



Integrated Upland Vegetation and Soils Monitoring for Grand Canyon National Park

2010 Summary Report

Natural Resource Data Series NPS/SCPN/NRDS—2013/512



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). For the sake of simplicity, we refer to the first as the mixed conifer ecological site, although it is technically composed of 2 distinct ecological sites: Loamy Hills, and Loamy Hills, Cold. The second is the Limestone Upland 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).

The mixed conifer forest is a unique ecosystem. There are few extensive areas of this system on the Colorado Plateau, and climate change and altered fire regimes threaten its integrity. The Limestone Upland ecological site is characterized as relatively undisturbed pinyon-juniper woodland. It faces numerous threats, including changing fire regimes, climate change, soil erosion, and invasion by nonnative species.

In 2007 the SCPN integrated upland monitoring project began its work at GRCA with the installation of 16 plots in the mixed conifer ecological site. We sampled vegetation in nested quadrats annually for 3 years to determine the range of temporal variability for key metrics. In 2010 we established 23 additional plots. The original 16 plots were not sampled. The total number of plots installed in the mixed conifer ecological site is 39. In 2010 we also established and sampled 10 plots in the Limestone Upland ecological site. In this report, we document monitoring activities during the 2010 field season and report these data. For the mixed conifer ecological site, we report the 2010 data in the context of the data collected in 2007, 2008 and 2009.

2 Methods

2.1 Sampling frame

We derived our base sampling frames (figs. 1 and 2) from maps of the ecological sites, which were 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. For the mixed conifer ecological site, we derived the sampling frame from the maps of its 2 ecological sites: Loamy Hills Cold and Loamy Hills.

To make final adjustments to our sampling frames, 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 (roads, buildings and other infrastructure, and for the mixed conifer ecological site, elevations below 2500 m)
- expected to differ substantially from the norm, such as burned areas and mechanically treated areas in the mixed conifer ecological site, because these areas would have increased ecological variation and made it more difficult to detect trends
- potentially at risk for erosion as a result of sampling (slopes $\geq 30\%$ for the mixed conifer ecological site and slopes $\geq 20\%$ for the Limestone Upland ecological site)

For each ecological site, we generated a set of spatially distributed sampling points using the Generalized Random Tessellation Stratified (GRTS) design (Stevens and Olsen 2004). Park staff reviewed the sampling points and rejected those points that landed too close to archeological sites and other sensitive resources. In each ecological site, the integrated upland crew visited the points in consecutive order and conducted an ecological site assessment, rejecting sites that deviated substantially from the ecological site, had a slope greater than 20%

(Limestone Upland) or 30% (mixed conifer), or contained a major disturbance.

In the Limestone Upland ecological site, we rejected 7 sites: 6 sites were in close proximity to an archeological site, and 1 site was outside the range of variability for the ecological site. In the mixed conifer ecological site, we rejected 18 points: 6 sites had been moderately or severely burned, 5 sites had slopes exceeding 30%, 2 sites were outside the range of variability for the ecological site, 2 sites were in proximity to an archeological site, one site was in proximity to a trail, one site was inaccessible (>2 hours hiking time), and one site was less than 200 m from an established plot.

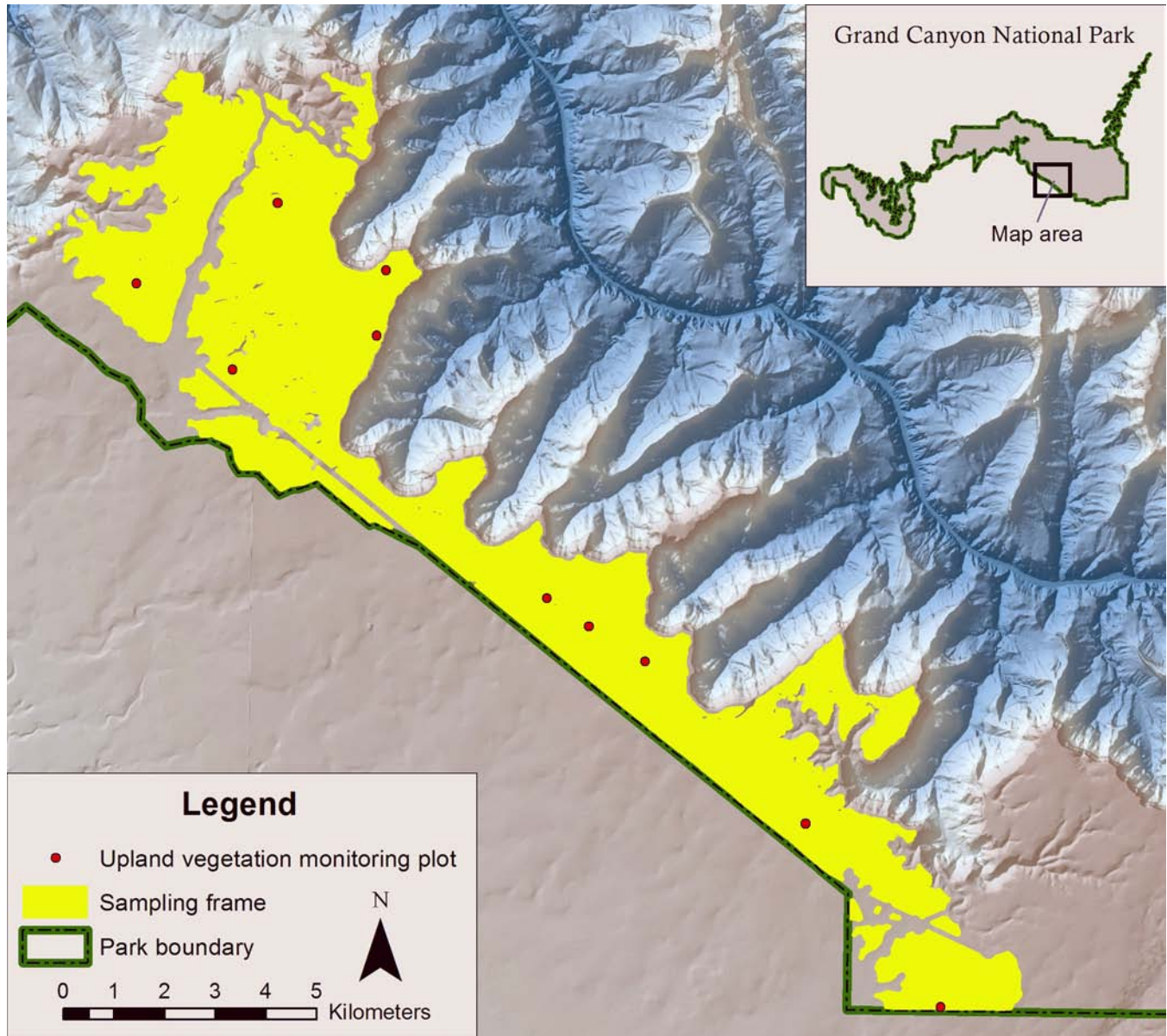


Figure 1. Sampling frame of Limestone Upland ecological site at GRCA with the 10 plots established in 2010.

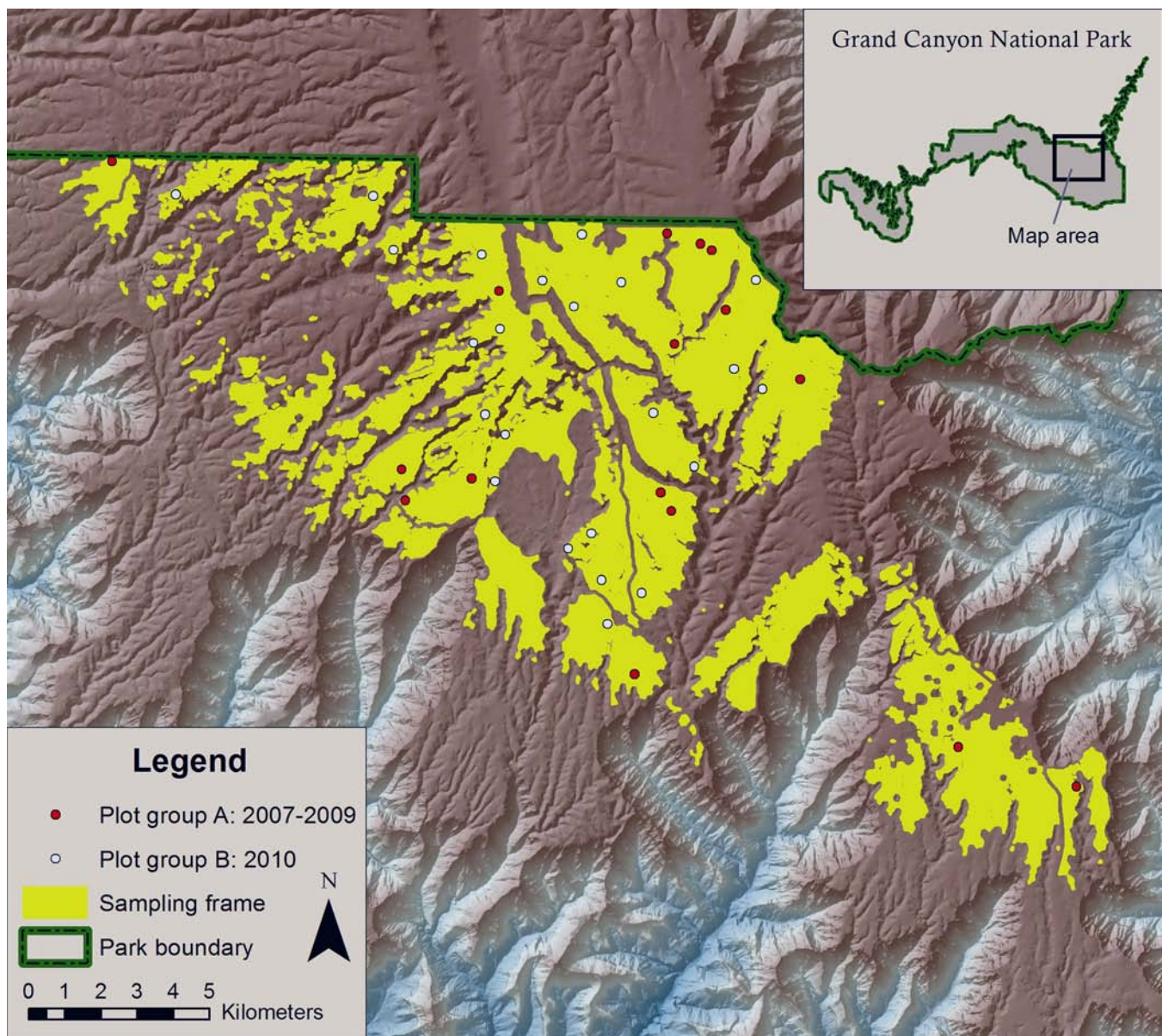


Figure 2. Sampling frame of the mixed conifer ecological site at GRCA with the 16 plots sampled in 2007–2009, and the 23 plots sampled in 2010.

2.2 Field methods

In the Limestone Upland ecological site, the SCPN integrated upland crew established 10 monitoring plots in 2010. In the mixed conifer ecological site they established 16 monitoring plots in 2007, and resampled these 16 plots in 2008 and 2009. In 2010, the crew established 23 additional plots. The 16 plots established in 2007 were not sampled in 2010.

In all years we conducted our field work for the mixed conifer ecological site in late June through late July. We conducted our work for the Limestone Upland ecological site in the first half of September, with the exception of one plot that was sampled in late October.

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 composition, soil surface cover, tree seedling density and tree canopy on all 3 transects within each plot. We also collected overstory tree and sapling data in subplots located between 2 of the transects. For the Limestone Upland ecological site we collected

soil stability and basal gap data along the transects. These data were not collected for the mixed conifer ecological site, where thick litter and duff make soil erosion less of a threat.

During plot establishment in 2007 for mixed conifer and 2010 in Limestone Upland, we collected the full suite of data at each site. For the mixed conifer plots resampled in 2008 and 2009, we collected a subset of the data: species cover and frequency, functional group cover, and soil surface features. In 2008 we also collected canopy closure data in the mixed conifer plots. 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. In mixed conifer, we collected these data in the initial 16 plots in 2007, 2008 and 2009, and collected the same set of data for the 23 new plots established in 2010. We also collected these data for the 10 Limestone Upland plots established in 2010.

2.2.2 Overstory trees, saplings, and seedlings

In the first year of sampling for both ecological sites, we measured overstory trees in a 20×50 m (0.1 ha) plot located between 2 of the transects. We measured junipers at root crown, and all other tree species at breast height. Within this overstory tree plot, we tallied saplings by size class and species in a smaller, 10 × 25 m plot (0.25 ha). We tallied seedlings by size class and species in the fifteen 10 m² quadrats along the 3 transects.

We measured canopy using 2 methods. For the Limestone Upland ecological site, we measured tree canopy cover using the line intercept method along transects. For the mixed conifer ecological site, we measured canopy closure using a spherical densiometer at 5 points along each transect.

2.2.3 Soil stability and hydrologic function

In the mixed conifer ecological site, 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 collected these data for 3 consecutive years in the plots established in 2007, and for one year in the plots established in 2010.

In the Limestone Upland ecological site, we collected 3 types of soil data. We measured percent cover of soil surface features in the 1 m² quadrat, we measured basal gaps as the length of bare ground between plant bases along each transect. We also conducted a soil stability test in the Limestone Upland site using 18 soil samples per plot collected along the transects. For these, we also noted whether there was vegetation cover over the sample point.

2.3 Data summary

For the Limestone Upland ecological site, where there is only one year of data, we report these data as an initial characterization of the vegetation and soils.

For the mixed conifer ecological site, we compare the data collected in 23 new plots in 2010 to the data collected in the 16 original plots sampled yearly from 2007 through 2009. It must be stressed that the differences between these 2 plot groups do not represent change over time, but rather indicate differences in composition and structure resulting largely from spatial variation. We refer to these 2 groups of plots as Plot Group A for the plots established in 2007, and Plot Group B for the plots established in 2010.

The sample unit for summary and analysis is the plot; hence, we summarized data at the level of the plot. For most metrics, we then calculated the mean and standard deviation for the ecological site (for the Limestone Upland ecological site) or plot group (for the mixed conifer ecological site) from the plot means. (Ecological site

species diversity metrics were the exception.) For Plot Group A in the mixed conifer, where there were 3 years of data, we calculated the mean value and a standard deviation for the 16 plots for each year, and then calculated the mean of the means and the mean of the standard deviations for the 3 years. Metrics with 3 years of data include species cover and frequency, functional group cover and soil surface features.

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

For herbaceous and shrub vegetation, percent cover was estimated for each species from the cover class midpoints, e.g., 7.5% for cover class 5%–10%. For each year, mean cover of each species was calculated for each plot, and the mean and standard deviation were calculated for the ecological site or plot group from the plot means. Species frequency was calculated for quadrats (mean percentage of 10 m² quadrats per plot where the species occurred) and for plots (percentage of plots where the species occurred).

2.3.2 Species diversity

Four diversity measures were calculated for herbaceous and shrub species for each year (Magurran 1988), first for all species and then for native species only:

(1) Species richness (S) is the number of species at a given spatial scale. This was calculated at the level of the plot and at the level of the ecological site.

(2) The Shannon Diversity Index (H') provides a measure of species diversity that takes into account the relative abundance of each species:

$$- \sum_{i=1}^n p_i \ln p_i$$

where p_i is the abundance of each species.

(3) Species evenness (E) is a measure of the degree to which all species are equal in abundance:

$$H' / \ln(S)$$

(4) Beta diversity (β_w) is a measure of within-ecological site heterogeneity:

$$S_e / (S_p - 1)$$

where S_e is the total number of species found in the ecological site, and S_p is the mean number of species found per plot.

For plot richness, Shannon diversity and evenness, the mean was calculated for each plot and year, and the mean and standard deviation were then calculated for the ecological site for each year. We calculated the ecological site means for the 2 metrics, ecological site richness and beta diversity, using 16 plot values from only one year of data from plot group A—the year with the median value for Shannon diversity—combined with the 23 plots from plot group B.

2.3.3 Trees

For the mixed conifer ecological site, tree metrics were calculated for each plot group; for the Limestone Upland ecological site, tree metrics were calculated for the ecological site. Tree basal area (the total area of the tree cross-sections at breast height or at root crown for junipers) for living trees and snags was calculated for each overstory tree species in terms of m²/ha. Mean diameter of living overstory trees was also calculated for each species. Tree density was calculated for all species and all size classes for overstory living trees and snags, saplings and seedlings in terms of stems/ha. Each metric was calculated for each plot, and the mean and standard deviation were then calculated for the ecological site or for the plot group. Canopy closure in the mixed conifer site and canopy cover in the Limestone Upland site were calculated by first deriving the mean value for each plot, and then the mean and standard deviation were calculated for the entire ecological site or plot group.

2.3.4 Basal gaps and soil stability

For the Limestone Upland ecological site, we calculated 5 metrics for each year of basal gap data: median basal gap size, percentage of transects comprised by gaps and plant bases, percentage of transects comprised by each gap size class, and total number of gaps. For each plot, the mean for each metric was calculated, and then the mean and standard deviation were calculated for the ecological site.

We calculated the mean soil aggregate stability index for each plot and then calculated the mean and standard deviation for all plots in the ecological site. This index ranges between 1 and 6, where 1 indicates low aggregate stability and 6 indicates high aggregate stability. The index was also calculated separately for samples with vegetative cover and for samples without vegetative cover.

3 Results

3.1 Limestone Upland ecological site

3.1.1 Shrub and herbaceous vegetation

Shrubs and perennial grasses co-dominated the shrub and herbaceous layer of the Limestone Upland ecological site (table 1 and fig. 3). The foliar cover of perennial grasses was 3.23%, and the foliar cover of shrubs was 3.31%. All other living functional groups were less than 1%. Standing dead herbaceous cover and standing dead woody cover were slightly more than 1%. Standard deviations were moderately high, indicating fairly large among-plot variation.

We compare species-level data for the most abundant herbs and shrubs in Table 2 (foliar cover and frequency) and Figure 4 (foliar cover). Dominant perennial grasses included *Bouteloua gracilis* (blue grama) and *Poa fendleriana* (muttongrass). The dominant shrubs included *Purshia stansburiana* (Stansbury cliffrose), *Artemisia tridentata* (basin big sagebrush),

Table 1. Foliar cover of functional groups in the Limestone Upland ecological site at GRCA.

Functional groups	Mean (%)	SD
Total live foliar cover	7.02	2.35
Perennial grasses	3.23	2.57
Annual grasses	0.05	0.13
Forbs	0.38	0.26
Shrubs	3.31	1.86
Cacti/succulents	0.12	0.17
Standing dead herbaceous	1.43	1.46
Standing dead woody	1.02	0.59

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 3. Mean percent foliar cover by functional group in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation.

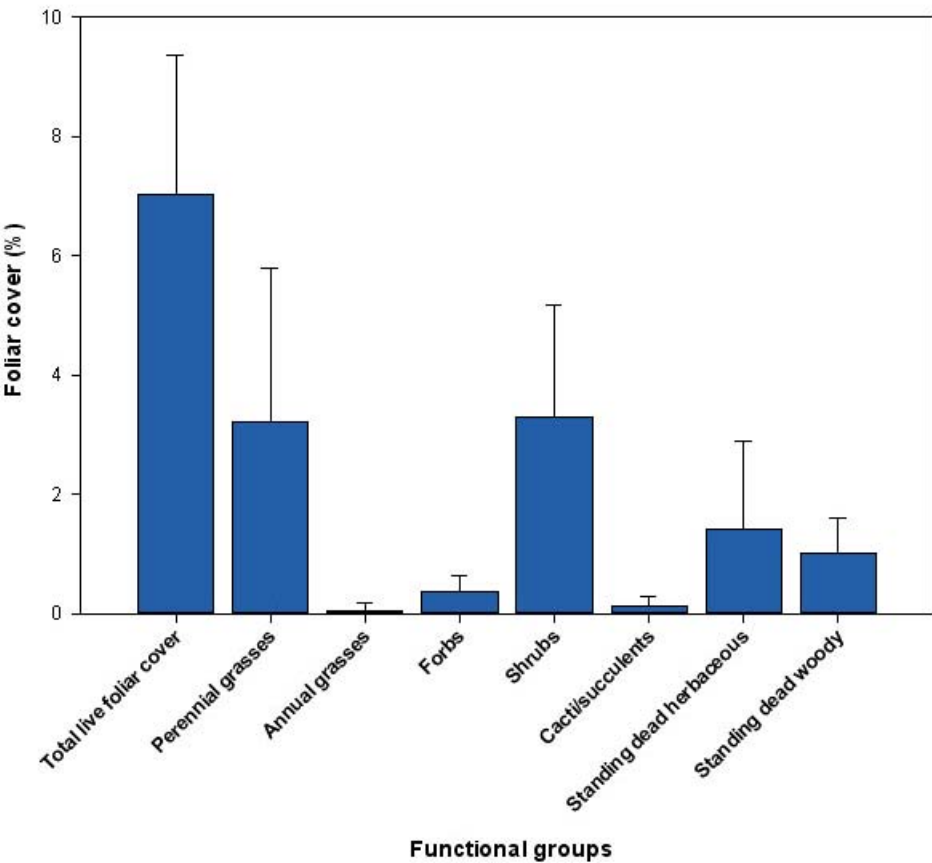


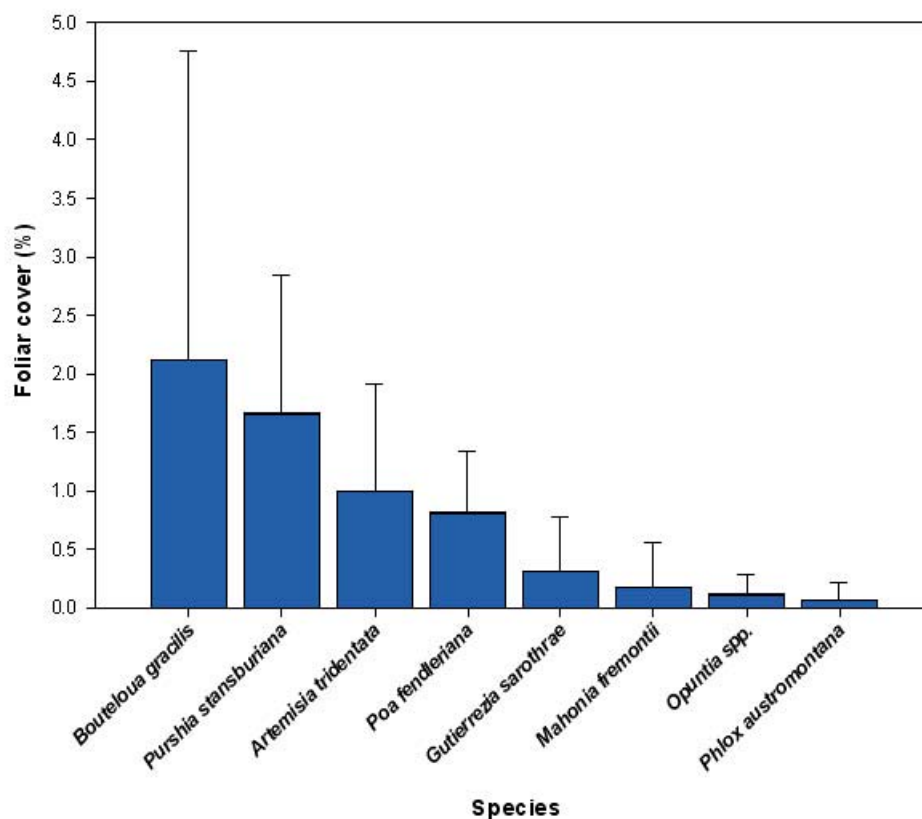
Table 2. Mean foliar cover, standard deviation, and range, and mean quadrat and plot frequencies of the 15 most abundant shrub and herbaceous species and all nonnative species for the 10 plots in the Limestone Upland ecological site at GRCA in 2010.

Species	Foliar cover (%)			Frequency (%)	
	Mean	SD	Range	Quadrat	Plot
<i>Bouteloua gracilis</i>	2.126	2.628	0.130–8.87	64.00	90.00
<i>Purshia stansburiana</i>	1.661	1.184	0.020–3.057	38.67	100.00
<i>Artemisia tridentata</i>	0.999	0.915	0.070–2.927	49.33	100.00
<i>Poa fendleriana</i>	0.813	0.520	0.213–2.073	92.00	100.00
<i>Gutierrezia sarothrae</i>	0.313	0.473	0.003–1.58	44.00	100.00
<i>Mahonia fremontii</i>	0.179	0.377	0.853–0.933	2.67	20.00
<i>Opuntia spp.</i>	0.115	0.168	0.003–0.577	22.67	100.00
<i>Phlox austromontana</i>	0.068	0.149	0.257–0.423	5.33	20.00
<i>Ephedra viridis</i>	0.066	0.161	0.007–0.503	4.00	30.00
<i>Cordylanthus parviflorus</i>	0.044	0.069	0.037–0.193	22.67	40.00
<i>Eriogonum racemosum</i>	0.043	0.120	0.003–0.383	12.00	30.00
<i>Bromus tectorum</i> ^a	0.043	0.131	0.003–0.417	7.33	40.00
<i>Penstemon barbatus</i>	0.030	0.030	0.020–0.077	13.33	60.00
<i>Elymus elymoides</i>	0.028	0.047	0.003–0.15	16.00	70.00
<i>Comandra umbellata</i>	0.027	0.059	0.040–0.187	11.33	30.00
<i>Portulaca oleracea</i> ^a	0.001	0.002	0.003–0.007	2.67	30.00

Note: We report the minimum value for the range in foliar cover only from plots where the species occurs. (Many species do not occur in every plot of an ecological site; for these species, the minimum range of 0% is not provided.)

^aNonnative species.

Figure 4. Mean percent foliar cover of the 8 most abundant shrub and herbaceous species in the Limestone Upland ecological site at GRCA. Error bars represent one standard deviation.



Gutierrezia sarothrae (broom snakeweed), *Mahonia fremontii* (Fremont’s mahonia) and *Ephedra viridis* (mormon tea). Dominant forbs included *Phlox austromontana* (mountain phlox) and *Corydalis parviflorus* (Wright’s bird’s beak). *Opuntia* spp. (prickly pear) was the most frequent succulent. The only annual grass was *Bromus tectorum* (cheatgrass). Large standard deviations indicate high among-plot variability.

Species occurred in different patterns of spatial distribution. Quadrat frequencies varied, even for species that had high plot frequency (90–100%). For example, *Poa fendleriana* and *Purshia stansburiana* both occurred in all of the plots, however the former occurred in 92.00% of the quadrats, while the latter occurred only in 38.67% of the quadrats. *Mahonia fremontii* had relatively high foliar cover where it occurred, but low plot and quadrat frequencies.

Two nonnative species occurred in the plot. *Bromus tectorum* occurred in 40% of the plots, with a foliar cover of 0.043%. *Portulaca oleracea* (little hogweed) occurred in 30% of the plots with a foliar cover of 0.001%. Appendix A lists all species, along with common names, families, mean foliar covers, and plot frequencies.

The shrub/herbaceous layer had low to moderate species diversity (table 3). Plot species richness was 21.9; Shannon diversity (which takes into account relative abundance of species and generally ranges between 1.5 and 3.5) was 1.598; evenness (the degree to which all species are of equal abundance, ranging between 0 and 1) was 0.523. On the scale of the ecological site, species richness was 70, and beta diversity (a measure of within-site heterogeneity, generally ranging between 1 and 5) was 3.349. When we recalculated the metrics using only native species, the metrics only showed nominal change.

3.1.2 Trees

Two species of trees were represented in the plots: *Juniperus osteosperma* (Utah juniper) and *Pinus edulis* (twoneedle pinyon). *Juniperus osteosperma* dominated the living overstory with a density of 185.0 stems/ha, and a basal area of 16.12 m²/ha. In contrast, the density of *Pinus edulis* in the living overstory was 137.0 stems/ha, and its basal area was 5.39 (table 4 and figure 5). Living *Juniperus osteosperma* individuals were larger, with a mean diameter at root crown of 31.1, while the mean diameter of living *Pinus edulis* trees at breast height was 21.5. Snags of both species had low densities and basal areas. The size structure of the 2 species showed typical size class distribution of higher densities in the smaller size classes, although the differences between the highest and lowest size classes were greater for *Pinus edulis* (fig. 6). The large error bars for *Juniperus osteosperma* basal area, and for density of both species, indicate high among-plot variability.

In contrast to the overstory, *Pinus edulis* dominated the sapling and seedling layers. *Pinus edulis* had higher densities in all of the sapling size classes (fig. 7). Sapling densities for each species were distributed fairly evenly among the 3 sapling size classes. *Pinus edulis* also had higher seedling densities (fig. 8). There was an inverse relationship between height class and density for *Pinus edulis*, but the densities of the 2 size classes were comparable for *Juniperus osteosperma*.

Table 3. Species diversity metrics for all species, and for native species only, in the 10 plots of the Limestone Upland ecological site at GRCA in 2010.

	Mean	SD
All species		
Plot		
Plot richness	21.9	6.2
Shannon diversity	1.598	0.415
Evenness	0.523	0.119
Ecological site		
Ecological site richness	70 ^a	
Beta diversity	3.349 ^a	
Native species		
Plot		
Plot richness	21.2	6.0
Shannon diversity	1.586	0.404
Evenness	0.525	0.115
Ecological site		
Ecological site richness	68 ^a	
Beta diversity	3.366 ^a	

^aThese are not mean values.

While overstory trees exhibited the typical distribution pattern of lower densities in the largest size classes, this was not true for the sapling layer where tree density was lower than expected (fig. 9). Tree canopy cover was 37.8%, with a standard deviation of 3.3.

Table 4. Mean density, mean basal area, and mean diameter of trees in the Limestone Upland ecological site at GRCA.

Species	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 ^b (cm)
<i>Juniperus osteosperma</i>	313.3	140.0	185.0	28.0	16.12	2.71	31.1
<i>Pinus edulis</i>	1653.3	416.0	137.0	15.0	5.39	0.63	21.5
Total ^c	1966.7	556.0	322.0	43.0	21.51	3.34	27.0

^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 diameter of trees is provided as DBH for *Pinus edulis* and as DRC for *Juniperus osteosperma*.

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

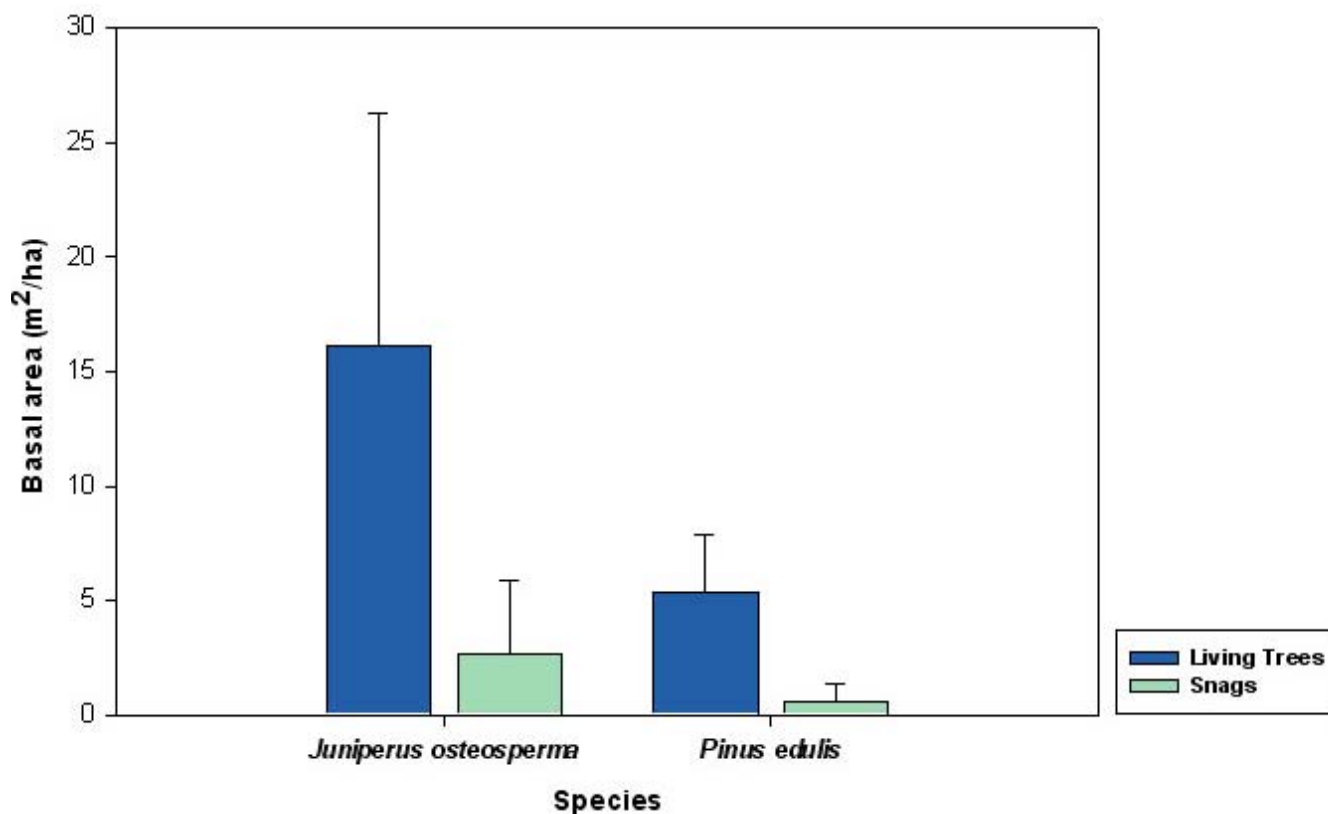


Figure 5. Mean basal area for living trees and snags, by species, in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation.

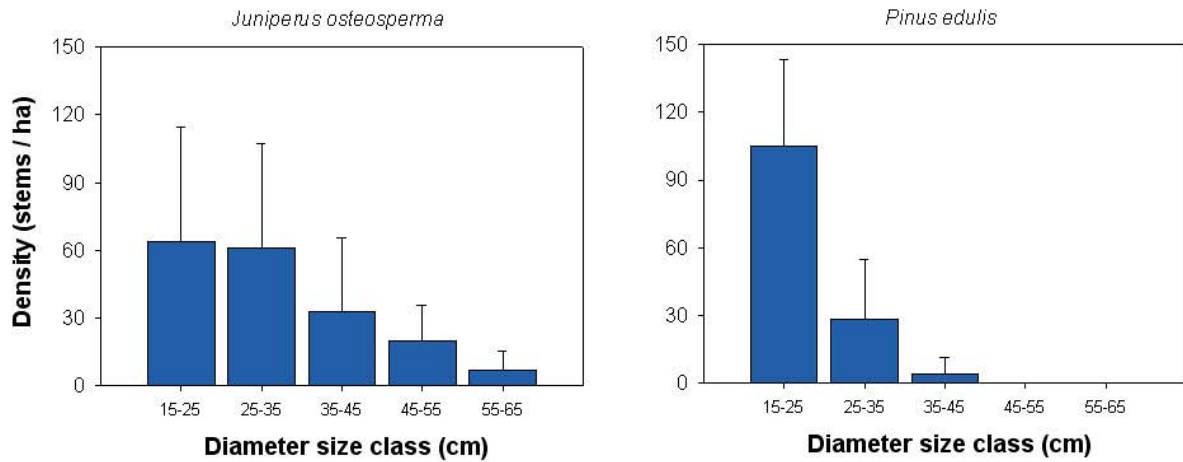


Figure 6. Size structure for living overstory tree species in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation.

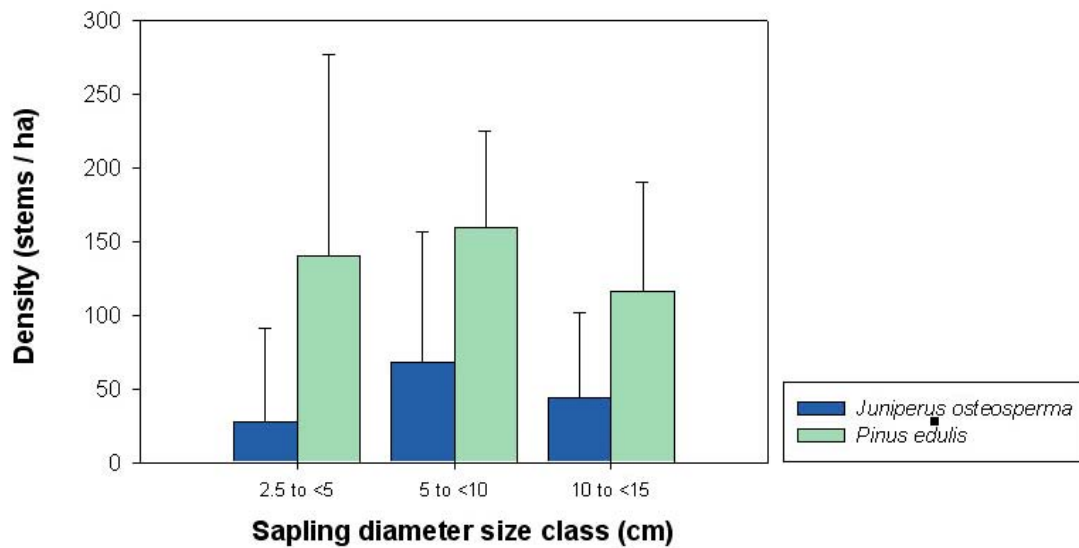


Figure 7. Mean density of saplings in different diameter size classes by species in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation.

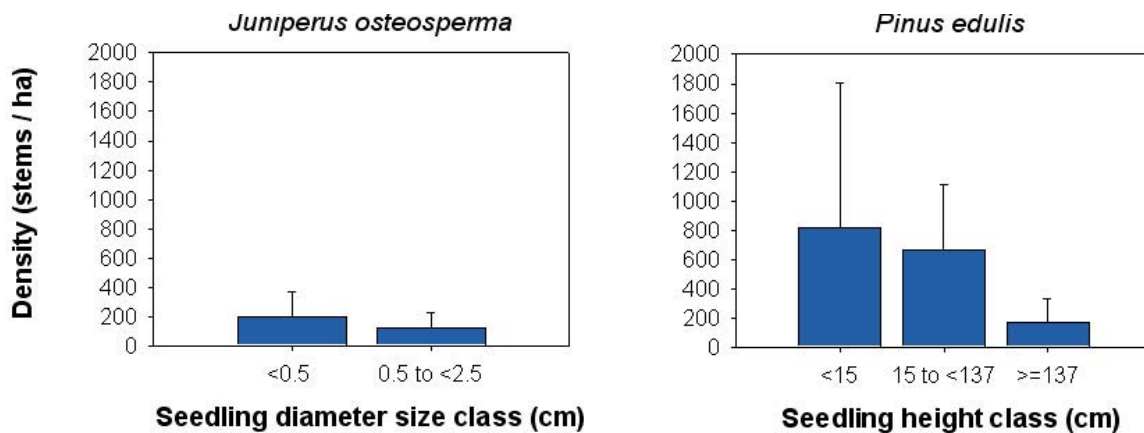
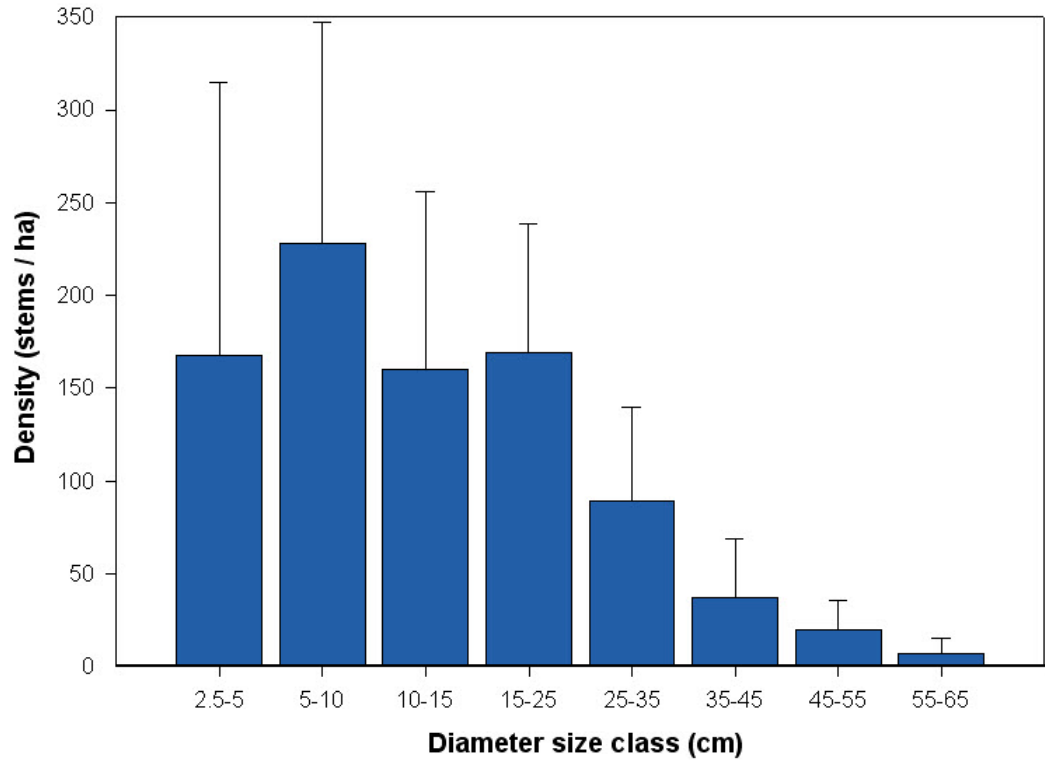


Figure 8. Mean density of seedlings in different size classes, by species, in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation. The seedling category includes all trees <2.5 cm DBH (seedling diameter for *Juniperus osteosperma* is measured at root crown [DRC]).

Figure 9. Size structure of living overstory trees and saplings in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation.



3.1.3 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.

The soil surface features with the greatest cover were duff / litter, undifferentiated crust, and fine gravel (table 5 and fig. 10). Duff/litter had 46.30% cover. Undifferentiated crust had 15.36% cover. Cover of bare soil and coarse gravel were each between 6 and 7%. Cover of cyanobacteria was approximately 3.42%. The remaining features had a cover value of less than 1%.

The basal gap data shows that the ecological site is dominated by large gaps; i.e., there are large spaces between the plant bases (table 6 and fig. 11). Gaps greater than 100 cm comprised a mean of 81.1% of the transects, and over 90% of the transects on average were comprised of gaps 50 cm or larger. Note that these data show a somewhat higher estimate of the cover of plant bases: 2.8% versus the 1.8% of the combined plant bases in the soil surface feature data.

Table 5. Cover of soil surface features in the Limestone Upland ecological site at GRCA.

Soil surface feature	Mean (%)	SD
Live plant base	0.93	0.44
Dead woody base	0.20	0.19
Dead herbaceous base	0.64	0.57
Bare soil	6.71	4.39
Duff/litter	46.30	11.23
Undifferentiated crust	15.36	11.17
Moss	0.62	0.52
Lichen	0.08	0.16
Cyanobacteria ^a	3.42	4.72
Fine gravel (0.2 to <2 cm)	11.02	12.66
Coarse gravel (2 to <7.5 cm)	6.69	6.90
Cobble (7.5 to <25 cm)	2.16	2.92
Stone, bedrock (≥25 cm)	1.14	2.54
Woody debris	2.43	1.47

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

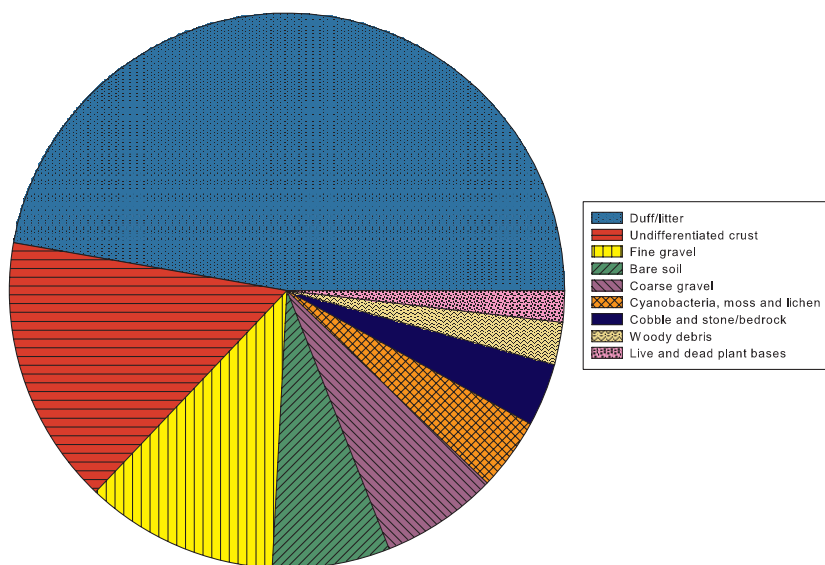


Figure 10. Mean percent cover of soil surface features in the Limestone Upland ecological site at GRCA.

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

Metric	Mean	SD
Number of gaps	106.9	51.5
Median gap size (cm)	84.2	90.6
Percentage of transect in gaps	97.2	1.6
Percentage of transect in gaps 0-19 cm	2.0	1.3
Percentage of transect in gaps 20-49 cm	4.8	3.5
Percentage of transect in gaps 50-99 cm	9.3	5.2
Percentage of transect in gaps ≥ 100 cm	81.1	10.7
Percentage of transect in plant bases	2.8	1.6

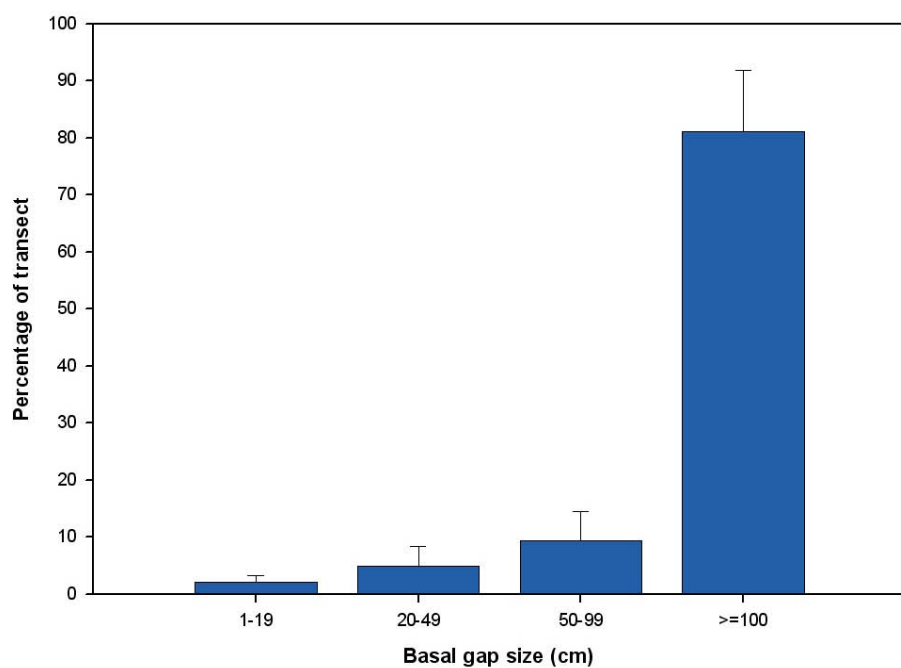


Figure 11. Mean percentage of transect by gap size class in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation.

Soil stability for the ecological site was moderately high, with a mean of 4.08 (table 7). This metric ranges from 1 to 6, with 6 representing the most stable soil. There were large differences between soil stability under vegetative cover and soil stability in areas without vegetative cover. This was probably a result of the large amount of litter found under juniper canopies. Litter receives the highest rating.

Table 7. Soil stability rating for all samples, and for samples with and without vegetative cover, in the Limestone Upland ecological site at GRCA.

	Mean	SD
All samples	4.08	0.68
Samples under vegetative cover	4.87	0.57
Samples not under vegetative cover	3.03	1.25

Note: Ratings ranged from 1-6, with 1 being the lowest stability and 6 being the highest.

3.2 Mixed conifer ecological site

3.2.1 Shrub and herbaceous vegetation

The herbaceous/shrub layer of the mixed conifer ecological site was relatively sparse, with a total live foliar cover of 8.30% (Plot Group A) and 5.27% (Plot Group B) (table 8 and fig. 12). This layer comprised a combination of perennial grasses and graminoids, shrubs, and forbs. Foliar cover in these live functional groups was fairly similar, and ranged from 1.50% to 3.00%. There were no annual grasses or cacti/succulents. Cover of standing dead herbaceous and standing dead woody (which does not include trees) was less than 1.00%. Foliar cover of functional groups was similar for the 2 plot groups. The large error bars demonstrate large among-plot variation.

We present species-level data for the most abundant herbs and shrubs in both plot groups in Figure 13 (foliar cover) and Table 9 (foliar cover and frequency). The dominant shrubs were *Juniperus communis* (common juniper) and *Robinia neomexicana* (New Mexico locust). Dominant graminoids were *Carex rossii* (Ross' sedge), *Carex siccata* (dry-spike sedge), and *Poa fendleriana* (mutton grass). Dominant forbs were *Fragaria virginiana* (Virginia strawberry), *Pteridium aquilinum* (western bracken fern), and *Pedicularis centranthera* (dwarf lousewort). Many of the dominant species had high plot frequencies, indicating a fairly even distribution across the ecological site. Several species, *Robinia neomexicana* and to a lesser extent *Pteridium aquilinum*, had low frequencies despite relatively high foliar cover, indicating a patchy distribution. The plot and quadrat frequencies of many of the dominant species were similar between the 2 plot groups. There were some differences in foliar cover between the groups, but these differences are moderated by the large standard deviations. For example, Plot Group B had much higher cover of *Juniperus communis* and *Pteridium aquilinum*, and lower cover of *Carex rossii* and *Fragaria virginiana*.

Table 8. Foliar cover of functional groups for Plot Group A and Plot Group B in the mixed conifer ecological site at GRCA.

Functional groups	Plot Group A 2007–2009		Plot Group B 2010	
	Mean (%)	SD	Mean (%)	SD
Total live foliar cover	8.30	4.56	5.27	3.91
Perennial grasses	1.73	1.45	0.99	1.62
Annual grasses	0	0	0	0
Forbs	1.58	1.55	1.55	1.95
Shrubs	1.60	2.12	2.70	3.35
Cacti/succulents	0	0	0	0
Standing dead herbaceous	0.80	0.85	0.59	1.73
Standing dead woody	0.21	0.14	0.22	0.32

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.

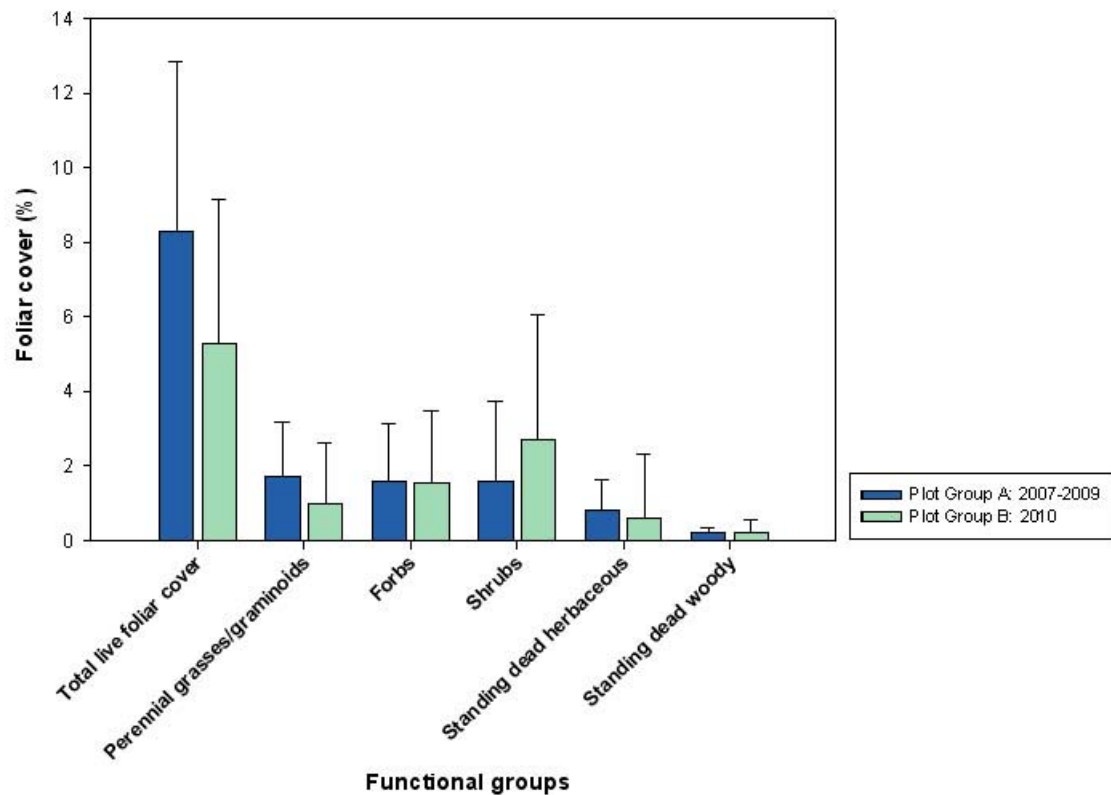


Figure 12. Mean percent foliar cover by functional group for Plot Group A and Plot Group B in the mixed conifer ecological site at GRCA. Error bars represent one standard deviation.

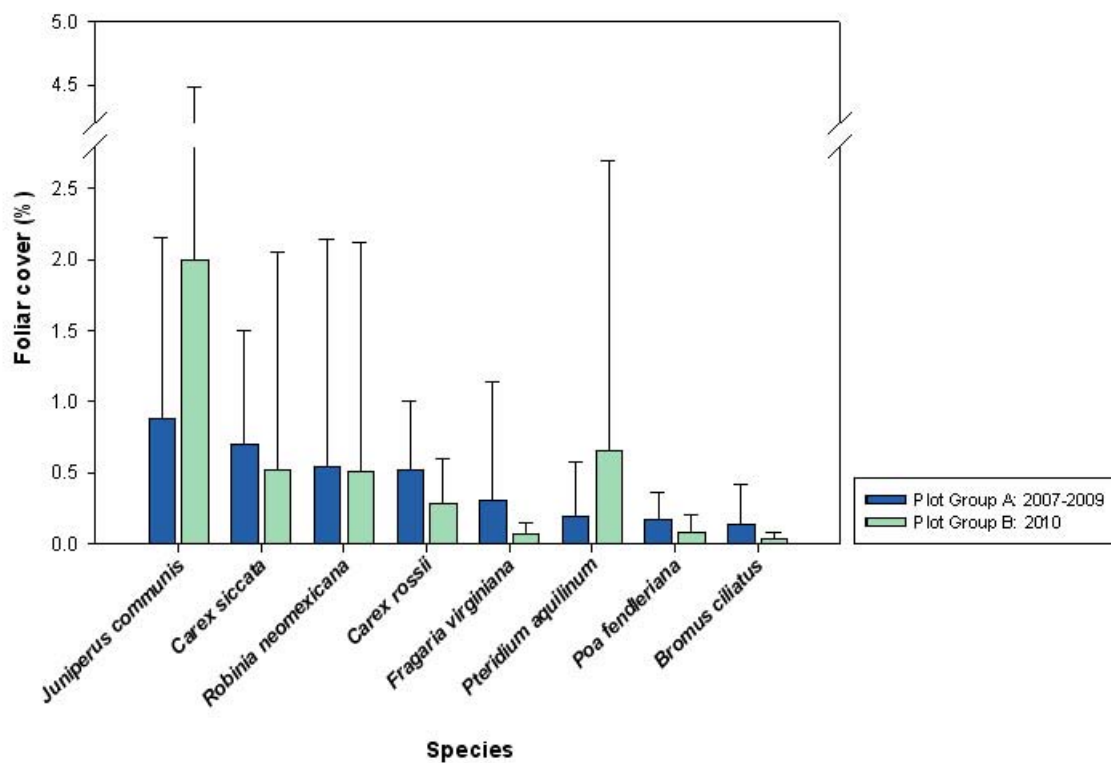


Figure 13. Mean foliar cover of the 8 most abundant shrub and herbaceous species for Plot Group A, compared with the foliar cover of the same species in Plot Group B, in the mixed conifer ecological site at GRCA. Error bars represent one standard deviation.

Table 9. Mean foliar cover and standard deviation, and mean quadrat and plot frequencies of the 15 most abundant shrub and herbaceous species for Plot Group A, and for the same species in Plot Group B, in the mixed conifer ecological site at GRCA. All nonnative species are included from both plot groups.

Species	Plot Group A 2007–2009				Plot Group B 2010			
	Foliar cover (%)	SD	Quadrat freq. (%)	Plot freq. (%)	Foliar cover (%)	SD	Quadrat freq. (%)	Plot freq. (%)
<i>Juniperus communis</i>	0.883	1.271	19.58	66.67	1.992	2.498	24.64	65.22
<i>Carex siccata</i>	0.693	0.806	42.78	83.33	0.518	1.539	41.16	91.30
<i>Robinia neomexicana</i>	0.537	1.607	7.64	12.50	0.507	1.613	5.22	13.04
<i>Carex rossii</i>	0.513	0.487	70.69	100.00	0.283	0.309	69.57	100.00
<i>Fragaria virginiana</i>	0.305	0.831	23.75	100.00	0.067	0.081	20.87	86.96
<i>Pteridium aquilinum</i>	0.189	0.386	8.33	35.42	0.655	2.036	11.88	30.43
<i>Poa fendleriana</i>	0.165	0.200	36.53	93.75	0.076	0.129	20.87	91.30
<i>Bromus ciliatus</i>	0.140	0.272	32.64	100.00	0.038	0.043	30.14	91.30
<i>Pedicularis centranthera</i>	0.123	0.112	38.33	89.58	0.131	0.170	33.33	82.61
<i>Geranium richardsonii</i>	0.109	0.295	10.97	25.00	0.011	0.028	4.93	34.78
<i>Mahonia repens</i>	0.089	0.120	17.22	68.75	0.105	0.188	21.45	69.57
<i>Chamerion angustifolium</i>	0.077	0.168	9.44	50.00	0.016	0.027	4.64	39.13
<i>Erigeron formosissimus</i>	0.075	0.125	15.56	41.67	0.006	0.020	2.90	13.04
<i>Ligusticum porteri</i>	0.061	0.144	9.31	43.75	0.020	0.058	5.51	26.09
<i>Antennaria marginata</i>	0.050	0.130	6.39	39.58	0.028	0.063	5.51	39.13
<i>Taraxacum officinale</i> ^a	0.003	0.010	1.53	14.58	<0.001	0.001	0.58	8.70

Note: Species are arranged in descending order by their mean foliar cover for Plot Group A. The following species also have a mean foliar cover ≥ 0.50 in Plot Group B: *Erigeron speciosus*, *Oreochrysum parryi* and *Pseudostellaria jamesiana*.

^aNonnative species.

There was only one nonnative species found in the plots, *Taraxacum officinale* (common dandelion), which had both low cover and frequencies in both plot groups. Appendix B lists all species, along with common names, families, mean foliar cover and plot frequencies by plot group.

Despite its sparseness, the herbaceous and shrub vegetation was moderately diverse overall (table 10). On the scale of the plot, diversity was low to moderate. Plot richness was moderate, with 22 to 23 species per plot. Shannon diversity (which takes into account relative species abundance and generally ranges between 1.5 and 3.5) was low, with values less than 2. Evenness (the degree to which all species are of equal abundance, ranging between 0 and 1) was moderate. On the scale of the ecological site, diversity was moderately high. Ecological site richness was relatively high, with 83 to 86 species per site. Beta diversity (a measure of within-site heterogeneity, generally ranging between 1 and 5) was also fairly high, greater than 3.9. Diversity patterns between the 2 groups were similar, but Shannon diversity and evenness were lower for the Plot Group B than Plot Group A. These patterns suggest that while plot diversity was not high, the ecological site as a whole was fairly diverse, with relatively large differences in species abundances among plots. When these metrics were recalculated using only native species, they changed very little.

Table 10. Species diversity metrics for all species and for native species only for Plot Group A and Plot Group B in the mixed conifer ecological site at GRCA.

	Plot Group A (2007–2009)		Plot Group B (2010)	
	Mean	SD	Mean	SD
All species				
Plot				
Plot richness	23.0	5.8	22.3	6.3
Shannon diversity	1.907	0.440	1.578	0.575
Evenness	0.610	0.122	0.510	0.166
Ecological site				
Ecological site richness	86.7		84 ^a	
Beta diversity	3.933		3.951 ^a	
Native species				
Plot				
Plot richness	22.9	5.7	22.2	6.2
Shannon diversity	1.904	0.438	1.578	0.575
Evenness	0.611	0.122	0.510	0.166
Ecological site				
Ecological site richness	85.7		83 ^a	
Beta diversity	3.914		3.920 ^a	

^aThese are not mean values.

3.2.2 Trees

The tree layer was comprised of 7 species. *Pinus ponderosa* (ponderosa pine, PIPO) and *Abies concolor* (white fir, ABCO) had the highest living overstory basal area, followed by *Picea engelmannii* (Engelmann spruce, PIEN), *Populus tremuloides* (quaking aspen, POTR) and *Pseudotsuga menziesii* (Douglas fir, PSME) (table 11 and fig. 14). *Abies concolor* had the highest basal area for snags. *Abies concolor* also had the highest living overstory density, followed by *Picea engelmannii*, then *Pinus ponderosa*, *Populus tremuloides* and *Pseudotsuga menziesii*. *Abies lasiocarpa* (sub-alpine fir, ABLA) and *Picea pungens* (Colorado blue spruce, PIPU) represented minor components of the overstory. *Pinus ponderosa* had the greatest mean diameter.

There were moderate differences in basal area and overstory density between the 2 plot groups. Most species showed an inverse size class distribution, i.e., a decrease in density with increased size (fig. 15). The exceptions were *Pinus ponderosa* and *Picea pungens*, which had fairly even size distributions, and *Populus tremuloides*, which had a distribution restricted to smaller overstory size classes.

The seedling and sapling layers are measures of forest regeneration, and indicate the potential for change in species composition. The most abundant species in the sapling layer were *Abies concolor*, *Picea engelmannii*, and *Populus tremuloides* (fig. 16). For many species there was a pattern of decreasing density with increasing size class, although large error bars indicate high among-plot variation. The patterns were similar for both groups.

The highest density of seedlings was in the intermediate size class for most species (fig. 17). The exception was *Pinus ponderosa*, which had highest densities in the smallest seedling size class, particularly in Plot Group A. The patterns of seedling densities were similar for the 2 plot groups, with the exception of *Pinus ponderosa*. Large among-plot variation is demonstrated by the large error bars.

Table 11. Mean density, mean basal area, and mean diameter of trees for Plot Group A and Plot Group B in the mixed conifer ecological site at GRCA. Species codes are as follows: ABCO—*Abies concolor*, ABLA—*Abies lasiocarpa*, PIEN—*Picea engelmannii*, PIPU—*Picea pungens*, PIPO—*Pinus ponderosa*, POTR—*Populus tremuloides*, PSME—*Pseudotsuga menziesii*.

	Plot group	Individual species							All species ^a
		ABCO	ABLA	PIEN	PIPU	PIPO	POTR	PSME	
Seedling ^b density (stems/ha)	A: 2007	2483.3	1283.3	445.8	162.5	3612.5	4695.9	129.2	12812.6
	B: 2010	2481.2	605.8	446.4	34.8	150.7	3794.2	142.0	7,655.1
Sapling ^b density (stems/ha)	A: 2007	327.5	85.0	232.5	82.5	7.5	167.5	67.5	970.0
	B: 2010	205.2	57.4	173.9	8.7	43.5	231.3	33.0	753.0
Overstory ^b density (stems/ha)	A: 2007	61.3	23.8	38.1	14.4	43.1	47.5	31.3	259.4
	B: 2010	74.3	11.3	70.9	8.7	54.8	44.3	37.0	301.3
Snag ^b density (stems/ha)	A: 2007	44.4	11.9	8.1	0.6	10.6	30.6	6.3	112.5
	B: 2010	43.5	15.2	10.4	2.6	8.3	58.3	13.5	151.8
Overstory basal area (m ² /ha)	A: 2007	5.82	1.25	3.38	2.06	9.44	3.41	2.87	28.24
	B: 2010	5.71	0.51	5.22	0.66	9.78	2.91	2.57	27.37
Snag basal area (m ² /ha)	A: 2007	7.23	0.47	0.99	0.03	2.33	1.92	1.20	14.17
	B: 2010	6.03	0.93	0.59	0.20	0.57	2.80	1.62	12.75
Mean overstory diameter ^c (cm)	A: 2007	32.1	22.7	32.1	30.0	51.8	29.4	29.4	33.7
	B: 2010	29.0	23.8	27.8	32.5	45.7	29.1	29.9	31.6

^aValues in the “All species” column represent all species 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 all tree species.

^bSize 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.

^cMean diameter of tree is provided as DBH.

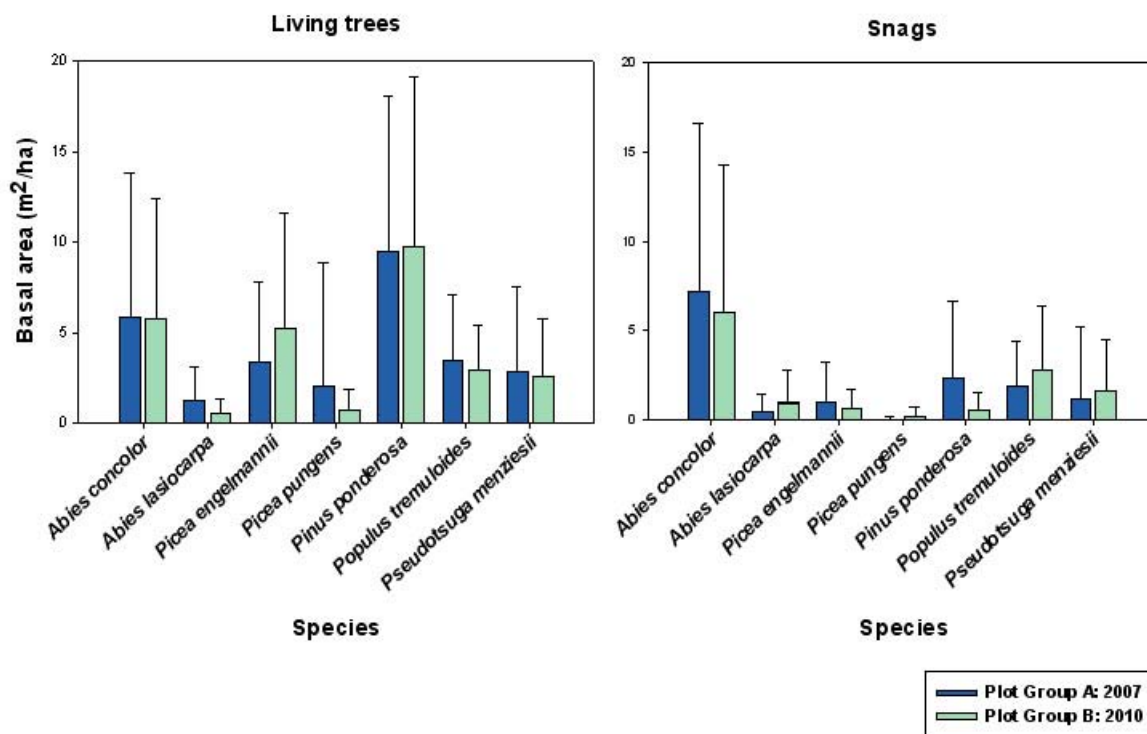


Figure 14. Mean basal area for living trees and snags, by species, for Plot Group A and Plot Group B in the mixed conifer ecological site at GRCA. Error bars represent 1 standard deviation.

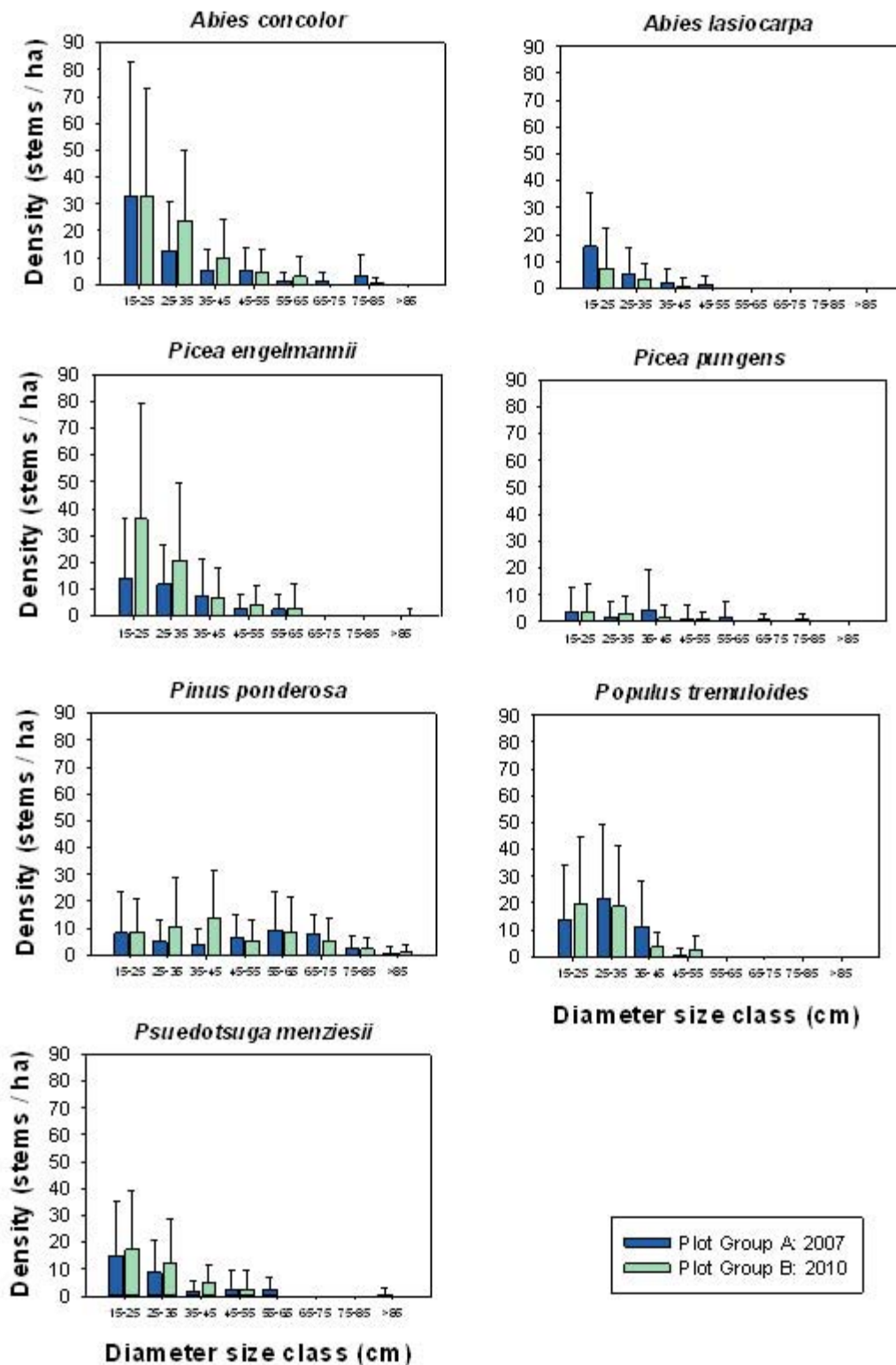


Figure 15. Size structure of living overstory tree species for Plot Group A and Plot Group B in the mixed conifer ecological site at GRCA. Error bars represent 1 standard deviation.

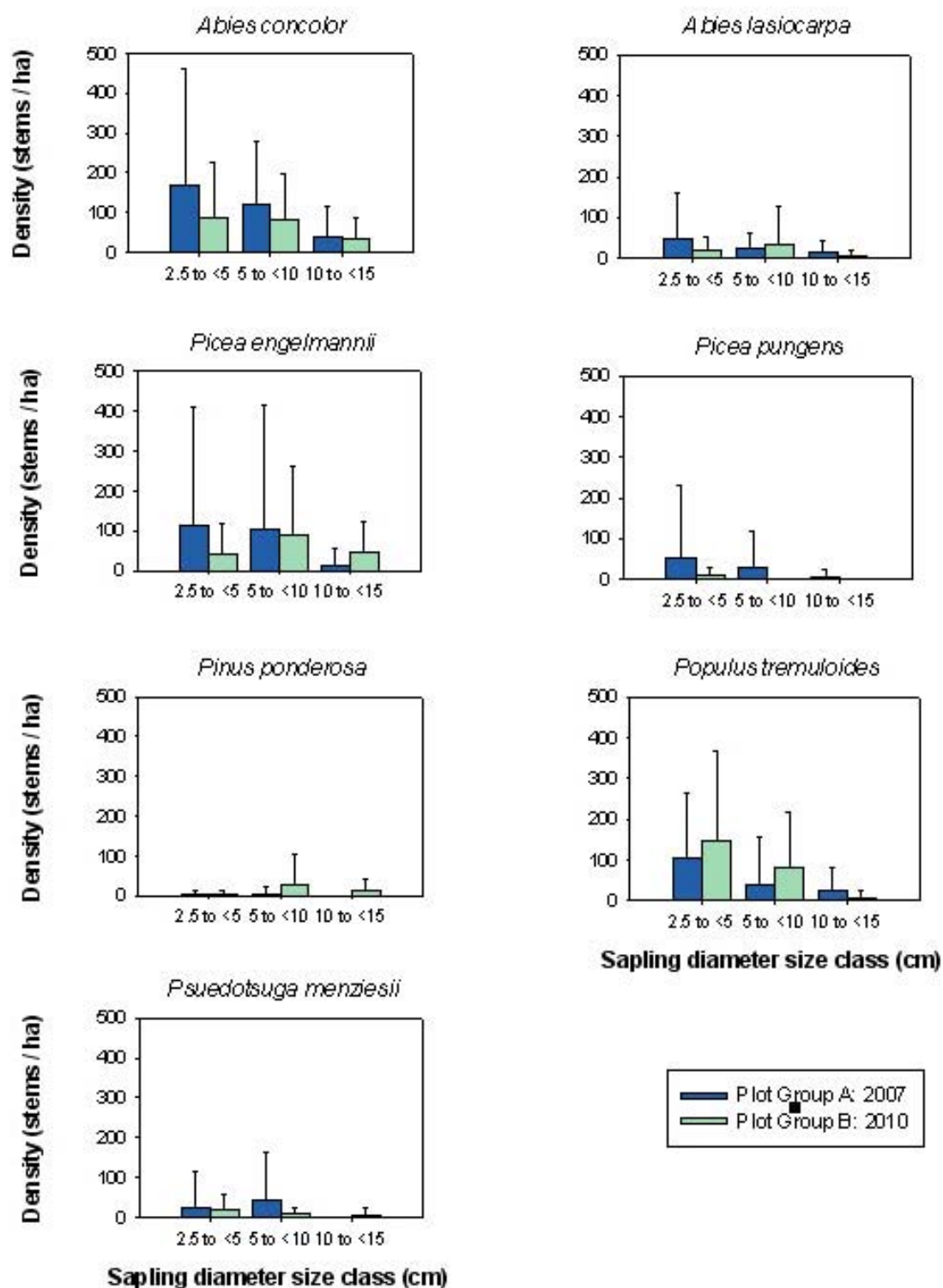


Figure 16. Mean density of saplings in different diameter size classes, by species, for Plot Group A and Plot Group B in the mixed conifer ecological site at GRCA. Error bars represent 1 standard deviation.

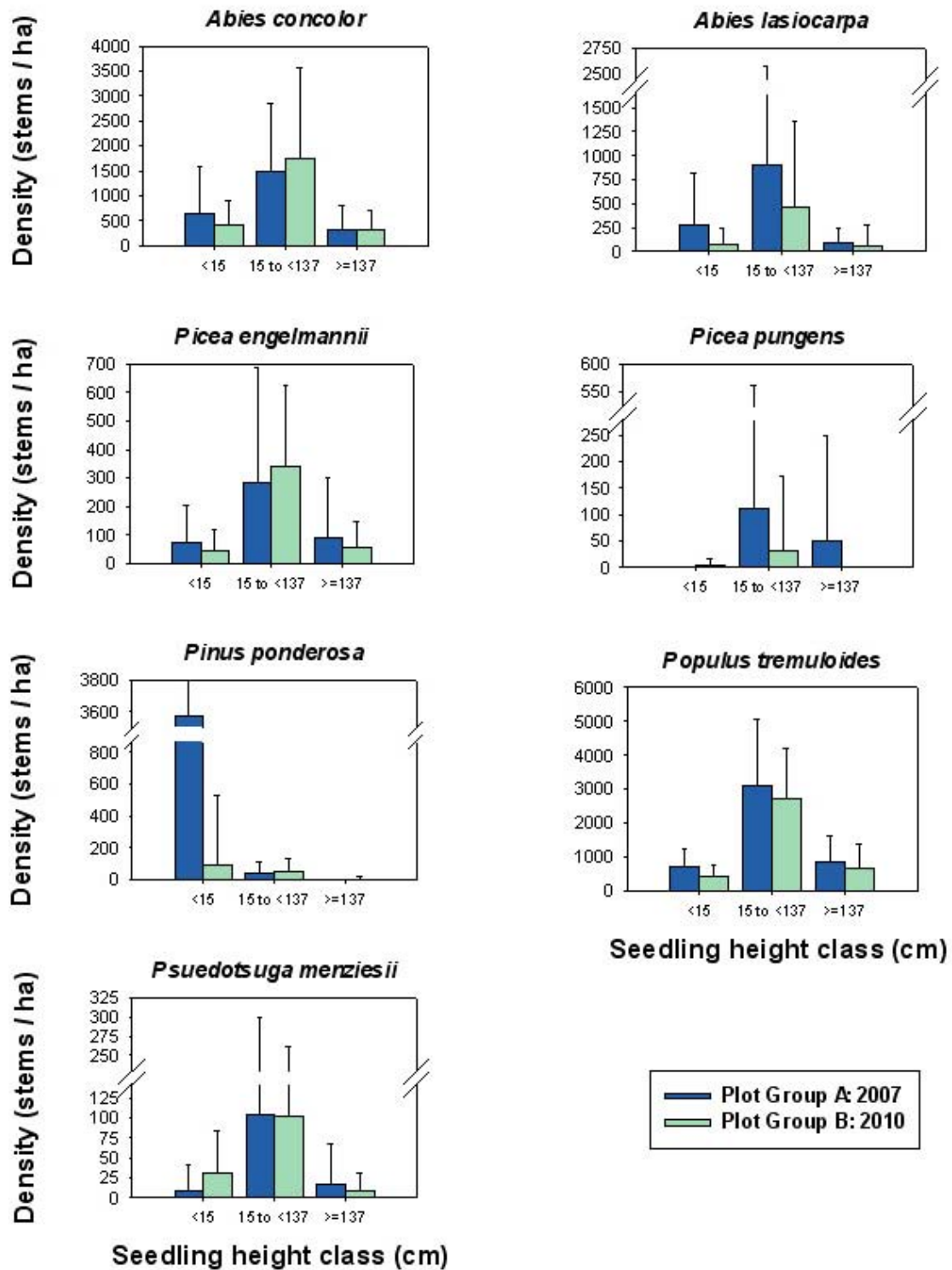


Figure 17. Mean density of seedlings in different size classes, by species, for Plot Group A and Plot Group B in the mixed conifer ecological site at GRCA. Error bars represent 1 standard deviation. Note that the scales on the vertical axes of the graphs vary. The seedling category includes all trees <2.5 cm DBH.

The overall tree structure demonstrated the expected pattern of decreased density with increased size (fig. 18). The pattern was consistent for the 2 plot groups, with the exception of the smallest size class, where Plot Group B had similar densities for the smallest 2 size classes.

Canopy closure showed moderately large differences between the plot groups: 71.2% for Plot Group A and 55.1% for Plot Group B (fig. 19).

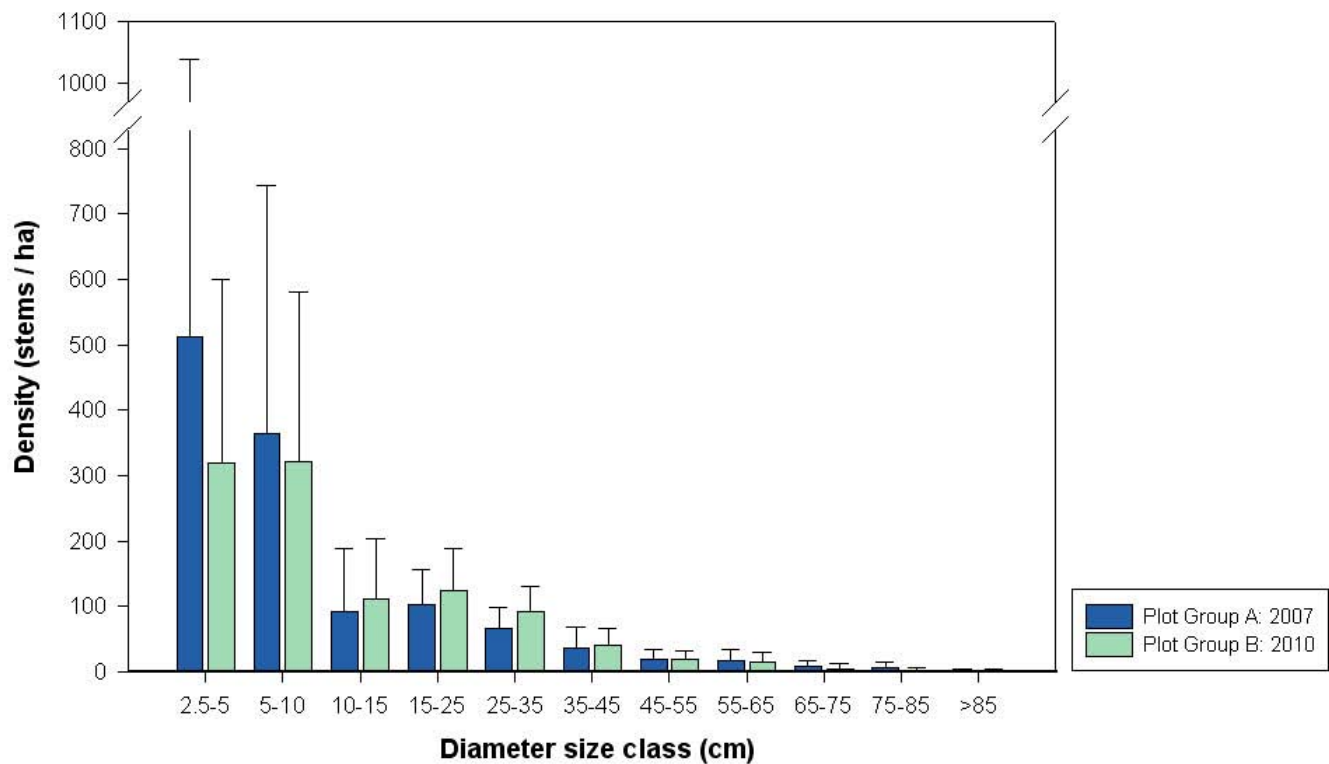
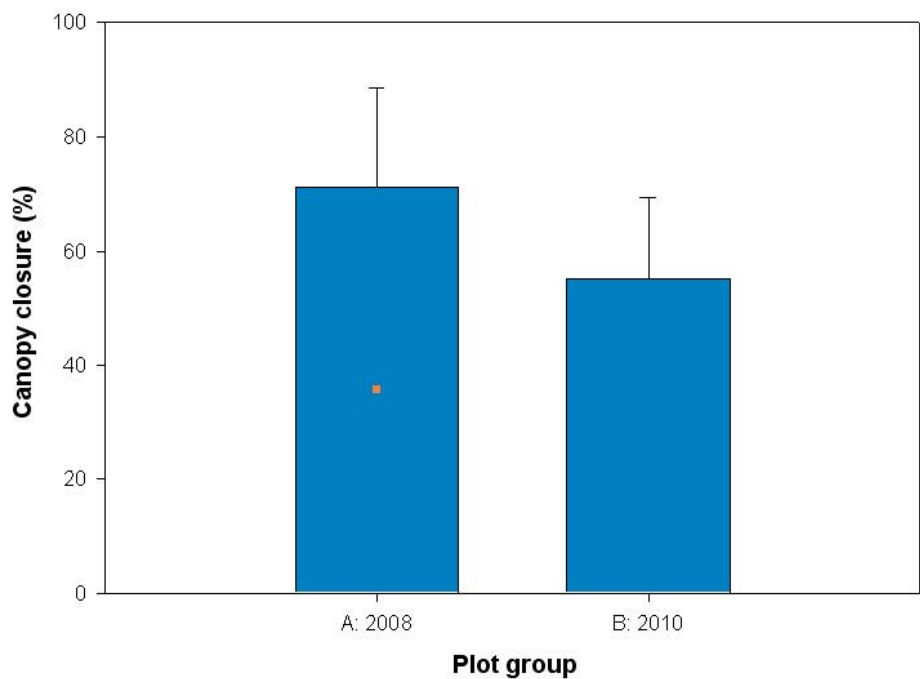


Figure 18. Size structure of living overstory trees and saplings for Plot Group A and Plot Group B in the mixed conifer ecological site at GRCA. Error bars represent 1 standard deviation.

Figure 19. Mean canopy closure for Plot Group A and Plot Group B in the mixed conifer ecological site at GRCA. Error bars indicate 1 standard deviation.



3.2.3 Soil surface features

We measured the amount of soil surface potentially subject to erosion using cover estimates of soil surface features in quadrats. Duff/litter dominated the soil surface, comprising between 80% and 82% of the total soil surface cover (table 12 and fig. 20). Woody debris was the second most abundant feature, with 9% to 10% cover. All the other features were less than 2% of the total cover. There were only small differences between the 2 plot groups for the soil surface features.

Table 12. Cover of soil surface features for Plot Group A and Plot Group B in the mixed conifer ecological site at GRCA.

Soil surface feature	Plot Group A 2007–2009		Plot Group B 2010	
	Mean (%)	SD	Mean (%)	SD
Live plant base	1.74	1.58	1.16	1.32
Dead woody base	0.47	0.75	0.24	0.51
Dead herbaceous base	0.14	0.18	0.09	0.12
Bare soil	1.15	1.60	0.84	1.11
Duff/litter	80.43	5.01	81.90	4.05
Undifferentiated crust	0.13	0.50	0	0
Moss	0.34	0.31	0.45	0.55
Lichen	0.09	0.15	0.25	0.65
Cyanobacteria ^a	0	0	<0.01	<0.01
Fine gravel (0.2 to <2 cm)	0.19	0.29	0.20	0.31
Coarse gravel (2 to <7.5 cm)	0.46	0.73	0.41	0.44
Cobble (7.5 to <25 cm)	0.34	0.70	0.21	0.25
Stone, bedrock (≥25 cm)	0.46	1.24	0.02	0.06
Woody debris	9.04	4.59	9.87	4.05

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

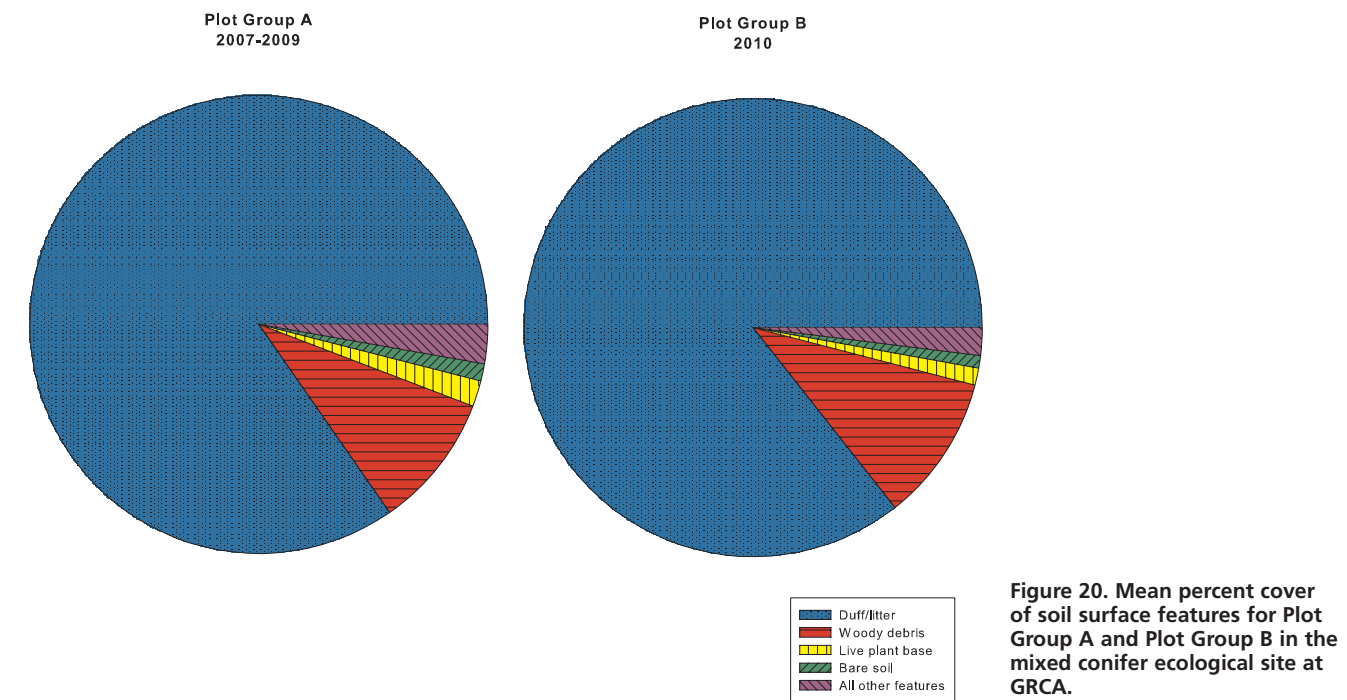
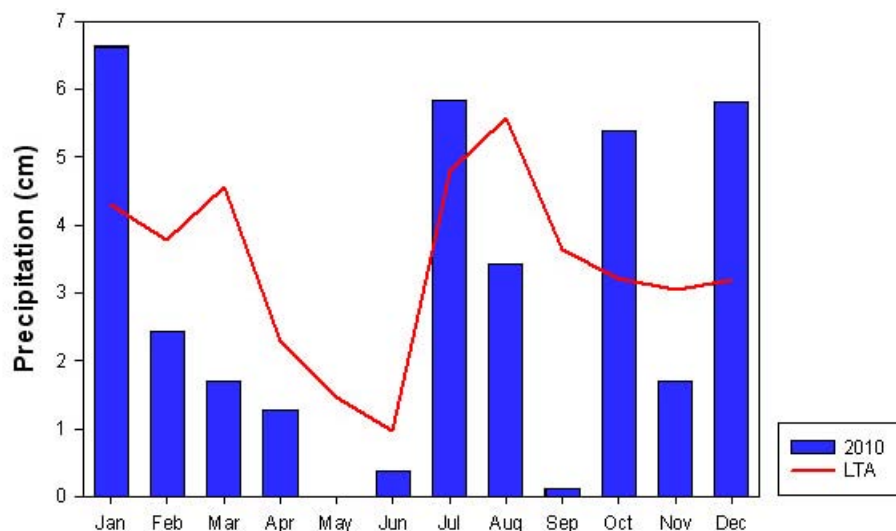


Figure 20. Mean percent cover of soil surface features for Plot Group A and Plot Group B in the mixed conifer ecological site at GRCA.

3.3 Western Regional Climate Center precipitation data

Precipitation records for GRCA are available from the Western Regional Climate Center (2012). Figure 21 shows the total monthly precipitation for 2010, compared with the long term average precipitation by month for the period 1948–2010.

Figure 21. Total monthly precipitation for 2010 at Grand Canyon NP 2 station (023596), AZ. The red line long term average (LTA) represents the mean monthly totals from 1948 through 2010, collected by the Western Regional Climate Center.



4 Discussion

4.1 Limestone Upland ecological site

The data from the Limestone Upland ecological site at GRCA site represent the first year of baseline sampling for this site. The data indicate that the understory was dominated by the perennial grasses, *Bouteloua gracilis* and *Poa fendleriana*, and the shrubs, *Purshia stansburiana* and *Artemisia tridentata*. Species diversity was moderately low on the scale of the plot, and moderate on the landscape scale of the ecological site. The tree data suggest a moderately healthy size structure for a pinyon-juniper woodland, with a relatively high abundance of *Pinus edulis* saplings and seedlings. There was no evidence of a recent mortality event for *Pinus edulis*, as is found throughout much of the Southwest. The large amount of exposed soil, as demonstrated in the basal gap data, suggests high potential for soil erosion. This is offset, however, by the high cover of duff/litter and the relatively high soil stability rating. The precipitation data from 2010 suggests that the growing season generally had below-average precipitation, with a stronger than average monsoon in July.

Our plan for the Limestone Upland ecological site is to sample the quadrats and gap intercept transects annually for the next 3 years to determine the range of variability for key metrics. We will then establish additional plots. We expect that 30 plots will provide sufficient power to detect change in the key metrics.

4.2 Mixed conifer

The data from the mixed conifer ecological site suggests that the 23 plots established in 2010 were fairly similar to the original 16 plots established in 2007. The largest differences were in the cover of a few of the dominant species, in the overstory density and basal areas of several tree species, and in the density of *Pinus ponderosa* seedlings of the smallest size class. We would expect minor differences in species composition and structure between the 2 groups, particularly for groups with small sample sizes, due to random spatial variation. These 2 groups represent different plots in different locations. Due to endogenous and exogenous factors, the species composition and structure and soil characteristics naturally vary. Differences in climatic factors in the year of the sampling may influence tree seedlings and the abundance of some of the forb species. For example, the high density of the smallest class of *Pinus ponderosa* seedlings may have been the result of the seed germination resulting from a wet growing season. Unfortunately, there is not a weather station in the vicinity of our mixed conifer site, so the precipitation data presented in Figure 21 should not be used to interpret annual variation in vegetation data for the mixed conifer ecological site.

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, slight differences 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 on methods and species identification and remain calibrated on cover estimation.

In 2011, we installed and sampled an additional 7 plots in the mixed-conifer ecological site. These data will be reported once they have been verified, validated and summarized. Power analysis indicates that a total of 45 plots should provide a large enough sample size to detect trends in key metrics. Data from these plots will be used to describe the baseline conditions of the vegetation and soils of this ecological site and monitor long-term changes.

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Appendix A: Complete species list for the Limestone Upland ecological site at GRCA.

Table A1. Shrub and herbaceous species, with mean foliar cover and plot frequency for 10 plots in the Limestone Upland ecological site at GRCA in 2010.

Species	Common name	Family	Foliar cover (%)	Plot frequency (%)
<i>Allium cernuum</i>	nodding onion	Liliaceae	0.001	10.00
<i>Arabis</i> spp.	rockcress	Brassicaceae	0.002	40.00
<i>Arceuthobium divaricatum</i>	pinyon dwarf mistletoe	Viscaceae	<0.001	10.00
<i>Artemisia tridentata</i>	basin big sagebrush	Asteraceae	0.999	100.00
<i>Astragalus</i> spp.	milkvetch	Fabaceae	0.006	50.00
<i>Astragalus newberryi</i>	Newberry's milkvetch	Fabaceae	0.020	70.00
<i>Bahia dissecta</i>	ragleaf bahia	Asteraceae	<0.001	10.00
<i>Bouteloua gracilis</i>	blue grama	Poaceae	2.126	90.00
<i>Bromus tectorum</i> ^a	cheatgrass	Poaceae	0.043	40.00
<i>Calochortus nuttallii</i>	sego lily	Liliaceae	0.001	30.00
<i>Chaetopappa ericoides</i>	rose heath	Asteraceae	0.003	30.00
<i>Chamaesyce</i> spp.	sandmat	Euphorbiaceae	0.008	20.00
<i>Chenopodium graveolens</i>	fetid goosefoot	Chenopodiaceae	0.001	20.00
<i>Chrysothamnus depressus</i>	longflower rabbitbrush	Asteraceae	0.002	10.00
<i>Comandra umbellata</i>	bastard toadflax	Santalaceae	0.027	30.00
<i>Cordylanthus parviflorus</i>	purple bird's-beak	Scrophulariaceae	0.044	40.00
<i>Cordylanthus wrightii</i>	Wright's bird's beak	Scrophulariaceae	0.013	10.00
<i>Cryptantha</i> spp.	cryptantha	Boraginaceae	0.005	20.00
<i>Delphinium scaposum</i>	barestem larkspur	Ranunculaceae	0.004	10.00
<i>Echinocereus</i> sp.	hedgehog cactus	Cactaceae	0.003	20.00
<i>Elymus elymoides</i>	squirreltail	Poaceae	0.028	70.00
<i>Ephedra viridis</i>	mormon tea	Ephedraceae	0.066	30.00
<i>Ericameria nauseosa</i>	rubber rabbitbrush	Asteraceae	0.007	20.00
<i>Erigeron concinnus</i>	Navajo fleabane	Asteraceae	0.013	40.00
<i>Erigeron divergens</i>	spreading fleabane	Asteraceae	<0.001	10.00
<i>Erigeron flagellaris</i>	trailing fleabane	Asteraceae	0.001	20.00
<i>Eriogonum alatum</i>	winged buckwheat	Polygonaceae	0.004	10.00
<i>Eriogonum jamesii</i>	James' buckwheat	Polygonaceae	0.004	10.00
<i>Eriogonum microthecum</i>	Simpson's buckwheat	Polygonaceae	0.014	50.00
<i>Eriogonum racemosum</i>	redroot buckwheat	Polygonaceae	0.043	30.00
<i>Eriogonum umbellatum</i>	sulphur-flowered buckwheat	Polygonaceae	0.021	30.00
<i>Escobaria</i> spp.	foxtail cactus	Cactaceae	0.001	30.00
<i>Gilia</i> spp.	Gilia	Polemoniaceae	0.007	30.00
<i>Gutierrezia sarothrae</i>	broom snakeweed	Asteraceae	0.313	100.00
<i>Hedeoma drummondii</i>	Drummond's false pennyroyal	Lamiaceae	0.006	20.00
<i>Hesperostipa comata</i>	needle and thread	Poaceae	0.023	10.00
<i>Hymenopappus filifolius</i>	fineleaf hymenopappus	Asteraceae	0.010	40.00
<i>Hymenoxys richardsonii</i>	Colorado rubberweed	Asteraceae	0.005	10.00
<i>Ipomopsis multiflora</i>	manyflowered ipomopsis	Polemoniaceae	0.007	40.00

Table A1 (continued)

Species	Common name	Family	Foliar cover (%)	Plot frequency (%)
<i>Koeleria macrantha</i>	prairie junegrass	Poaceae	0.004	10.00
<i>Lesquerella intermedia</i>	mid bladderpod	Brassicaceae	0.012	40.00
<i>Lupinus</i> spp.	Lupine	Fabaceae	0.004	10.00
<i>Lupinus kingii</i>	King's lupine	Fabaceae	0.003	10.00
<i>Machaeranthera tanacetifolia</i>	tanseyleaf tansyaster	Asteraceae	<0.001	10.00
<i>Mahonia fremontii</i>	Fremont's mahonia	Berberidaceae	0.179	20.00
<i>Mentzelia</i> spp.	blazingstar	Loasaceae	0.003	20.00
<i>Mirabilis linearis</i>	narrowleaf four o'clock	Nyctaginaceae	0.002	20.00
<i>Nama dichotomum</i>	wishbone fiddleleaf	Hydrophyllaceae	0.002	10.00
<i>Opuntia</i> spp.	prickly pear	Cactaceae	0.115	100.00
<i>Opuntia whipplei</i>	Whipple's cholla	Cactaceae	0.002	10.00
<i>Packera neomexicana</i>	New Mexico groundsel	Asteraceae	0.005	40.00
<i>Penstemon</i> spp.	penstemon	Scrophulariaceae	0.021	60.00
<i>Penstemon barbatus</i>	beardlip penstemon	Scrophulariaceae	0.030	60.00
<i>Penstemon caespitosus</i>	mat penstemon	Scrophulariaceae	0.002	10.00
<i>Phlox austromontana</i>	mountain phlox	Polemoniaceae	0.068	20.00
<i>Phlox longifolia</i>	longleaf phlox	Polemoniaceae	0.001	20.00
<i>Poa fendleriana</i>	muttongrass	Poaceae	0.813	100.00
<i>Polygonum douglasii</i>	Douglas' knotweed	Polygonaceae	0.008	60.00
<i>Portulaca oleracea</i> ^a	little hogweed	Portulacaceae	0.001	30.00
<i>Portulaca pilosa</i>	kiss me quick	Portulacaceae	<0.001	10.00
<i>Psoralidium tenuiflorum</i>	slimflower scurfpea	Fabaceae	<0.001	10.00
<i>Purshia stansburiana</i>	Stansbury cliffrose	Rosaceae	1.661	100.00
<i>Quercus gambelii</i>	Gambel oak	Fagaceae	0.010	10.00
<i>Sanvitalia abertii</i>	Albert's creeping zinnia	Asteraceae	0.001	10.00
<i>Sphaeralcea</i> spp.	globemallow	Malvaceae	0.003	20.00
<i>Stephanomeria</i> sp.	wirelettuce	Asteraceae	<0.001	10.00
<i>Thlaspi montanum</i>	alpine pennycress	Brassicaceae	0.003	30.00
<i>Townsendia incana</i>	hoary Townsend daisy	Asteraceae	<0.001	10.00
<i>Yucca baccata</i>	banana yucca	Agavaceae	0.004	50.00
unknownGRCA20100904_1			0.002	10.00

^aNonnative species.**Table A2. Tree species, with mean basal area and plot frequency for the 10 plots in the Limestone Upland ecological site at GRCA in 2010.**

Species	Common name	Family	Basal area (m ² /ha) ^a	Plot frequency (%) ^b
<i>Juniperus osteosperma</i>	Utah juniper	Cupressaceae	16.12	100.00
<i>Pinus edulis</i>	twoneedle pinyon	Pinaceae	5.39	100.00

^aBasal area measures only overstory trees.^bPlot frequency includes overstory trees, saplings, and seedlings.

Appendix B: Complete species list for Plot Group A (sampled between 2007 and 2009) and plot Group B (sampled in 2010) in the mixed conifer ecological site at GRCA.

Table B1. Shrub and herbaceous species, with mean foliar cover and plot frequency, for Plot Group A and Plot Group B in the mixed conifer ecological site at GRCA.

Species	Common name	Family	Plot Group A 2007–2009		Plot Group B 2010	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Achillea millefolium</i>	western yarrow	Asteraceae	0.033	37.50	0.020	43.48
<i>Achnatherum nelsonii</i>	Columbia needlegrass	Poaceae	0	0	0.001	4.35
<i>Agastache pallidiflora</i>	Bill Williams Mountain giant hyssop	Lamiaceae	0	0	<0.001	4.35
<i>Agoseris glauca</i>	pale agoseris	Asteraceae	<0.001	8.33	0	0
<i>Agrostis scabra</i>	rough bentgrass	Poaceae	0.002	14.58	0	0
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae	<0.001	6.25	0	0
<i>Amelanchier utahensis</i>	Utah serviceberry	Rosaceae	0.002	6.25	0	0
<i>Androsace septentrionalis</i>	pygmy rock jasmine	Primulaceae	0.001	14.58	<0.001	13.04
<i>Antennaria marginata</i>	white margin pussytoes	Asteraceae	0.050	39.58	0.028	39.13
<i>Antennaria parvifolia</i>	small leaf pussytoes	Asteraceae	0.038	54.17	0.030	52.17
<i>Apocynum androsaemifolium</i>	spreading dogbane	Apocynaceae	0	0	<0.001	4.35
<i>Aquilegia coerulea</i>	Colorado blue columbine	Ranunculaceae	0.003	6.25	0	0
<i>Arenaria fendleri</i>	Fendler's sandwort	Caryophyllaceae	0.004	16.67	0.004	13.04
<i>Arenaria lanuginosa</i>	spreading sandwort	Caryophyllaceae	0.002	12.50	0.002	17.39
<i>Arnica chamissonis</i>	Chamisso arnica	Asteraceae	0	0	0.002	4.35
<i>Astragalus</i> sp.	milkvetch	Fabaceae	0	0	<0.001	4.35
<i>Bahia dissecta</i>	ragleaf bahia	Asteraceae	<0.001	6.25	0	0
<i>Blepharoneuron tricholepis</i>	pine dropseed	Poaceae	0.008	14.58	0.003	13.04
<i>Brickellia grandiflora</i>	mountain brickellbush	Asteraceae	0.022	6.25	0	0
<i>Bromus anomalus</i>	nodding brome	Poaceae	0.001	12.5	0	0
<i>Bromus ciliatus</i>	fringed brome	Poaceae	0.140	100.00	0.038	91.30
<i>Carex occidentalis</i>	western sedge	Cyperaceae	0	0	0.006	13.04
<i>Carex rossii</i>	Ross' sedge	Cyperaceae	0.513	100.00	0.283	100.00
<i>Carex siccata</i>	dry-spike sedge	Cyperaceae	0.693	83.33	0.518	91.30
<i>Castilleja austromontana</i>	Rincon Indian paintbrush	Scrophulariaceae	0.002	12.50	0	0
<i>Castilleja linariifolia</i>	Wyoming Indian paintbrush	Scrophulariaceae	<0.001	6.25	0.001	13.04

Table B1 (continued)

Plot Group A 2007–2009			Plot Group B 2010			
Species	Common name	Family	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Ceanothus fendleri</i>	Fendler's ceanothus	Rhamnaceae	0.004	18.75	0.008	17.39
<i>Chamerion angustifolium</i>	fireweed	Onagraceae	0.077	50.00	0.016	39.13
<i>Chenopodium album</i>	lambsquarters	Chenopodiaceae	0.032	14.58	0	0
<i>Chenopodium fremontii</i>	Fremont's goosefoot	Chenopodiaceae	0	0	<0.001	8.70
<i>Chenopodium graveolens</i>	fetid goosefoot	Chenopodiaceae	0.009	6.25	0	0
<i>Chenopodium leptophyllum</i>	narrowleaf goosefoot	Chenopodiaceae	<0.001	6.25	0	0
<i>Chimaphila umbellata</i>	common pipsissewa	Pyrolaceae	0.002	8.33	0.001	4.35
<i>Cirsium wheeleri</i>	Wheeler's thistle	Asteraceae	0.010	25.00	0.014	34.78
<i>Collinsia parviflora</i>	blue-eyed Mary	Scrophulariaceae	<0.001	12.5	0.001	13.04
<i>Collomia linearis</i>	narrow-leaf mountain-trumpet	Polemoniaceae	0	0	<0.001	4.35
<i>Coryza canadensis</i>	Canadian horseweed	Asteraceae	<0.001	6.25	0	0
<i>Corallorrhiza maculata</i>	spotted coralroot	Orchidaceae	0.001	22.92	0.001	17.39
<i>Cryptantha setosissima</i>	bristly cryptantha	Boraginaceae	0	0	0.001	8.70
<i>Elymus canadensis</i>	Canada wildrye	Poaceae	0.026	14.58	0	0
<i>Elymus elymoides</i>	squirreltail	Poaceae	0.018	68.75	0.018	69.57
<i>Epilobium brachycarpum</i>	autumn willowherb	Onagraceae	<0.001	6.25	<0.001	4.35
<i>Erigeron divergens</i>	spreading fleabane	Asteraceae	0.010	16.67	0	0
<i>Erigeron formosissimus</i>	beautiful fleabane	Asteraceae	0.075	41.67	0.006	13.04
<i>Erigeron speciosus</i>	aspen fleabane	Asteraceae	0.031	20.83	0.126	82.61
<i>Eriogonum racemosum</i>	redroot buckwheat	Polygonaceae	0.007	25.00	0.004	30.43
<i>Euphorbia brachycera</i>	horned spurge	Euphorbiaceae	0.001	6.25	0	0
<i>Festuca arizonica</i>	Arizona fescue	Poaceae	0	0	0.008	4.35
<i>Fragaria virginiana</i>	Virginia strawberry	Rosaceae	0.305	100.00	0.067	86.96
<i>Frasera speciosa</i>	elkweed	Gentianaceae	0	0	0.005	8.70
<i>Fritillaria atropurpurea</i>	spotted fritillary	Liliaceae	<0.001	6.25	<0.001	4.35
<i>Gayophytum diffusum</i>	spreading groundsmoke	Onagraceae	0.004	22.92	0.001	13.04
<i>Geranium caespitosum</i>	piney-woods geranium	Geraniaceae	0.001	6.25	0.001	4.35
<i>Geranium richardsonii</i>	Richardson's geranium	Geraniaceae	0.109	25.00	0.011	34.78
<i>Goodyera oblongifolia</i>	western rattlesnake plantain	Orchidaceae	0.046	85.42	0.037	100.00

Table B1 (continued)

Plot Group A 2007–2009			Plot Group B 2010			
Species	Common name	Family	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Helianthus nuttallii</i>	Nuttall's sunflower	Asteraceae	0	0	0.001	4.35
<i>Heliomeris multiflora</i>	showy goldeneye	Asteraceae	0.008	2.08	0.001	4.35
<i>Hesperidanthus linearifolius</i>	slimleaf plains mustard	Brassicaceae	<0.001	6.25	0	0
<i>Hesperostipa comata</i>	needle and thread	Poaceae	0.003	6.25	0	0
<i>Heterotheca villosa</i>	hairy false goldenaster	Asteraceae	0.001	6.25	<0.001	4.35
<i>Hieracium fendleri</i>	yellow hawkweed	Asteraceae	0.014	66.67	0.009	78.26
<i>Hymenoxys subintegra</i>	Arizona rubberweed	Asteraceae	0.001	6.25	<0.001	8.70
<i>Juniperus communis</i>	common juniper	Cupressaceae	0.883	66.67	1.992	65.22
<i>Kelloggia galioides</i>	milk kelloggia	Rubiaceae	0.002	6.25	<0.001	4.35
<i>Koeleria macrantha</i>	prairie junegrass	Poaceae	0.001	10.42	0.003	21.74
<i>Ligusticum porteri</i>	Porter's licorice root	Apiaceae	0.061	43.75	0.020	26.09
<i>Lithospermum multiflorum</i>	many flowered puccoon	Boraginaceae	0	0	0.001	4.35
<i>Lotus utahensis</i>	Utah bird's-foot trefoil	Fabaceae	0.040	56.25	0.049	52.17
<i>Lotus wrightii</i>	Wright's deervetch	Fabaceae	0.002	9.38	0	0
<i>Lupinus argenteus</i>	silvery lupine	Fabaceae	0	0	0.008	26.09
<i>Lupinus hillii</i>	hill lupine	Fabaceae	0.001	10.42	0	0
<i>Mahonia repens</i>	creeping barberry	Berberidaceae	0.089	68.75	0.105	69.57
<i>Maianthemum stellatum</i>	starry false solomon's-seal	Liliaceae	0.001	6.25	0.002	8.70
<i>Muhlenbergia montana</i>	mountain muhly	Poaceae	0.020	29.17	0.023	17.39
<i>Oreochrysum parryi</i>	Parry's goldenrod	Asteraceae	0.034	41.67	0.096	34.78
<i>Orthilia secunda</i>	sidebells wintergreen	Pyrolaceae	0.008	27.08	0.001	13.04
<i>Osmorhiza depauperata</i>	blunt-fruit sweet-cicely	Apiaceae	0.008	20.83	0	0
<i>Packera multilobata</i>	lobeleaf groundsel	Asteraceae	0.012	35.42	0.017	52.17
<i>Packera wernerifolia</i>	hoary groundsel	Asteraceae	0.004	18.75	0.009	34.78
<i>Pascopyrum smithii</i>	western wheatgrass	Poaceae	0.001	6.25	0	0
<i>Pedicularis centranthera</i>	dwarf lousewort	Scrophulariaceae	0.123	89.58	0.131	82.61
<i>Penstemon barbatus</i>	beardlip penstemon	Scrophulariaceae	0.017	18.75	0.003	4.35
<i>Penstemon virgatus</i>	upright blue pestemon	Scrophulariaceae	0.010	27.08	0.002	13.04
<i>Phacelia heterophylla</i>	variable-leaf scorpionweed	Hydrophyllaceae	0.014	22.92	<0.001	4.35

Table B1 (continued)

		Plot Group A 2007–2009			Plot Group B 2010		
Species	Common name	Family	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	
<i>Phlox austromontana</i>	mountain phlox	Polemoniaceae	0	0	<0.001	4.35	
<i>Poa fendleriana</i>	muttongrass	Poaceae	0.165	93.75	0.076	91.30	
<i>Polygonum douglasii</i>	Douglas' knotweed	Polygonaceae	0.001	21.88	0.002	26.09	
<i>Potentilla hippiana</i>	woolly cinquefoil	Rosaceae	<0.001	6.25	0.001	8.70	
<i>Pseudocymopterus montanus</i>	alpine false springparsley	Apiaceae	0.008	39.58	0.005	56.52	
<i>Pseudognaphalium macounii</i>	Macoun's cudweed	Asteraceae	0.003	16.67	0	0	
<i>Pseudostellaria jamesiana</i>	tuber starwort	Caryophyllaceae	0.042	39.58	0.130	30.43	
<i>Pteridium aquilinum</i>	western bracken fern	Dennstaedtiaceae	0.189	35.42	0.655	30.43	
<i>Pterospora andromedea</i>	woodland pinedrops	Monotropaceae	<0.001	6.25	<0.001	4.35	
<i>Pyrola chlorantha</i>	green flowered wintergreen	Pyrolaceae	0.001	14.58	<0.001	4.35	
<i>Pyrola picta</i>	white veined wintergreen	Pyrolaceae	0.005	27.08	0.002	17.39	
<i>Robinia neomexicana</i>	New Mexico locust	Fabaceae	0.537	12.50	0.507	13.04	
<i>Rosa woodsii</i>	Woods' rose	Rosaceae	0	0	0.013	13.04	
<i>Rubus idaeus</i>	western red raspberry	Rosaceae	0.011	18.75	0.025	8.70	
<i>Salix scouleriana</i>	Scouler's willow	Salicaceae	0.001	6.25	0	0	
<i>Sambucus nigra</i>	black elderberry	Caprifoliaceae	0.002	6.25	0.021	8.70	
<i>Senecio wootonii</i>	Wooton's ragwort	Asteraceae	0.002	14.58	<0.001	4.35	
<i>Silene scouleri</i>	simple campion	Caryophyllaceae	0.002	27.08	0.004	34.78	
<i>Solidago velutina</i>	threenerve goldenrod	Asteraceae	0.045	12.50	0.005	13.04	
<i>Solidago wrightii</i>	Wright's goldenrod	Asteraceae	0.019	6.25	0	0	
<i>Sorbus dumosa</i>	Arizona mountain ash	Rosaceae	0.012	6.25	0.006	17.39	
<i>Symphoricarpos oreophilus</i>	mountain snowberry	Caprifoliaceae	0.047	6.25	0.001	4.35	
<i>Taraxacum officinale</i> ^a	common dandelion	Asteraceae	0.003	14.58	<0.001	8.70	
<i>Thalictrum fendleri</i>	meadowrue	Ranunculaceae	0.008	8.33	0.002	8.70	
<i>Thlaspi montanum</i>	alpine pennycress	Brassicaceae	0.003	27.08	0.003	56.52	
unknownGRC A20080619_1			<0.001	6.25	0	0	
unknownGRC A20070707_1			<0.001	6.25	0	0	

^aNonnative species.

Table B2. Tree species, with mean basal area and plot frequency, for Plot Group A and Plot Group B in the mixed conifer ecological site at GRCA.

Species	Common name	Family	Plot Group A 2007		Plot Group B 2010	
			Basal area (m ² /ha) ^a	Plot frequency (%) ^b	Basal area (m ² /ha) ^a	Plot frequency (%) ^b
<i>Abies concolor</i>	white fir	Pinaceae	5.82	93.75	5.71	95.65
<i>Abies lasiocarpa</i>	subalpine fir	Pinaceae	1.25	56.25	0.51	65.22
<i>Picea engelmannii</i>	Engelmann spruce	Pinaceae	3.38	68.75	5.22	78.26
<i>Picea pungens</i>	Colorado blue spruce	Pinaceae	2.06	25.00	0.66	39.13
<i>Pinus ponderosa</i>	ponderosa pine	Pinaceae	9.44	87.5	9.78	86.96
<i>Populus tremuloides</i>	quaking aspen	Salicaceae	3.41	100.00	2.91	100.00
<i>Pseudotsuga menziesii</i>	Douglas fir	Pinaceae	2.87	75.00	2.57	82.61

^aBasal area measures only overstory trees.

^bPlot frequency includes overstory trees, saplings, and seedlings.