



Integrated Upland Vegetation and Soils Monitoring for Grand Canyon National Park

2012 Summary Report

Natural Resource Data Series NPS/SCPN/NRDS—2014/695



ON THE COVER

Integrated upland monitoring in Grand Canyon National Park

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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 2 ecological sites for long-term monitoring of upland vegetation and soils at Grand Canyon National Park (GRCA): the Limestone Upland ecological site and the mixed conifer ecological site. 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). In 2012 we only sampled plots in the Limestone Upland ecological site; hence we will not report any data for the mixed conifer site here.

The Limestone Upland ecological site is characterized as relatively intact pinyon-juniper woodland. It faces numerous threats, including changing fire regimes, climate change, and invasion by nonnative species. In 2010 we established and sampled 10 plots in the Limestone Upland ecological site. In 2011 and 2012 we resampled the nested quadrat vegetation and measured basal gaps in these 10 plots. In 2012 we also established and sampled 10 additional plots.

In this report, we document monitoring activities during the 2012 field season and report these data in the context of the data collected in 2010 and 2011.

2 Methods

2.1 Sampling frame

We derived our base sampling frame for the Limestone Upland ecological site (Figure 1) from a map of the ecological site, which was developed by the U.S. Natural Resources Conservation Service (see Appendix A of DeCoster et al. 2012). 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 make final adjustments to our sampling frame, we modified the map of the ecological site using Geographical Information System (GIS) technology. These modifications were necessary to avoid areas that were

- outside of the target ecological site (i.e., roads)
- potentially at risk for erosion as a result of sampling (slopes $\geq 20\%$)

We generated a set of spatially distributed sampling points using the Generalized Random Tessellation Stratified (GRTS) design (Stevens and Olsen 2004). Park staff visited the sampling points and rejected those points that landed too close to archeological sites and other sensitive resources. The integrated upland crew visited the first 33 GRTS points and conducted an ecological site assessment, rejecting sites that deviated substantially from the ecological site, had a slope greater than 20%, or contained a major disturbance.

We established the first 10 plots in 2010 after rejecting 7 sites: 6 sites were in close proximity to an archeological site, and 1 site deviated substantially from the ecological site. We established the next 10 plots in 2012 after rejecting 6 sites: 3 sites were in close proximity to an archeological site, 1 site deviated substantially from the ecological site, and 2 sites contained fences.

2.2 Field methods

In the Limestone Upland ecological site, the SCPN integrated upland crew established 10 monitoring plots in 2010, and resampled them in 2011 and 2012. They established 10 additional plots in 2012. We conducted our work from late August through September, with the exception of one plot that was sampled in late October 2010 and one plot that was established and sampled in November 2012.

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 cover, tree

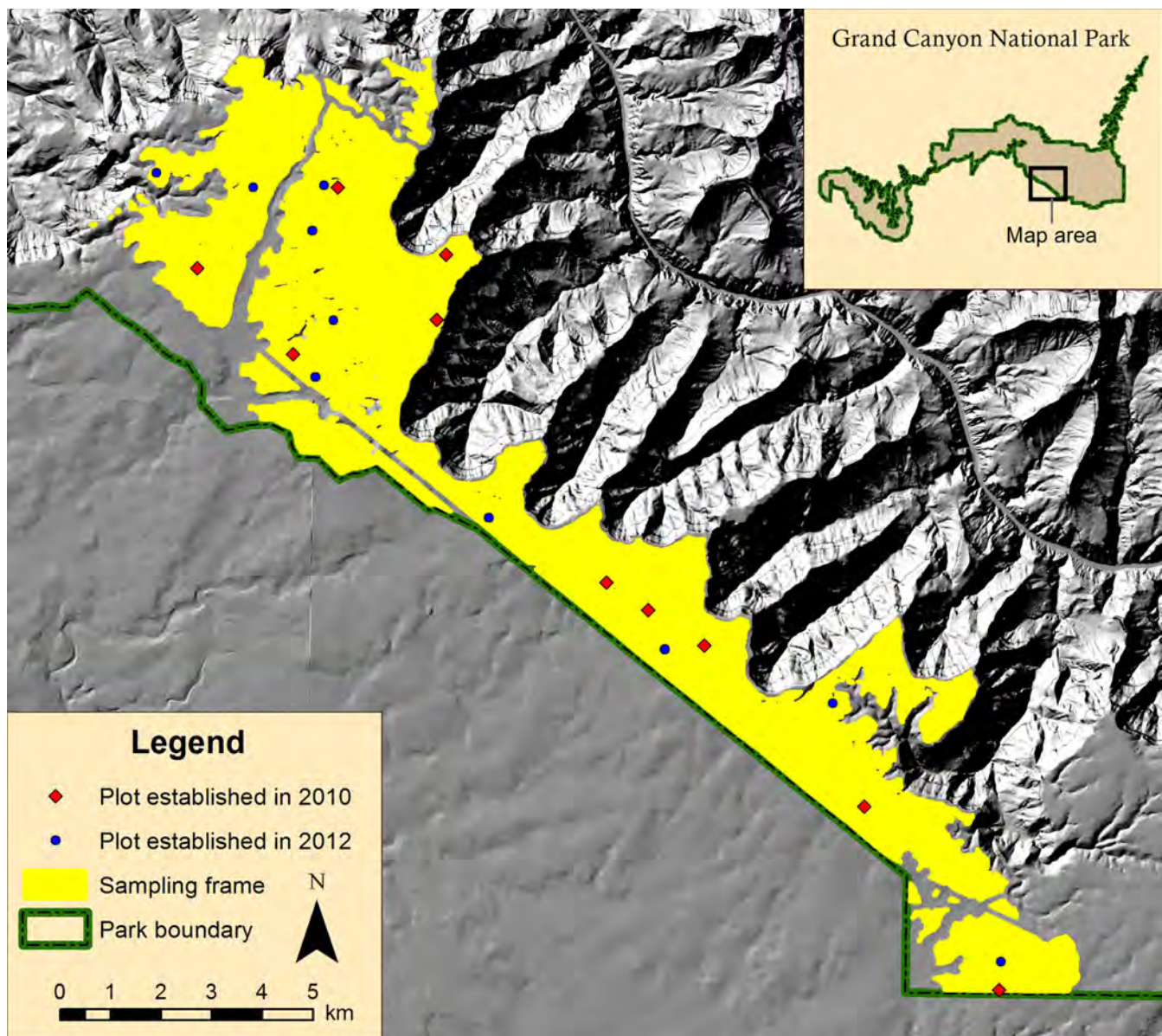


Figure 1. Sampling frame of the Limestone Upland ecological site at GRCA showing the 10 plots established in 2010 and the 10 plots established in 2012.

seedling density, tree canopy, soil stability and basal gap data on all 3 transects within each plot. We also collected overstory tree and sapling data in subplots located between 2 of the transects.

During plot establishment, we collected the full suite of data at each site. For plot revisits of the original 10 plots in 2011 and 2012, we collected a subset of the data: in 2011 we did not collect data for living overstory trees, snags, saplings, canopy cover, and soil stability, and in 2012 we did not collect data for snags and saplings. 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 m² (2 × 5 m), with 4 smaller quadrats nested inside (0.01 m², 0.1 m², 1 m², 5 m²). We recorded the presence

of each herbaceous and shrub species within each nested sub-quadrat. We estimated the percent cover of each species in the 10 m² quadrat and assigned it to 1 of 12 cover classes (e.g., 2%–5%, 5%–10%, etc.). We also estimated the percent cover for functional groups (e.g., perennial grasses, forbs, shrubs) in the 10 m² quadrats and recorded the cover class.

2.2.2 Overstory trees, saplings, and seedlings

We measured living overstory tree and snag diameter in a 20 × 50 m (0.1 ha) plot located between 2 of the transects in the first year of sampling. For *Pinus edulis*, diameter was measured at breast height, while for *Juniperus osteosperma*, it was measured at crown base. Within this overstory tree plot, we tallied saplings by size class and species in a smaller, nested 10 × 25 m plot (0.025 ha). We tallied seedlings by size class and species in the fifteen 10 m² quadrats along the 3 transects.

We measured tree canopy cover using the line intercept method along transects for the 10 plots in 2010 and for the 20 plots in 2012.

2.2.3 Soil stability and hydrologic function

We estimated the percent cover of soil surface features in the 1 m² quadrats along transects, and recorded cover in 1 of 12 cover classes. We also measured basal gaps as the distance between plant bases along each transect. Basal gap measurements and soil surface features were collected on each plot visit. We attempted to collect soil aggregate stability data in the 10 plots in 2010, and in all 20 plots in 2012. We did not collect those data, however, when the soils were wet, as the results are not accurate under those conditions.

2.2.4 Precipitation

We report precipitation data collected by the Western Regional Climate Center at its Grand Canyon Airport station (USW00003195) AZ.

2.3 Data summary

The data we collected consists of 10 plots sampled in 3 consecutive years and 10 plots that were only sampled one year. We make 2 comparisons: we examine the variation in the first set of plots over the 3 years, and we compare the second plot group to the first. We refer to these 2 groups of plots as plot group A for the 10 plots established in 2010, and plot group B for the 10 plots established in 2012. Differences among the 3 years of data for plot group A represent temporal variability. Differences between plot group A and plot group B represent spatial variability.

The sample unit for summary and analysis is the plot; hence, we summarized data at the level of the plot. For each year and each plot group, we calculated the mean and standard deviation for most metrics from the means of the 10 plots. Metrics with 3 years of data include species cover and frequency, functional group cover, basal gaps and soil surface features. Three metrics—plot frequency, ecological site richness and beta diversity—were calculated across all plots and were therefore not calculated by averaging plot values. We discuss how we summarized these data below in sections 2.3.1 and 2.3.2.

2.3.1 Shrub and herbaceous species, functional groups and soil surface features

For herbaceous and shrub vegetation, percent foliar cover was estimated for each species from the cover class midpoints, e.g., 7.5% for cover class 5%–10%. Mean percent foliar cover was calculated for each plot, and then the mean and standard deviation calculated for each year and plot group. Mean cover and standard deviation of functional groups and surface features were calculated in a similar fashion. For each year and plot group, species frequency was calculated for quadrats (mean percentage of 10 m² quadrats per plot in which the species occurs) and for plots (percentage of plots in which the species occurs).

2.3.2 Species diversity

Four diversity measures were calculated for herbaceous and shrub species for each year and plot group (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 both 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.

We calculated plot richness, Shannon diversity, and evenness for each plot and year, and the mean and standard deviation were then calculated for the ecological site for each plot group and year. Ecological site richness and beta diversity, which are not based on plot means, were calculated for the ecological site for each year and plot group.

2.3.3 Trees

All tree measurements were collected in the first year that the plots were established. For plot group A, living overstory trees were also measured in 2012, and seedlings were measured in all 3 years. For plot group A, we use 2012 data for living overstory trees, and 2010 data for saplings and snags. We present seedling data for all 3 years.

Tree basal area (the total area of the tree cross-sections) for living trees and snags was calculated for each overstory tree species in terms of m^2/ha . Mean diameter of living overstory trees was also calculated for each species. For *Pinus edulis*, diameter and basal area calculations were made at breast height, while for *Juniperus osteosperma*, these calculations were made at crown base. Tree density was calculated for all species and all size classes for overstory living trees, snags, saplings and seedlings in terms of stems/ha. Each metric was calculated for each plot and year, and the mean and standard deviation were then calculated for each plot group and year.

We present canopy cover data only for 2012. Canopy cover was calculated by first deriving the mean value for each plot, and then the mean and standard deviation were calculated for the plot group.

2.3.4 Basal gaps

We calculated 4 metrics from the basal gap data for each plot and year: median basal gap size, percentage of transects comprised by gaps, percentage of transects comprised by each gap size class, and total number of gaps. We then calculated the mean and standard deviation of each metric for each year and plot group.

We present soil aggregate stability data for plot group A only in 2010 because the sample size for 2012 was much smaller due to wet soils. We calculated the mean soil aggregate stability index for each plot, and then calculated the mean and standard deviation for all plots in the plot group. The index ranges from 1 to 6, where 1 indicates low aggregate stability and 6 indicates high aggregate stability. The index was also calculated separately for samples with vegetative cover and for samples without vegetative cover.

3 Results

In reporting 2012 results, we compare plot groups A and B, which represent spatial variability, and examine the variation over 3 years of sampling for plot group A, which represents temporal variability.

3.1 Shrub and herbaceous vegetation

Perennial grasses and shrubs co-dominated the Limestone Upland ecological site. Mean foliar covers for plot group B were generally comparable to values for plot group A, except that total live foliar cover and perennial grasses cover were lower for plot group B (Table 1 and Figure 2). The mean total live foliar cover ranged from 6.36% to 9.60% for plot group A, and was 5.72% for plot group B. Mean foliar cover of perennial grasses ranged from 2.35% to 3.81% for plot group A, and was 1.78% in plot group B.

Table 1. Foliar cover of functional groups for plot groups A and B in the Limestone Upland ecological site at GRCA.

Functional groups	Plot group A (n = 10)						Plot group B (n = 10)	
	2010		2011		2012		2012	
	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Total live foliar cover	7.02	2.35	9.60	3.49	6.36	1.89	5.72	1.79
Perennial grasses	3.23	2.57	3.81	2.45	2.35	1.01	1.78	1.17
Annual grasses	0.05	0.13	0.71	2.13	0.31	0.91	0.15	0.40
Forbs	0.38	0.26	0.56	0.32	0.53	0.35	0.53	0.40
Shrubs	3.31	1.86	4.41	2.15	3.38	1.48	3.60	1.48
Cacti/succulents	0.12	0.17	0.21	0.21	0.10	0.09	0.14	0.17
Standing dead herbaceous	1.43	1.46	1.13	0.74	1.32	0.69	0.79	0.53
Standing dead woody	1.02	0.59	0.85	0.62	0.99	0.81	1.13	0.66

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

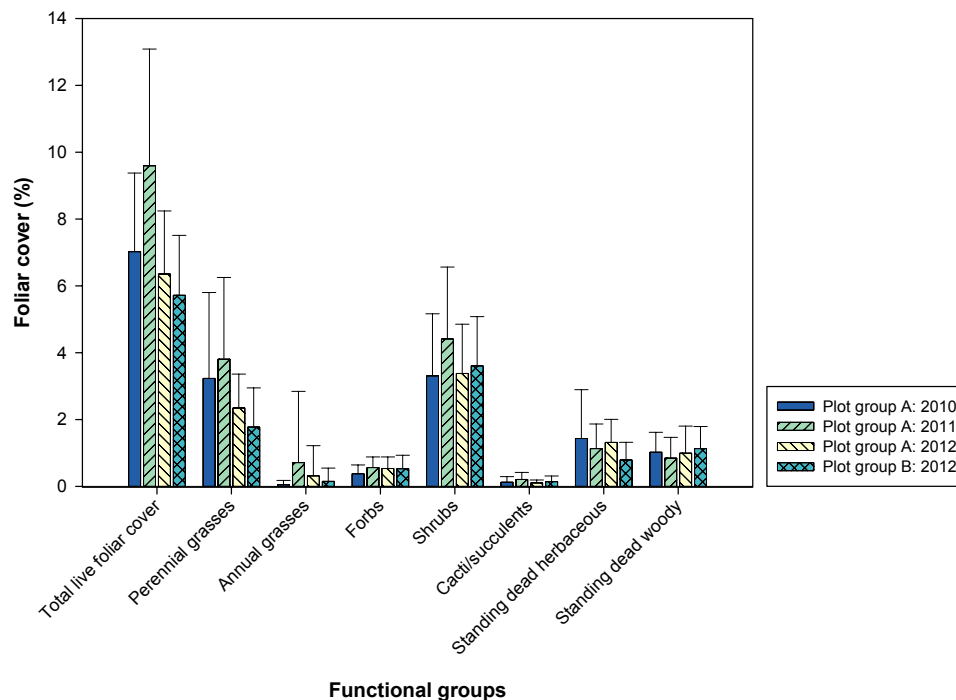


Figure 2. Mean percent foliar cover of functional groups for plot group A and plot group B in the Limestone Upland ecological site at GRCA. Error bars represent one standard deviation.

The among year variation in plot group A was moderately high for many of the functional groups, but these differences were offset by large standard deviations, which indicates large among-plot variation. Mean foliar cover of shrubs ranged from 3.31 to 4.41 for plot group A. Mean forb cover ranged from 0.38% to 0.56%. Mean foliar cover of cacti and succulents was less than 0.25%. Foliar cover of annual grasses showed large annual variation, ranging from 0.05% to 0.71%. Mean covers of standing dead herbaceous and standing dead woody were less than 2% in all 3 years.

Bouteloua gracilis (blue grama) and *Poa fendleriana* (muttongrass) were the dominant perennial grasses (Figure 3 and Table 2). The mean foliar cover of *Bouteloua gracilis* ranged from 0.551% to 2.147% for all years and plot groups. The mean foliar cover of *Poa fendleriana* ranged from 0.813% to 1.814%. The most abundant shrub was *Purshia stansburiana* (Stansbury cliffrose), and its mean foliar cover ranged from 1.661 to 2.301. Other abundant shrubs included *Artemisia tridentata* (basin big sagebrush), *Gutierrezia sarothrae* (broom snakeweed), and *Mahonia fremontii* (Freemont mahonia). Common forbs included *Erigeron divergens* (spreading fleabane), *Phlox austromontana* (mountain phlox), and *Draba cuneifolia* (wedgeleaf draba). *Opuntia* spp. (prickly pear) was the most abundant cactus/succulent. *Bromus tectorum* (cheatgrass) was the most abundant annual grass. Most of the species with high mean foliar cover also had high plot frequency. *Mahonia fremontii* and *Bromus tectorum* were the only species with a mean foliar cover greater than 0.1% that did not occur in at least 90% of the plots, indicating that they had high foliar cover where they occurred.

The mean foliar cover of many species in plot group A showed moderate variability among the 3 years. Annual species (*Bromus tectorum* and *Draba cuneifolia*) and several perennial forbs (e.g., *Erigeron divergens*) showed high interannual variation. The majority of the species showed their highest cover in 2011, although there were exceptions: *Erigeron divergens* (spreading fleabane), and *Astragalus* spp. had their greatest cover in 2012 and *Mahonia fremontii* had its greatest cover in 2010. Plot group B had a similar composition to plot group A, although there were some differences: mean foliar covers of *Bouteloua gracilis* and *Mahonia fremontii* were lower, and the mean foliar cover of *Quercus gambelii* (Gambel's oak) was higher. The large standard deviations suggest that many of the differences among years and between plot groups, however, were nominal.

Phemeranthus sp. occurred in one plot in 2012. Unfortunately, the specimen could not be identified to species. It is possible it was the rare species, *Phemeranthus validulus* (Tusayan fameflower), but may have been *P. brevifolius*. An attempt will be made to provide a positive identification in subsequent visits to the plot. Appendix A lists all species that occurred in the ecological site, along with their common names, families, mean foliar cover and plot frequencies, by year and plot group.

Figure 3. Mean percent foliar cover of the most abundant shrub and herbaceous species for plot group A and plot group B in the Limestone Upland ecological site at GRCA. Species with foliar cover greater than 0.150 in any of the plot group/year combinations were included. Error bars represent one standard deviation.

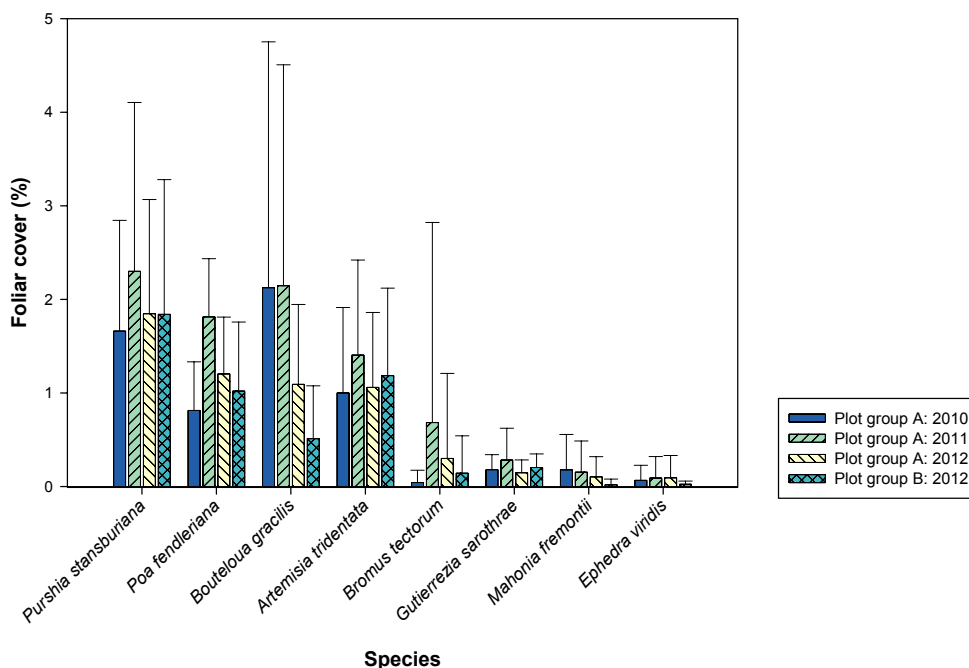


Table 2. Mean foliar cover and standard deviation, and mean quadrat and plot frequencies of all shrub and herbaceous species that had foliar cover >0.050 in any year for plot group A or for plot group B in the Limestone Upland ecological site at GRCA. All nonnative species and rare species are included from all years.

Species	Plot group A (n = 10)								Plot group B (n = 10)							
	2010				2011				2012				2012			
	Foliar cover (%)	SD	Quad. freq. (%)	Plot freq. (%)	Foliar cover (%)	SD	Quad. freq. (%)	Plot freq. (%)	Foliar cover (%)	SD	Quad. freq. (%)	Plot freq. (%)	Foliar cover (%)	SD	Quad. freq. (%)	Plot freq. (%)
<i>Purshia stansburiana</i>	1.661	1.184	38.67	100.00	2.301	1.804	36.67	100.00	1.848	1.220	38.67	100.00	1.841	1.440	46.67	100.00
<i>Poa fendleriana</i>	0.813	0.520	92.00	100.00	1.814	0.622	97.33	100.00	1.203	0.609	99.33	100.00	1.020	0.737	96.00	100.00
<i>Bouteloua gracilis</i>	2.126	2.628	64.00	90.00	2.147	2.360	66.00	90.00	1.092	0.855	66.00	90.00	0.511	0.565	55.33	90.00
<i>Artemisia tridentata</i>	0.999	0.915	49.33	100.00	1.405	1.017	50.67	100.00	1.059	0.802	50.67	100.00	1.185	0.936	52.00	90.00
<i>Bromus tectorum</i> ^a	0.043	0.131	7.33	40.00	0.683	2.140	20.67	70.00	0.300	0.909	24.00	80.00	0.142	0.399	26.67	50.00
<i>Gutierrezia sarothrae</i>	0.179	0.161	43.33	100.00	0.283	0.340	45.33	100.00	0.147	0.137	45.33	100.00	0.203	0.144	55.33	100.00
<i>Mahonia fremontii</i>	0.179	0.377	2.67	20.00	0.153	0.333	2.67	20.00	0.103	0.216	3.33	20.00	0.019	0.060	2.67	10.00
<i>Ephedra viridis</i>	0.066	0.161	4.00	30.00	0.091	0.229	5.33	40.00	0.093	0.238	6.00	40.00	0.024	0.034	8.00	50.00
<i>Erigeron divergens</i>	0.001	0.001	1.33	20.00	0.023	0.042	22.67	50.00	0.090	0.145	34.00	70.00	0.038	0.052	22.67	70.00
<i>Opuntia</i> spp.	0.115	0.168	22.67	100.00	0.189	0.211	26.00	100.00	0.087	0.082	32.67	100.00	0.117	0.132	32.00	100.00
<i>Phlox austromontana</i>	0.068	0.149	5.33	20.00	0.079	0.171	5.33	20.00	0.054	0.142	5.33	20.00	0.082	0.168	19.33	30.00
<i>Draba cuneifolia</i>	0.002	0.004	3.33	20.00	0.086	0.068	71.33	100.00	0.054	0.108	23.33	60.00	0.044	0.088	24.00	40.00
<i>Eriogonum racemosum</i>	0.043	0.120	12.00	30.00	0.060	0.185	12.67	30.00	0.053	0.149	12.67	30.00	0.025	0.050	14.00	30.00
<i>Quercus gambelii</i>	0.010	0.032	0.67	10.00	0.050	0.158	0.67	10.00	0.050	0.158	0.67	10.00	0.145	0.426	2.00	20.00
<i>Elymus elymoides</i>	0.028	0.047	16.00	70.00	0.052	0.055	26.00	80.00	0.042	0.058	22.00	80.00	0.088	0.113	35.33	70.00
<i>Astragalus</i> spp.	0.027	0.029	20.67	70.00	0.022	0.024	24.67	70.00	0.042	0.049	30.67	90.00	0.059	0.095	22.67	80.00
<i>Nama dichotoma</i>	0.002	0.005	3.33	10.00	0.002	0.006	0.67	10.00	0.026	0.039	21.33	70.00	0.069	0.139	33.33	80.00
<i>Erodium cicutarium</i> ^a	0	0	0	0	0	0	0	0	0.012	0.038	1.33	10.00	0.001	0.002	1.33	10.00
<i>Portulaca oleracea</i> ^a	0.001	0.002	2.67	30.00	0	0	0	0	0.007	0.009	7.33	80.00	0.006	0.015	4.67	20.00
<i>Salsola tragus</i> ^a	0	0	0	0	0	0	0	0	<0.001	0.001	0.67	10.00	0	0	0	0
<i>Ceratocephala testiculata</i> ^a	0	0	0	0	0.027	0.073	8.67	50.00	<0.001	0.001	0.67	10.00	0.002	0.007	1.33	10.00
<i>Gilia</i> spp.	0.007	0.015	11.33	30.00	0.055	0.038	60.67	100.00	<0.001	0.001	0.67	10.00	<0.001	0.001	0.67	10.00
<i>Phemeranthus</i> sp. ^b	0	0	0	0	0	0	0	0	0	0	0	0	<0.001	0.001	0.67	10.00

Note: Species are arranged in descending order by the cover of plot group A in 2012.

^aNonnative species.

^bRare species.

We encountered 5 nonnative species in the plots. The annual grass, *Bromus tectorum* (cheatgrass), ranged in mean foliar cover from 0.043% to 0.683%, and its plot frequency ranged from 40 to 80% in plot group A. Its foliar cover and frequencies for plot group B were within this range. It was the species with the fifth greatest mean foliar cover for plot group A in both 2011 and 2012, and had the sixth greatest mean foliar cover for plot group B. In 2010 it had much lower mean foliar cover. The remaining non-native species—*Erodium cicutarium* (stork's bill), *Portulaca oleracea* (little hogweed), *Ceratocephala testiculata* (curvseed butterwort), and *Salsola tragus* (prickly Russian thistle)—generally occurred in trace amounts, having low foliar cover, and low plot and quadrat frequencies in the years and plot groups where they did occur. The exception was *Ceratocephala testiculata*, which occurred in 50% of the plots in 2011, with low mean foliar cover.

Species diversity in this ecological site was moderately low on the scale of the plot, and moderate on the scale of the ecological site. Over the 3 years of sampling in plot group A, mean plot richness ranged between 21.7 and 29.6 species (Table 3). Mean Shannon diversity (which takes the relative abundance of each species into account, and generally ranges between 1.5 and 3.5) ranged between 1.596 and 1.830. Mean evenness (the degree to which all species are of equal abundance, ranging from 0 to 1) ranged between 0.524 and 0.549. On the scale of the ecological site, species richness ranged between 70 and 82. Beta diversity (a measure of within-ecological site heterogeneity, generally ranging between 1 and 5) ranged between 2.797 and 3.382. Comparing among years in plot group A, 2010 had the highest value for beta diversity, 2011 had the highest value for mean plot richness, and 2012 had the highest values for mean Shannon diversity and evenness, as well as ecological site richness.

Values for plot group B indices were within the range of the plot group A values, with the exception of slightly higher mean Shannon diversity and mean evenness values.

When we calculated the metrics using only native species, all the metrics showed slight decreases except for evenness and beta diversity in all years for plot group A.

Table 3. Species diversity metrics for all species, and for native species only, for plot group A and plot group B in the Limestone Upland ecological site at GRCA.

	Plot group A (n = 10)						Plot group B (n = 10)	
	2010		2011		2012		2012	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
All species								
Plot								
Plot richness	21.7	6.3	29.6	5.9	28.3	5.6	28.7	5.5
Shannon diversity	1.596	0.415	1.775	0.291	1.830	0.310	1.989	0.378
Evenness	0.525	0.121	0.524	0.067	0.549	0.78	0.595	0.104
Ecological site								
Ecological site richness ^a	70		80		82		79	
Beta diversity ^a	3.382		2.797		3.004		2.852	
Native species								
Plot								
Plot richness	21.0	6.0	28.4	5.7	26.4	6.0	27.8	5.3
Shannon diversity	1.585	0.405	1.762	0.293	1.816	0.315	1.955	0.373
Evenness	0.526	0.117	0.527	0.066	0.557	0.078	0.590	0.103
Ecological site								
Ecological site richness ^a	68		78		77		75	
Beta diversity ^a	3.400		2.847		3.031		2.799	

^aEcological site richness and beta diversity values are not means.

3.2 Trees

We report tree density (stems/ha) by species for seedlings, saplings, overstory trees, and snags (standing dead trees) for plot groups A and B. We also report basal area for overstory trees by species, grouped as living trees or snags (Table 4).

There were 2 tree species in our plots: *Juniperus osteosperma* (Utah juniper) and *Pinus edulis* (twoneedle pinyon). *Juniperus osteosperma* was more abundant than *Pinus edulis* both in terms of living overstory density and basal area (Table 4). Basal area for *Juniperus osteosperma* was 15.87 m²/ha and 18.62 m²/ha for plot groups A and B, respectively. In contrast, basal area for *Pinus edulis* was much lower: 5.32 m²/ha and 4.94 m²/ha for plot groups A and B, respectively (Figure 4). Snag basal area for *Juniperus osteosperma* was 2.71 m²/ha and 1.23 m²/ha for plot groups A and B, respectively, and snag basal area for *Pinus edulis* was less than 1 m²/ha for both plot groups.

Table 4. Mean density, mean basal area, and mean diameter of trees in the 10 plots in group A from 2010 to 2012 and the 10 plots in group B in 2012 in the Limestone Upland ecological site at GRCA.

Species	Plot group	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 overstory diameter (cm) ^b
<i>Juniperus osteosperma</i>	B	266.7	200.0	185.0	22.0	18.62	1.23	33.2
<i>Pinus edulis</i>	B	1693.3	452.0	115.0	7.0	4.94	0.34	22.5
All species ^d	B	1960.0	652.0	300.0	29.0	23.56	1.57	29.1

^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.

^bMean overstory diameter is provided as DBH for *Pinus edulis* and DRC for *Juniperus osteosperma*.

^cPlot group A metrics were measured in 2012, with the exception of sapling density, snag density, and snag basal area, which were measured in 2010.

^dValues in the "All species" row represent both *Juniperus osteosperma* and *Pinus edulis*, combined. "All species" density and basal area metrics are the sum of the individual species' mean values. "All species" overstory diameter is the mean diameter across both tree species.

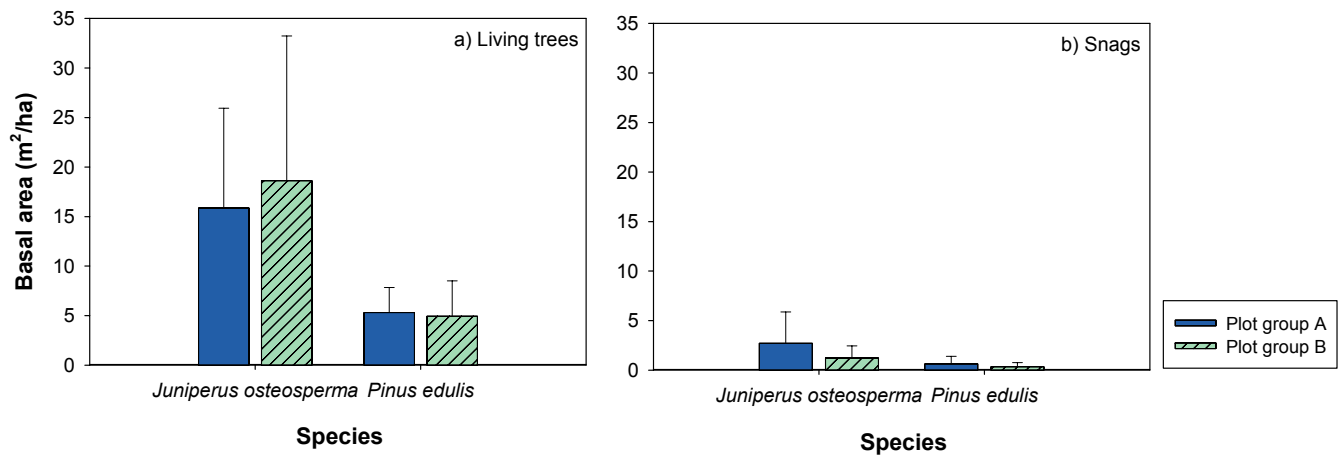


Figure 4. Mean basal area by species for a) living trees and b) snags, in plot group A and plot group B in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation.

Living overstory tree density for *Juniperus osteosperma* was 188.0 for plot group A and 185.0 for plot group B. *Pinus edulis* overstory density was 137.0 and 115.0 stems/ha for plot groups A and B, respectively. Both species showed an inverse size distribution, with the highest density in the smallest size class and decreasing density with size (Figure 5). However, with *Juniperus osteosperma*, the smallest two size classes were similar. Across both plot groups, *Juniperus osteosperma* ranged in size from 15 to 85 cm

DRC, while *Pinus edulis* ranged in size from 15 to 45 cm DBH. Mean diameter for *Juniperus osteosperma* was 30.5 and 33.2 cm for plot groups A and B, respectively; mean diameter for *Pinus edulis* was 21.3 and 22.5 cm for plot groups A and B, respectively.

Sapling and seedling densities provide measures of forest regeneration, and indicate the potential for change in species composition. In contrast to the overstory, *Pinus edulis* had greater sapling densities than *Juniperus osteosperma*, with 416.0 and 452.0 stems/ha for plot groups A and B, respectively. In contrast, sapling densities of *Juniperus osteosperma* were 140.0 and 200.0 stems/ha for plot groups A and B, respectively. For both species, the saplings were distributed fairly evenly among size classes (Figure 6).

Seedling densities were much greater for *Pinus edulis* than *Juniperus osteosperma*. *Pinus edulis* had seedling densities of 1953.3 stems/ha and 1693.3 stems/ha for plot groups A and B, respectively, while the seedling densities for *Juniperus osteosperma* were 266.7 stems/ha for both plot groups. Seedlings were fairly evenly distributed among size classes for both species, except for the largest size class of *Pinus edulis*, which had a much lower density (Figure 7). The differences in densities in the seedling size classes showed small variation among years and between plot groups. The large error bars indicate large among-plot variation.

The overall size class structure of overstory and saplings of both species combined showed an inverse relationship for both plot groups, where density decreased with increasing size (Figure 8). This relationship, however, was not perfect, as the smallest size class had lower densities than the second smallest size class. Standard deviations were large, particularly for the sapling size classes, indicating large among-plot variation. Variation between the 2 plot groups was relatively small.

Mean canopy cover for the 2 plot groups was similar: 36.7% for plot group A and 39.4% for plot group B (Figure 9).

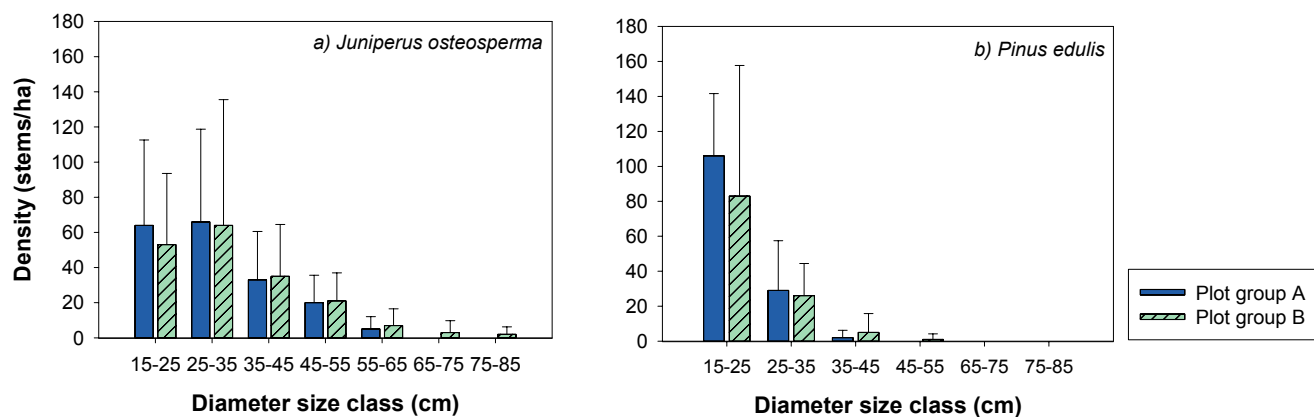


Figure 5. Size structure of living overstory trees for a) *Juniperus osteosperma* and b) *Pinus edulis* in plot group A and plot group B in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation.

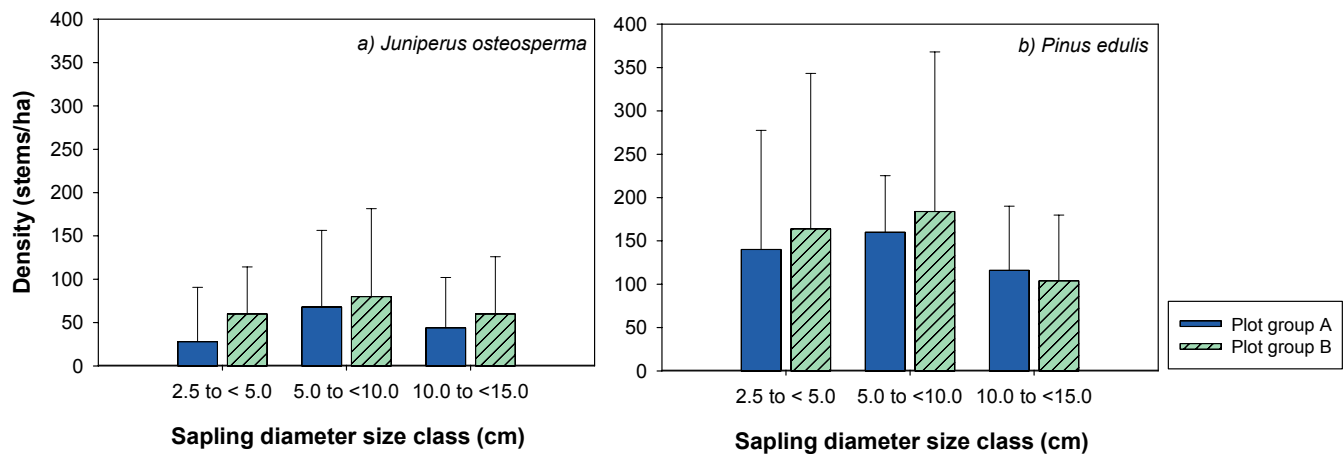


Figure 6. Mean density of saplings in different diameter size classes for a) *Juniperus osteosperma* and b) *Pinus edulis* for plot groups A and B in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation. Sapling diameter is measured at root crown for *Juniperus osteosperma*, and at breast height for *Pinus edulis*.

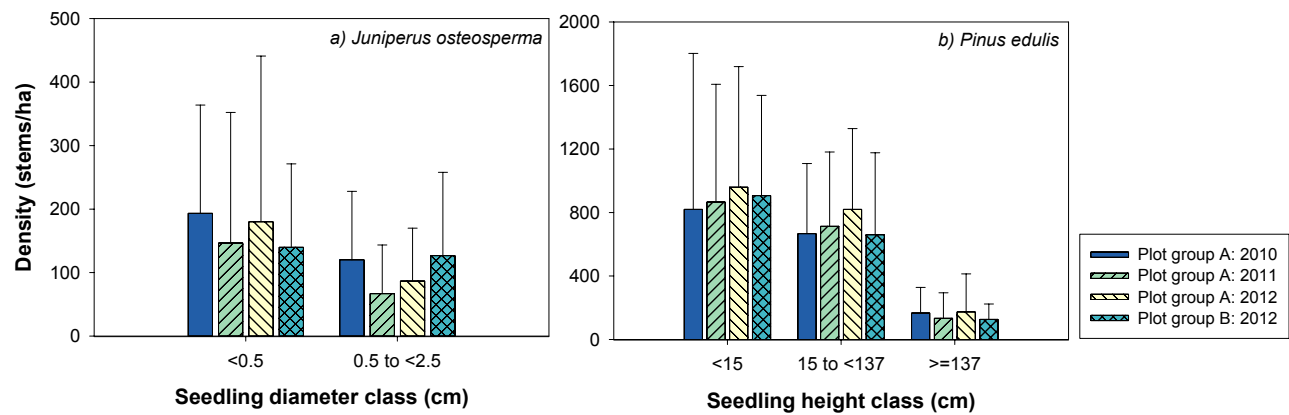


Figure 7. Mean density of seedlings in different size classes for a) *Juniperus osteosperma* and b) *Pinus edulis* in plot groups A and B in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation. Seedling diameter is measured at root crown for *Juniperus osteosperma*. Note that the scales for the 2 graphs differ.

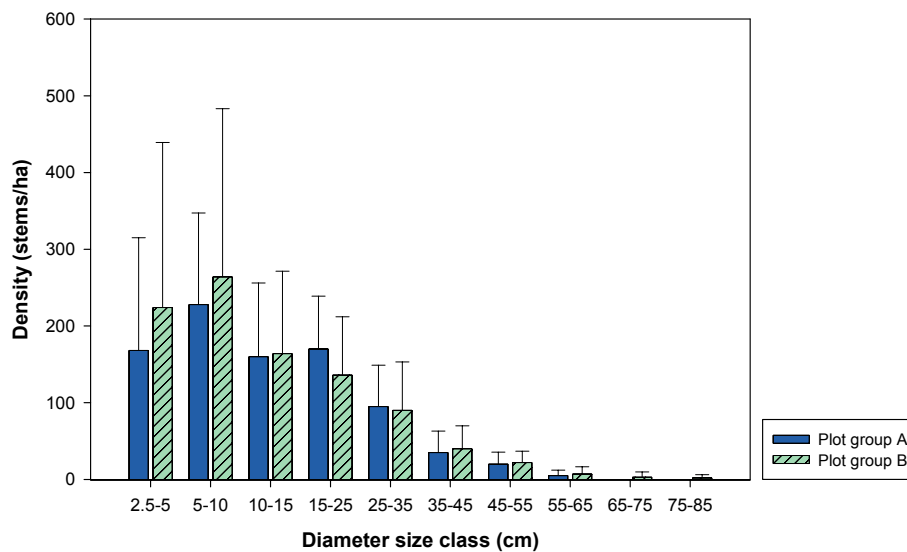


Figure 8. Size structure of all living overstory trees and saplings for plot group A and plot group B in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation. Overstory tree and sampling diameter is measured at root crown for *Juniperus osteosperma*, and at breast height for *Pinus edulis*.

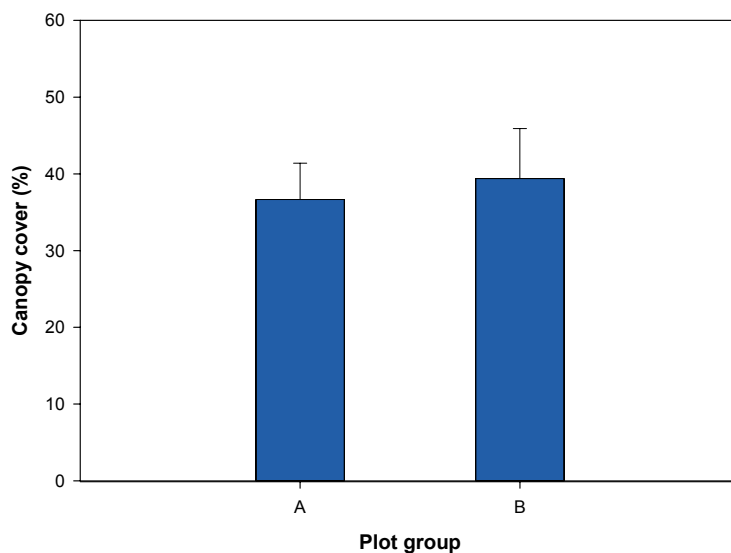


Figure 9. Mean percent canopy cover for plot group A and plot group B in 2012 in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation.

3.3 Soil stability and hydrologic function

We measured the amount of soil surface potentially subject to erosion in 2 ways: cover estimates of soil surface features in quadrats, and measurements of basal gaps along transects. Duff/litter was the soil surface feature with the greatest mean cover, ranging between 46.30% and 48.45% for plot group A (Figure 10 and Table 5). Other important features included undifferentiated crust, bare soil, fine gravel, and coarse gravel, all having between 4% and 20% mean cover. There was moderate variation in the cover of several of the features among the 3 years in plot group A, including live plant base, bare soil, undifferentiated crust, moss, lichen, cyanobacteria and coarse gravel. The mean covers of features for plot group A and plot group B were similar; the values for the plot group B metrics generally fell within the ranges of the plot group A metrics.

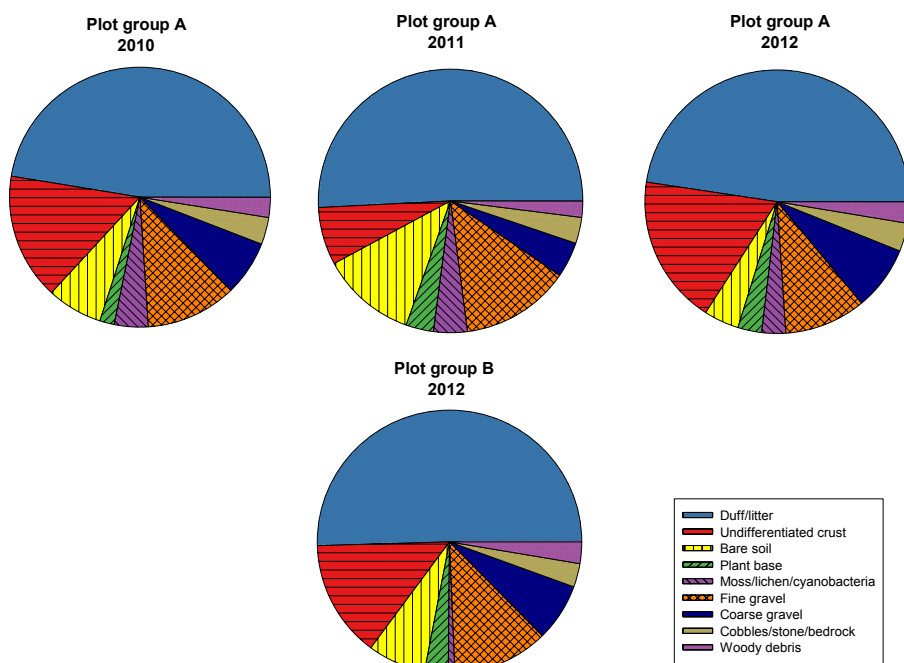


Figure 10. Mean percent cover of soil surface features for plot group A and plot group B in the Limestone Upland ecological site at GRCA.

Table 5. Cover of soil surface features for plot group A and plot group B in the Limestone Upland ecological site at GRCA.

Soil surface feature	Plot group A (n = 10)						Plot group B (n = 10)	
	2010		2011		2012		2012	
	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Live plant base	0.93	0.44	2.06	0.83	1.83	0.63	2.01	1.16
Dead woody base	0.20	0.19	0.24	0.33	0.35	0.33	0.35	0.37
Dead herbaceous base	0.64	0.57	0.93	0.66	0.88	0.48	0.60	0.38
Bare soil	6.71	4.39	11.13	6.74	4.36	4.54	7.30	8.28
Duff/litter	46.30	11.23	48.45	11.28	48.36	13.08	51.85	12.25
Undifferentiated crust	15.36	11.17	6.74	4.93	18.60	9.99	14.78	10.10
Moss	0.62	0.52	2.24	1.97	2.01	1.58	0.46	0.38
Lichen	0.08	0.16	0.61	1.83	0.19	0.44	0.29	0.64
Cyanobacteria	3.42	4.72	1.10	1.66	0.77	1.37	0.07	0.10
Fine gravel (0.2 to <2 cm)	11.02	12.66	12.79	14.46	10.15	11.03	12.06	9.91
Coarse gravel (2 to <7.5 cm)	6.69	6.90	4.15	5.68	8.01	8.47	7.27	5.63
Cobble (7.5 to <25 cm)	2.16	2.92	2.12	2.94	2.52	3.32	2.35	1.57
Stone, bedrock (≥25 cm)	1.14	2.54	0.93	2.27	1.03	2.08	0.63	0.86
Woody debris	2.43	1.47	1.90	1.44	2.65	1.56	2.72	1.73

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.

The basal gap data showed large distances between plant bases, indicating large areas of exposed soil. Gaps of 100 cm or greater comprised the majority of the transect lengths. The average percentage of transects comprised of large gaps ranged between 80.1% and 84.2% for all plot groups and years (Figure 11 and Table 6). Gaps less than 20 cm comprised between 1 and 2% of the transects among the years and plot groups. The median gap size ranged between 80.1 cm and 108.6 cm among the years and plot groups. With the exception of number of gaps per transect, most metrics showed little variation among years for plot group A. Metrics for plot group B tended towards fewer but larger basal gaps.

Soil stability was moderately high. Mean plot stability was 4.08 for plot group A and 4.90 for plot group B (Table 7). Samples under vegetative cover were greater than samples without vegetative cover.

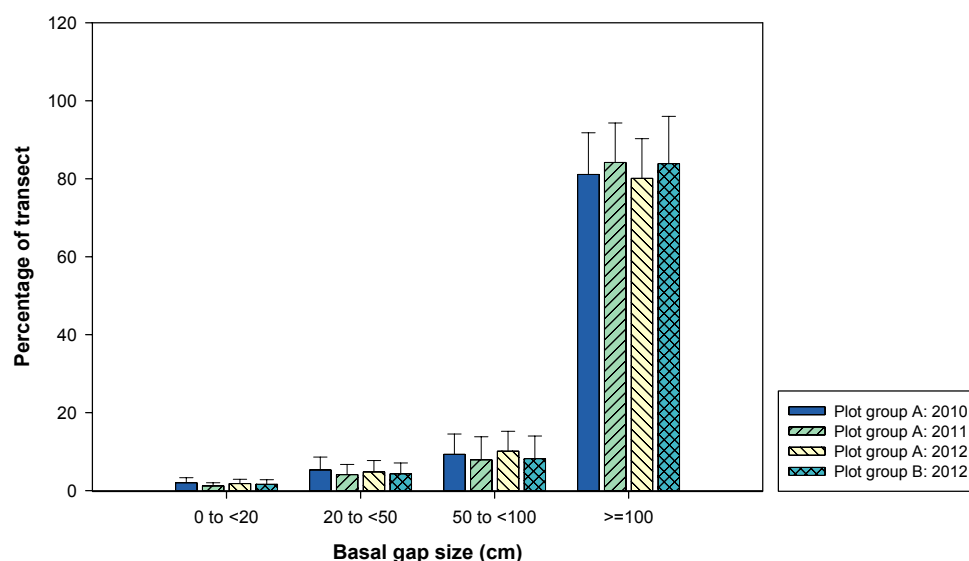


Figure 11. Mean percentage of transect by gap size class for plot group A and plot group B in the Limestone Upland ecological site at GRCA. Error bars represent one standard deviation.

Table 6. Number of basal gaps, median gap size, and percentage of transect in different gap size classes for plot group A and plot group B in the Limestone Upland ecological site at GRCA.

Metric	Plot group A (n = 10)						Plot group B (n = 10)	
	2010		2011		2012		2012	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Number of gaps	106.9	51.5	84.0	36.5	108.7	40.2	98.4	47.8
Median gap size (cm)	84.1	90.5	81.4	35.1	80.1	50.4	108.6	96.9
Percentage of transect in gaps	97.2	1.6	97.4	1.4	96.8	3.8	98.0	4.3
Percentage of transect in gaps 0 to <20 cm	2.0	1.3	1.2	0.8	1.8	1.1	1.6	1.2
Percentage of transect in gaps 20 to <50 cm	5.3	3.3	4.1	2.6	4.8	2.9	4.3	2.8
Percentage of transect in gaps 50 to <100 cm	9.3	5.2	7.9	5.9	10.1	5.1	8.2	5.8
Percentage of transect in gaps ≥100 cm	81.1	10.7	84.2	10.1	80.1	10.2	83.9	12.1

Table 7. Soil stability rating for all samples, and for samples with and without vegetative cover, in the Limestone Upland ecological site at GRCA. Measurements were collected for plot group A in 2010, and for plot group B in 2012.

	Plot group A (n = 9) ^a		Plot group B (n = 8) ^a	
	Mean	SD	Mean	SD
All samples	4.08	0.68	4.90	0.54
Samples under vegetative cover	4.87	0.57	5.50	0.50
Samples not under vegetative cover	3.03	1.25	4.42	0.76

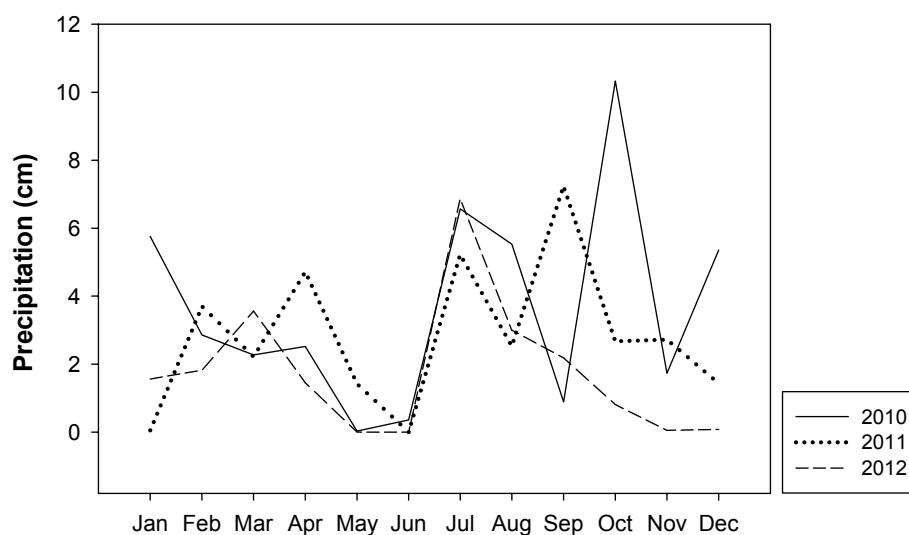
Note: Ratings range from 1–6, with 1 being the lowest stability and 6 being the highest.

^aSoils were too wet to conduct soil stability tests at all 10 plots in 2010 and 2012.

3.4 Western Regional Climate Center precipitation data

Precipitation records for GRCA are available from the Western Regional Climate Center (2012). Figure 12 shows the total monthly precipitation for 2010, 2011 and 2012.

Figure 12. Total monthly precipitation for 2010, 2011, and 2012 at Grand Canyon Airport (USW00003195), collected by the Western Regional Climate Center.



4 Discussion

We present 3 years of data from the first 10 plots established in the Limestone Upland ecological site at GRCA to gain a better understanding of the temporal variability in the data, and compare these data with 10 additional plots established and sampled in 2012.

At the ecological site level, combining both plot groups, the shrub/herbaceous vegetation was co-dominated by shrubs and perennial grasses. Dominant shrubs included *Purshia stansburiana*, *Artemisia tridentata*, *Gutierrezia sarothrae* and *Mahonia fremontii*. Dominant perennial grasses included *Bouteloua gracilis* and *Poa fendleriana*. Five nonnative species were found in the plots, but only one was abundant. *Bromus tectorum* was the species with the fifth greatest mean foliar cover in both 2011 and 2012, but had lower abundance in 2010. *Portulaca oleracea*, *Erodium cicutarium*, *Salsola tragus* and *Ceratocephala testiculata* occurred in lower abundance. Species diversity was moderately low on the scale of the plot, and moderate on the scale of the ecological site.

The tree data showed a woodland dominated by *Juniperus osteosperma*, with lower but substantial abundance of *Pinus edulis*. The overstory density and basal area of *Pinus edulis* was greater than other pinyon-juniper woodlands we monitor. The drought of the previous decade caused much less mortality in this ecological site. The low density of the smallest sapling size class for both species suggests a bottleneck for recruitment into the canopy, but this may be offset by the abundance of *Pinus edulis* seedlings.

The soils data indicated that there is not a large potential for erosion. While the basal gap data showed that there were large distances between plant bases, the majority of the area was mostly composed of duff and litter, and the soil stability indices were moderately high.

Looking at spatial variation, the vegetation and soil metrics for plot group B were generally comparable to plot group A, but there were some differences in species composition. Total foliar cover and perennial grass cover were somewhat lower in plot group B, as were the foliar covers of *Bouteloua gracilis* and *Mahonia fremontii*. The foliar cover of *Quercus gambelii* was higher in plot group B. *Pinus edulis* was less abundant in plot group B in terms of overstory density, basal area, and seedling density, but had higher sapling density. *Juniperus osteosperma* had similar overstory density but higher basal area and higher sapling density in plot group B. Soil metrics were similar for the 2 plot groups.

Differences in the vegetation and soil data between plot group A and plot group B were largely the result of random spatial variation. The plot groups represent different plots in different locations. Due to endogenous factors such as soils and topography, and exogenous factors such as climate and disturbance, species composition and structure naturally vary.

Looking at temporal variation, there were moderate differences in species composition among the 3 years of sampling of plot group A. Foliar covers of the living functional groups were invariably higher in 2011. Similarly, foliar cover of several dominant perennial grass and shrub species was higher for 2011. Over the 3 years of sampling, a number of species were present in 1 or 2 of the 3 years. As a result, ecological site species richness varied over the 3 years, with 2010 having the lowest value. The other diversity metrics varied over the 3 years, with 2010 tending to have lower values than the other 2 years. There were also some differences in the mean cover of soil surface features over the 3 years, particularly with undifferentiated crust, bare soil and cyanobacteria. Basal gap metrics were comparable.

The differences in the vegetation and soil data in the 3 years of plot group A are likely the result of differences in precipitation. Variation in precipitation has been associated with changes in cover and frequency of herbaceous plants, particularly for annual species and forbs. Spatial variability accounts for the majority of the differences among the plot groups, but additional variation may result from annual climatic variation, particularly for the herbaceous/shrub layer. The similarity in vegetation composition of plot group B with the 2012 sampling of plot group A was expected; these 2 sets of data experienced the same precipitation regimes. Precipitation may also account for some of the year to year differences in the soil surface features. These variations may be attributable to how soil surface features appear in wet conditions versus dry conditions. When the ground surface is wet, cyanobacteria are much more visible, and undifferentiated crust becomes more difficult to distinguish from bare soil. In addition, physical crust is formed by raindrop impact and decreases with increasing time since the last rainfall.

Precipitation records for GRCA gathered by the Western Regional Climate Center showed some variation in the precipitation regimes among the 3 years, although the differences were not large. The largest difference was in September, which had much more precipitation in 2011 than in the other 2 years. As this was the month that sampling occurred in all 3 years, it is likely that the 2011 sampling captured more species and biomass as a result of germination and growth of herbaceous plants following precipitation events.

Variability may also be attributable to sampling error. Although we strive to reduce sampling error through training and diligence while collecting data, sampling error is inevitable. Cover estimation may vary among individuals (and crews), species may be misidentified, a slight difference among observers in applying sampling methods may go unnoticed and the location of transects and quadrats vary slightly from year to year. We minimize this source of error by ensuring that transect lines are as straight as possible, quadrats are placed correctly, and field crews are thoroughly trained in methods and species identification and remain calibrated on cover estimation.

We will implement the 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 each revisit, and monitoring a new set of plots 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 plots into 3 panels, and sample 2 of the panels every other year (Table 8). The first year of our panel design is 2012. Plot group A represents the first panel (panel A) and plot group B represents the second panel (panel B). In 2014 we will resample plot group B and also establish 10 additional plots that will represent the third panel (panel C).

Table 8. The panel design we are currently planning to use for the revisit design at the Limestone Upland ecological site at GRCA. "X" represents 10 plots 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
A	X				X		X				X	
B	X		X				X		X			
C			X		X				X		X	
Sum/yr	2X	0	2X	0	2X	0	2X	0	2X	0	2X	0

5 Literature cited

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Appendix A: Complete species list for plots sampled in the Limestone Upland ecological site at GRCA, 2010–2012.

Table A1. Shrub and herbaceous species with mean foliar cover and plot frequency for plot groups A and B in the Limestone Upland ecological site at GRCA.

Species	Common name	Family	Plot group A (n = 10)						Plot group B (n = 10)	
			2010		2011		2012		2012	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Achnatherum hymenoides</i>	Indian ricegrass	Poaceae	0	0	0	0	0	0	0.002	20
<i>Allium cernuum</i>	nodding onion	Liliaceae	0.001	10	0	0	0	0	0	0
<i>Amaranthus powellii</i>	Powell's amaranth	Amaranthaceae	0	0	0	0	<0.001	10	0.001	20
<i>Androsace septentrionalis</i>	pygmy rock jasmine	Primulaceae	0	0	0.020	90	0.008	60	0.017	40
<i>Arceuthobium divaricatum</i>	pinyon dwarf mistletoe	Viscaceae	<0.001	10	0.004	40	0.035	40	0.003	50
<i>Artemisia tridentata</i>	basin big sagebrush	Asteraceae	0.999	100	1.405	100	1.059	100	1.185	90
<i>Astragalus</i> spp.	milkvetch	Fabaceae	0.027	70	0.022	70	0.042	90	0.059	80
<i>Bahia dissecta</i>	ragleaf bahia	Asteraceae	<0.001	10	0	0	0	0	0.002	10
<i>Boechera perennans</i>	perennial rockcress	Brassicaceae	0.002	40	0.013	60	0.041	40	0.006	60
<i>Boechera</i> sp.	rockcress	Brassicaceae	0	0	<0.001	10	<0.001	10	0	0
<i>Bouteloua gracilis</i>	blue grama	Poaceae	2.126	90	2.147	90	1.092	90	0.511	90
<i>Brickellia californica</i>	California brickellbush	Asteraceae	0	0	0	0	0	0	0.011	20
<i>Bromus tectorum</i> ^a	cheatgrass	Poaceae	0.043	40	0.683	70	0.300	80	0.142	50
<i>Calochortus nuttallii</i>	sego lily	Liliaceae	0.001	30	0.001	20	0	0	0	0
<i>Castilleja</i> spp.	Indian paintbrush	Scrophulariaceae	0	0	0	0	0.001	10	0	0
<i>Castilleja linariifolia</i>	Wyoming Indian paintbrush	Scrophulariaceae	0	0	0	0	<0.001	10	0	0
<i>Ceratocephala testiculata</i> ^a	curvseed butterwort	Ranunculaceae	0	0	0.027	50	<0.001	10	0.002	10
<i>Chaetopappa ericoides</i>	rose heath	Asteraceae	0.003	30	0.006	40	0.007	40	0.013	40
<i>Chamaebatiaria millefolium</i>	fernbrush	Rosaceae	0	0	0	0	0	0	0.024	10
<i>Chamaesyce</i> spp.	annual sandmats	Euphorbiaceae	0.008	20	0.003	10	0.009	40	0.051	90
<i>Chenopodium fremontii</i>	Fremont's goosefoot	Chenopodiaceae	0	0	0	0	0	0	0.001	20
<i>Chrysothamnus depressus</i>	longflower rabbitbrush	Asteraceae	0.002	10	0.002	20	0.002	10	0.009	20
<i>Collinsia parviflora</i>	blue-eyed Mary	Scrophulariaceae	0	0	0	0	0	0	<0.001	10
<i>Comandra umbellata</i>	bastard toadflax	Santalaceae	0.027	30	0.030	30	0.020	30	0.011	20
<i>Cordylanthus parviflorus</i>	purple bird's-beak	Scrophulariaceae	0.044	40	0.017	40	0	0	0	0
<i>Cordylanthus wrightii</i>	Wright's bird's beak	Scrophulariaceae	0.013	10	0.007	20	<0.001	10	0	0
<i>Cryptantha</i> spp.	cryptantha	Boraginaceae	0.005	20	0.001	20	0.001	20	0	0

Table A1 (continued)

Species	Common name	Family	Plot group A (n = 10)						Plot group B (n = 10)	
			2010		2011		2012		2012	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Dasyochloa pulchella</i>	low woollygrass	Poaceae	0	0	0	0	0	0	<0.001	10
<i>Delphinium scaposum</i>	barestem larkspur	Ranunculaceae	0.004	10	0	0	0	0	0	0
<i>Descurainia pinnata</i>	western tansymustard	Brassicaceae	0	0	0.025	90	0.003	50	0.008	50
<i>Draba cuneifolia</i>	wedgeleaf draba	Brassicaceae	0.002	20	0.086	100	0.054	60	0.044	40
<i>Dysphania graveolens</i>	fetid goosefoot	Chenopodiaceae	0.001	20	0	0	0.005	20	0.009	60
<i>Echinocereus</i> spp.	hedgehog cactus	Cactaceae	0.003	20	0.002	20	0.005	40	0.003	30
<i>Elymus elymoides</i>	squirreltail	Poaceae	0.028	70	0.052	80	0.042	80	0.088	70
<i>Enneapogon desvauxii</i>	nineawn pappusgrass	Poaceae	0	0	0	0	0	0	<0.001	10
<i>Ephedra viridis</i>	Mormon tea	Ephedraceae	0.066	30	0.091	40	0.093	40	0.024	50
<i>Epilobium brachycarpum</i>	autumn willowherb	Onagraceae	0	0	<0.001	10	0	0	0	0
<i>Eragrostis mexicana</i>	Mexican lovegrass	Poaceae	0	0	0	0	0	0	<0.001	10
<i>Ericameria nauseosa</i>	rubber rabbitbrush	Asteraceae	0.007	20	0.009	20	0.008	40	0.017	20
<i>Erigeron</i> spp.	fleabane	Asteraceae	0	0	0	0	<0.001	10	0	0
<i>Erigeron concinnus</i>	Navajo fleabane	Asteraceae	0.012	40	0.027	40	0.020	50	0.012	50
<i>Erigeron divergens</i>	spreading fleabane	Asteraceae	0.001	20	0.023	50	0.090	70	0.038	70
<i>Erigeron flagellaris</i>	trailing fleabane	Asteraceae	0.001	20	0.006	20	0.004	30	0.003	20
<i>Erigeron formosissimus</i>	beautiful fleabane	Asteraceae	0	0	<0.001	10	<0.001	10	0	0
<i>Eriogonum alatum</i>	winged buckwheat	Polygonaceae	0.004	10	0.010	10	0.004	10	0	0
<i>Eriogonum jamesii</i>	James' buckwheat	Polygonaceae	0	0	0	0	0	0	0.004	20
<i>Eriogonum microthecum</i>	Simpson's buckwheat	Polygonaceae	0.014	50	0.019	50	0.018	50	0.016	30
<i>Eriogonum racemosum</i>	redroot buckwheat	Polygonaceae	0.043	30	0.060	30	0.053	30	0.025	30
<i>Eriogonum umbellatum</i>	sulphur-flowered buckwheat	Polygonaceae	0.025	30	0.040	30	0.031	30	0.005	20
<i>Eriogonum wrightii</i>	bastardsage	Polygonaceae	0	0	0	0	<0.001	10	0.044	10
<i>Erodium cicutarium</i> ^a	stork's bill	Geraniaceae	0	0	0	0	0.012	10	0.001	10
<i>Escobaria vivipara</i>	spinystar	Cactaceae	0.003	30	0.009	30	0.003	30	0.005	60
<i>Fallugia paradoxa</i>	Apache plume	Rosaceae	0	0	0	0	0	0	0.028	10
<i>Frasera albomarginata</i>	desert fraseria	Gentianaceae	0	0	0	0	0	0	<0.001	10
<i>Gilia</i> spp.	gilia	Polemoniaceae	0.007	30	0.055	100	<0.001	10	<0.001	10
<i>Gutierrezia sarothrae</i>	broom snakeweed	Asteraceae	0.179	100	0.283	100	0.147	100	0.203	100

Table A1 (continued)

Species	Common name	Family	Plot group A (n = 10)						Plot group B (n = 10)	
			2010		2011		2012		2012	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Hedeoma drummondii</i>	Drummond's false pennyroyal	Lamiaceae	0.006	20	0.018	30	0.017	30	0	0
<i>Hesperostipa comata</i>	needle and thread	Poaceae	0.023	10	0.010	10	0.024	10	0.054	30
<i>Heterotheca villosa</i>	false hairy goldenaster	Asteraceae	0	0	<0.001	10	<0.001	10	0	0
<i>Hymenopappus filifolius</i>	fineleaf hymenopappus	Asteraceae	0.010	40	0.010	40	0.011	40	0.029	60
<i>Hymenoxys richardsonii</i>	Colorado rubberweed	Asteraceae	0.002	10	0	0	0.004	10	0	0
<i>Ipomopsis multiflora</i>	manyflowered ipomopsis	Polemoniaceae	0.007	40	0.015	20	0.009	20	0.003	20
<i>Koeleria macrantha</i>	prairie junegrass	Poaceae	0.004	10	0.008	20	0.002	10	0	0
<i>Lesquerella intermedia</i>	mid bladderpod	Brassicaceae	0.012	40	0.021	40	0.030	40	0.021	70
<i>Linum lewisii</i>	prairie flax	Linaceae	0	0	0.001	10	<0.001	10	0.005	10
<i>Lupinus kingii</i>	King's lupine	Fabaceae	0.008	20	0.009	30	0.006	30	0.002	30
<i>Machaeranthera gracilis</i>	slender goldenweed	Asteraceae	0	0	0.009	80	0	0	0.001	10
<i>Machaeranthera tanacetifolia</i>	tanseyleaf tansyaster	Asteraceae	<0.001	10	<0.001	10	0.001	20	0	0
<i>Mahonia fremontii</i>	Fremont's mahonia	Berberidaceae	0.179	20	0.153	20	0.103	20	0.019	10
<i>Mentzelia albicaulis</i>	whitestem blazingstar	Loasaceae	0.003	20	0.005	30	0	0	0	0
<i>Mirabilis linearis</i>	narrowleaf four o'clock	Nyctaginaceae	0.002	20	0.001	20	0.007	20	0.003	10
<i>Muhlenbergia brevis</i>	short muhly	Poaceae	0	0	0	0	0	0	0.001	20
<i>Myosurus minimus</i>	tiny mousetail	Ranunculaceae	0	0	0.004	20	0	0	0	0
<i>Nama dichotoma</i>	wishbone fiddleleaf	Hydrophyllaceae	0.002	10	0.002	10	0.026	70	0.069	80
<i>Opuntia</i> spp.	prickly pear	Cactaceae	0.115	100	0.189	100	0.087	10	0.117	100
<i>Opuntia whipplei</i>	Whipple's cholla	Cactaceae	0.002	10	0.002	10	0.002	10	0	0
<i>Orobanche ludoviciana</i>	Louisiana broomrape	Orobanchaceae	0	0	<0.001	10	0	0	0	0
<i>Packera multilobata</i>	lobeleaf groundsel	Asteraceae	0.003	30	0.007	50	0.017	50	0.009	30
<i>Packera neomexicana</i>	New Mexico groundsel	Asteraceae	0.002	30	0.002	40	0.019	60	0.017	60
<i>Penstemon barbatus</i>	beardlip penstemon	Scrophulariaceae	0.029	60	0.025	70	0.026	60	0.018	70
<i>Penstemon caespitosus</i>	mat penstemon	Scrophulariaceae	0.002	10	0.002	20	0.002	10	0.009	10
<i>Penstemon ophianthus</i>	Arizona beardtongue	Scrophulariaceae	0.005	10	0.013	10	0.009	10	0	0
<i>Penstemon pachyphyllus</i>	thickleaf beardtongue	Scrophulariaceae	0.016	50	0.013	50	0.008	50	0.024	70
<i>Phemeranthus</i> spp.	fameflower	Portulacaceae	0	0	0	0	0	0	<0.001	10
<i>Phlox</i> sp.	phlox	Polemoniaceae	0	0	0.002	20	0	0	0	0

Table A1 (continued)

Species	Common name	Family	Plot group A (n = 10)						Plot group B (n = 10)	
			2010		2011		2012		2012	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Phlox austromontana</i>	mountain phlox	Polemoniaceae	0.068	20	0.079	20	0.054	20	0.082	30
<i>Phlox gracilis</i>	slender phlox	Polemoniaceae	0	0	0.001	10	0	0	0	0
<i>Phlox longifolia</i>	longleaf phlox	Polemoniaceae	0.001	20	0.013	50	0.003	50	0.002	30
<i>Phoradendron juniperinum</i>	juniper mistletoe	Viscaceae	0	0	0	0	0.003	30	0	0
<i>Plantago patagonica</i>	woolly plantain	Plantaginaceae	0	0	0.006	10	0.001	10	0.002	30
<i>Poa fendleriana</i>	muttongrass	Poaceae	0.813	100	1.814	100	1.203	100	1.020	100
<i>Polygonum sawatchense</i>	Sawatch knotweed	Polygonaceae	0.008	60	0.008	50	0.003	20	0.002	10
<i>Portulaca oleracea</i> ^a	little hogweed	Portulacaceae	0.001	30	0	0	0.007	80	0.006	20
<i>Portulaca pilosa</i>	kiss me quick	Portulacaceae	<0.001	10	0	0	<0.001	10	0.005	10
<i>Psilostrophe sparsiflora</i>	greenstem paperflower	Asteraceae	0	0	<0.001	10	<0.001	10	0	0
<i>Psoralidium</i> sp.	scurfpea	Fabaceae	0	0	<0.001	10	0	0	0	0
<i>Psoralidium tenuiflorum</i>	slimflower scurfpea	Fabaceae	<0.001	10	<0.001	10	0	0	0	0
<i>Purshia stansburiana</i>	Stansbury cliffrose	Rosaceae	1.661	100	2.301	100	1.848	100	1.841	100
<i>Purshia tridentata</i>	antelope bitterbrush	Rosaceae	0	0	0	0	0	0	0.028	10
<i>Quercus gambelii</i>	Gambel oak	Fagaceae	0.010	10	0.050	10	0.050	10	0.145	20
<i>Salsola tragus</i> ^a	prickly Russian thistle	Chenopodiaceae	0	0	0	0	<0.001	10	0	0
<i>Sanvitalia abertii</i>	Albert's creeping zinnia	Asteraceae	0.001	10	0	0	0.015	10	0.007	30
<i>Schkuhria multiflora</i>	many-flower false threadleaf	Asteraceae	0	0	0	0	0.001	30	0.001	20
<i>Silene antirrhina</i>	sleepy catchfly	Caryophyllaceae	0	0	0.001	10	0	0	0	0
<i>Sphaeralcea</i> spp.	globemallow	Malvaceae	0.003	20	0.001	20	0.006	30	0.004	40
<i>Sporobolus cryptandrus</i>	sand dropseed	Poaceae	0	0	0	0	<0.001	10	0	0
<i>Stephanomeria</i> spp.	wire lettuce	Asteraceae	<0.001	10	<0.001	10	0.002	10	0	0
<i>Tetranneuris acaulis</i>	stemless four-nerve daisy	Asteraceae	0.002	10	0.004	10	0	0	0.003	20
<i>Thlaspi montanum</i>	alpine pennycress	Brassicaceae	0.001	20	0.003	20	0.002	30	0.016	50
<i>Townsendia incana</i>	hoary Townsend daisy	Asteraceae	<0.001	10	0.002	10	0.001	20	0.002	10
<i>Vulpia octoflora</i>	sixweeks fescue	Poaceae	0	0	0.026	70	0.013	30	0.009	40
<i>Yucca baccata</i>	banana yucca	Agavaceae	0.004	50	0.007	40	0.009	40	0.024	60

^aNonnative species.

Table A2. Tree species with mean foliar cover and plot frequency for plot group A and plot group B in the Limestone Upland ecological site at GRCA.

Species	Common name	Family	Plot group A (n = 10) 2010–2012		Plot group B (n = 10) 2012	
			Basal area (m ² /ha) ^a	Plot frequency (%) ^b	Basal area (m ² /ha) ^a	Plot frequency (%) ^b
<i>Juniperus osteosperma</i>	Utah juniper	Cupressaceae	15.87	100	18.62	100
<i>Pinus edulis</i>	twoneedle pinyon	Pinaceae	5.32	100	4.94	100

^aBasal area measurements only include overstory trees and were taken from the 2012 measurements for plot group A.

^bPlot frequency includes overstory trees, saplings (measured only in 2010 for plot group A), and seedlings.

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