



Integrated Upland Vegetation and Soils Monitoring for Wupatki National Monument

2009 Summary Report

Natural Resource Data Series NPS/SCPN/NRDS—2011/174



ON THE COVER

Crew members collecting data in a plot in the Limy Upland ecological site at Wupatki National Monument

Photograph by: Jeff Organ

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

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Introduction and Background

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

SCPN and park staff selected two ecological sites for long-term monitoring of upland vegetation and soils at Wupatki National Monument (WUPA): Limy Upland and Sandstone Upland. 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 ecological sites both represent large areas of the park, and they are relatively distinct from each other. They face numerous threats, including climate change, and invasion by nonnative species.

In 2007 the Integrated Upland Monitoring program of SCPN began monitoring upland sites at WUPA with the installation of 10 plots in each ecological site. We have sampled the quadrats transects annually for three years to determine the range of temporal variability for key metrics. In this report, we document monitoring activities in the 2009 field season and compare these data with the data collected in 2007 and 2008.

Methods

Sampling frame

We derived the sampling frame from the maps of the Limy Upland and Sandstone Upland ecological sites, which were developed by the US Natural Resources Conservation Service (See Appendix A of DeCoster et al., in review). The sampling frame is the area from which we randomly select our sites, and hence the area to which statistical inferences can be made. To create the sampling frame, we modified the map of the ecological site using Geographical Information System (GIS) technology by removing slopes that exceeded 20%, roads, buildings, and other infrastructure (fig. 1).

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 an archaeologist examined the sites and rejected points that landed too close to archaeological sites. Before establishing a plot, the Integrated Upland crew conducted an ecological site assessment for each sampling point and rejected sites that did not fall within the ecological site, had a slope greater than 20%, or contained a major disturbance. In the Limy Upland ecological site, two points were rejected: one point was in proximity to an archaeological site and one occurred in the wrong ecological site. One point was rejected in the Sandstone Upland ecological site because it occurred in the wrong ecological site.

Field methods

In 2009, the SCPN Upland Monitoring crew sampled all 20 plots that were established at WUPA. The plots were 0.50 ha in size, measuring 71 × 71 m. Shrub and herbaceous data and soil data were collected on three 50 m transects, spaced 25 m apart, within each plot. In 2007 the crew collected the data in all the plots between late August and early September; in 2008 and 2009 they collected data in late August. Field methodology is provided in detail in the SCPN Integrated Upland Protocol (DeCoster et al. in review).

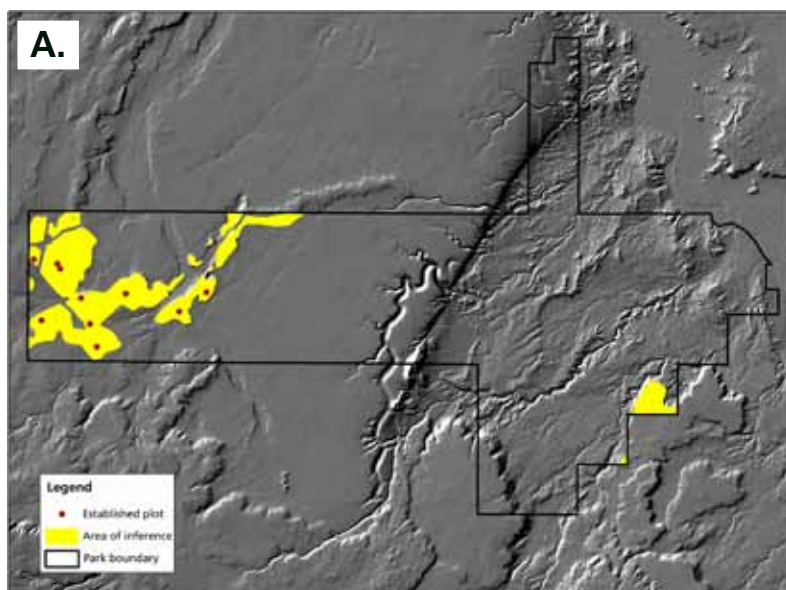
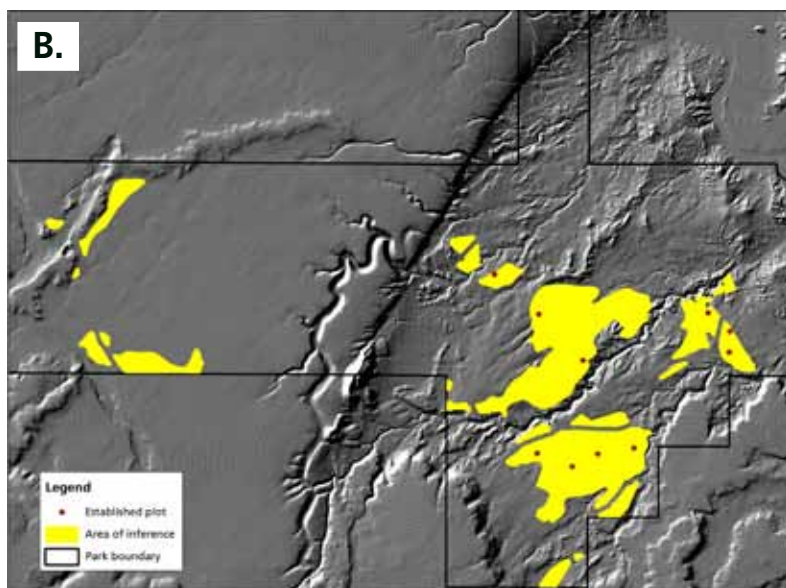


Figure 1. Sampling frame of A) Limy Upland and B) Sandstone Upland ecological sites each showing 10 plots sampled in 2007, 2008, and 2009



Shrub and herbaceous vegetation

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

Overstory trees and saplings

We measured and mapped trees in 2007, but did not remeasure them in 2008 or 2009. In 2008 we

measured tree canopy closure with a hemispherical densiometer at five points along each transect. In 2009 we took no measurements of the trees or canopy.

Soil stability and hydrologic function

The crew estimated the percent cover of soil surface features in the 1 m² quadrats in conjunction with shrub and herbaceous data and recorded the cover in one of 12 cover classes. In 2007 the crew recorded the length of basal gaps (the space between plant bases) along each transect and conducted a soil aggregate stability test using 18 soil samples collected along the transects. These procedures were not repeated in 2008 or 2009.

Data summary

The sample unit for summary and analysis is the plot; hence, we summarized data at the level of the plot. In order to calculate summary statistics for the ecological site, 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 midpoints, e.g. using 7.5% for cover class 5%–10%. The mean cover was calculated for each plot, and the mean and standard deviation (SD) were calculated for the ecological site from the plot means. 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 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 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.

Results

Limy Upland ecological site

Shrub and herbaceous vegetation

Perennial grasses dominated the vegetation of the Limy Upland ecological site at WUPA (table 1 and fig. 2), with less cover of shrubs, forbs, and cacti/succulents. The mean cover of total live vegetation ranged between 14.19% and 18.44%. Cover of shrubs, cacti/succulents, and standing dead woody remained under 1%. There were no annual grasses. Forb cover increased over the three years, from 0.72% in 2007 to 5.19% in 2009. Standing dead herbaceous cover ranged from 3.56% to 6.17%.

The dominant grasses in the Limy Upland ecological site were *Pleuraphis jamesii* (James' galleta), *Bouteloua eriopoda* (black grama), and *Hesperostipa comata* (needle and thread). Many of the dominant species showed little change in cover among the three years, especially considering the large standard deviations (table 2 and fig. 3). Two species, however, did change substantially. *Salsola tragus* (prickly Russian thistle) increased over the three years, from 0.260% in 2007 to 4.998% in 2009. Cover of *Chenopodium leptophyllum* (narrowleaf goosefoot) increased from 0.115% in 2007 to 0.998% in 2008, and then decreased to 0.102% in 2009. *Chamaesyce* spp. (two groups of annual sandmats based on morphological characteristics) showed large decreases in 2008. *Aristida harvardii* (Harvard's three awn) also showed a large decrease in 2008 and was not present in 2009. Quadrat and plot frequencies showed similar trends: most species did not change substantially between years, with the exception of those species that demonstrated substantial changes in cover.

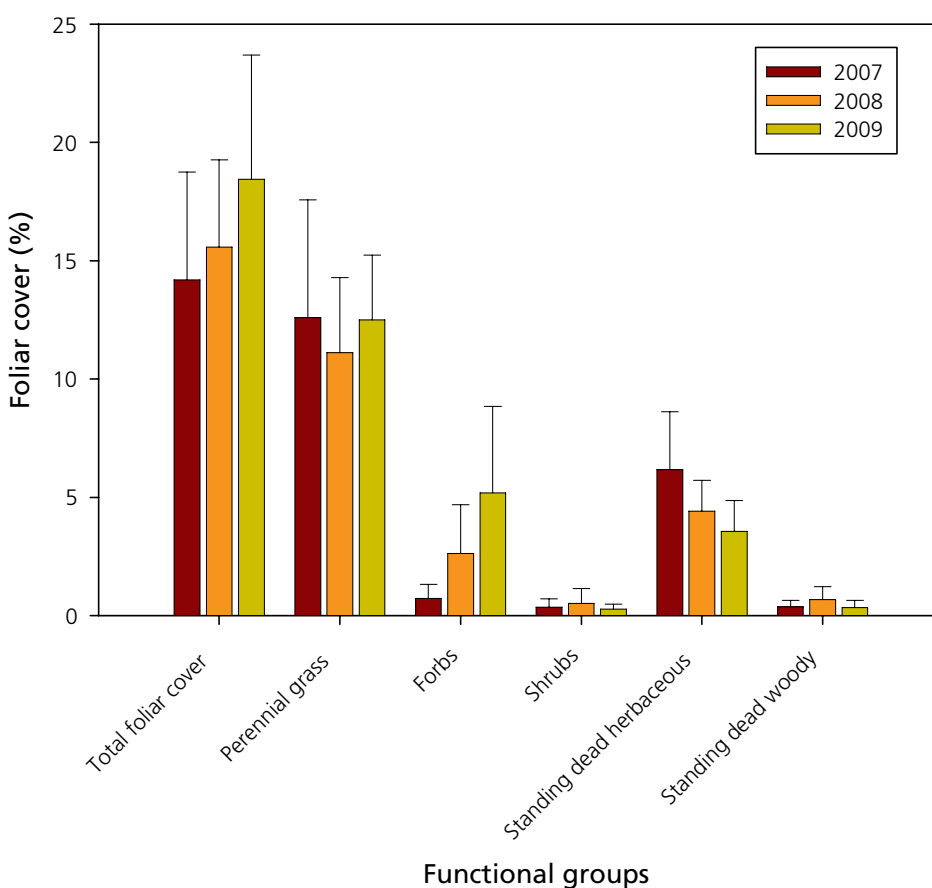


Figure 2. Mean cover of functional groups (except cacti/succulents) at the Limy Upland ecological site in 2007, 2008, and 2009. Error bars represent one standard deviation.

Table 1. Mean foliar cover of functional groups for 2007, 2008, and 2009 in the Limy Upland ecological site

Functional groups	Foliar cover (%)					
	2007		2008		2009	
	Mean	(SD)	Mean	(SD)	Mean	(SD)
Total live foliar cover	14.19	(4.56)	15.58	(3.69)	18.44	(5.26)
Perennial grasses, graminoids	12.60	(4.97)	11.12	(3.17)	12.50	(2.74)
Annual grasses	0	(0)	0	(0)	0	(0)
Forbs	0.72	(0.60)	2.63	(2.06)	5.19	(3.65)
Shrubs	0.36	(0.35)	0.52	(0.64)	0.28	(0.22)
Cacti, succulents	0.01	(0.02)	0.01	(0.03)	<0.01	(<0.01)
Standing dead herbaceous	6.17	(2.45)	4.42	(1.31)	3.56	(1.31)
Standing dead woody	0.38	(0.27)	0.68	(0.56)	0.34	(0.30)

Note: Understory tree cover was only measured in 2007, and was included in the total foliar cover

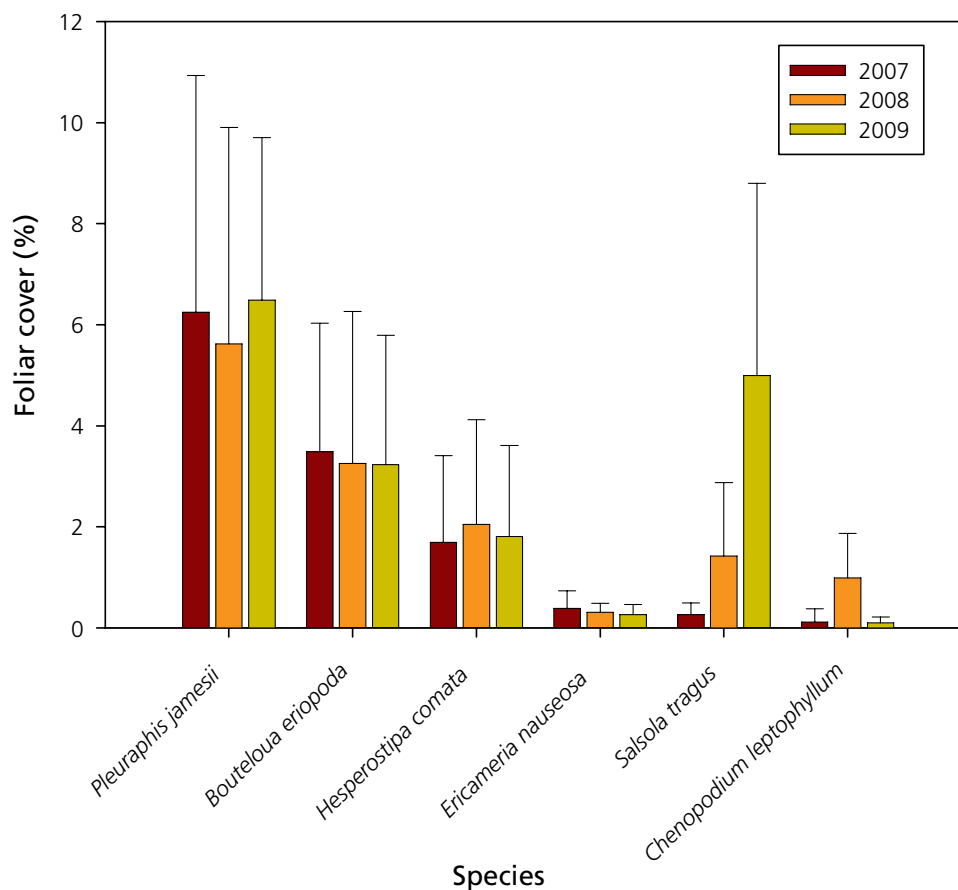


Figure 3. Mean foliar cover of the ten most abundant shrub and herbaceous species in 2007, 2008, and 2009 in the Limy Upland ecological site. Error bars represent one standard deviation.

Table 2. Mean foliar cover and frequency of the fifteen most abundant vascular species and all nonnative species in 2007, 2008, and 2009 at the Limy Upland ecological site

Species	2007				2008				2009			
	Mean cover (%)	SD	Quad freq	Plot freq	Mean cover (%)	SD	Quad freq	Plot freq	Mean cover (%)	SD	Quad freq	Plot freq
<i>Pleuraphis jamesii</i>	6.251	4.683	96.00	100	5.618	4.285	96.67	100	6.486	3.219	94.67	100
<i>Bouteloua eriopoda</i>	3.492	2.538	78.67	100	3.252	3.012	78.67	100	3.236	2.554	76.00	100
<i>Hesperostipa comata</i>	1.691	1.718	76.67	90	2.048	2.072	78.00	100	1.807	1.807	68.00	100
<i>Ericameria nauseosa</i>	0.387	0.352	28.67	100	0.310	0.177	28.67	100	0.264	0.200	20.67	80
<i>Salsola tragus</i> ^a	0.260	0.240	40.67	80	1.422	1.456	84.00	90	4.998	3.801	83.33	90
<i>Chenopodium leptophyllum</i>	0.115	0.267	16.00	50	0.990	0.881	93.33	100	0.102	0.112	46.67	90
<i>Sporobolus airoides</i>	0.098	0.240	3.33	20	0.119	0.342	4.00	20	0.127	0.293	4.00	30
<i>Sphaeralcea hastulata</i>	0.090	0.141	15.33	50	0.063	0.118	14.00	50	0.066	0.130	11.33	30
<i>Chamaesyce</i> spp. Group A	0.074	0.136	47.33	100	0.009	0.013	14.67	50	0.086	0.192	24.00	80
<i>Chamaesyce</i> spp. Group B	0.068	0.080	58.67	100	0.001	0.001	1.33	20	0.035	0.061	20.00	70
<i>Aristida havardii</i>	0.034	0.101	4.00	20	0.002	0.006	0.67	10	0	0	0	0
<i>Bouteloua curtipendula</i>	0.023	0.074	0.67	10	0.002	0.006	0.67	10	0.005	0.016	0.67	10
<i>Zinnia grandiflora</i>	0.017	0.031	10.00	40	0.014	0.024	6.00	40	0.014	0.029	10.67	50
<i>Chaetopappa ericoides</i>	0.016	0.020	16.67	90	0.020	0.021	20.00	90	0.023	0.027	19.33	90
<i>Evolvulus nuttallianus</i>	0.011	0.019	12.00	50	0.009	0.020	11.33	40	0.006	0.010	8.67	60
<i>Kochia scoparia</i> ^a	0	0	0	0	<0.001	0.001	0.67	10	0.002	0.004	4.67	40

Note: Species are arranged in descending order by their 2007 cover.

^aNonnative species.

There were, however, a number of species that were not present in the plots in all three years. Some species were present in only one of the three years and are referred to here as unique species. Others were present in two of the three years. In 2007 there were nine unique species (not including the two unknowns); in 2008 there were two, and in 2009 there were five (Appendix A).

We found two nonnative species in the plots in each of the three years. *Salsola tragus* increased over the three years, as described above. *Kochia scoparia* (Mexican burning bush) occurred in 2008 and 2009 in low cover and frequencies. Appendix A lists all species, along with common names, families, mean foliar covers, and plot frequencies by year.

The diversity indices showed moderately small among-year variation (table 3). On the scale of the plot, species richness varied among the three years between 13.1 to 13.8 species per plot, with 2008 having the lowest value (table 3). Shannon diversity (which takes into account relative species abundance, and generally ranges between 1.5 and 3.5) ranged between 1.175 and 1.365; and evenness (the degree to which all species are of equal abundance, ranging from 0 to 1) ranged between 0.449 and 0.538 (Margalef 1972). On the scale of the ecological site, species richness ranged between 36 and 41 species, with 2009 having the lowest value; and beta diversity (a measure of within site heterogeneity, generally ranging between 1 and 5) ranged between 2.880 and 3.306 (McClune and Grace 2002). When these indices were recalculated using only native species, all indices were slightly lower, except beta diversity, which was higher.

Table 3. Species diversity metrics for all species and for native species only at the Limy Upland ecological site

	2007		2008		2009	
	Mean	(SD)	Mean	(SD)	Mean	(SD)
All species						
Plot						
Plot richness	13.8	(2.4)	13.1	(2.3)	13.5	(2.2)
Shannon diversity	1.175	(0.317)	1.365	(0.268)	1.250	(0.275)
Evenness	0.449	(0.114)	0.538	(0.119)	0.480	(0.095)
Ecological site						
Ecological site richness	41		40		36	
Beta diversity	3.203		3.306		2.880	
Native species						
Plot						
Plot richness	13.0	(2.3)	12.1	(2.5)	12.9	(2.2)
Shannon diversity	1.105	(0.288)	1.208	(0.213)	1.034	(0.233)
Evenness	0.434	(0.114)	0.494	(0.109)	0.414	(0.087)
Ecological site						
Ecological site richness	40		38		34	
Beta diversity	3.333		3.423		3.036	

Soil stability and hydrologic function

The crew monitored soil surface features in all three years. The largest components were fine gravel and coarse gravel (i.e. volcanic cinders). As expected, most changes in the surface features were relatively small (table 4 and fig. 4).

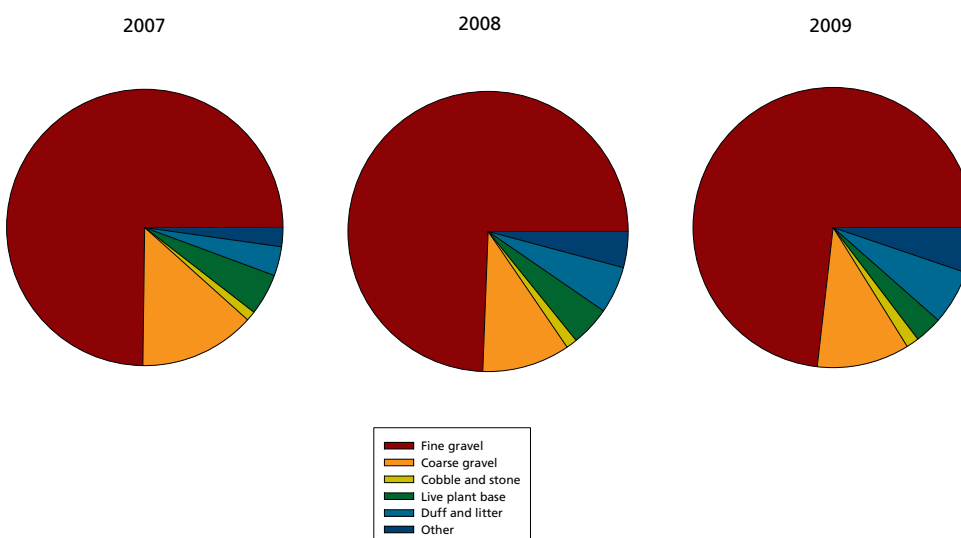


Figure 4. Mean cover of soil surface features at the Limy Upland ecological site in 2007, 2008, and 2009.

Table 4. Cover of soil surface features at the Limy Upland ecological site

Surface feature	2007		2008		2009	
	Mean (%)	(SD)	Mean (%)	(SD)	Mean (%)	(SD)
Live plant base	4.87	(1.60)	4.64	(1.96)	3.16	(1.34)
Dead woody base	0.02	(0.02)	0.07	(0.08)	0.16	(0.27)
Dead herbaceous base*	0.06	(0.19)	1.83	(0.68)	1.48	(0.77)
Bare soil	0.83	(0.61)	0.28	(0.28)	1.00	(1.98)
Duff and litter	3.42	(1.67)	5.48	(2.42)	6.27	(3.36)
Undifferentiated crust	1.35	(1.35)	2.02	(0.99)	2.58	(1.58)
Moss	0	(0)	0	(0)	0	(0)
Lichen	0	(0)	0	(0)	0	(0)
Cyanobacteria	0	(0)	0	(0)	0	(0)
Fine gravel (0.2–2 cm)	75.08	(14.77)	75.22	(12.27)	73.15	(13.08)
Coarse gravel (2–7.5 cm)	13.61	(15.40)	10.26	(11.99)	10.67	(13.71)
Cobble (7.5–25 cm)	0.65	(0.53)	0.81	(0.65)	0.87	(0.86)
Stone, bedrock (>25 cm)	0.50	(0.76)	0.48	(0.62)	0.61	(0.94)
Woody debris	0	(0)	0	(0)	0.01	(0.02)

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

Sandstone Upland ecological site

Shrub and herbaceous vegetation

Shrubs dominated the vegetation of the Sandstone Upland ecological site at WUPA (table 5 and fig. 5), with less cover of perennial grasses, forbs, and cacti/succulents. The mean cover of the total live vegetation ranged between 5.38% and 8.07%. Shrubs ranged between 3.51% and 4.76%. Annual grasses and cacti/succulents occurred in trace amounts, annual grasses only occurred in 2007, and cacti/succulents only occurred in 2007 and 2008. All of the functional groups had their highest cover in 2008 with the exception of annual grasses.

The dominant shrubs in the Sandstone Upland ecological site were *Artemisia filifolia* (sand sagebrush), *Ephedra torreyana* (Torrey's jointfir), and *Fallugia paradoxa* (Apache plume); the dominant grasses were *Pleuraphis jamesii* (James' galleta) and *Muhlenbergia porteri* (bush muhly); and the dominant forbs were *Chamaesyce* spp. (annual sandmats) and *Tetradlea coulteri* (Coulter's wrinklefruit). Cover of individual species differed among the three years, but most of these changes were quite small, especially considering the large standard deviations (table 6 and fig. 6). As with the functional groups, many of the species had their greatest cover in 2008.

Quadrat and plot frequencies did not change substantially among years, with one exception: *Chamaesyce* spp. Group A (a grouping of annual sandmats based on morphological features) decreased in quadrat and plot frequency over the three years. In 2007 there was one unique species (not including the two unknowns), four unique species in 2008 (not including the unknowns), and one unique species in 2009 (See Appendix B).

Table 5. Mean foliar cover of functional groups for 2007, 2008, and 2009 in the Sandstone Upland ecological site

Functional groups	Foliar cover (%)					
	2007		2008		2009	
	Mean	(SD)	Mean	(SD)	Mean	(SD)
Total live foliar cover	5.38	(2.95)	8.07	(3.70)	6.03	(3.67)
Perennial grasses, graminoids	1.35	(1.56)	2.46	(3.19)	1.75	(2.16)
Annual grasses	<0.01	(<0.01)	0	(0)	0	(0)
Forbs	0.44	(0.35)	0.66	(0.80)	0.17	(0.12)
Shrubs	3.51	(1.87)	4.76	(2.49)	3.91	(2.32)
Cacti, succulents	<0.01	(<0.01)	<0.01	(<0.01)	0	(0)
Standing dead herbaceous	0.82	(0.88)	1.05	(1.19)	0.77	(0.69)
Standing dead woody	2.47	(1.18)	3.50	(1.38)	2.23	(1.08)

Table 6. Mean foliar cover and frequency of the fifteen most abundant vascular species and all nonnative species in 2007, 2008, and 2009 at the Sandstone Upland ecological site

Species	2007				2008				2009			
	Mean cover (%)	SD	Quad freq	Plot freq	Mean cover (%)	SD	Quad freq	Plot freq	Mean cover (%)	SD	Quad freq	Plot freq
<i>Artemisia filifolia</i>	1.161	1.510	34.00	40	1.760	2.321	34.67	40	1.399	1.878	32.67	40
<i>Ephedra torreyana</i>	0.933	0.984	40.00	100	1.792	1.361	42.67	100	1.271	0.958	40.00	100
<i>Pleuraphis jamesii</i>	0.777	1.145	41.33	70	1.437	2.469	40.67	70	1.082	1.737	38.00	70
<i>Fallugia paradoxa</i>	0.633	1.392	12.67	30	0.449	0.904	13.33	30	0.643	1.503	11.33	30
<i>Muhlenbergia porteri</i>	0.305	0.452	28.00	80	0.550	0.864	33.33	80	0.420	0.685	26.67	80
<i>Chamaesyce</i> spp. Group A	0.254	0.267	59.33	80	0.024	0.026	22.67	80	0.036	0.068	14.67	40
<i>Ericameria nauseosa</i>	0.173	0.260	11.33	60	0.189	0.227	13.33	60	0.084	0.082	10.67	70
<i>Atriplex confertifolia</i>	0.170	0.298	18.00	30	0.223	0.390	16.00	30	0.150	0.289	14.00	30
<i>Bouteloua eriopoda</i>	0.111	0.231	12.00	40	0.194	0.404	10.00	30	0.138	0.286	10.67	30
<i>Gutierrezia sarothrae</i>	0.106	0.130	18.00	60	0.152	0.187	16.67	50	0.096	0.120	14.67	50
<i>Atriplex canescens</i>	0.064	0.105	6.67	50	0.100	0.133	8.67	60	0.105	0.127	8.67	60
<i>Tetradlea coulteri</i>	0.049	0.076	5.33	50	0.012	0.017	5.33	50	0.032	0.073	4.00	40
<i>Sporobolus airoides</i>	0.047	0.100	3.33	20	0.070	0.164	2.00	20	0.040	0.086	2.67	20
<i>Sphaeralcea grossulariifolia</i>	0.035	0.067	6.00	40	0.041	0.093	5.33	30	0.010	0.032	3.33	10
<i>Sphaeralcea hastulata</i>	0.030	0.049	12.00	50	0.056	0.108	10.00	40	0.012	0.021	8.00	40
<i>Salsola tragus</i> ^a	0.002	0.006	0.67	10	0.330	0.796	26.00	50	0.038	0.058	23.33	40

Note: Species are arranged in descending order by their 2007 cover.

^a Nonnative species.

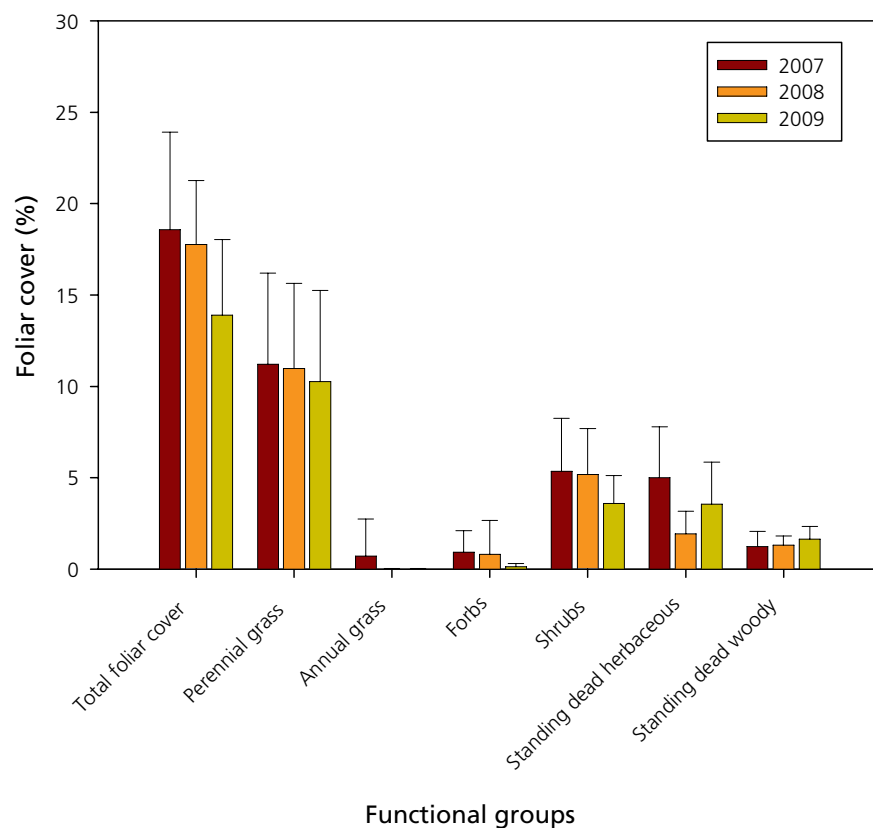


Figure 5. Mean cover of functional groups (except cacti/succulents) at the Sandstone Upland ecological site in 2007, 2008, and 2009. Error bars represent one standard deviation.

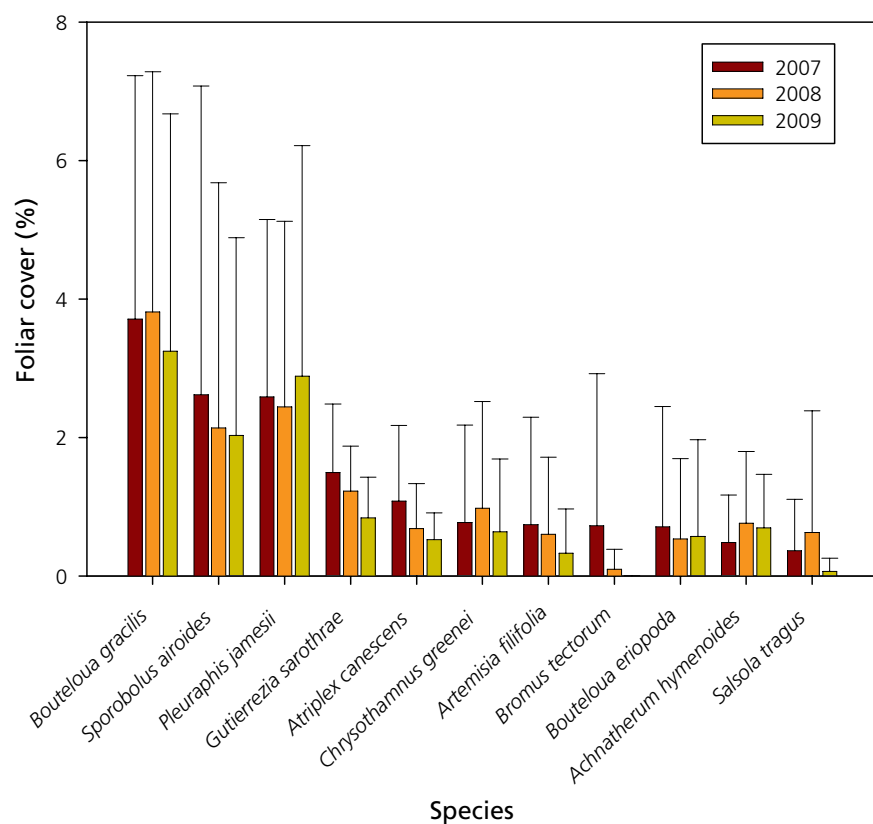


Figure 6. Mean foliar cover of the ten most abundant vascular species at the Sandstone Upland ecological site in 2007, 2008, and 2009. Error bars represent one standard deviation.

We found only one nonnative species—*Salsola tragus* (prickly Russian thistle)—in the plots. It had trace cover and occurred in only one plot in 2007, and increased in cover to 0.330% and frequency to five plots in 2008. In 2009 its frequency decreased slightly, but it showed a large decrease in cover. Appendix B lists all species, along with common names, families, mean foliar covers, and plot frequencies by year.

The diversity indices showed moderately small among-year variation (table 7). On the scale of the plot, species richness ranged between 12.8 to 14.8 species per plot, with 2008 having the highest value. Shannon diversity (which takes into account relative species abundance, and generally ranges between 1.5 and 3.5) ranged between 1.389 and 1.505, and evenness (the degree to which all species are of equal abundance, ranging from 0 to 1) ranged between 0.558 and 0.597 (Margalef 1972). On the scale of the ecological site, species richness ranged between 33 and 40 species, with 2008 having the highest value. Beta diversity (a measure of within site heterogeneity, generally ranging between 1 and 5) ranged between 2.881 and 3.113 (McClune and Grace 2002). When these indices were recalculated using only native species, all indices did not substantially change.

Table 7. Species diversity metrics for all species and for native species only at the Sandstone Upland ecological site

	2007		2008		2009	
	Mean	(SD)	Mean	(SD)	Mean	(SD)
All species						
Plot						
Plot richness	12.8	(3.3)	14.8	(2.8)	11.6	(3.1)
Shannon diversity	1.505	(0.259)	1.494	(0.226)	1.389	(0.212)
Evenness	0.597	(0.076)	0.558	(0.081)	0.574	(0.062)
Ecological site						
Ecological site richness	34		40		33	
Beta diversity	2.881		2.899		3.113	
Native species						
Plot						
Plot richness	12.7	(3.4)	14.3	(2.7)	11.2	(3.1)
Shannon diversity	1.501	(0.262)	1.481	(0.200)	1.337	(0.226)
Evenness	0.598	(0.077)	0.560	(0.065)	0.561	(0.055)
Ecological site						
Ecological site richness	33		39		32	
Beta diversity	2.821		2.932		3.137	

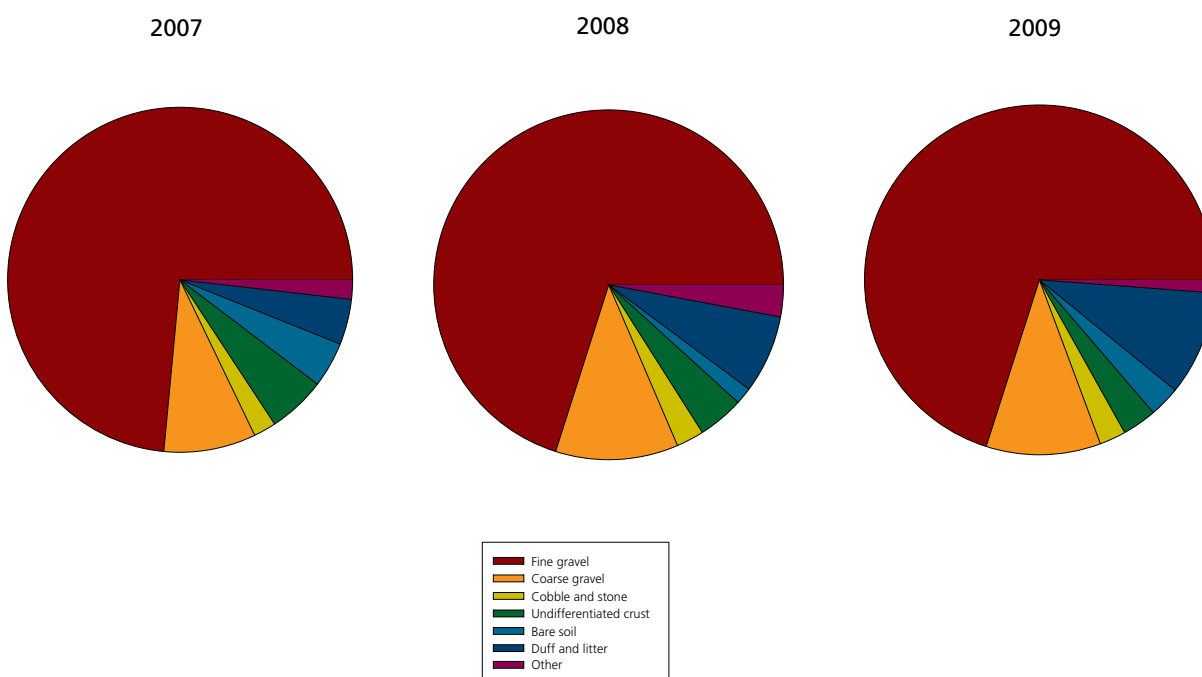
Soil stability and hydrologic function

The crew monitored the cover of soil surface features in all three years (table 8 and fig. 7). The dominant features were fine gravel, coarse gravel (i.e. volcanic cinders), undifferentiated crust, duff/litter, and bare soil. As expected, there was relatively little change in the soil surface features over the three years.

Table 8. Cover of soil surface features at the Sandstone Upland ecological site

Surface feature	2007		2008		2009	
	Mean (%)	(SD)	Mean (%)	(SD)	Mean (%)	(SD)
Live plant base	1.22	(0.98)	1.71	(1.43)	0.58	(0.57)
Dead woody base	0.34	(0.21)	0.64	(0.30)	0.24	(0.20)
Dead herbaceous base	0.10	(0.21)	0.50	(0.52)	0.32	(0.32)
Bare soil	4.08	(3.99)	1.53	(1.17)	2.78	(3.94)
Duff and litter	4.09	(1.86)	7.09	(3.64)	9.44	(5.92)
Undifferentiated crust	5.22	(7.17)	4.19	(2.36)	3.12	(4.39)
Moss	0	(0)	0	(0)	0	(0)
Lichen	0	(0)	0	(0)	0	(0)
Cyanobacteria	0	(0)	0	(0)	0	(0.01)
Fine gravel (0.2–2 cm)	70.56	(15.88)	68.79	(16.66)	68.46	(15.26)
Coarse gravel (2– 7.5 cm)	8.28	(9.06)	11.13	(13.00)	10.34	(12.49)
Cobble (7.5– 25 cm)	1.17	(1.83)	1.71	(2.22)	1.43	(1.97)
Stone, bedrock (>25 cm)	0.85	(1.65)	0.79	(1.55)	0.94	(1.86)
Woody debris	0.08	(0.18)	0.04	(0.05)	0.02	(0.05)

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

**Figure 7.** Mean cover of soil surface features at the Sandstone Upland ecological site in 2007, 2008, and 2009

Discussion

The two ecological sites we are monitoring in WUPA are quite distinct. The Limy Upland site is dominated by grasses, including *Pleuraphis jamesii*, *Bouteloua eriopoda*, and *Hesperostipa comata*. In contrast, the Sandstone Upland site is dominated by shrubs, including *Artemisia filifolia*, *Ephedra torreyana*, and *Fallugia paradoxa*. Despite these differences, the data indicates that these two ecosystems showed similar patterns in annual variation. In general there was relatively small variation in the vegetation and surface features in both ecological sites among the years 2007, 2008, and 2009. Variation in functional group and species cover and frequencies were minor, especially considering the high variability among plots. Similarly, the species diversity indices showed small among-year variation. The largest changes occurred in annual species: *Chamaesyce* spp., *Chenopodium leptophyllum*, and *Salsola tragus*.

The variation that did occur is, in part, attributable to variation in precipitation. 2008 had an extremely wet winter, and both 2007 and 2008 had strong summer monsoons. In contrast, 2009 was generally drier, only rising above the long term precipitation average in the growing season in May (fig.10). The timing and the amount of precipitation differentially influences germination, growth, and flowering of species.

Two nonnative species were found in the plots in 2007. *Salsola tragus* occurred in both ecological sites, and reached its highest cover and frequencies in 2008. *Kochia scoparia* occurred in the Limy Upland ecological site in 2008 and 2009, with low cover and frequencies. Cover of soil surface features showed small variation among years in both ecological sites.

We stress that the differences noted between years are not indicative of any trend, since trends cannot be determined with only three years of sampling. Nor should they be interpreted as being ecologically significant. Differences are due to ecological variability, such as annual climatic fluctuation,

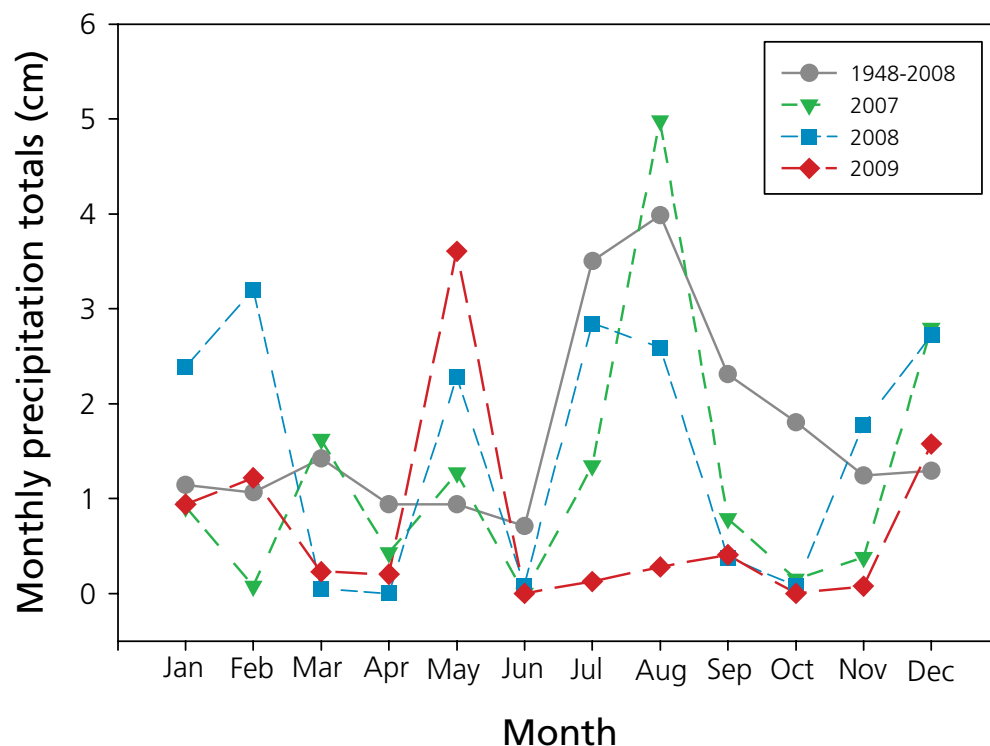


Figure 10. Total monthly precipitation for 2007, 2008, and 2009 with the mean monthly totals for 1948 through 2009 (WRCC 2010)

or sampling errors inherent in the field sampling process. Cover estimation may vary among individuals (and crews), species may be mis-identified, slight differences between observers in applying sampling methods may go unnoticed, and the location of transects and quadrats vary slightly from year to year. We strive to minimize these errors by ensuring that transect lines are as straight as possible, quadrats are placed correctly, and field crews are thoroughly trained on methods and species identification and remain calibrated on cover estimation.

We plan to conduct power analysis using the three years of data, which will help determine the total number of plots necessary to detect change in the key metrics. A temporal sampling design will then be implemented, with the installation of additional plots in subsequent years. Each year's data will be compared to the previously collected data to analyze changes through time in vegetation composition and structure and in soil stability and hydrologic function. Trend analyses will be conducted once sufficient data have been collected.

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Appendix A

Complete species list for the Limy Upland ecological site with mean foliar cover and frequency for species in 2007, 2008, and 2009. Annual *Chamaesyce* spp. that were not identifiable to species in the field are placed in one of two groups based on leaf morphology.

Species	Common name	Family	2007			2008			2009		
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Foliar cover (%)	Plot frequency (%)	Plot frequency (%)
<i>Aristida havardii</i>	Havard's threawn	Poaceae	0.034	20	0.002	0	10	0	0	0	0
<i>Aristida purpurea</i>	Fendler's threawn	Poaceae	0.004	20	0.030	0	50	0.020	0.020	60	60
<i>Astragalus</i> sp.	milkvetch	Fabaceae	0	0	0	0	0	0.001	0.001	10	10
<i>Bouteloua curtipendula</i>	sideoats grama	Poaceae	0.023	10	0.002	0	10	0.005	0.005	10	10
<i>Bouteloua eriopoda</i>	black grama	Poaceae	3.492	100	3.252	0	100	3.236	3.236	100	100
<i>Bouteloua gracilis</i>	blue grama	Poaceae	0	0	0.002	0	10	0.002	0.002	10	10
<i>Caesalpinia drepanocarpa</i>	sicklepod holdback	Fabaceae	0.002	20	0.002	0	10	<0.001	<0.001	10	10
<i>Caesalpinia jamesii</i>	James' holdback	Fabaceae	0.002	20	0	0	0	0.002	0.002	10	10
<i>Chaetopappa ericoides</i>	rose heath	Asteraceae	0.016	90	0.020	0	90	0.023	0.023	90	90
<i>Chamaesyce</i> spp. Group A	annual sandmats	Euphorbiaceae	0.074	100	0.009	0	50	0.086	0.086	80	80
<i>Chamaesyce</i> spp. Group B	annual sandmats	Euphorbiaceae	0.068	100	0.001	0	20	0.035	0.035	70	70
<i>Chamaesyce albomarginata</i>	whitemargin sandmat	Euphorbiaceae	0	0	<0.001	0	10	0	0	0	0
<i>Chamaesyce fendleri</i>	Fendler's sandmat	Euphorbiaceae	0.001	10	0.004	0	10	0	0	0	0
<i>Chenopodium fremontii</i>	Fremont's goosefoot	Chenopodiaceae	<0.001	10	0.012	0	10	0.001	0.001	10	10
<i>Chenopodium leptophyllum</i>	narrowleaf goosefoot	Chenopodiaceae	0.115	50	0.990	0	100	0.102	0.102	90	90
<i>Cuscuta</i> sp.			0	0	0.002	0	10	0	0	0	0
<i>Elymus elymoides</i>	squirreltail	Poaceae	0	0	0	0	0	0.002	0.002	10	10
<i>Ericameria nauseosa</i>	rubber rabbitbrush	Asteraceae	0.387	100	0.310	0	100	0.264	0.264	80	80
<i>Euphorbia exstipulata</i>	squareseed spurge	Euphorbiaceae	0.006	20	0	0	0	0	0	0	0
<i>Evolvulus nuttallianus</i>	shaggy dwarf morning-glory	Convolvulaceae	0.011	50	0.009	0	40	0.006	0.006	60	60
<i>Gilia</i> sp.	gilia	Polemoniaceae	0	0	<0.001	0	10	0	0	0	0
<i>Glandularia gooddingii</i>	southwestern mock vervain	Verbenaceae	0.007	10	0	0	0	<0.001	<0.001	10	10
<i>Gutierrezia sarothrae</i>	broom snakeweed	Asteraceae	<0.001	10	<0.001	0	10	<0.001	<0.001	10	10
<i>Hesperostipa comata</i>	needle and thread	Poaceae	1.691	90	2.048	0	100	1.807	1.807	100	100
<i>Kochia scoparia</i> ^a	Mexican burningbush	Chenopodiaceae	0	0	<0.001	0	10	0.002	0.002	40	40

Appendix A continued

Species	Common name	Family	2007		2008		2009	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Krascheninnikovia lanata</i>	winterfat	Chenopodiaceae	0.005	10	0.010	10	0.010	10
<i>Lithospermum incisum</i>	narrowleaf gromwell	Boraginaceae	<0.001	10	0.001	10	0.002	10
<i>Lycium andersonii</i>	water jacket	Solanaceae	0	0	0.010	10	<0.001	10
<i>Machaeranthera canescens</i>	hoary tansyaster	Asteraceae	0.001	10	0	0	0	0
<i>Opuntia</i> sp.	prickly pear	Cactaceae	0.005	10	0.005	10	0	0
<i>Opuntia whipplei</i>	Whipple's cholla	Cactaceae	0.002	20	0.005	10	0.001	20
<i>Pleuraphis jamesii</i>	James' galleta	Poaceae	6.251	100	5.618	100	6.486	100
<i>Polanisia dodecandra</i>	redwhisker clammyweed	Capparaceae	0.001	10	<0.001	10	0	0
<i>Salsola tragus</i> ^a	prickly Russian thistle	Chenopodiaceae	0.260	80	1.422	90	4.998	90
<i>Senecio flaccidus</i>	threadleaf ragwort	Asteraceae	0.011	40	0.017	30	0.007	20
<i>Sphaeralcea</i> sp.	globemallow	Malvaceae	0.006	50	0.007	60	0.005	40
<i>Sphaeralcea ambigua</i>	apricot globemallow	Malvaceae	0	0	0	0	0.002	10
<i>Sphaeralcea hastulata</i>	spear globemallow	Malvaceae	0.090	50	0.063	50	0.066	30
<i>Sporobolus airoides</i>	alkali sacaton	Poaceae	0.098	20	0.119	20	0.127	30
<i>Sporobolus cryptandrus</i>	sand dropseed	Poaceae	0.001	10	0.002	10	0	0
<i>Stephanomeria</i> sp.	wirelettuce	Asteraceae	0	0	0	0	<0.001	10
<i>Stephanomeria minor</i>	lesser wirelettuce	Asteraceae	<0.001	10	<0.001	10	<0.001	10
<i>Stephanomeria pauciflora</i>	brownplume wirelettuce	Asteraceae	0.002	10	0.008	30	0.009	30
<i>Stephanomeria thurberi</i>	Thurber wire lettuce	Asteraceae	0.000	10	0.000	10	0	0
<i>Tragia ramosa</i>	branched noseburn	Euphorbiaceae	0.004	10	0.002	10	0.004	10
<i>Zinnia grandiflora</i>	Rocky Mountain zinnia	Asteraceae	0.017	40	0.014	40	0.014	50
Unknown WUPA011			0.005	10	0	0	0	0
Unknown 08122009-1			0	0	0	0	<0.001	10
Unknown 08212007-1			<0.001	10	0	0	0	0
Unknown 08212007-2			<0.001	10	0	0	0	0
Unknown 08222008-2			0	0	0.001	10	0	0
Unknown 08232007-5			<0.001	10		0		0
Unknown08232008-1			0	0	0.001	20	0	0

¹ Nonnative species

Appendix B

Complete species list at the Sandstone Upland ecological site with mean foliar cover and frequency for species in 2007, 2008, and 2009. Annual *Chamaesyce* spp. that were not identifiable to species in the field are placed in one of two groups based on leaf morphology.

Species	Common name	Family	2007			2008			2009		
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Foliar cover (%)	Plot frequency (%)	Plot frequency (%)
<i>Achnatherum hymenoides</i>	Indian ricegrass	Poaceae	0.015	50	0.037	0.037	50	0.025	0.025	50	50
<i>Aristida purpurea</i>	Fendler's threeawn	Poaceae	0.014	20	0.025	0.025	20	0.012	0.012	20	20
<i>Artemisia filifolia</i>	sand sagebrush	Asteraceae	1.161	40	1.760	1.760	40	1.399	1.399	40	40
<i>Atriplex canescens</i>	fourwing saltbush	Chenopodiaceae	0.064	50	0.100	0.100	60	0.105	0.105	60	60
<i>Atriplex confertifolia</i>	shadscale saltbush	Chenopodiaceae	0.170	30	0.223	0.223	30	0.150	0.150	30	30
<i>Bouteloua eriopoda</i>	black grama	Poaceae	0.111	40	0.194	0.194	30	0.138	0.138	30	30
<i>Brickellia oblongifolia</i>	Mohave brickellbush	Asteraceae	0.011	40	0.016	0.016	30	0.011	0.011	30	30
<i>Chaetopappa ericoides</i>	rose heath	Asteraceae	0.001	20	0.005	0.005	20	0.002	0.002	10	10
<i>Chamaesaracha coronopus</i>	greenleaf five eyes	Solanaceae	0.001	10	0.001	0.001	20	0.003	0.003	30	30
<i>Chamaesyce fendleri</i>	Fendler's sandmat	Euphorbiaceae	0.007	40	0.005	0.005	50	0.035	0.035	60	60
<i>Chamaesyce</i> spp. Group A	annual sandmats	Euphorbiaceae	0.254	80	0.024	0.024	80	0.036	0.036	40	40
<i>Chamaesyce</i> spp. Group B	annual sandmats	Euphorbiaceae	0	0	<0.001	<0.001	10	0	0	0	0
<i>Chenopodium leptophyllum</i>	narrowleaf goosefoot	Chenopodiaceae	0	0	<0.001	<0.001	10	0	0	0	0
<i>Dasychloa pulchella</i>	low woollygrass	Poaceae	0.020	40	0.022	0.022	50	0.008	0.008	30	30
<i>Ephedra torreyana</i>	Torrey's jointfir	Ephedraceae	0.933	100	1.792	1.792	100	1.271	1.271	100	100
<i>Ephedra viridis</i>	mormon tea	Ephedraceae	0.007	20	0.020	0.020	30	0.012	0.012	20	20
<i>Ericameria nauseosa</i>	rubber rabbitbrush	Asteraceae	0.173	60	0.189	0.189	60	0.084	0.084	70	70
<i>Eriogonum cernuum</i>	nodding buckwheat	Polygonaceae	0	0	0.064	0.064	40	0.016	0.016	30	30
<i>Eriogonum corymbosum</i>	crisp-leaf buckwheat	Polygonaceae	0.008	30	0.010	0.010	20	0.025	0.025	20	20
<i>Eriogonum leptoclados</i>	sand buckwheat	Polygonaceae	0.015	10	0.010	0.010	20	0.005	0.005	10	10
<i>Fallugia paradoxa</i>	Apache plume	Rosaceae	0.633	30	0.449	0.449	30	0.643	0.643	30	30
<i>Gilia</i> sp.	<i>Gilia</i> sp.	Polemoniaceae	0	0	0.012	0.012	90	0	0	0	0
<i>Gutierrezia sarothrae</i>	broom snakeweed	Asteraceae	0.106	60	0.152	0.152	50	0.096	0.096	50	50
<i>Hesperostipa comata</i>	needle and thread	Poaceae	0	0	0	0	0	<0.001	<0.001	10	10

Appendix B continued

Species	Common name	Family	2007			2008			2009		
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)
<i>Muhlenbergia porteri</i>	bush muhly	Poaceae	0.305	80	0.550	80	0.420	80	0.420	80	0.420
<i>Pleuraphis jamesii</i>	James' galleta	Poaceae	0.777	70	1.437	70	1.082	70	1.082	70	1.082
<i>Salsola tragus</i> ^a	prickly Russian thistle	Chenopodiaceae	0.002	10	0.330	50	0.038	40	0.038	40	0.038
<i>Sphaeralcea</i> spp.	globemallow	Malvaceae	0.001	20	0.019	50	<0.001	10	<0.001	10	<0.001
<i>Sphaeralcea grossulariifolia</i>	gooseberryleaf globemallow	Malvaceae	0.035	40	0.041	30	0.010	10	0.010	10	0.010
<i>Sphaeralcea hastulata</i>	spear globemallow	Malvaceae	0.030	50	0.056	40	0.012	40	0.012	40	0.012
<i>Sphaeralcea parvifolia</i>	smallflower globemallow	Malvaceae	0.030	20	0.002	10	0	0	0	0	0
<i>Sporobolus airoides</i>	alkali sacaton	Poaceae	0.047	20	0.070	20	0.040	20	0.040	20	0.040
<i>Stephanomeria</i> spp.	wirelettuce	Asteraceae	0.002	50	0	0	0	0	0	0	0
<i>Stephanomeria minor</i>	lesser wirelettuce	Asteraceae	0.002	10	0.001	20	<0.001	10	<0.001	10	<0.001
<i>Stephanomeria pauciflora</i>	brownplume wirelettuce	Asteraceae	0.011	60	0.010	50	0.003	40	0.003	40	0.003
<i>Tetradlea coulteri</i>	Coulter's wrinklefruit	Verbenaceae	0.049	50	0.012	50	0.032	40	0.032	40	0.032
<i>Tiquilia hispidissima</i>	hairy crinklemat	Boraginaceae	0	0	0.025	10	0.002	20	0.002	20	0.002
<i>Yucca angustissima</i>	narrowleaf yucca	Agavaceae	0.002	10	0.002	10	0	0	0	0	0
<i>Zinnia grandiflora</i>	Rocky Mountain zinnia	Asteraceae	0.002	10	0.002	10	0.002	10	0.002	10	0.002
Unknown 08212007-1			<0.001	10	0	0	0	0	0	0	0
Unknown 08242008-1			0	0	0.003	10	0	0	0	0	0
Unknown 08272008-1			0	0	0.001	20	0	0	0.001	20	0

¹ Nonnative species