot frequency (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Plot frequency (%)
<i>Tetradlea coulteri</i>	Coulter's wrinklefruit	Verbenaceae	0.031	46.67	0.026	0.026	40.00	0.028	42.22	42.22
<i>Tiquilia hispida</i>	hairy crinklemat	Boraginaceae	0.009	10.00	0.001	0.001	5.00	0.004	6.67	6.67
<i>Tiquilia nuttallii</i>	Nuttall's crinklemat	Boraginaceae	0	0	0.033	0.033	40.00	0.022	26.67	26.67
<i>Yucca angustissima</i>	narrowleaf yucca	Agavaceae	0.001	6.67	0	0	0	<0.001	2.22	2.22
<i>Zinnia grandiflora</i>	Rocky Mountain zinnia	Asteraceae	0.002	10.00	0.048	0.048	25.00	0.033	20.00	20.00
unknownWUPA20070821_1			<0.001	3.33	0	0	0	<0.001	1.11	1.11
unknownWUPA20080827_1			<0.001	6.67	0	0	0	<0.001	2.22	2.22
unknownWUPA20100822_1			0	0	<0.001	<0.001	5.00	<0.001	3.33	3.33

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

^aNonnative species.

Table B2. Tree species with mean basal area and plot frequency for plots sampled in 2008 (Plot Group A), plots sampled in 2010 (Plot Group B), and all plots (ecological site mean), in the Sandstone Upland ecological site at WUPA.

Species	Common name	Family	Plot Group A 2008			Plot Group B 2010			Ecological site mean	
			Basal area (m ² /ha)	Plot frequency (%)	Plot frequency (%)	Basal area (m ² /ha)	Plot frequency (%)	Basal area (m ² /ha)	Plot frequency (%)	Plot frequency (%)
<i>Juniperus monosperma</i>	oneseed juniper	Cupressaceae	0.16	30.00	0.11	0.11	10.00	0.13	16.67	16.67