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# 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
Photography by: Scott Massed/SCPN

# Integrated Upland Vegetation and Soils Monitoring for Grand Canyon National Park

## *2012 Summary Report*

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

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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 ≥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

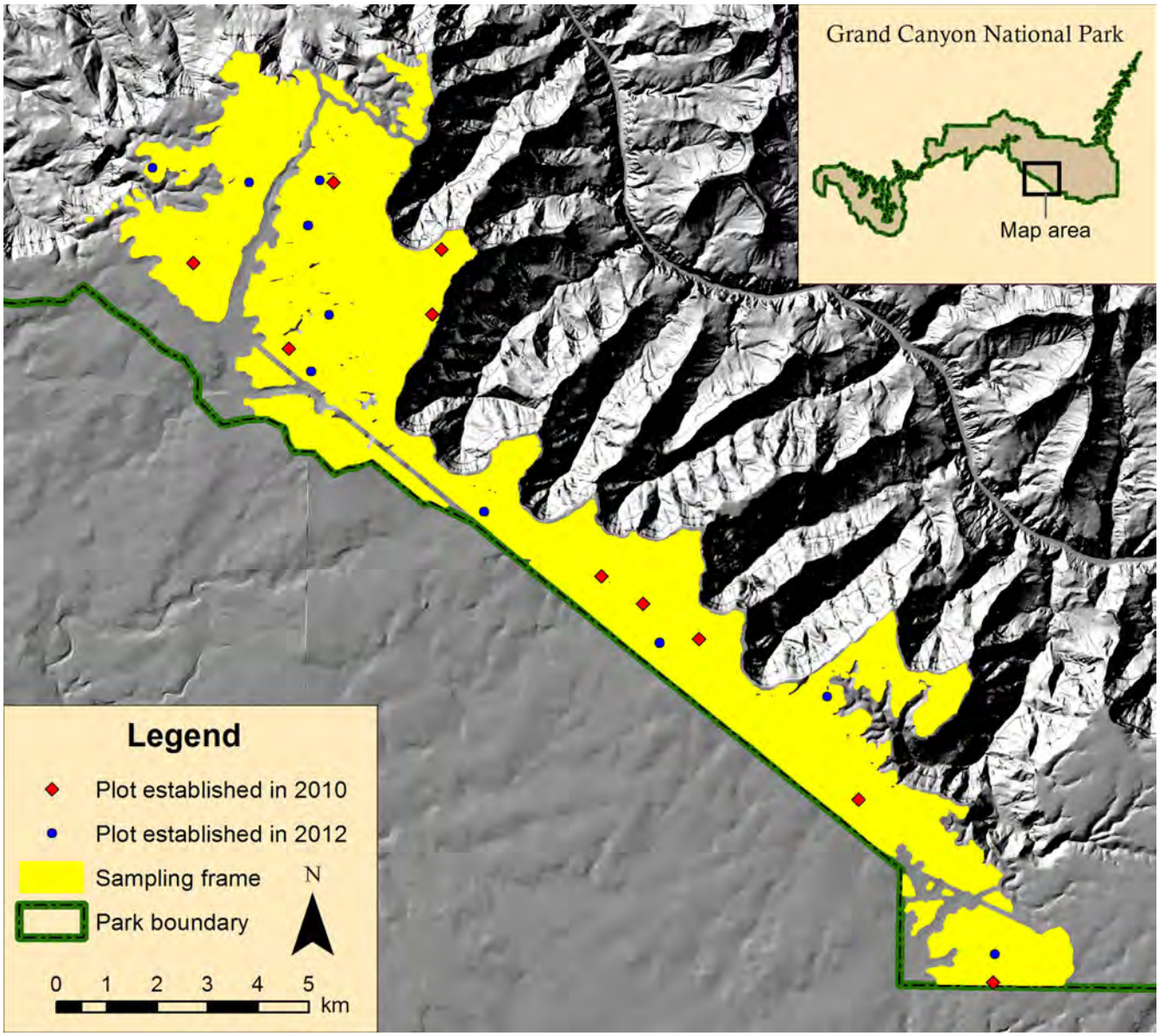



Figure 1. Sampling frame of the Limestone Upland ecological site at GRCA showing the 10 plots established in 2010 and the 10 plots established in 2012.

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 collected 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 $m^2$ (2 × 5 m), with 4 smaller quadrats nested inside (0.01 $m^2$, 0.1 $m^2$, 1 $m^2$, 5 $m^2$). We recorded the presence

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

### *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 $m^2$ 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 $m^2$ 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 $m^2$ 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 ($\beta_w$) 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.

| | Plot group A (*n* = 10) | | | | | | Plot group B (*n* = 10) | |
|---|---|---|---|---|---|---|---|---|
| | 2010 | | 2011 | | 2012 | | 2012 | |
| **Functional groups** | **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.

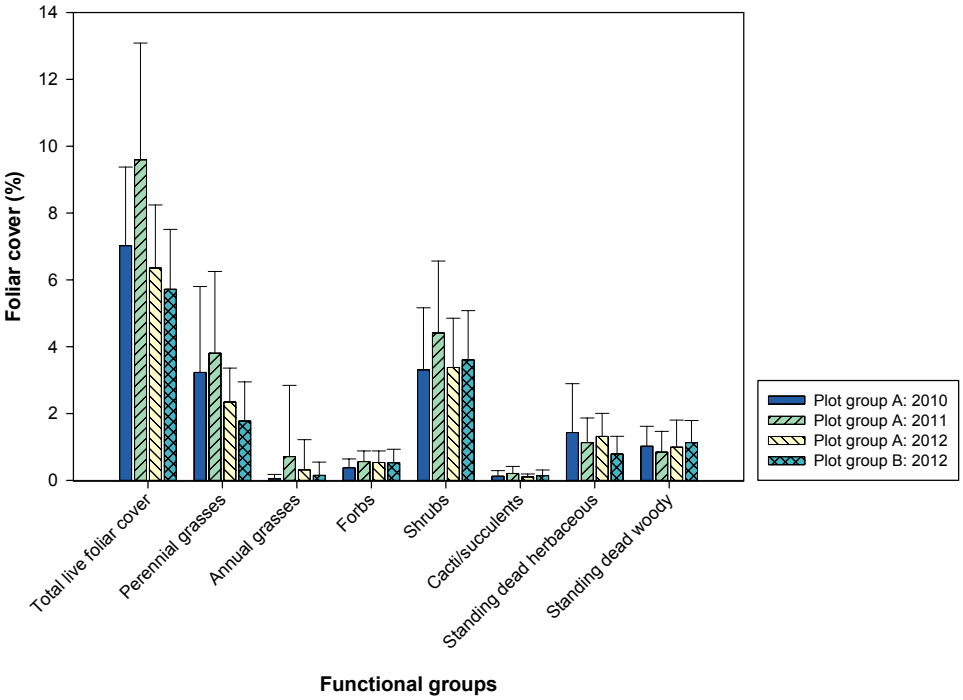



Figure 2. Mean percent foliar cover of functional groups for plot group A and plot group B in the Limestone Upland ecological site at GRCA. Error bars represent one standard deviation.

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.

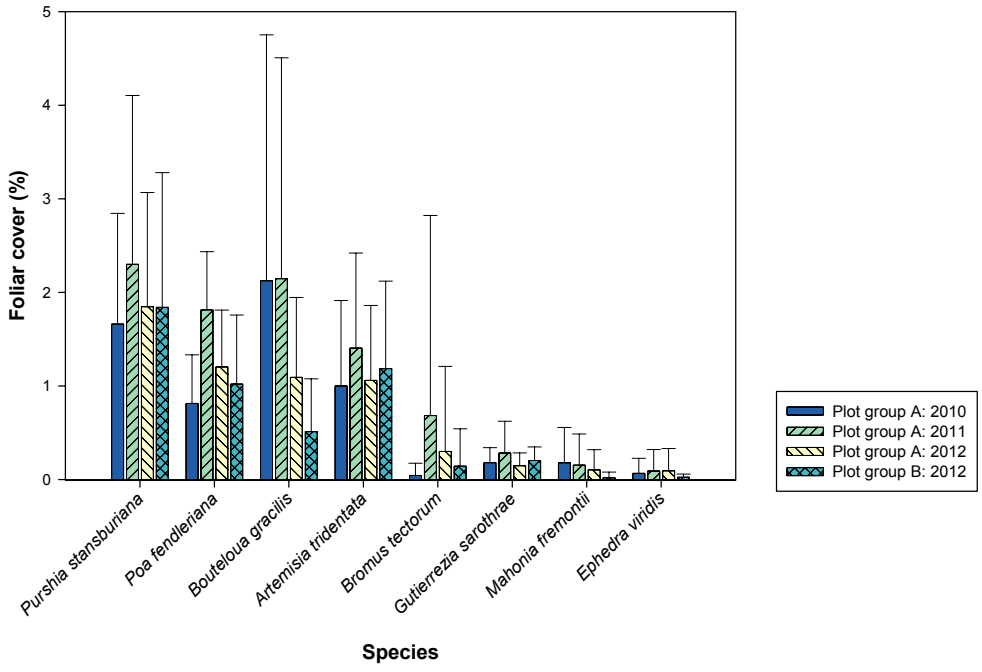



Figure 3. Mean percent foliar cover of the most abundant shrub and herbaceous species for plot group A and plot group B in the Limestone Upland ecological site at GRCA. Species with foliar cover greater than 0.150 in any of the plot group/year combinations were included. Error bars represent one standard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

| | Plot group A (*n* = 10) | | | | | | | | | | | | Plot group B (*n* = 10) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | | | | 2011 | | | | 2012 | | | | 2012 | | | |
| **Species** | **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. (%)** |
| *Purshia stansburiana* | 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 |
| *Poa fendleriana* | 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 |
| *Bouteloua gracilis* | 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 |
| *Artemisia tridentata* | 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 |
| *Bromus tectorum* [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 |
| *Gutierrezia sarothrae* | 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 |
| *Mahonia fremontii* | 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 |
| *Ephedra viridis* | 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 |
| *Erigeron divergens* | 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 |
| *Opuntia* 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 |
| *Phlox austromontana* | 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 |
| *Draba cuneifolia* | 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 |
| *Eriogonum racemosum* | 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 |
| *Quercus gambelii* | 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 |
| *Elymus elymoides* | 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 |
| *Astragalus* 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 |
| *Nama dichotoma* | 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 |
| *Erodium cicutarium* [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 |
| *Portulaca oleracea* [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 |
| *Salsola tragus* [a] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | <0.001 | 0.001 | 0.67 | 10.00 | 0 | 0 | 0 | 0 |
| *Ceratocephala testiculata* [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 |
| *Gilia* 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 |
| *Phemeranthus* 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.

[a]Nonnative species.

[b]Rare 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 nonnative species—*Erodium cicutarium* (stork's bill), *Portulaca oleracea* (little hogweed), *Ceratocephala testiculata* (curveseed 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 | |

[a]Ecological 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 $m^2$/ha and 18.62 $m^2$/ha for plot groups A and B, respectively. In contrast, basal area for *Pinus edulis* was much lower: 5.32 $m^2$/ha and 4.94 $m^2$/ha for plot groups A and B, respectively (Figure 4). Snag basal area for *Juniperus osteosperma* was 2.71 $m^2$/ha and 1.23 $m^2$/ha for plot groups A and B, respectively, and snag basal area for *Pinus edulis* was less than 1 $m^2$/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] |
|---|---|---|---|---|---|---|---|---|
| *Juniperus osteosperma* | | | | | | | | |
| | B | 266.7 | 200.0 | 185.0 | 22.0 | 18.62 | 1.23 | 33.2 |
| *Pinus edulis* | | | | | | | | |
| | 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 |

[a]Size 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.

[b]Mean overstory diameter is provided as DBH for *Pinus edulis* and DRC for *Juniperus osteosperma*.

[c]Plot group A metrics were measured in 2012, with the exception of sapling density, snag density, and snag basal area, which were measured in 2010.

[d]Values 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.

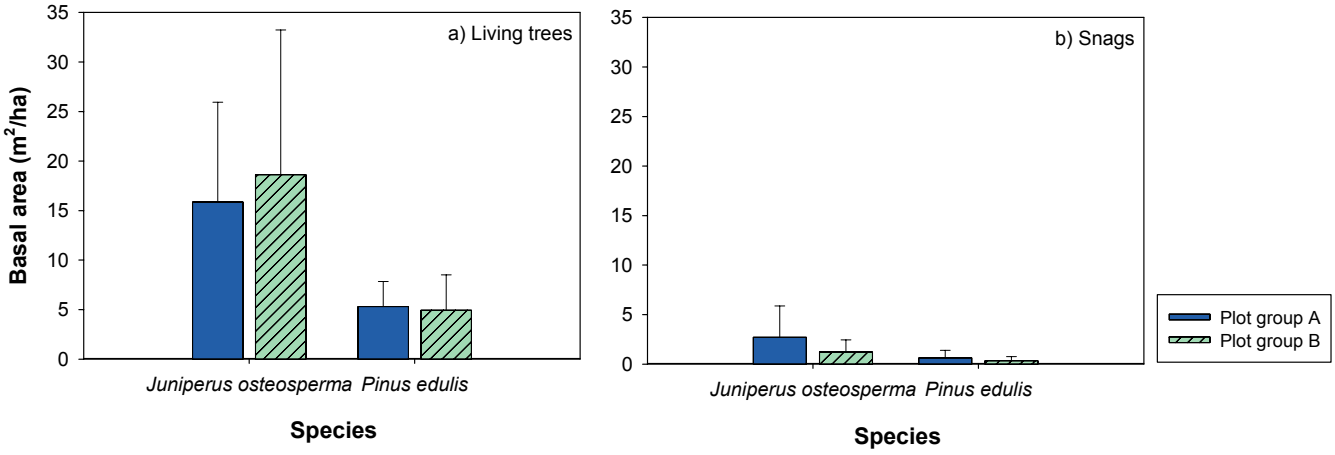



Figure 4. Mean basal area by species for a) living trees and b) snags, in plot group A and plot group B in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation.

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).

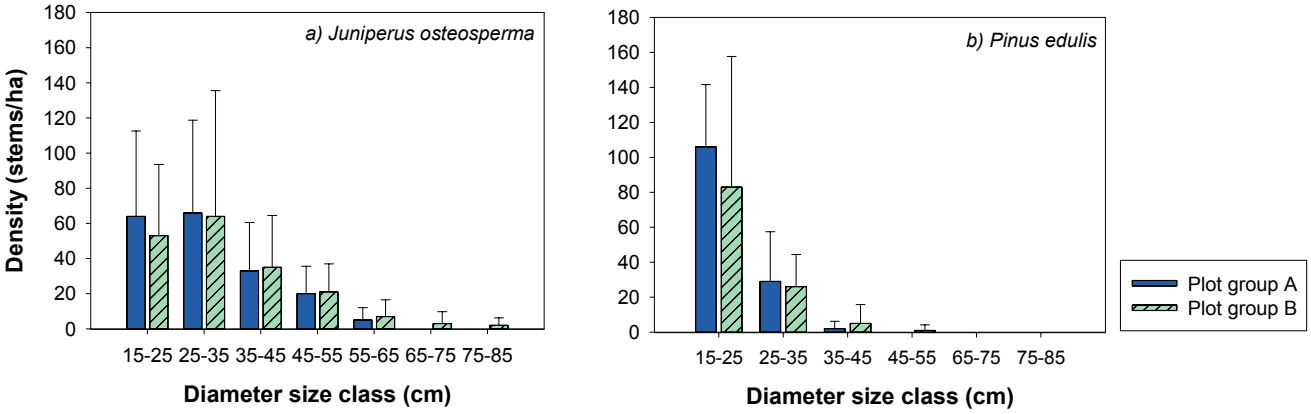



Figure 5. Size structure of living overstory trees for a) *Juniperus osteosperma* and b) *Pinus edulis* in plot group A and plot group B in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation.

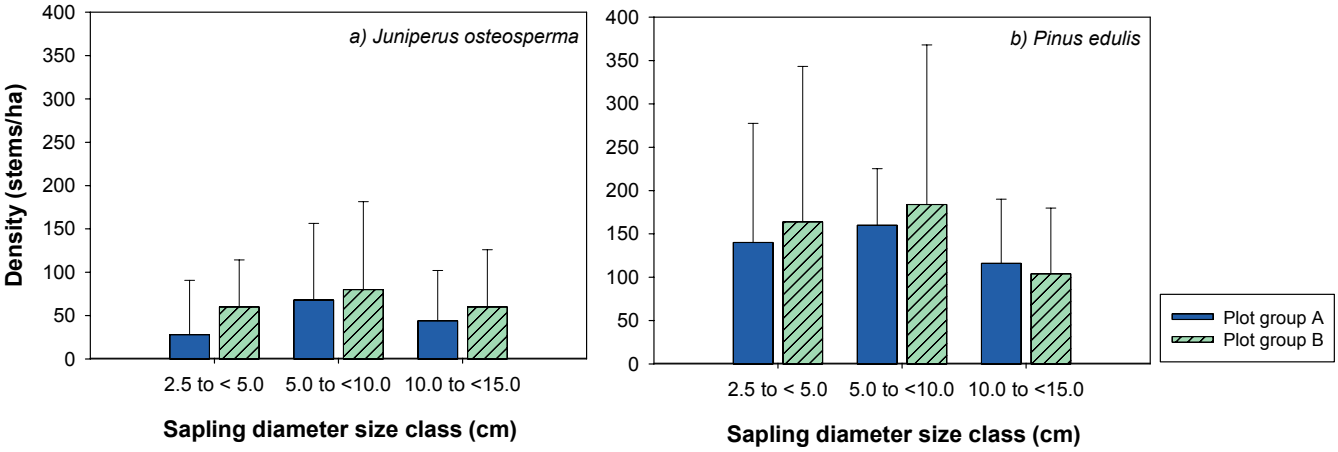



Figure 6. Mean density of saplings in different diameter size classes for a) *Juniperus osteosperma* and b) *Pinus edulis* for plot groups A and B in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation. Sapling diameter is measured at root crown for *Juniperus osteosperma*,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

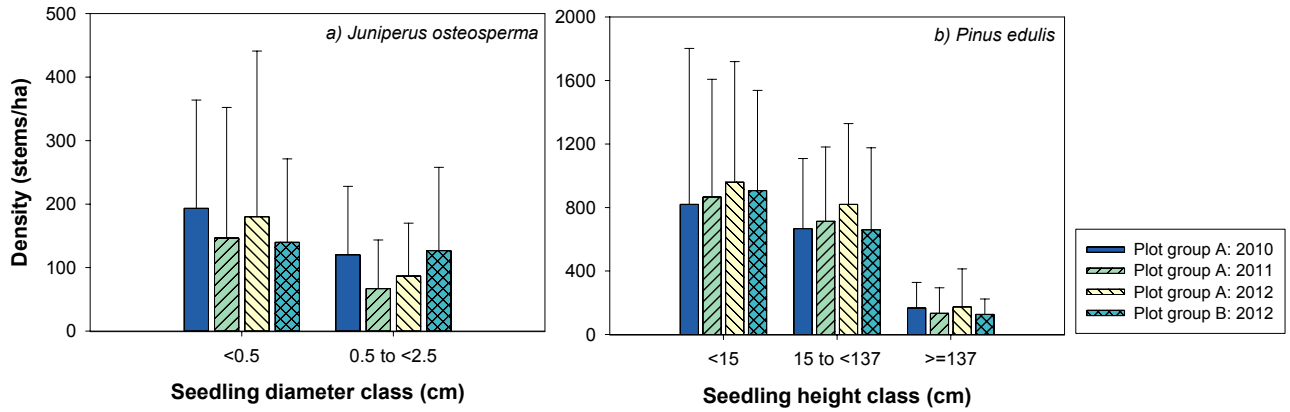



Figure 7. Mean density of seedlings in different size classes for a) *Juniperus osteosperma* and b) *Pinus edulis* in plot groups A and B in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation. Seedling diameter is measured at root crown for *Juniperus osteosperma*.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

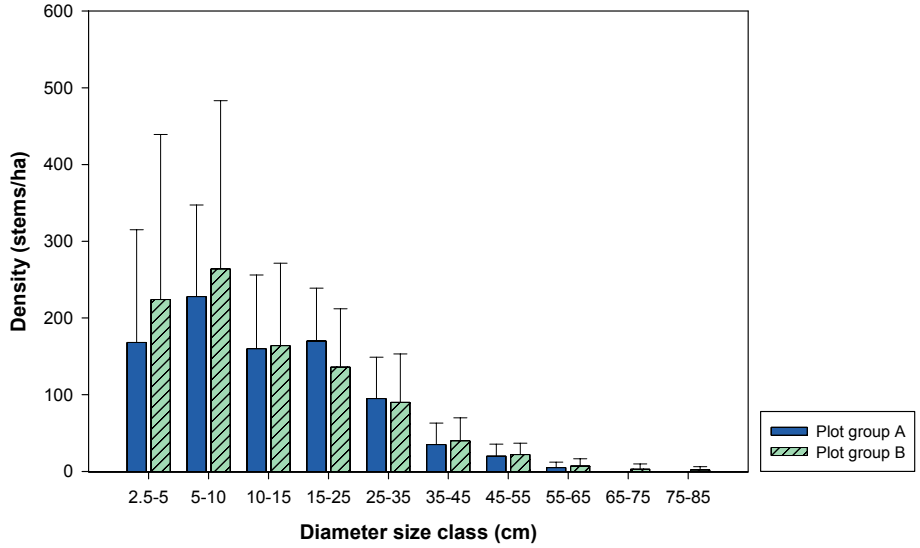



Figure 8. Size structure of all living overstory trees and saplings for plot group A and plot group B in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation. Overstory tree and sampling diameter is measured at root crown for *Juniperus osteosperma*, and at breast height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

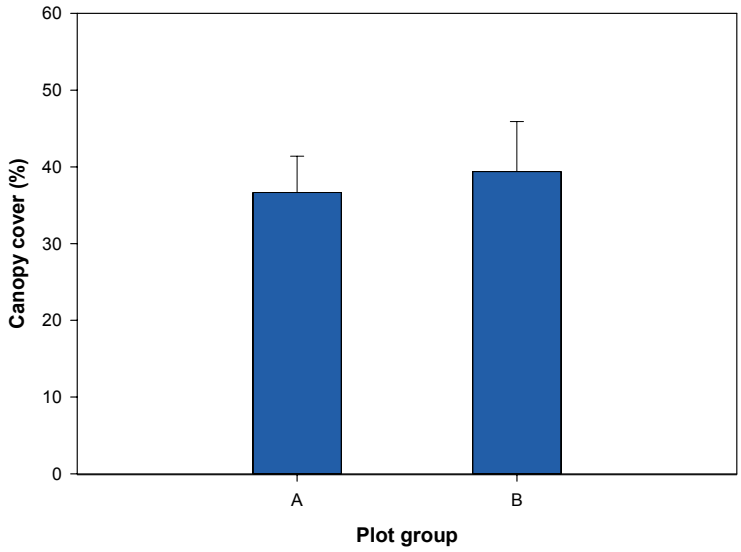



Figure 9. Mean percent canopy cover for plot group A and plot group B in 2012 in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation.

## 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.

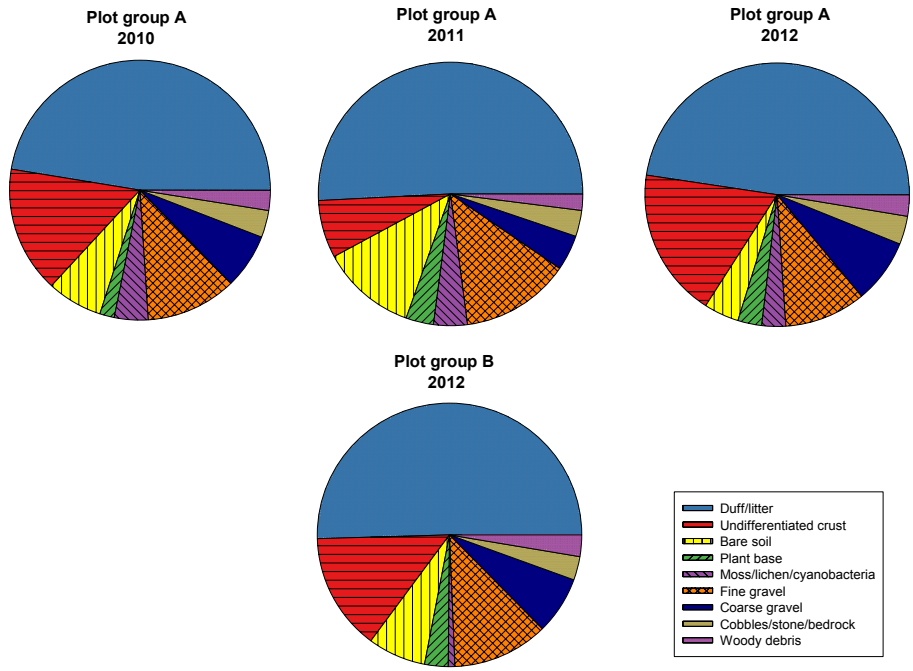



Figure 10. Mean percent cover of soil surface features for plot group A and plot group B in the Limestone Upland ecological site at GRCA.

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

| | Plot group A (*n* = 10) | | | | | | Plot group B (*n* = 10) | |
|---|---|---|---|---|---|---|---|---|
| | 2010 | | 2011 | | 2012 | | 2012 | |
| **Soil surface feature** | **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.

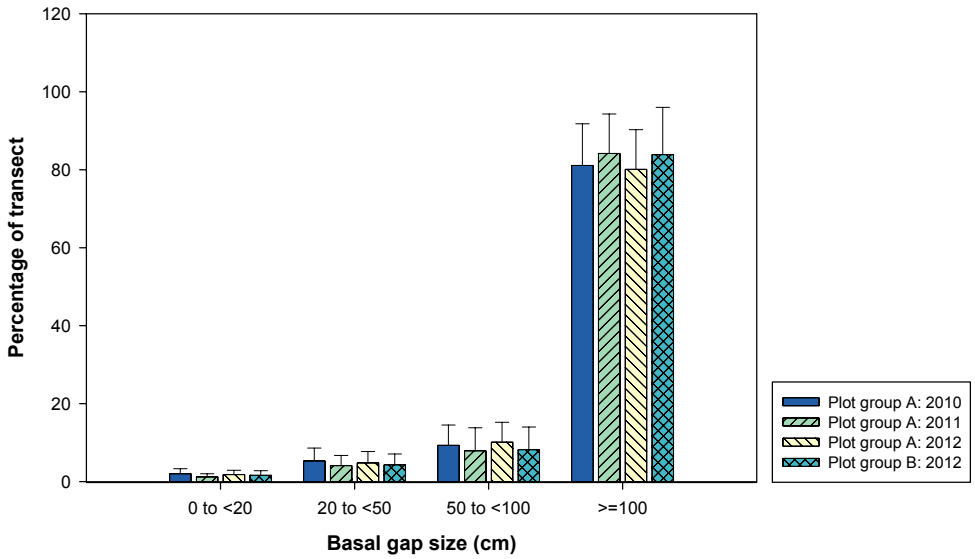



Figure 11. Mean percentage of transect by gap size class for plot group A and plot group B in the Limestone Upland ecological site at GRCA. Error bars represent one standard deviation.

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.

| | Plot group A (*n* = 10) | | | | | | Plot group B (*n* = 10) | |
|---|---|---|---|---|---|---|---|---|
| | 2010 | | 2011 | | 2012 | | 2012 | |
| **Metric** | **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 |

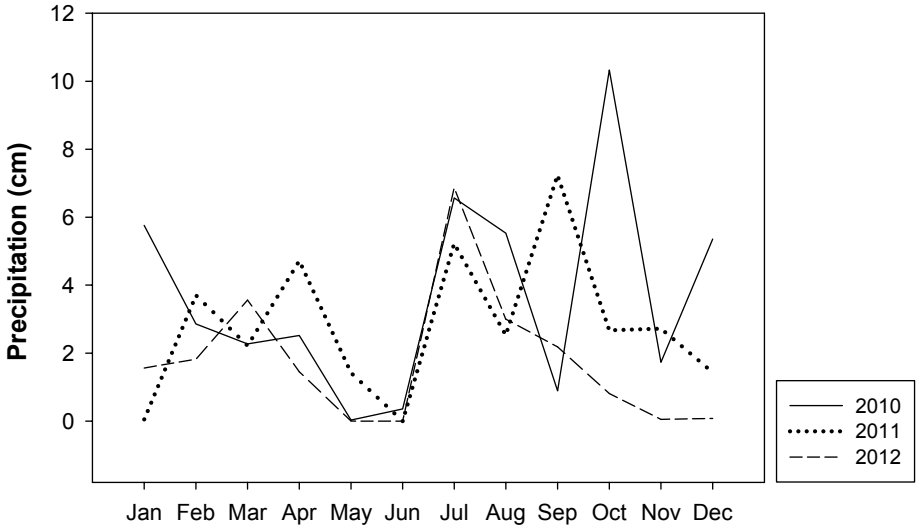
*Note*: Ratings range from 1–6, with 1 being the lowest stability and 6 being the highest.

[a]Soils 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.

| | Year | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Panel** | **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 |

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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.

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

Table A1 (*continued*)

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

Table A1 (*continued*)

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

Table A1 (*continued*)

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

[a]Nonnative 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.

| | | | Plot group A (*n* = 10) 2010–2012 | | Plot group B (*n* = 10) 2012 | |
|---|---|---|---|---|---|---|
| **Species** | **Common name** | **Family** | **Basal area ($m^2$/ha)[a]** | **Plot frequency (%)[b]** | **Basal area ($m^2$/ha)[a]** | **Plot frequency (%)[b]** |
| *Juniperus osteosperma* | Utah juniper | Cuppressaceae | 15.87 | 100 | 18.62 | 100 |
| *Pinus edulis* | twoneedle pinyon | Pinaceae | 5.32 | 100 | 4.94 | 100 |

[a]Basal area measurements only include overstory trees and were taken from the 2012 measurements for plot group A.

[b]Plot frequency includes overstory trees, saplings (measured only in 2010 for plot group A), and seedlings.

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