



Integrated Upland Vegetation and Soils Monitoring for Grand Canyon National Park

2011 Summary Report

Natural Resource Data Series NPS/SCPN/NRDS—2013/518



ON THE COVER

Integrated upland monitoring in Grand Canyon National Park
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1 Introduction and background

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

SCPN and park staff selected 2 ecological sites for long-term monitoring of upland vegetation and soils at Grand Canyon National Park (GRCA). The first is the Limestone Upland ecological site. For the sake of simplicity, we refer to the second as the mixed conifer ecological site, although it is technically composed of 2 distinct ecological sites: Loamy Hills, and Loamy Hills, Cold. 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 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. 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.

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, and in 2011 we established 7 more plots. The total number of plots installed in the mixed conifer ecological site is 46. Our power analysis suggests that this will be a sufficient sample size to detect trends in key metrics.

In 2010 we also established and sampled 10 plots in the Limestone Upland ecological site. In 2011 we resampled the nested quadrat vegetation and measured basal gaps in these 10 plots.

In this report, we document monitoring activities during the 2011 field season and report these data. For the Limestone Upland ecological site, we examine the 2011 data in the context of the data collected in 2010. For the mixed conifer ecological site, we summarize the data collected between 2007 and 2011 as the baseline conditions for the ecological site.

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 component ecological sites: Loamy Hills and 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, at 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)

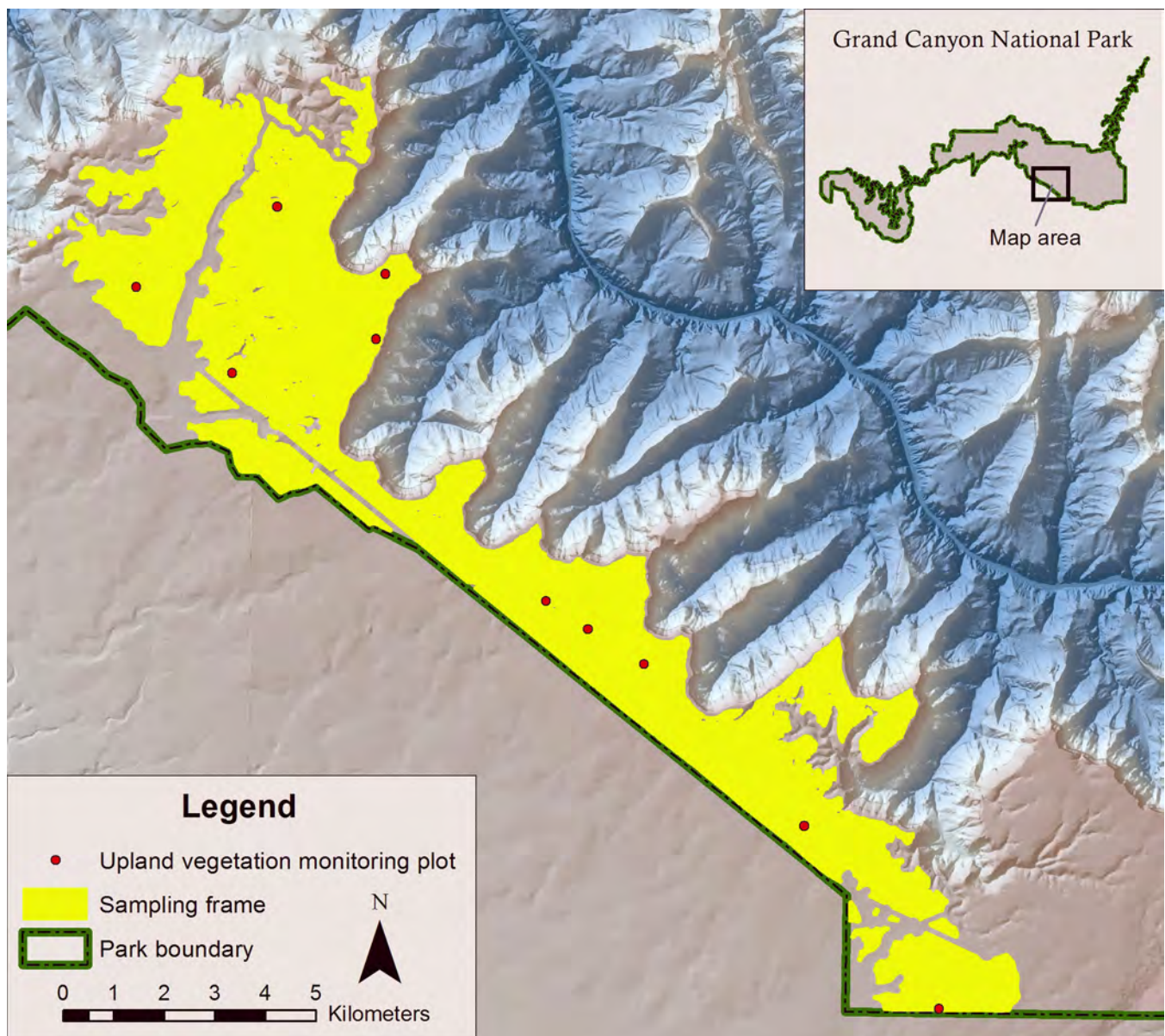


Figure 1. Sampling frame of the Limestone Upland ecological site at GRCA with the 10 plots established in 2010 and resampled in 2011.

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 deviated substantially from the ecological site. In the mixed conifer ecological site, we rejected a total of 22 points for the following reasons: the sites had been moderately or severely burned, they had slopes exceeding 30%, they deviated substantially from the ecological site, they were in proximity to an archeological site, they were in proximity to a trail, they were inaccessible (>2 hours hiking time), or they were less than 200 m from an established plot.

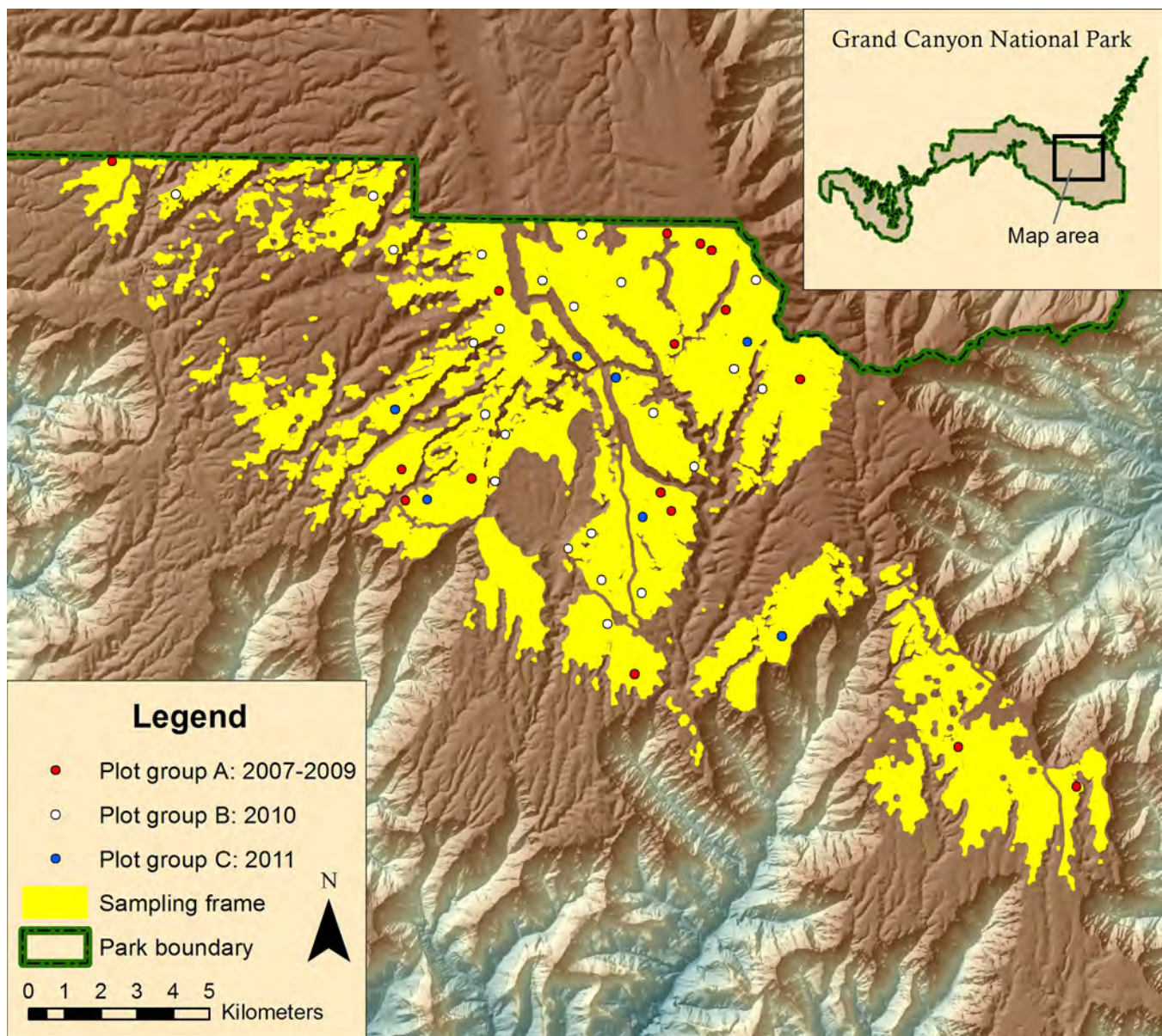


Figure 2. Sampling frame of the mixed conifer ecological site at GRCA with the 16 plots sampled in 2007–2009, the 23 plots sampled in 2010, and the 7 plot sampled in 2011.

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. In the mixed conifer ecological site, the crew established 16 monitoring plots in 2007, and resampled these 16 plots in 2008 and 2009, but not in 2010 or 2011. New mixed conifer plots were established in 2010 (23 plots) and 2011 (7 plots), and were only sampled once.

We conducted our work for the Limestone Upland ecological site in the first half of September, with the exception of one plot in 2010 that was sampled in late October. In all years we conducted our field work for the mixed conifer ecological site in late June through late July.

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. We collected canopy closure one time for all plots

in both sites. In the Limestone Upland ecological site, we also collected canopy cover in 2010. We collected soil stability and basal gap data along the transects at the Limestone Upland ecological site. These data were not collected for the mixed conifer ecological site, where high levels of litter and duff make soil erosion less of a threat.

During plot establishment in 2007, 2010 and 2011 for mixed conifer, and 2010 in Limestone Upland, we collected the full suite of data at each site. For plot revisits (2008 and 2009 in the mixed conifer ecological site and 2011 in the Limestone Upland ecological site), we collected a subset of the data: species cover and frequency, functional group cover, and soil surface features for both ecological sites and basal gaps for the Limestone Upland ecological site. Field methodology is provided in detail in the SCPN integrated upland monitoring protocol (DeCoster et al. 2012).

2.2.1 Shrub and herbaceous vegetation

We sampled shrub and herbaceous vegetation within 5 sets of nested quadrats at 10 m intervals along each transect. The largest quadrat size was 10 m² (2 × 5 m), with 4 smaller quadrats nested inside (0.01 m², 0.1 m², 1 m², 5 m²). We recorded the presence of each herbaceous and shrub species within each nested sub-quadrat. We estimated the percent cover of each species in the 10 m² quadrat and assigned it to 1 of 12 cover classes (e.g., 2%–5%, 5%–10%, etc.). We also estimated the percent cover for functional groups (e.g., perennial grasses, forbs, shrubs) in the 10 m² quadrats and recorded the cover class.

2.2.2 Overstory trees, saplings, and seedlings

In the mixed conifer ecological site, we measured living overstory tree and snag diameter at breast height (DBH) in a 20 × 50 m (0.1 ha) plot located between 2 of the transects in the first year of sampling only. Within this overstory tree plot, we tallied saplings by size class and species in a smaller, 10 × 25 m plot (0.025 ha). We tallied seedlings by size class and species in the fifteen 10 m² quadrats along the 3 transects.

We collected tree data for the Limestone ecological site in 2010, but did not remeasure the overstory trees and saplings in these plots in 2011. Tree seedlings were measured as described above.

We measured canopy using 2 methods. For the Limestone Upland ecological site, we measured tree canopy cover using the line intercept method along transects when the plots were first established in 2010. For the mixed conifer ecological site, we measured canopy closure using a spherical densiometer at 5 points along each transect, once for each plot in 2008 only. We also used the canopy closure method for the Limestone Upland ecological site in 2011.

2.2.3 Soil stability and hydrologic function

In both the Limestone Upland ecological site and 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.

In the Limestone Upland ecological site, we also measured basal gaps as the length of bare ground between plant bases along each transect. We collected soil aggregate stability data for these plots in 2010, but we did not repeat these measurements in 2011.

2.3 Data summary

For the Limestone Upland ecological site, we compared all data collected in the 10 plots in 2011 with the data collected in 2010.

For the mixed conifer ecological site, we summarized data for all 30 plots as the ecological site mean. These data represent the baseline conditions for vegetation composition and structure in the mixed conifer ecological site. We also compare the 3 plot groups to one another. It must be stressed that the differences between these 3 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 3 groups of plots as plot group A for the 16 plots established in 2007, plot group B for the 23 plots established in 2010, and plot group C for the 7 plots established in 2011.

The sample unit for summary and analysis is the plot; hence, we summarized data at the level of the plot. For the Limestone Upland ecological site, for each year we calculated the mean and standard deviation for most metrics from the means of the 10 plots. For the mixed conifer ecological site, we calculated the mean and standard deviation for plot groups and for the ecological site from the plot means. For plot group A, where there were 3 years of data, we calculated the mean value and 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. For plot group B and plot group C, we calculated the mean and standard deviation based on a single year of data. The ecological site means were calculated from all 46 plots, where the values for each of the 16 plots from plot group A are averaged across all 3 years.

For both ecological sites, 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 section 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 calculated for each year, plot group, or at the ecological site level, as appropriate. Mean cover and standard deviation of functional groups and surface features were calculated in a similar fashion. Species frequency was calculated for quadrats (mean percentage of 10 m² quadrats per plot where the species occurs) and for plots (percentage of plots where the species occurs). For the mixed conifer ecological site, plot frequency was calculated for each plot group. We calculated plot frequency for all 46 plots at the ecological site using a weighted mean based on the 3-year mean value for the 16 plots in plot group A, and the single year values for the 23 plots in plot group B and the 7 plots group C.

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 the Limestone Upland ecological site, we calculated the mean values for 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 year. Ecological site richness and beta diversity, which are not based on plot means, were calculated for the ecological site.

For the mixed conifer ecological site, the mean values were calculated for plot richness, Shannon diversity, and evenness, for each plot, and then were calculated for each plot group and the ecological site. To calculate 2 metrics for the ecological site, richness and beta diversity, we combined plot values from 1 of the 3 years of available data from plot group A (the year with the median value for Shannon diversity) with data from plot groups B and C.

2.3.3 Trees

In the mixed conifer ecological site, tree basal area (the total area of the tree cross-sections at breast height) 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, 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, and for each plot group (for the mixed conifer ecological site).

Canopy cover and canopy closure values were calculated by first deriving the mean value for each plot, and then the mean and standard deviation were calculated for the year, the plot group, or for the entire ecological site, as appropriate.

2.3.4 Basal gaps

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.

3 Results

3.1 Limestone Upland ecological site

3.1.1 Shrub and herbaceous vegetation

Perennial grasses and shrubs co-dominated the Limestone Upland ecological site. In 2011, the mean total live foliar cover was 9.60%, and the mean foliar covers of perennial grasses and shrubs were 3.81% and 4.41%, respectively (table 1 and fig. 3). The mean covers for these 2 functional groups in 2010 were somewhat smaller. The other live functional groups had less than 1% mean cover. Standing dead herbaceous and standing dead woody had mean covers of 1.13% and 0.85%, respectively. The mean covers of these 2 groups were higher in 2010. The differences were offset by large standard deviations, which indicated large among-plot variation.

Table 1. Foliar cover of functional groups for 2010 and 2011 in the Limestone Upland ecological site at GRCA.

Functional groups	2010 (n = 10)		2011 (n = 10)	
	Mean (%)	SD	Mean (%)	SD
Total live foliar cover	7.02	2.35	9.60	3.49
Perennial grasses	3.23	2.57	3.81	2.45
Annual grasses	0.05	0.13	0.71	2.13
Forbs	0.38	0.26	0.56	0.32
Shrubs	3.31	1.86	4.41	2.15
Cacti/succulents	0.12	0.17	0.21	0.21
Standing dead herbaceous	1.43	1.46	1.13	0.74
Standing dead woody	1.02	0.59	0.85	0.62

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

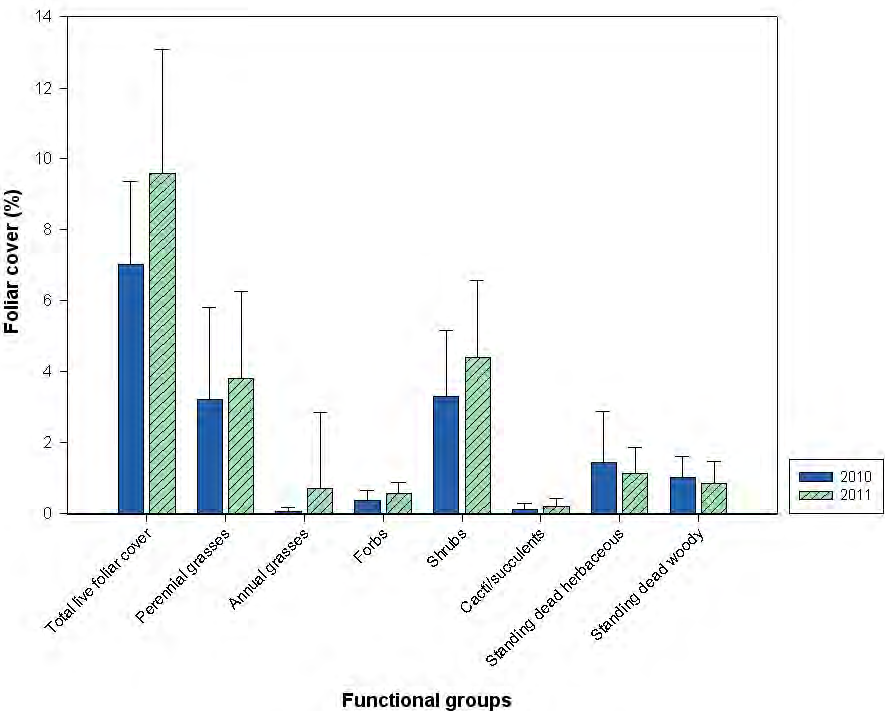


Figure 3. Mean percent foliar cover of functional groups for 2010 and 2011 in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation.

We examine species-level data for the most abundant herbaceous and shrub species from the 2011 sampling year, compared with 2010 results (table 2 and fig. 4). *Bouteloua gracilis* (blue grama) and *Poa fendleriana* (muttongrass) were the dominant perennial grasses. Dominant shrubs included *Purshia stansburiana* (Stansbury cliffrose), *Artemisia tridentata* (basin big sagebrush), *Gutierrezia sarothrae* (broom snakeweed), and *Mahonia fremontii* (Freemont mahonia). Common forbs included *Phlox austromontana*, (mountain phlox) and *Cordylanthus parviflorus* (purple bird's-beak). *Opuntia* spp. (prickly pear) was the most abundant cactus/succulent. Most of the dominant species showed higher foliar cover in 2011 than in 2010. The large standard deviations, however, suggest that such differences are nominal. Most of the species with high mean foliar cover also had high plot frequency. *Mahonia fremontii* was the only species with a mean foliar cover greater than 0.1% that did not occur in 90–100% of the plots—it only occurred in 20% of the plots, but had high foliar cover where it occurred. 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.

We encountered 3 nonnative species in the plots. The annual grass *Bromus tectorum* (cheatgrass) had a mean foliar cover of 0.043% and occurred in 40% of the plots in 2010; it had a mean foliar cover of 0.683% and occurred in 70% of the plots in 2011. *Portulaca oleraceae* (little hogweed) occurred in 30% of the plots in 2010 with a mean foliar cover of 0.001%, and did not occur in any plot in 2011. In contrast, *Ceratocephala testiculata* (curvedseed butterwort) occurred in 50% of the plots in 2011 with a mean foliar cover of 0.027%, but did not occur in any plot in 2010.

Table 2. Mean foliar cover, standard deviation, and mean quadrat and plot frequencies of the 15 most abundant shrub and herbaceous species for 2011 compared with the same species for 2010 in the Limestone Upland ecological site at GRCA. All nonnative species are included for each year.

Species	2010 (n = 10)				2011 (n = 10)			
	Foliar cover (%)	SD	Quadrat freq. (%)	Plot freq. (%)	Foliar cover (%)	SD	Quadrat freq. (%)	Plot freq. (%)
<i>Purshia stansburiana</i>	1.661	1.184	38.67	100.00	2.301	1.804	36.67	100.00
<i>Bouteloua gracilis</i>	2.126	2.628	64.00	90.00	2.147	2.360	66.00	90.00
<i>Poa fendleriana</i>	0.813	0.520	92.00	100.00	1.814	0.622	97.33	100.00
<i>Artemisia tridentata</i>	0.999	0.915	49.33	100.00	1.405	1.017	50.67	100.00
<i>Bromus tectorum</i> ^a	0.043	0.131	7.33	40.00	0.683	2.140	20.67	70.00
<i>Gutierrezia sarothrae</i>	0.179	0.161	43.33	100.00	0.283	0.340	45.33	100.00
<i>Opuntia</i> spp.	0.115	0.168	22.67	100.00	0.189	0.211	26.00	100.00
<i>Mahonia fremontii</i>	0.179	0.377	2.67	20.00	0.153	0.333	2.67	20.00
<i>Ephedra viridis</i>	0.066	0.161	4.00	30.00	0.091	0.229	5.33	40.00
<i>Draba cunefolia</i>	0.002	0.004	3.33	20.00	0.086	0.068	71.33	100.00
<i>Phlox austromontana</i>	0.068	0.149	5.33	20.00	0.079	0.171	5.33	20.00
<i>Eriogonum racemosum</i>	0.043	0.120	12.00	30.00	0.060	0.185	12.67	30.00
<i>Gilia</i> spp.	0.007	0.015	11.33	30.00	0.055	0.038	60.67	100.00
<i>Elymus elymoides</i>	0.028	0.047	16.00	70.00	0.052	0.055	26.00	80.00
<i>Quercus gambelii</i>	0.010	0.032	0.67	10.00	0.050	0.158	0.67	10.00
<i>Ceratocephala testiculata</i> ^a	0	0	0	0	0.027	0.073	8.67	50.00
<i>Portulaca oleraceae</i> ^a	0.001	0.002	2.67	30.00	0	0	0	0

Note: Species are arranged in descending order by their mean foliar cover for 2011.

^aNonnative species.

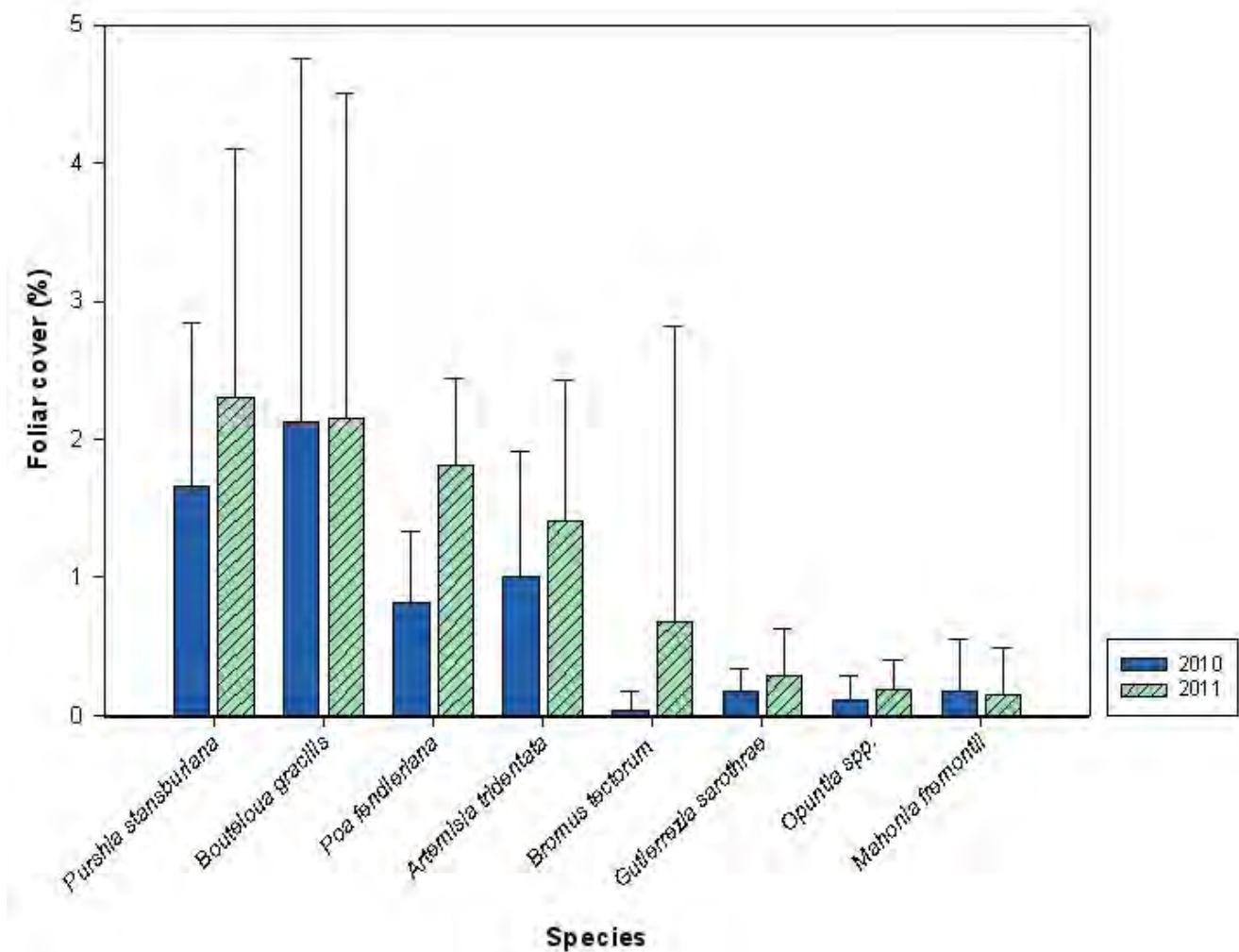


Figure 4. Mean percent foliar cover of the 8 most abundant shrub and herbaceous species for 2011, compared with cover of the same species for 2010 in the Limestone Upland ecological site at GRCA. Error bars represent one standard deviation.

Species diversity in this ecological site was moderately low on the scale of the plot, and moderate on the scale of the ecological site. At both scales, species richness was higher in 2011 than in 2010. On the scale of the plot, richness was 21.7 species in 2010 and 29.6 in 2011 (table 3). Shannon diversity (which takes the relative abundance of each species into account, and generally ranges between 1.5 and 3.5) was 1.596 in 2010 and 1.775 in 2011. Evenness (the degree to which all species are of equal abundance, ranging from 0 to 1) was similar for the 2 years: 0.525 in 2010 and 0.524 in 2011. On the scale of the ecological site, species richness was 70 in 2010 and 80 in 2011. Beta diversity (a measure of within-ecological site heterogeneity, generally ranging between 1 and 5) was lower in 2011 than 2010, at 2.797 and 3.382, respectively. When we calculated the metrics using only native species, evenness and beta diversity increased slightly and the other metrics decreased slightly.

3.1.2 Trees

Trees were originally sampled in 2010 and not remeasured in 2011, with the exception of seedlings and canopy closure. In the seedling layer, 2 tree species occurred in the plots: *Juniperus osteosperma* (Utah juniper) and *Pinus edulis* (twoneedle pinyon). Seedling density for *Juniperus osteosperma* was 313.3 stems/ha in 2010 and 213.3 stems/ha in 2011. Seedling density for *Pinus edulis* was 1653.3 in 2010 and 1713.3 in 2011. The size class distribution of the seedlings showed lower densities with the larger size classes for each species, particularly for the largest size class of *Pinus edulis* (fig. 5). The standard deviations were moderately large, indicating large among plot variation.

Table 3. Species diversity metrics for all species, and for native species only, for 2010 and 2011 in the Limestone Upland ecological site at GRCA.

	2010 (n = 10)		2011 (n = 10)	
	Mean	SD	Mean	SD
All species				
Plot				
Plot richness	21.7	6.3	29.6	5.9
Shannon diversity	1.596	0.415	1.775	0.291
Evenness	0.525	0.121	0.524	0.067
Ecological site				
Ecological site richness ^a	70		80	
Beta diversity ^a	3.382		2.797	
Native species				
Plot				
Plot richness	21.0	6.0	28.4	5.7
Shannon diversity	1.585	0.405	1.762	0.293
Evenness	0.526	0.117	0.527	0.066
Ecological site				
Ecological site richness ^a	68		78	
Beta diversity ^a	3.400		2.847	

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

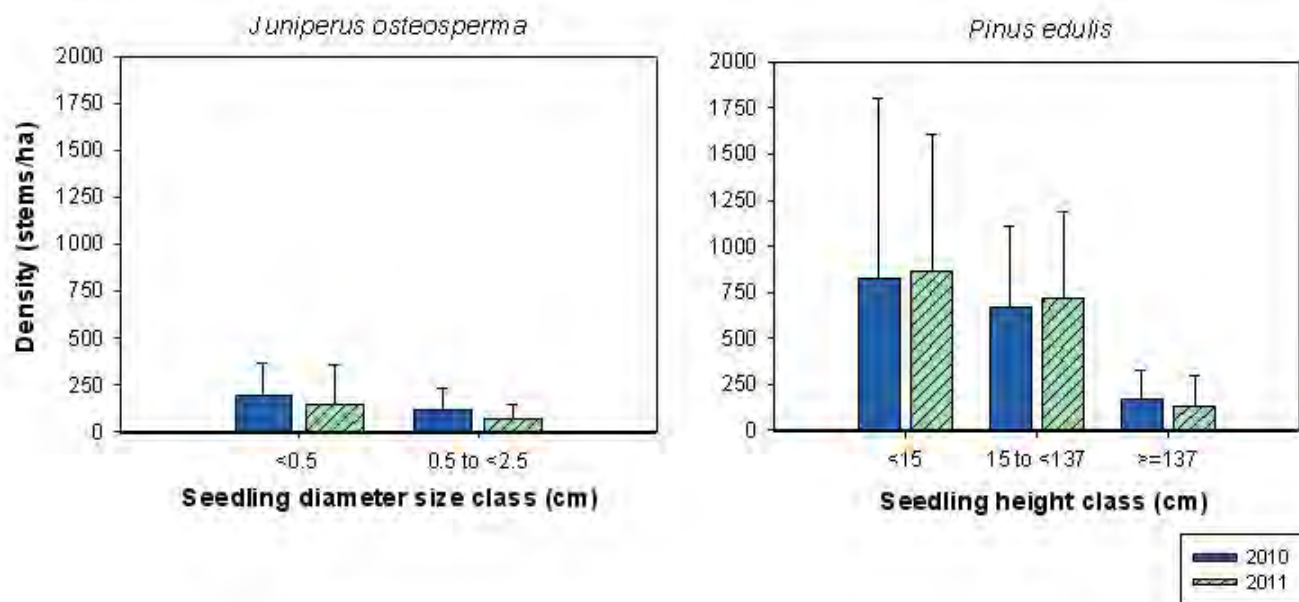


Figure 5. Mean density of tree seedlings in different size classes, by species, in 2010 and 2011 in the Limestone Upland ecological site in GRCA. Error bars represent 1 standard deviation. The seedling category includes all trees <2.5 cm diameter. *Juniperus osteosperma* stems are measured at root crown (DRC); *Pinus edulis* stems are measured at breast height (DBH).

Canopy cover measurements between the 2 years were similar, despite the use of different methods. In 2010 we measured canopy cover using line intercept methods, and in 2011 we used canopy closure using a spherical densiometer. Canopy closure refers to the proportion of the hemisphere of sky obscured by vegetation when viewed from a single point; canopy cover measures the proportion of the forest floor covered by the vertical projection of tree crowns (Jennings et al. 1999). Canopy cover measured in 2010 was 37.8%, and canopy closure measured in 2011 was 38.3% (fig. 6).

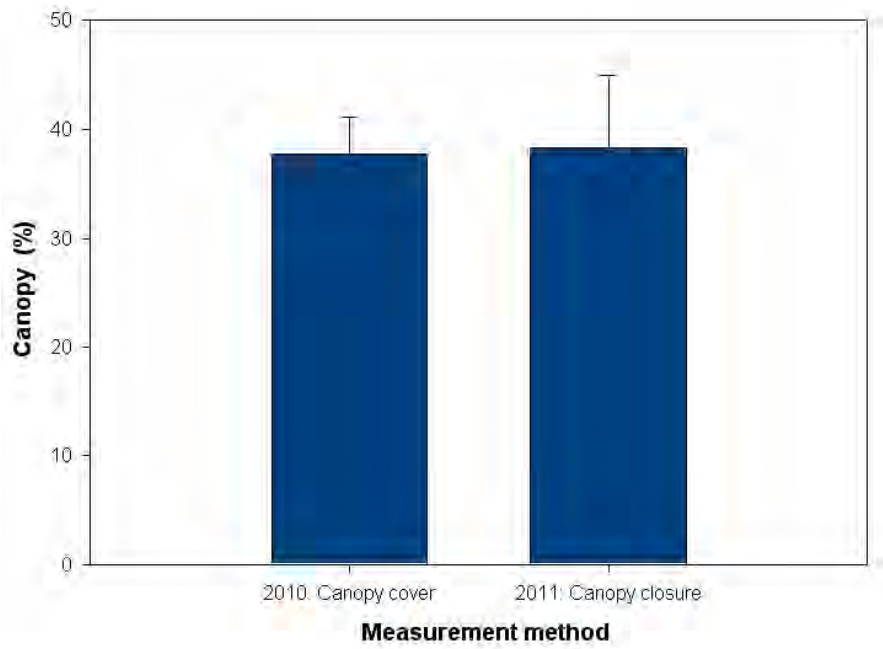


Figure 6. Mean percent canopy cover measured in 2010 and mean percent canopy closure measured in 2011 in the Limestone Upland ecological site. Error bars indicate 1 standard deviation.

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. Duff/litter was the soil surface feature with the greatest mean cover: 46.30% in 2010 and 48.45% in 2011 (fig. 7 and table 4). Other important features included fine gravel, undifferentiated crust, bare soil and coarse gravel, all having between 4% and 15% mean cover. There was moderate variation in the cover of many of the features between the 2 years.

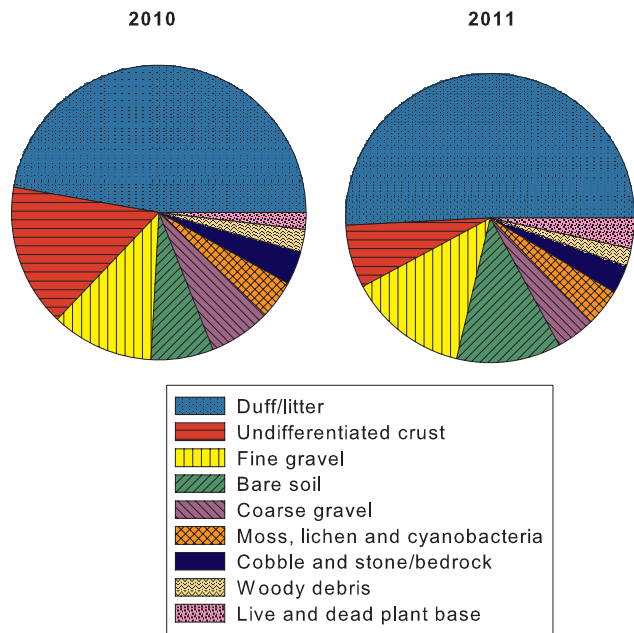


Figure 7. Mean percent cover of soil surface features for 2010 and 2011 in the Limestone Upland ecological site at GRCA.

Table 4. Cover of soil surface features for 2010 and 2011 in the Limestone Upland ecological site at GRCA.

Soil surface feature	2010 (n = 10)		2011 (n = 10)	
	Mean (%)	SD	Mean (%)	SD
Live plant base	0.93	0.44	2.06	0.83
Dead woody base	0.20	0.19	0.24	0.33
Dead herbaceous base	0.64	0.57	0.93	0.66
Bare soil	6.71	4.39	11.13	6.74
Duff/litter	46.30	11.23	48.45	11.28
Undifferentiated crust	15.36	11.17	6.74	4.93
Moss	0.62	0.52	2.24	1.97
Lichen	0.08	0.16	0.61	1.83
Cyanobacteria ^a	3.42	4.72	1.10	1.66
Fine gravel (0.2 to <2 cm)	11.02	12.66	12.79	14.46
Coarse gravel (2 to <7.5 cm)	6.69	6.90	4.15	5.68
Cobble (7.5 to <25 cm)	2.16	2.92	2.12	2.94
Stone, bedrock (≥25 cm)	1.14	2.54	0.93	2.27
Woody debris	2.43	1.47	1.90	1.44

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

^aIn 2010 we used a different method for classifying cyanobacteria.

The basal gap data showed large distances between the plant bases. The majority of the transects were comprised of gaps of 100 cm or greater, 81.1% in 2010 and 84.2% in 2011 (fig. 8 and table 5). Gaps less than 20 cm comprised only 2.0% and 1.2% of the transects in 2010 and 2011, respectively. The median gap size was 84.2 cm in 2010 and 81.4 cm in 2011.

Figure 8. Mean percentage of transect by gap size class for 2010 and 2011 in the Limestone Upland ecological site at GRCA. Error bars represent 1 standard deviation.

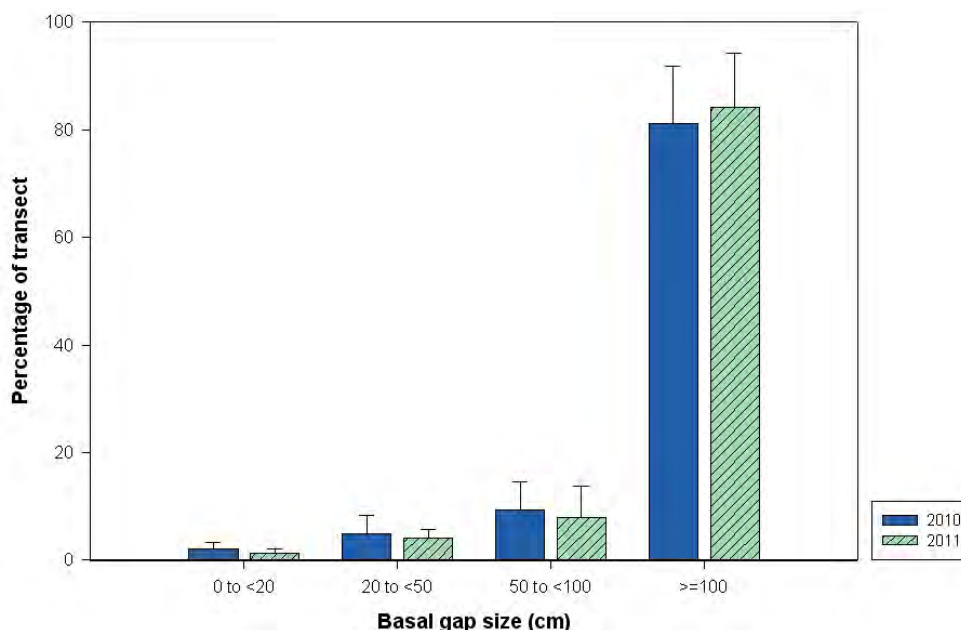


Table 5. Number of basal gaps, median gap size and percentage of transect in different gap size classes for 2010 and 2011 in the Limestone Upland ecological site at GRCA.

Metric	2010 (n = 10)		2011 (n = 10)	
	Mean	SD	Mean	SD
Number of gaps	106.9	51.5	84.0	36.5
Median gap size (cm)	84.2	90.6	81.4	35.1
Percentage of transect in gaps	97.2	1.6	97.4	1.4
Percentage of transect in gaps 0 to <20 cm	2.0	1.3	1.2	0.8
Percentage of transect in gaps 20 to <50 cm	4.8	3.5	4.1	2.6
Percentage of transect in gaps 50 to <100 cm	9.3	5.2	7.9	5.9
Percentage of transect in gaps ≥100 cm	81.1	10.7	84.2	10.1
Percentage of transect in plant bases	2.8	1.6	2.6	1.4

3.2 Mixed conifer ecological site

We describe results generally for the ecological site mean, based on all plots, but specify whenever data comes from only one of the plot groups.

3.2.1 Shrub and herbaceous vegetation

Overall the shrub and herbaceous vegetation of the mixed conifer ecological site was sparse, with a mean foliar cover of 6.47% (table 6 and fig. 9). The functional groups with the greatest mean covers were shrubs (2.21%), forbs (1.74%) and perennial grasses/graminoids (1.25%). There were no annual grasses or cacti/succulents. Standing dead herbaceous and standing dead woody covers were 0.68% and 0.20%, respectively. (Standing dead woody only included shrubs; it did not include trees.) There was some variation in the mean cover of functional groups among the plots groups, but these differences were offset by the moderately large standard deviations which indicate large among-plot variation.

We present species-level data for the most abundant herbaceous and shrub species in the ecological site in Table 7 (foliar cover and frequency) and Figure 10 (foliar cover). The dominant shrubs were *Juniperus communis* (common juniper), *Robinia neomexicana* (New Mexico locust) and *Mahonia repens* (creeping barberry). The most abundant forbs (including ferns) were *Pteridium aquilinum* (western bracken fern), *Fragaria virginiana*, (Virginia strawberry), *Pedicularis centrathera* (dwarf lousewort), and *Pseudostellaria jamesiana* (tuber starwort). The most abundant perennial grasses and graminoids were *Carex siccata* (dry-spike sedge), *Carex rossii* (Ross' sedge), *Poa fendleriana* (mutton grass), and *Bromus ciliatus* (fringed brome). The species with the highest frequency was *Carex rossii*, which occurred in all of the plots, and 68.94% of the quadrats. Most of the dominant species had plot frequencies greater than 50%. *Robinia neomexicana*, *Pteridium aquilinum*, and *Pseudostellaria jamesiana* had low frequencies, indicating patchy distributions but had relatively high foliar cover where they occurred. There was moderate variation in the mean foliar covers for many species among the plot groups, and the standard deviations indicate high among-plot variability. However, there was lower variation in the quadrat and plot frequencies among the plot groups. Appendix B lists all species, along with their common names, families, mean foliar covers and plot frequencies.

Only one nonnative species was found in the plots. *Taraxacum officinale* (common dandelion) occurred in 11.59% of the plots, with a mean foliar cover of 0.007%. It was most abundant in plot group C.

Species diversity in this ecological site was moderately low on the scale of the plot, and high on the scale of the ecological site (table 8). On the scale of the plot, species richness was 22.4 species. Shannon diversity (which takes relative species abundance into account, and generally ranges between 1.5 and 3.5) was 1.736. Evenness (the degree to which all species are of equal abundance, ranging from 0 to 1) was 0.560. On the scale of the ecological

Table 6. Foliar cover of functional groups for plot group A, plot group B, plot group C, and all plots (ecological site mean) in the mixed conifer ecological site at GRCA.

Functional groups	Plot group A 2007–2009 (n = 16)		Plot group B 2010 (n = 23)		Plot group C 2011 (n = 7)		Ecological site (n = 46)	
	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Total live foliar cover	8.30	4.56	5.27	3.91	6.23	3.80	6.47	3.85
Perennial grasses/graminoids	1.73	1.45	0.99	1.62	1.03	0.85	1.25	1.42
Annual grasses	0	0	0	0	0	0	0	0
Forbs	1.58	1.55	1.55	1.95	2.72	2.78	1.74	1.94
Shrubs	1.60	2.12	2.70	3.35	2.00	1.90	2.21	2.76
Cacti/succulents	0	0	0	0	0	0	0	0
Standing dead herbaceous	0.80	0.85	0.59	1.73	0.73	1.15	0.68	1.33
Standing dead woody	0.21	0.14	0.22	0.32	0.07	0.11	0.20	0.24

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.

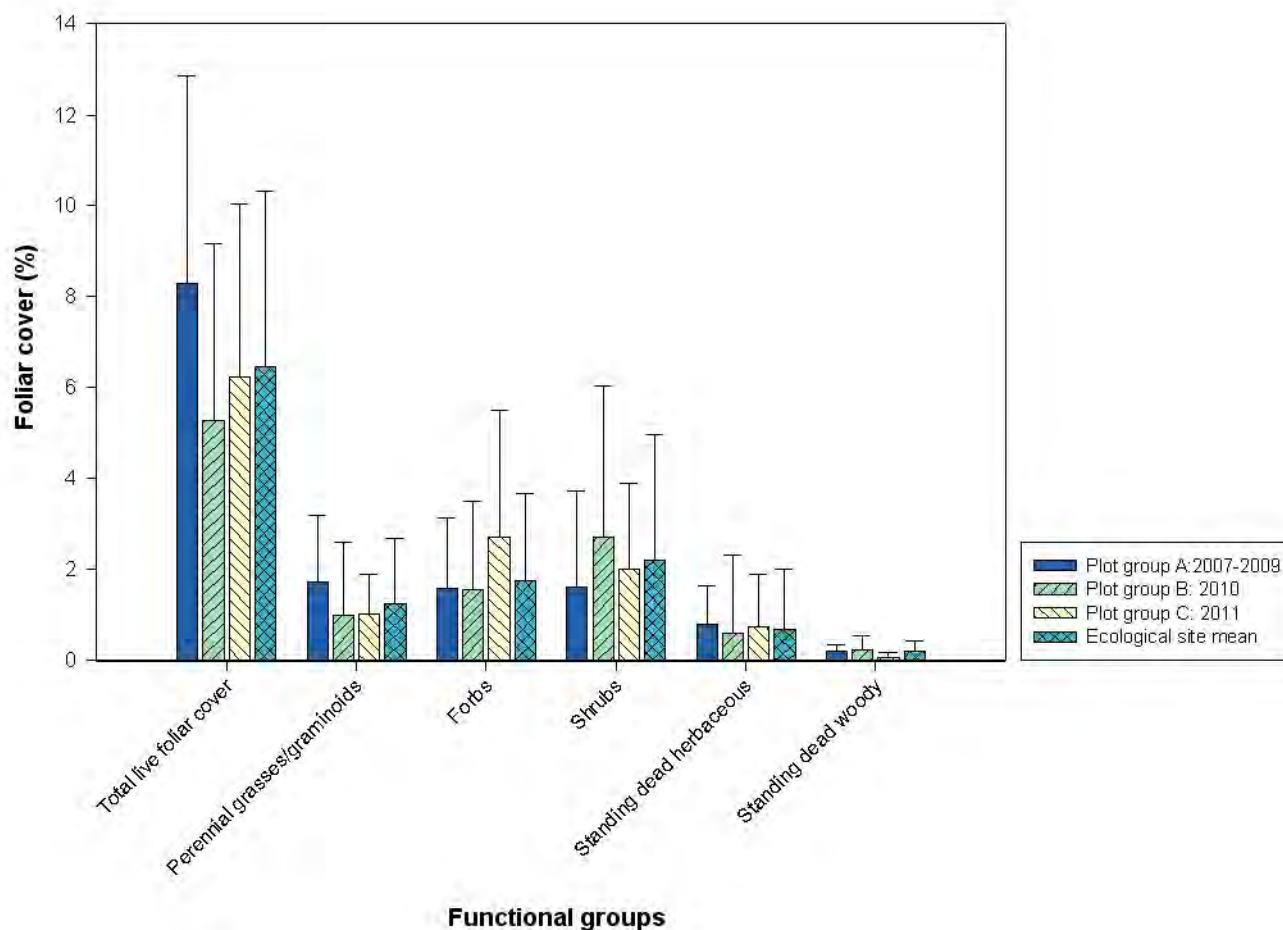


Figure 9. Mean percent foliar cover by functional group for plot group A, plot group B, plot group C, and all plots (ecological site mean) in the mixed conifer ecological site at GRCA. Error bars represent one standard deviation.

Table 7. Mean foliar cover and standard deviation, and mean quadrat and plot frequencies of the 15 most abundant shrub and herbaceous species and all nonnative species for all plots (ecological site mean), compared with the values for the same species for plot group A, plot group B and plot group C in the mixed conifer ecological site at GRCA.

Species	Plot group A 2007–2009 (n = 16)				Plot group B 2010 (n = 23)				Plot group C 2011 (n = 7)				Ecological site mean (n = 46)			
	Foliar cover (%)	SD	Quadr. freq. (%)	Plot freq. (%)	Foliar cover (%)	SD	Quadr. freq. (%)	Plot freq. (%)	Foliar cover (%)	SD	Quadr. freq. (%)	Plot freq. (%)	Foliar cover (%)	SD	Quadr. freq. (%)	Plot freq. (%)
<i>Juniperus communis</i>	0.883	1.271	19.58	66.67	1.992	2.498	24.64	65.22	1.597	1.637	20.95	57.14	1.546	2.038	22.32	64.49
<i>Carex siccata</i>	0.693	0.806	42.78	83.33	0.518	1.539	41.16	91.30	0.563	0.476	41.90	100.00	0.586	1.172	41.84	89.86
<i>Pteridium aquilinum</i>	0.189	0.386	8.33	35.42	0.655	2.036	11.88	30.43	0.652	1.643	16.19	28.57	0.492	1.574	11.30	31.88
<i>Robinia neomexicana</i>	0.537	1.607	7.64	12.50	0.507	1.613	5.22	13.04	0.322	0.852	2.86	14.29	0.490	1.494	5.70	13.04
<i>Carex rossii</i>	0.513	0.487	70.69	100.00	0.283	0.309	69.57	100.00	0.245	0.188	62.86	100.00	0.357	0.351	68.94	100.00
<i>Fragaria virginiana</i>	0.305	0.831	23.75	100.00	0.067	0.081	20.87	86.96	0.232	0.382	22.86	85.71	0.175	0.512	22.17	91.30
<i>Pedicularis centranthera</i>	0.123	0.112	38.33	89.58	0.131	0.170	33.33	82.61	0.080	0.105	22.86	57.14	0.120	0.140	33.48	81.16
<i>Poa fendleriana</i>	0.165	0.200	36.53	93.75	0.076	0.129	20.87	91.30	0.104	0.085	34.29	85.71	0.111	0.145	28.36	91.30
<i>Mahonia repens</i>	0.089	0.120	17.22	68.75	0.105	0.188	21.45	69.57	0.164	0.191	28.57	85.71	0.108	0.164	21.06	71.74
<i>Pseudostellaria jamesiana</i>	0.042	0.069	21.11	39.58	0.130	0.275	26.09	30.43	0.137	0.287	23.81	42.86	0.101	0.226	24.01	35.51
<i>Bromus ciliatus</i>	0.141	0.272	33.61	100.00	0.038	0.043	30.14	91.30	0.049	0.043	36.19	100.00	0.076	0.166	32.27	95.65
<i>Erigeron speciosus</i>	0.031	0.105	5.28	20.83	0.126	0.309	23.77	82.61	0.001	0.002	1.90	28.57	0.074	0.228	14.01	52.90
<i>Chenopodium fremontii</i>	0	0	0	0	<0.001	0.001	0.58	8.70	0.467	1.236	5.71	14.29	0.071	0.482	1.16	6.52
<i>Erigeron formosissimus</i>	0.078	0.125	15.83	45.83	0.006	0.020	2.90	13.04	0.248	0.401	25.71	85.71	0.068	0.181	10.87	35.51
<i>Oreochrysum parryi</i>	0.031	0.060	7.92	41.67	0.096	0.315	11.88	34.78	0.021	0.024	8.57	57.14	0.062	0.226	10.00	40.58
<i>Taraxacum officinale</i> ^a	0.003	0.010	1.53	14.58	<0.001	0.001	0.58	8.70	0.036	0.096	1.90	14.29	0.007	0.038	1.11	11.59

Note: Species are arranged in descending order by their mean foliar cover for the ecological site.

^aNonnative species.

Figure 10. Mean foliar cover of the 8 most abundant shrub and herbaceous species for all plots (ecological site mean) compared with the mean foliar cover of the same species for plot group A, plot group B, and plot group C in the mixed conifer ecological site at GRCA. Error bars represent one standard deviation.

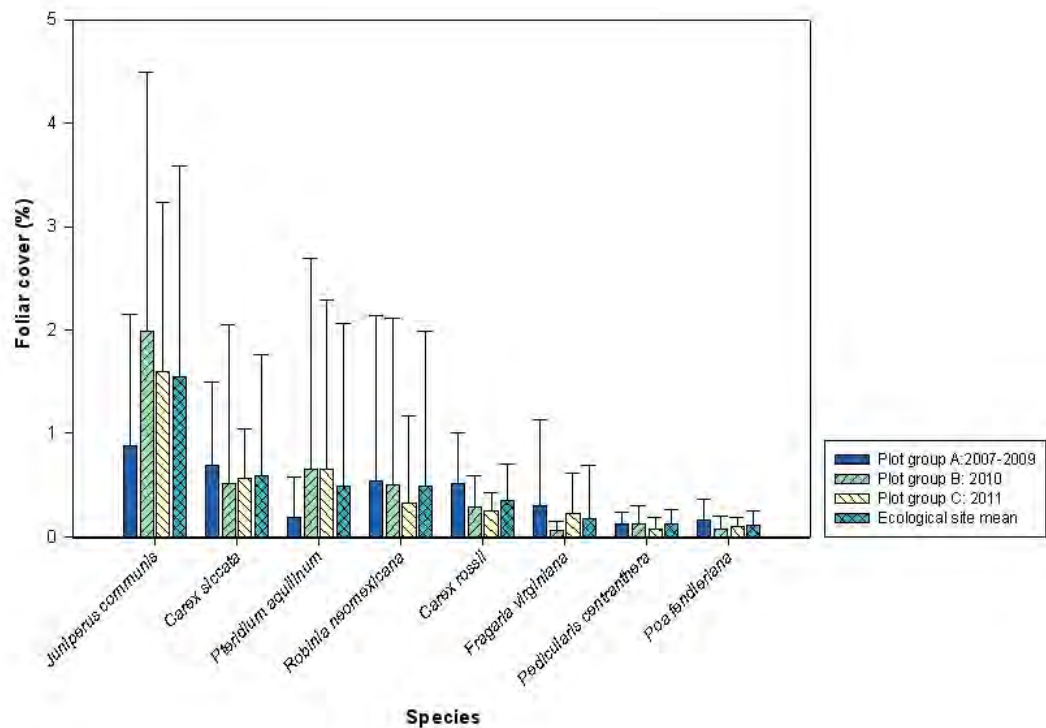


Table 8. Species diversity metrics for all species and for native species only for plot group A, plot group B, plot group C, and all plots (ecological site mean) in the mixed conifer ecological site at GRCA.

	Plot group A 2007–2009 (n = 16)		Plot group B 2010 (n = 23)		Plot group C 2011 (n = 7)		Ecological site (n = 46)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
All species								
Plot								
Plot richness	23.0	5.8	22.3	6.3	21.7	7.5	22.4	6.2
Shannon diversity	1.908	0.441	1.579	0.576	1.859	0.457	1.736	0.519
Evenness	0.611	0.123	0.510	0.166	0.609	0.118	0.560	0.148
Ecological site								
Ecological site richness ^a	86.0		84		66		111	
Beta diversity ^a	3.910		3.951		3.186		5.121	
Native species								
Plot								
Plot richness	22.9	5.7	22.2	6.2	21.6	7.2	22.3	6.1
Shannon diversity	1.905	0.439	1.579	0.576	1.852	0.445	1.734	0.517
Evenness	0.611	0.123	0.510	0.166	0.608	0.117	0.560	0.148
Ecological site								
Ecological site richness ^a	85.0		83		65		110	
Beta diversity ^a	3.890		3.920		3.160		5.106	

^aEcological site richness and beta diversity values are not means, except for the plot group A values which were derived from averaging across all 3 years.

site, species richness was 111, and beta diversity (a measure of within-ecological site heterogeneity, generally ranging between 1 and 5) was 5.121. The diversity metrics among plot groups were similar, but plot group C had lower values for the ecological site level metrics. This was probably a result of a smaller sample size—7 plots compared to 16 in plot group A and 23 in plot group B. When we calculated the metrics using only native species, all the metrics decreased slightly with the exception of evenness, which increased slightly.

3.2.2 Trees

We report tree density (stems/ha) by species for seedlings, saplings and overstory trees. We also report basal area for overstory trees by species, grouped as living trees or snags (dead trees) (table 9).

Table 9. Mean density, mean basal area and mean diameter of trees for plot group A, plot group B, plot group C, and all plots (ecological site mean) 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
	C: 2011	2790.5	666.7	161.9	95.2	66.7	5485.7	200.0	9466.7
	All plots	2529.0	850.7	402.9	88.4	1342.0	4365.2	146.4	9724.6
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
	C: 2011	525.7	40.0	97.1	34.3	11.4	125.7	51.4	885.7
	All plots	296.5	64.3	182.6	38.3	26.1	193.0	47.8	848.7
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
	C: 2011	94.3	30.0	54.3	17.1	27.1	91.4	21.4	335.7
	All plots	72.8	18.5	57.0	12.0	46.5	52.6	32.6	392.0
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
	C: 2011	31.4	1.4	18.6	1.4	2.9	34.3	5.7	95.7
	All plots	42.0	12.0	10.9	1.7	8.3	45.0	9.8	129.6
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
	C: 2011	7.74	1.61	4.03	3.14	6.94	6.63	2.68	32.77
	All plots	6.06	0.94	4.40	1.52	9.24	3.65	2.69	28.49
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
	C: 2011	3.48	0.07	1.19	0.60	0.64	2.13	1.54	9.65
	All plots	6.06	0.64	0.82	0.20	1.19	2.39	1.46	12.77
Mean overstory diameter (cm) ^c	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
	C: 2011	28.0	24.7	28.4	30.7	56.3	31.3	42.8	32.3
	All plots	29.7	23.4	29.1	31.5	49.4	29.6	32.1	32.5

^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.

We found a total of 7 tree species in the plots of the mixed conifer ecological site. *Pinus ponderosa* (ponderosa pine, PIPO) had the greatest mean basal area, with 9.24 m²/ha., followed by *Abies concolor* (white fir, ABCO), *Picea engelmannii* (Engelmann spruce, PIEN) and *Populus tremuloides* (quaking aspen, POTR) (fig. 11). *Abies concolor* was the species with the greatest mean snag basal area, with 6.06 m²/ha, followed by *Populus tremuloides*. In terms of living overstory density, *Abies concolor* had the greatest mean density with 72.8 stems/ ha, followed by *Picea engelmannii* and *Populus tremuloides*. The size class distributions for the individual species demonstrate that while most species showed an inverse relationship between density and size class, *Pinus ponderosa* and *Picea pungens* (Colorado blue spruce, PIPU) had fairly even distributions, and *Populus tremuloides* only had individuals in the smaller size classes—the highest density being in the 25–35 cm size class (fig. 12). *Populus tremuloides* had the highest mean snag density, followed by *Abies concolor*. *Pseudotsuga menziesii* (Douglas fir, PSME) had intermediate values for basal area and density. *Abies lasiocarpa* (subalpine fir, ABLA) and *Picea pungens* were minor components of the overstory, with low values for both basal area and density. There were small differences in overstory basal area and density among the plot groups. The high standard deviations for basal area and density of both living trees and snags indicate large among-plot variation.

Sapling and seedling densities provide measures of forest regeneration, and indicate the potential for change in species composition. The sapling layer was dominated by *Abies concolor*, *Picea engelmannii* and *Populus tremuloides* (fig. 13). Most species showed fairly even size class distributions, however *Populus tremuloides* had an inverse distribution, with the highest mean density in the smallest size class.

Populus tremuloides had the highest mean seedling density, followed by *Abies concolor* and *Pinus ponderosa* (fig. 14). Most species had the highest densities in the intermediate size class (15 to <137 cm). The exception was *Pinus ponderosa*, which had the highest density in the smallest size class (<15 cm). Differences among plot groups in species densities for saplings and seedlings were generally small and the standard deviations were moderately large, indicating large among-plot differences.

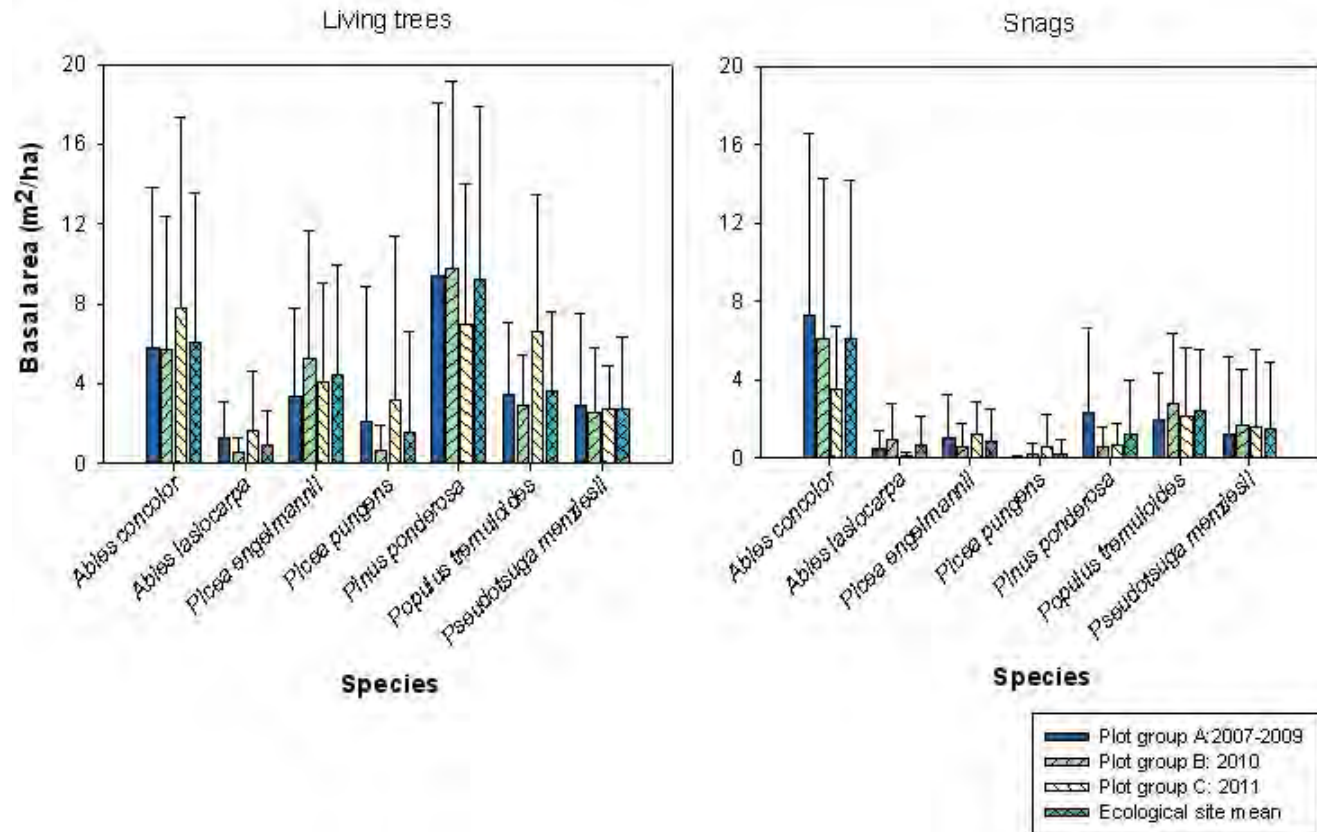


Figure 11. Mean basal area for living overstory trees and snags, by species, for plot group A, plot group B, plot group C, and all plots (ecological site mean) in the mixed conifer ecological site at GRCA. Error bars represent 1 standard deviation.

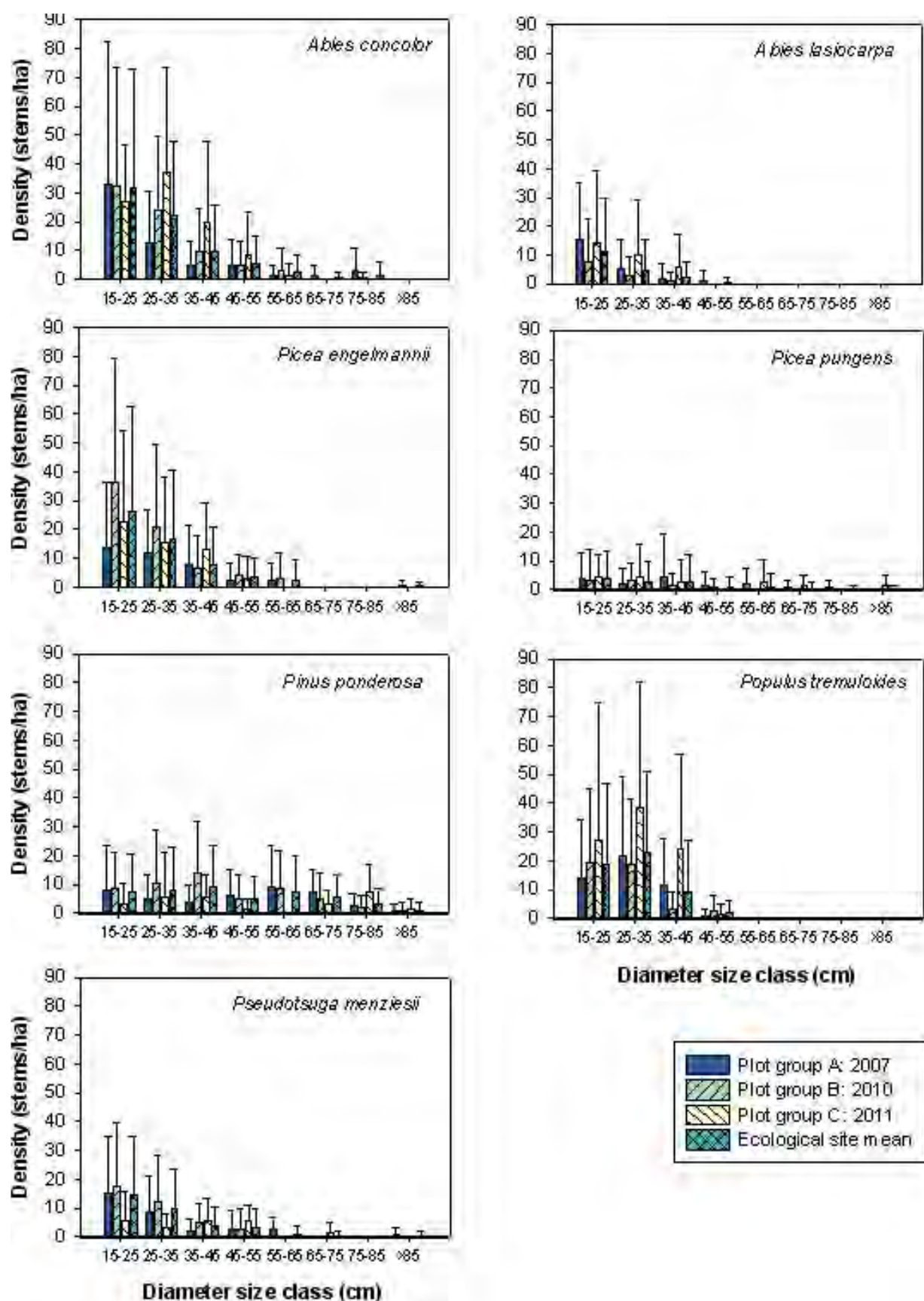


Figure 12. Size structure of living overstory tree species for plot group A, plot group B, plot group C, and all plots (ecological site mean) in the mixed conifer ecological site at GRCA. Error bars represent 1 standard deviation.

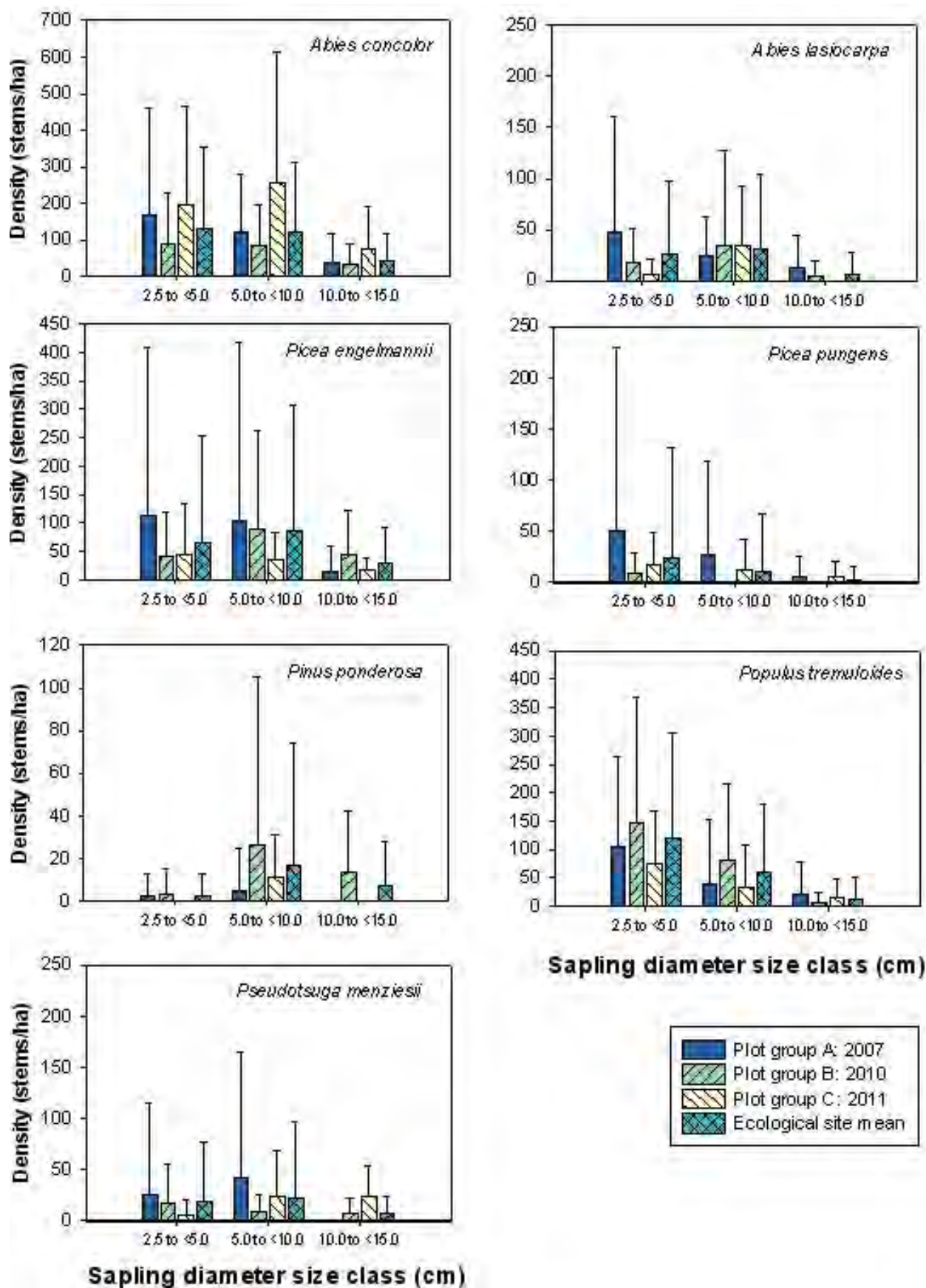


Figure 13. Mean density of saplings in different diameter size classes, by species, for plot group A, plot group B, plot group C and all plots (ecological site mean) in the mixed conifer ecological site at GRCA. Error bars represent 1 standard deviation.

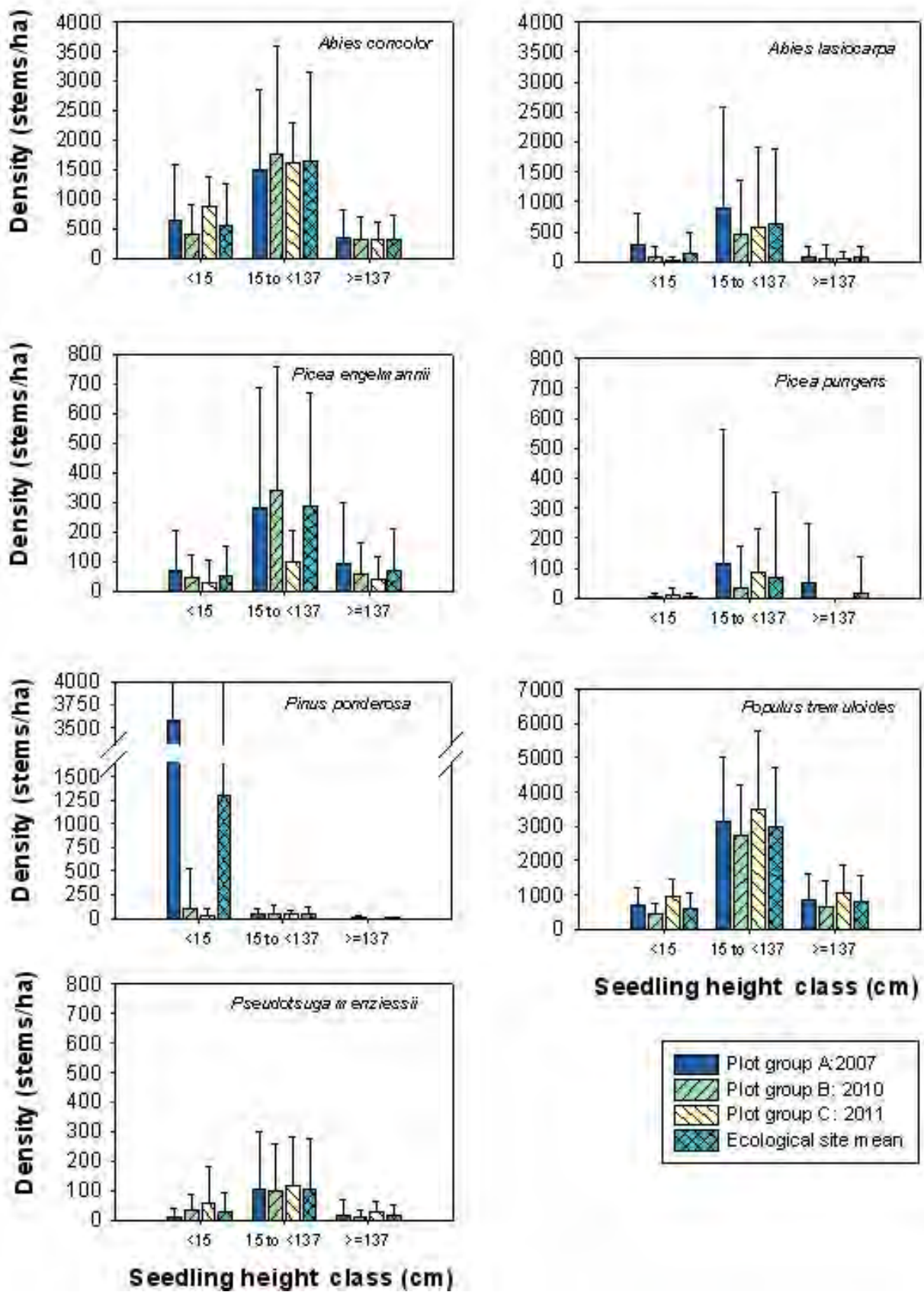


Figure 14. Mean density of seedlings in different size classes, by species, for plot group A, plot group B, plot group C, and all plots (ecological site mean) in the mixed conifer ecological site at GRCA. Error bars represent 1 standard deviation. Note the scales on the vertical axes of the graphs vary. The error bars for *Pinus ponderosa* for plot group A and the ecological site mean extend to 15,445.9 and 9,359.5, respectively.

The overall size class structure of overstory and saplings combined shows a fairly typical inverse distribution, with density decreasing as size class increases (fig. 15). The distribution is not smooth, however. The density of the size class, 5–10 cm, was larger than expected. Standard deviations were large, particularly for the sapling size classes, indicating large among-plot variation. Variation among plot groups was moderately small, with the exception of the smallest size class.

The mean canopy closure for trees in the mixed conifer ecological site was 62.5% (fig. 16). Standard deviations (indicating among-plot differences) for canopy closure were moderate.

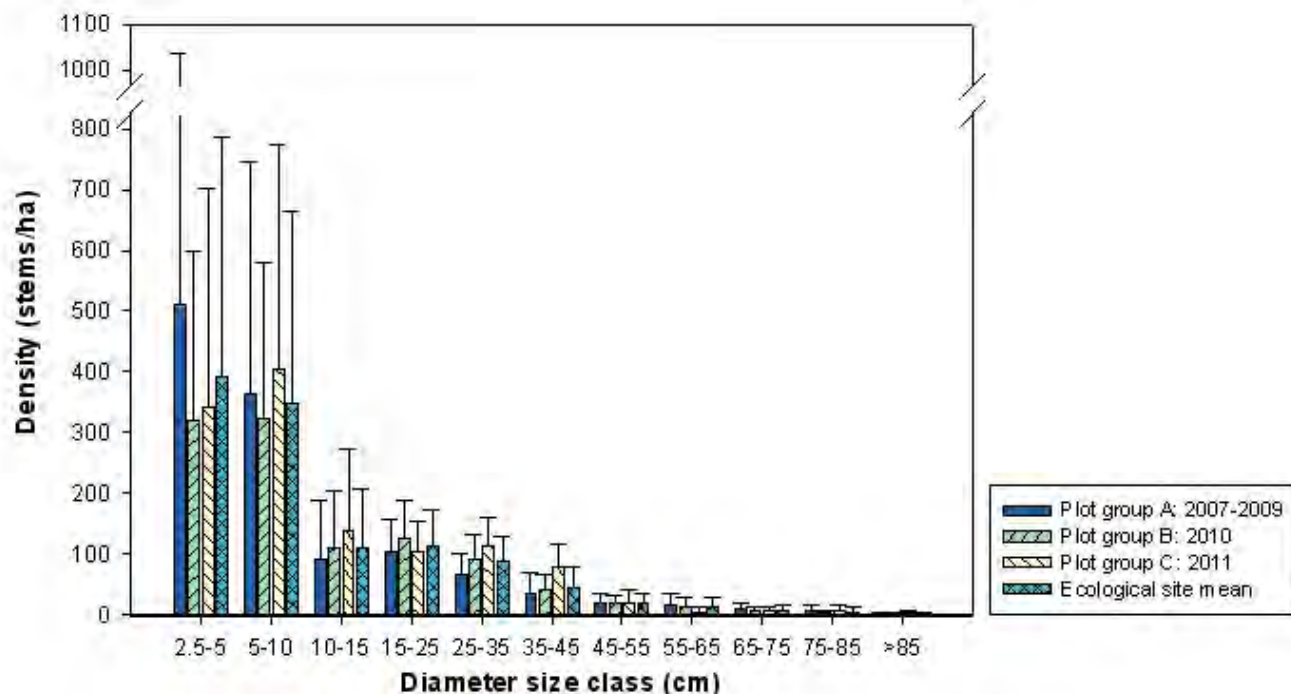
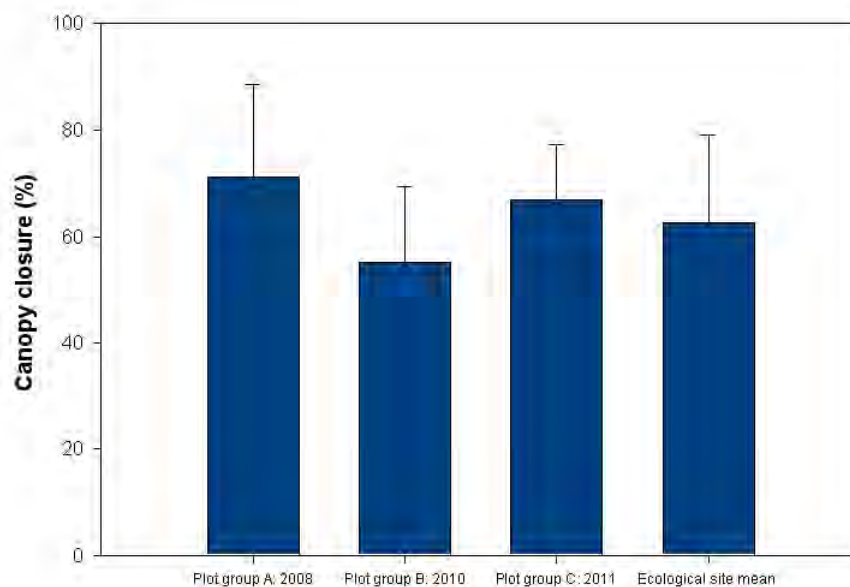


Figure 15. Size class structure of living overstory trees and saplings for plot group A, plot group B, plot group C, and all plots (ecological site mean) in the mixed conifer ecological site at GRCA. Error bars represent 1 standard deviation.

Figure 16. Mean canopy closure for plot group A, plot group B, plot group C, and all plots (ecological site mean) in the mixed conifer ecological site at GRCA. Error bars indicate 1 standard deviation.



3.2.3 Soil surface features

Duff/litter dominated the soil surface in the mixed conifer ecological site, with a mean cover of 81.16% (table 10 and fig. 17). The second most common soil surface feature was woody debris, with a mean cover of 9.76%. Live plant base had a mean cover of 1.47%. All other features had mean covers of less than 1%.

Table 10. Cover of soil surface features for plot group A, plot group B, plot group C and all plots (ecological site mean) in the mixed conifer ecological site at GRCA.

Soil surface feature	Plot group A 2007–2009 (n = 16)		Plot group B 2010 (n = 23)		Plot group C 2011 (n = 7)		Ecological site (n = 46)	
	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Live plant base	1.74	1.58	1.16	1.32	1.88	2.29	1.47	1.51
Dead woody base	0.47	0.75	0.24	0.51	0.09	0.09	0.30	0.51
Dead herbaceous base	0.14	0.18	0.09	0.12	0.11	0.10	0.11	0.12
Bare soil	1.15	1.60	0.84	1.11	0.32	0.68	0.87	1.15
Duff/litter	80.43	5.01	81.90	4.05	80.40	5.99	81.16	4.36
Undifferentiated crust	0.13	0.50	0	0	0.53	0.76	0.13	0.40
Moss	0.34	0.31	0.45	0.55	0.13	0.14	0.36	0.43
Lichen	0.09	0.15	0.25	0.65	0.11	0.22	0.17	0.47
Cyanobacteria	0	0	<0.01	<0.01	0	0	0	0
Fine gravel (0.2 to <2 cm)	0.19	0.29	0.20	0.31	0.14	0.18	0.19	0.27
Coarse gravel (2 to <7.5 cm)	0.46	0.73	0.41	0.44	0.33	0.42	0.41	0.54
Cobble (7.5 to <25 cm)	0.34	0.70	0.21	0.25	0.34	0.81	0.27	0.53
Stone, bedrock (≥25 cm)	0.46	1.24	0.02	0.06	0.07	0.19	0.18	0.70
Woody debris	9.04	4.59	9.87	4.05	11.07	3.61	9.76	3.95

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.

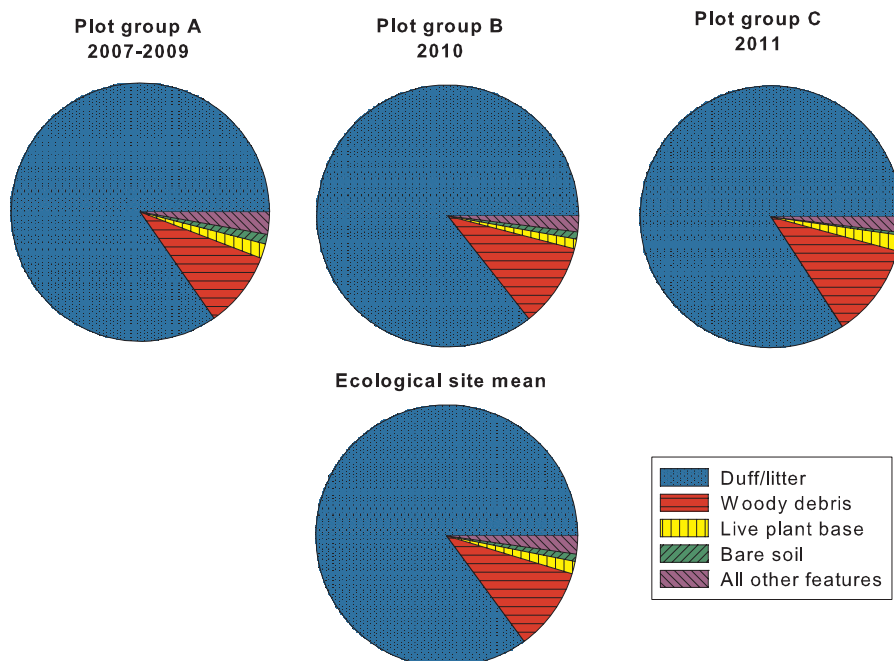
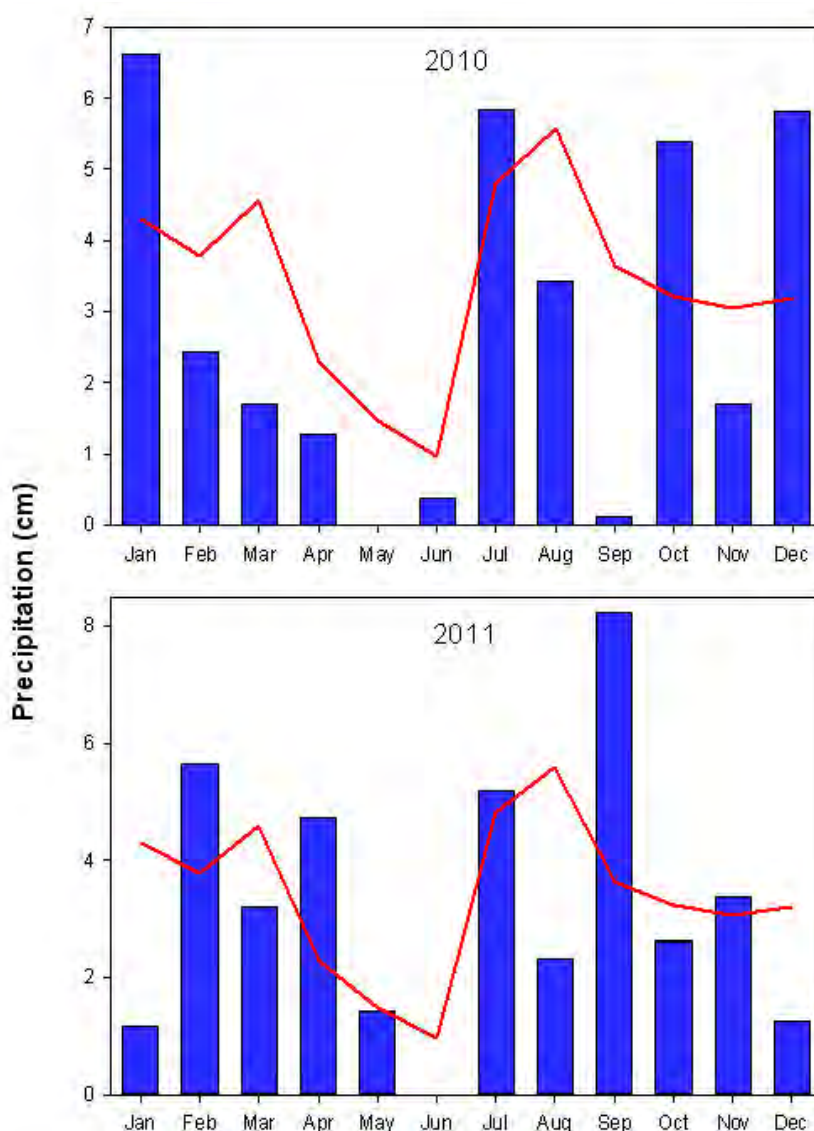


Figure 17. Mean percent cover of soil surface features for plot group A, plot group B, plot group C, and all plots (ecological site mean) in the mixed conifer ecological site at GRCA.

3.3 Western Regional Climate Center precipitation data

Precipitation records for GRCA are available from the Western Regional Climate Center (2012a, 2012b). Figure 18 shows the total monthly precipitation for 2010 and for 2011, compared with the long term average precipitation by month for the period 1948–2011.

Figure 18. Total monthly precipitation for 2010 and 2011. Data from 2010 is from the Grand Canyon NP 2 (023586), AZ, station, and data from 2011 is from the Grand Canyon Airport (9135) AZ, station. The red line long term average represents the mean monthly totals from 1948 through 2011, collected by the Western Regional Climate Center.



4 Discussion

4.1 Limestone Upland ecological site

We present 2 years of data from the 10 plots established in the Limestone Upland ecological site at GRCA to gain a better understanding of the temporal variability in the data.

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*. Three nonnative species were found in the plots. *Bromus tectorum* had moderate foliar cover in 2011, and low cover in 2010. *Portulaca oleracea* 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 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.

There were moderate differences in species composition between the 2 years of sampling. Foliar covers of the living functional groups were invariably higher in 2011. Similarly, foliar cover of the majority of the dominant perennial grass and shrub species was higher for 2011. While there were some species that were present in 2010 that were not present in 2011, there were many more species present only in 2011. As a result, ecological site species richness was higher in 2011, at 80 species, compared with 70 species in 2010. Plot species richness and Shannon diversity were also higher in 2011, but beta diversity was lower, suggesting that the plots were more similar to each other in composition in 2011. There were also some differences in the mean cover of some of the soil surface features between the 2 years, particularly with the cover of undifferentiated crust, bare soil and cyanobacteria. Basal gaps metrics and seedling densities were comparable.

The differences in the vegetation and soil data between 2010 and 2011 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. The higher richness at both the plot and ecological site level suggests such an effect. The moderate differences in foliar cover of perennial grasses and shrubs are somewhat surprising, however, particularly considering that the majority of the abundant forbs showed nominal differences in foliar cover between the 2 years.

Precipitation records for GRCA gathered by the Western Regional Climate Center showed some variation in the precipitation regimes between the 2 years, although the differences were not large. The largest difference was in September, which had much more precipitation in 2011 than 2010. As this was the month that sampling occurred in both 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, 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 2012 we resampled the 10 plots to provide a third year of data so that we can better understand the range of variability in the data, and established 10 additional plots in this ecological site. We will report these data once they are summarized. We plan to install a total of 30 plots. Our power analysis indicates that a sample size of 30 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 to monitor long-term changes.

4.2 Mixed conifer

The data summarized in this report represent baseline conditions for monitoring vegetation and soils for the mixed conifer ecological site at GRCA.

The tree overstory was comprised of 7 species. The dominant species included *Pinus ponderosa*, *Abies concolor*, *Picea engelmannii*, and *Populus tremuloides*. *Pinus ponderosa* had the largest basal area, and *Abies concolor* had the greatest overstory density. *Pseudotsuga menziesii* was intermediate in density and basal area. *Picea pungens* and *Abies lasiocarpa* were minor components of the overstory. The species composition of the seedling and sapling layers were comparable to the overstory, with the exception of *Pinus ponderosa*. All size classes of *Pinus ponderosa* seedlings and saplings had low density, with the exception of the smallest seedling size class. These seedlings were generally first year seedlings and had low chances for survival. This suggests that *Pinus ponderosa* may be limited in its potential to regenerate.

The herbaceous/shrub vegetation was comprised of a mixture of shrubs, forbs and perennial grasses/graminoids. Dominant shrubs included *Juniperus communis*, *Robinia neomexicana* and *Mahonia repens*. Dominant perennial grass/graminoids included *Carex siccata*, *Carex rossii* and *Bromus ciliatus*. Dominant forbs included *Pteridium aquilinum*, *Fragaria virginiana*, *Pedicularis centrathera* and *Pseudostellaria jamesii*. Only one nonnative species was found in the plots—*Taraxacum officinale*—and it occurred in low abundance. This indicates that nonnatives appear not to be a threat to this ecosystem. However, our sampling frame eliminated areas of human disturbance and moderate to high burn severity. Nonnative species may be more abundant in these disturbed areas, which we did not sample. Species diversity was moderately low on the scale of the plot, but moderately high on the landscape scale. The primary soil surface feature was duff/litter, which indicates soil erosion is not a threat to this ecosystem.

The plot groups varied in species composition and structure. We would expect such differences as a result of random spatial variation, especially for the sample sizes. 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. 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. Variation in precipitation has been associated with changes in cover and frequency of herbaceous plants, particularly for annual species and forbs. Given that 2 of the plot groups were sampled only once, their species composition may have been influenced by that year's precipitation regime. Unfortunately there is no weather station near the study site, so we are not able to correlate species composition of the plot groups with the annual rainfall.

Now that we have completed our baseline monitoring for this ecological site, we will begin to implement the revisit design. Our power analysis indicates that a sample size of 45 plots (we have established 46 in this ecological site) should provide a large enough sample size to detect trends in key metrics.

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 re-visit, and monitoring a new set of sites with each revisit, there are designs that provide some balance between repeated visit to individual plots and the total number of site 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 11).

Table 11. The panel design we are currently planning to use for the revisit design at GRCA. “X” represents 15 plots, for a total of 45 plots across 3 panels for the ecological site.

Panel	Year											
	1	2	3	4	5	6	7	8	9	10	11	12
1	X				X		X				X	
2	X		X				X		X			
3			X		X				X		X	
Sum/yr	2X	0	2X	0	2X	0	2X	0	2X	0	2X	0

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Appendix A: Complete species list for shrub and herbaceous species with mean foliar cover and plot frequency for 10 plots in the Limestone Upland ecological site at GRCA in 2010 and 2011.

Species	Common name	Family	2010		2011	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Allium cernuum</i>	nodding onion	Liliaceae	0.001	10.00	0	0
<i>Androsace septentrionalis</i>	pygmy rock jasmine	Primulaceae	0	0	0.020	90.00
<i>Arabis perennans</i>	perennial rockcress	Brassicaceae	0.002	40.00	0.013	60.00
<i>Arceuthobium divaricatum</i>	pinyon dwarf mistletoe	Viscaceae	<0.001	10.00	0.004	40.00
<i>Artemisia tridentata</i>	basin big sagebrush	Asteraceae	0.999	100.00	1.405	100.00
<i>Astragalus</i> spp.	milkvetch	Fabaceae	0.027	70.00	0.022	70.00
<i>Bahia dissecta</i>	ragleaf bahia	Asteraceae	<0.001	10.00	0	0
<i>Boechera</i> sp.	rockcress	Brassicaceae	0	0	<0.001	10.00
<i>Bouteloua gracilis</i>	blue grama	Poaceae	2.126	90.00	2.147	90.00
<i>Bromus tectorum</i> ^a	cheatgrass	Poaceae	0.043	40.00	0.683	70.00
<i>Calochortus nuttallii</i>	sego lily	Liliaceae	0.001	30.00	0.001	20.00
<i>Ceratocephala testiculata</i> ^a	curveseed butterwort	Ranunculaceae	0	0	0.027	50.00
<i>Chaetopappa ericoides</i>	rose heath	Asteraceae	0.003	30.00	0.006	40.00
<i>Chamaesyce</i> spp.	sandmat	Euphorbiaceae	0.008	20.00	0.003	10.00
<i>Chenopodium graveolens</i>	fetid goosefoot	Chenopodiaceae	0.001	20.00	0	0
<i>Chrysothamnus depressus</i>	longflower rabbitbrush	Asteraceae	0.002	10.00	0.002	20.00
<i>Comandra umbellata</i>	bastard toadflax	Santalaceae	0.027	30.00	0.030	30.00
<i>Cordylanthus parviflorus</i>	purple bird's-beak	Scrophulariaceae	0.044	40.00	0.017	40.00
<i>Cordylanthus wrightii</i>	Wright's bird's beak	Scrophulariaceae	0.013	10.00	0.007	20.00
<i>Cryptantha</i> spp.	cryptantha	Boraginaceae	0.005	20.00	0.001	20.00
<i>Delphinium scaposum</i>	barestem larkspur	Ranunculaceae	0.004	10.00	0	0
<i>Descurainia pinnata</i>	western tansymustard	Brassicaceae	0	0	0.025	90.00
<i>Draba cuneifolia</i>	wedgeleaf draba	Brassicaceae	0.002	20.00	0.086	100.00
<i>Echinocereus</i> spp.	hedgheg cactus	Cactaceae	0.003	20.00	0.002	20.00
<i>Elymus elymoides</i>	squirreltail	Poaceae	0.028	70.00	0.052	80.00
<i>Ephedra viridis</i>	mormon tea	Ephedraceae	0.066	30.00	0.091	40.00
<i>Epilobium brachycarpum</i>	autumn willowherb	Onagraceae	0	0	<0.001	10.00
<i>Ericameria nauseosa</i>	rubber rabbitbrush	Asteraceae	0.007	20.00	0.009	20.00

Appendix A (continued)

Species	Common name	Family	2010		2011	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Erigeron concinnus</i>	Navajo fleabane	Asteraceae	0.012	40.00	0.027	40.00
<i>Erigeron divergens</i>	spreading fleabane	Asteraceae	0.001	20.00	0.023	50.00
<i>Erigeron flagellaris</i>	trailing fleabane	Asteraceae	0.001	20.00	0.006	20.00
<i>Erigeron formosissimus</i>	beautiful fleabane	Asteraceae	0	0	<0.001	10.00
<i>Eriogonum alatum</i>	winged buckwheat	Polygonaceae	0.004	10.00	0.010	10.00
<i>Eriogonum microthecum</i>	Simpson's buckwheat	Polygonaceae	0.014	50.00	0.019	50.00
<i>Eriogonum racemosum</i>	redroot buckwheat	Polygonaceae	0.043	30.00	0.060	30.00
<i>Eriogonum umbellatum</i>	sulpher-flowered buckwheat	Polygonaceae	0.025	30.00	0.040	30.00
<i>Escobaria vivipara</i>	spiny star	Cactaceae	0.003	30.00	0.009	30.00
<i>Gilia</i> spp.	gilia	Polemoniaceae	0.007	30.00	0.055	100.00
<i>Gutierrezia sarothrae</i>	broom snakeweed	Asteraceae	0.179	100.00	0.283	100.00
<i>Hedeoma drummondii</i>	Drummond's false pennyroyal	Lamiaceae	0.006	20.00	0.018	30.00
<i>Hesperostipa comata</i>	needle and thread	Poaceae	0.023	10.00	0.010	10.00
<i>Heterotheca villosa</i>	hairy false goldenaster	Asteraceae	0	0	<0.001	10.00
<i>Hymenopappus filifolius</i>	fineleaf hymenopappus	Asteraceae	0.010	40.00	0.010	40.00
<i>Hymenoxys richardsonii</i>	Colorado rubberweed	Asteraceae	0.002	10.00	0	0
<i>Ipomopsis multiflora</i>	manyflowered ipomopsis	Polemoniaceae	0.007	40.00	0.015	20.00
<i>Koeleria macrantha</i>	prairie junegrass	Poaceae	0.004	10.00	0.008	20.00
<i>Lesquerella intermedia</i>	mid bladderpod	Brassicaceae	0.012	40.00	0.021	40.00
<i>Linum lewisii</i>	prairie flax	Linaceae	0	0	0.001	10.00
<i>Lupinus kingii</i>	King's lupine	Fabaceae	0.008	20.00	0.009	30.00
<i>Machaeranthera gracilis</i>	slender goldenweed	Asteraceae	0	0	0.009	80.00
<i>Machaeranthera tanacetifolia</i>	tansyleaf tansyaster	Asteraceae	<0.001	10.00	<0.001	10.00
<i>Mahonia fremontii</i>	Fremont's mahonia	Berberidaceae	0.179	20.00	0.153	20.00
<i>Mentzelia albicaulis</i>	whitestem blazingstar	Loasaceae	0.003	20.00	0.005	30.00
<i>Mirabilis linearis</i>	narrowleaf four o'clock	Nyctaginaceae	0.002	20.00	0.001	20.00
<i>Myosurus minimus</i>	tiny mouse tail	Ranunculaceae	0	0.00	0.004	20.00
<i>Nama dichotoma</i>	wishbone fiddleleaf	Hydrophyllaceae	0.002	10.00	0.002	10.00
<i>Opuntia</i> spp.	prickly pear	Cactaceae	0.115	100.00	0.189	100.00
<i>Opuntia whipplei</i>	Whipple's cholla	Cactaceae	0.002	10.00	0.002	10.00
<i>Orbanche ludoviciana</i>	broomrape	Orbanchaceae	0	0	<0.001	10.00

Appendix A (continued)

Species	Common name	Family	2010		2011	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Packera multilobata</i>	lobeleaf groundsel	Asteraceae	0.003	30.00	0.007	50.00
<i>Packera neomexicana</i>	New Mexico groundsel	Asteraceae	0.002	30.00	0.002	40.00
<i>Penstemon barbatus</i>	beardlip penstemon	Scrophulariaceae	0.029	60.00	0.025	70.00
<i>Penstemon caespitosus</i>	mat penstemon	Scrophulariaceae	0.002	10.00	0.002	20.00
<i>Penstemon ophianthus</i>	Arizona beardtongue	Scrophulariaceae	0.005	10.00	0.013	10.00
<i>Penstemon pachyphyllus</i>	thickleaf beardtongue	Scrophulariaceae	0.016	50.00	0.013	50.00
<i>Phlox</i> spp.	phlox	Polemoniaceae	0	0	0.002	20.00
<i>Phlox austromontana</i>	mountain phlox	Polemoniaceae	0.068	20.00	0.079	20.00
<i>Phlox gracilis</i>	slender phlox	Polemoniaceae	0	0	0.001	10.00
<i>Phlox longifolia</i>	longleaf phlox	Polemoniaceae	0.001	20.00	0.013	50.00
<i>Plantago patagonica</i>	woolly plantain	Plantaginaceae	0	0	0.006	10.00
<i>Poa fendleriana</i>	muttongrass	Poaceae	0.813	100.00	1.814	100.00
<i>Polygonum douglasii</i>	Douglas' knotweed	Polygonaceae	0.008	60.00	0.008	50.00
<i>Portulaca oleracea</i> ^a	little hogweed	Portulacaceae	0.001	30.00	0	0
<i>Portulaca pilosa</i>	kiss me quick	Portulacaceae	<0.001	10.00	0	0
<i>Psilostrophe sparsiflora</i>	greenstem paperflower	Asteraceae	0	0	<0.001	10.00
<i>Psoralidium</i> sp.	scurfpea	Fabaceae	0	0	<0.001	10.00
<i>Psoralidium tenuiflorum</i>	slimflower scurfpea	Fabaceae	<0.001	10.00	<0.001	10.00
<i>Purshia stansburiana</i>	Stansbury cliffrose	Rosaceae	1.661	100.00	2.301	100.00
<i>Quercus gambelii</i>	Gambel oak	Fagaceae	0.010	10.00	0.050	10.00
<i>Sanvitalia abertii</i>	Albert's creeping zinnia	Asteraceae	0.001	10.00	0	0
<i>Silene antirrhina</i>	sleepy catchfly	Caryophyllaceae	0	0	0.001	10.00
<i>Sphaeralcea</i> spp.	globemallow	Malvaceae	0.003	20.00	0.001	20.00
<i>Stephanomeria</i> spp.	wirelettuce	Asteraceae	<0.001	10.00	<0.001	10.00
<i>Tetranneuris acaulis</i>	stemless four-nerve daisy	Asteraceae	0.002	10.00	0.004	10.00
<i>Thlaspi montanum</i>	alpine pennycress	Brassicaceae	0.001	20.00	0.003	20.00
<i>Townsendia incana</i>	hoary Townsend daisy	Asteraceae	<0.001	10.00	0.002	10.00
<i>Vulpia octoflora</i>	sixweeks fescue	Poaceae	0	0	0.026	70.00
<i>Yucca baccata</i>	banana yucca	Agavaceae	0.004	50.00	0.007	40.00

^aNonnative species.

Appendix B: Complete species list for plots sampled 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, plot group B, plot group C, and all plots in the mixed conifer ecological site at GRCA.

Species	Common name	Family	Plot group A 2007–2009		Plot group B 2010		Plot group C 2011		All plots	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Achillea millefolium</i>	western yarrow	Asteraceae	0.033	37.50	0.020	43.48	0.137	42.86	0.042	41.30
<i>Achnatherum nelsonii</i>	Columbina needlegrass	Poaceae	0	0	0.001	4.35	0	0	0.001	2.17
<i>Agastache pallidiflora</i>	Bill Williams Mountain giant hyssop	Lamiaceae	0	0	<0.001	4.35	0	0	<0.001	2.17
<i>Agoseris glauca</i>	pale agoseris	Asteraceae	<0.001	8.33	0	0	0	0	<0.001	2.90
<i>Agrostis idahoensis</i>	Idaho bentgrass	Poaceae	0	0	0	0	0.015	14.29	0.002	2.17
<i>Agrostis scabra</i>	rough bentgrass	Poaceae	0.002	14.58	0	0	0	0	0.001	5.07
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae	<0.001	6.25	0	0	0	0	<0.001	2.17
<i>Amelanchier utahensis</i>	Utah serviceberry	Rosaceae	0.002	4.17	0	0	0	0	0.001	1.45
<i>Androsace septentrionalis</i>	pygmy rock jasmine	Primulaceae	0.001	14.58	<0.001	13.04	0	0	<0.001	11.59
<i>Antennaria marginata</i>	white margin pussytoes	Asteraceae	0.050	39.58	0.028	39.13	0.087	14.29	0.045	35.51
<i>Antennaria parvifolia</i>	small leaf pussytoes	Asteraceae	0.038	54.17	0.030	52.17	0.113	71.43	0.045	55.80
<i>Apocynum androsaemifolium</i>	spreading dogbane	Apocynaceae	0	0	<0.001	4.35	0	0	<0.001	2.17
<i>Aquilegia coerulea</i>	Colorado blue columbine	Ranunculaceae	0.003	6.25	0	0	0	0	0.001	2.17
<i>Arenaria fendleri</i>	Fendler's sandwort	Caryophyllaceae	0.004	16.67	0.004	13.04	0.009	14.29	0.004	14.49
<i>Arenaria lanuginosa</i>	spreading sandwort	Caryophyllaceae	0.002	12.50	0.002	17.39	0	0	0.001	13.04
<i>Arnica chamissonis</i>	Chamisso arnica	Asteraceae	0	0	0.002	4.35	0.003	14.29	0.001	4.35
<i>Astragalus</i> sp.	milkvetch	Fabaceae	0	0	<0.001	4.35	0	0	<0.001	2.17
<i>Bahia dissecta</i>	ragleaf bahia	Asteraceae	<0.001	6.25	0	0	0	0	<0.001	2.17
<i>Blepharoneuron tricholepis</i>	pine dropseed	Poaceae	0.008	14.58	0.003	13.04	0	0	0.004	11.59
<i>Brickellia grandiflora</i>	mountain brickellbush	Asteraceae	0.022	6.25	0	0	0	0	0.008	2.17
<i>Bromus ciliatus</i>	fringed brome	Poaceae	0.141	100.00	0.038	91.30	0.049	100.00	0.076	95.65
<i>Calochortus ambiguus</i>	doubting mariposa lily	Liliaceae	0	0	0	0	<0.001	14.29	<0.001	2.17
<i>Carex occidentalis</i>	western sedge	Cyperaceae	0	0	0.006	13.04	0.007	14.29	0.004	8.70

Table B1 (continued)

Species	Common name	Family	Plot group A 2007–2009		Plot group B 2010		Plot group C 2011		All plots	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Carex rossii</i>	Ross' sedge	Cyperaceae	0.513	100.00	0.283	100.00	0.245	100.00	0.357	100.00
<i>Carex siccata</i>	dry-spike sedge	Cyperaceae	0.693	83.33	0.518	91.30	0.563	100.00	0.586	89.86
<i>Castilleja austromontana</i>	Rincon Indian paintbrush	Scrophulariaceae	0.002	12.50	0	0	0.014	14.29	0.003	6.52
<i>Castilleja linariifolia</i>	Wyoming Indian paintbrush	Scrophulariaceae	<0.001	4.17	0.001	13.04	0	0	0.001	7.97
<i>Ceanothus fendleri</i>	Fendler's ceanothus	Rhamnaceae	0.004	18.75	0.008	17.39	0	0	0.005	15.22
<i>Chamerion angustifolium</i>	fireweed	Onagraceae	0.077	50.00	0.016	39.13	0.007	14.29	0.036	39.13
<i>Chenopodium album</i>	lambsquarters	Chenopodiaceae	0.032	14.58	0	0	0	0	0.011	5.07
<i>Chenopodium fremontii</i>	Fremont's goosefoot	Chenopodiaceae	0	0	<0.001	8.70	0.467	14.29	0.071	6.52
<i>Chenopodium graveolens</i>	fetid goosefoot	Chenopodiaceae	0.009	6.25	0	0	0	0	0.003	2.17
<i>Chenopodium leptophyllum</i>	narrowleaf goosefoot	Chenopodiaceae	<0.001	2.08	0	0	0	0	<0.001	0.72
<i>Chimaphila umbellata</i>	common pipsissewa	Pyrolaceae	0.002	8.33	0.001	4.35	<0.001	14.29	0.001	7.25
<i>Cirsium wheeleri</i>	Wheeler's thistle	Asteraceae	0.010	25.00	0.014	34.78	0.070	28.57	0.021	30.43
<i>Collinsia parviflora</i>	blue-eyed Mary	Scrophulariaceae	<0.001	4.17	0.001	13.04	0.002	28.57	0.001	12.32
<i>Collomia linearis</i>	narrow-leaf mountain-trumpet	Polemoniaceae	0	0	<0.001	4.35	0	0	<0.001	2.17
<i>Conyza canadensis</i>	Canadian horseweed	Asteraceae	<0.001	4.17	0	0	0.003	14.29	0.001	3.62
<i>Corallorrhiza maculata</i>	spotted coralroot	Orchidaceae	0.001	22.92	0.001	17.39	0.001	14.29	0.001	18.84
<i>Cryptantha setosissima</i>	bristly cryptantha	Boraginaceae	0	0	0.001	8.70	0	0	0.001	4.35
<i>Draba asprella</i>	rough draba	Brassicaceae	0	0	0	0	0.005	28.57	0.001	4.35
<i>Elymus canadensis</i>	Canada wildrye	Poaceae	0.026	14.58	0	0	0.007	14.29	0.010	7.25
<i>Elymus elymoides</i>	squirreltail	Poaceae	0.018	68.75	0.018	69.57	0.073	57.14	0.027	67.39
<i>Epilobium brachycarpum</i>	autumn willowherb	Onagraceae	<0.001	2.08	<0.001	4.35	0	0	<0.001	2.90
<i>Erigeron divergens</i>	spreading fleabane	Asteraceae	0.010	16.67	0	0	0	0	0.004	5.80
<i>Erigeron flagellaris</i>	trailing fleabane	Asteraceae	0	0	0	0	0.003	14.29	<0.001	2.17
<i>Erigeron formosissimus</i>	beautiful fleabane	Asteraceae	0.078	45.83	0.006	13.04	0.248	85.71	0.068	35.51
<i>Erigeron speciosus</i>	aspen fleabane	Asteraceae	0.031	20.83	0.126	82.61	0.001	28.57	0.074	52.90
<i>Eriogonum racemosum</i>	redroot buckwheat	Polygonaceae	0.007	25.00	0.004	30.43	0.003	14.29	0.005	26.09
<i>Euphorbia brachycera</i>	horned spurge	Euphorbiaceae	<0.001	4.17	0	0	0	0	<0.001	1.45
<i>Festuca arizonica</i>	Arizona fescue	Poaceae	0	0	0.008	4.35	0	0	0.004	2.17

Table B1 (continued)

Species	Common name	Family	Plot group A 2007–2009		Plot group B 2010		Plot group C 2011		All plots	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Fragaria virginiana</i>	Virginia strawberry	Rosaceae	0.305	100.00	0.067	86.96	0.232	85.71	0.175	91.30
<i>Frasera speciosa</i>	elkweed	Gentianaceae	0	0	0.005	8.70	0	0	0.003	4.35
<i>Fritillaria atropurpurea</i>	spotted fritillary	Liliaceae	<0.001	4.17	<0.001	4.35	0	0	<0.001	3.62
<i>Gayophytum diffusum</i>	spreading groundsmoke	Onagraceae	0.004	22.92	0.001	13.04	0.001	14.29	0.002	16.67
<i>Geranium caespitosum</i>	piney-woods geranium	Geraniaceae	0.001	6.25	0.001	4.35	0	0	0.001	4.35
<i>Geranium richardsonii</i>	Richardson's geranium	Geraniaceae	0.109	25.00	0.011	34.78	0.021	71.43	0.047	36.96
<i>Goodyera oblongifolia</i>	western rattlesnake plantain	Orchidaceae	0.046	85.42	0.037	100.00	0.059	100.00	0.044	94.93
<i>Helianthus nuttallii</i>	Nuttall's sunflower	Asteraceae	0	0	0.003	13.04	0	0	0.002	6.52
<i>Helomeris multiflora</i>	showy goldeneye	Asteraceae	0.003	4.17	0.001	4.35	0.003	14.29	0.002	5.80
<i>Hesperandanthus linearifolius</i>	slimleaf plains mustard	Brassicaceae	<0.001	6.25	0	0	0	0	<0.001	2.17
<i>Hesperostipa comata</i>	needle and thread	Poaceae	0.003	6.25	0	0	0	0	0.001	2.17
<i>Heterotheca villosa</i>	hairy false goldenaster	Asteraceae	0.001	6.25	<0.001	4.35	0.003	14.29	0.001	6.52
<i>Hieracium fendleri</i>	yellow hawkweed	Asteraceae	0.014	66.67	0.009	78.26	0.009	57.14	0.011	71.01
<i>Hymenoxys subintegra</i>	Arizona rubberweed	Asteraceae	0.001	6.25	<0.001	8.70	0.003	14.29	0.001	8.70
<i>Juniperus communis</i>	common juniper	Cupressaceae	0.883	66.67	1.992	65.22	1.597	57.14	1.546	64.49
<i>Kelloggia galioides</i>	milk kelloggia	Rubiaceae	0.002	6.25	<0.001	4.35	0	0	0.001	4.35
<i>Koeleria macrantha</i>	prairie junegrass	Poaceae	0.001	10.42	0.003	21.74	<0.001	14.29	0.002	16.67
<i>Ligusticum porteri</i>	Porter's licorice root	Apiaceae	0.061	43.75	0.020	26.09	0.003	14.29	0.032	30.43
<i>Lithospermum multiflorum</i>	many flowered puccoon	Boraginaceae	0	0	0.001	4.35	0	0	<0.001	2.17
<i>Lotus utahensis</i>	Utah bird's-foot trefoil	Fabaceae	0.040	56.25	0.049	52.17	0.140	42.86	0.060	52.17
<i>Lotus wrightii</i>	Wright's deerwetch	Fabaceae	0.001	6.25	0	0	0	0	<0.001	2.17
<i>Lupinus argenteus</i>	silvery lupine	Fabaceae	0	0	0.008	26.09	0	0	0.004	13.04
<i>Lupinus hillii</i>	hill lupine	Fabaceae	0.001	10.42	0	0	0	0	<0.001	3.62
<i>Mahonia repens</i>	creeping barberry	Berberidaceae	0.089	68.75	0.105	69.57	0.164	85.71	0.108	71.74
<i>Maianthemum stellatum</i>	starry false solomon's-seal	Liliaceae	0.001	6.25	0.002	8.70	0	0	0.001	6.52
<i>Muhlenbergia montana</i>	mountain muhly	Poaceae	0.020	29.17	0.023	17.39	0.015	14.29	0.021	21.01
<i>Oreochrysum parryi</i>	Parry's goldenrod	Asteraceae	0.031	41.67	0.096	34.78	0.021	57.14	0.062	40.58
<i>Orthilia secunda</i>	sidebells wintergreen	Pyrolaceae	0.008	27.08	0.001	13.04	0.007	28.57	0.004	20.29

Table B1 (continued)

Species	Common name	Family	Plot group A 2007–2009		Plot group B 2010		Plot group C 2011		All plots	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Osmorhiza depauperata</i>	blunt-fruit sweet-cicely	Apiaceae	0.008	20.83	0	0	0.004	14.29	0.003	9.42
<i>Packera multilobata</i>	lobeleaf groundsel	Asteraceae	0.012	35.42	0.017	52.17	0.017	28.57	0.015	42.75
<i>Packera werneriifolia</i>	hoary groundsel	Asteraceae	0.004	18.75	0.009	34.78	0	0	0.006	23.91
<i>Pascopyrum smithii</i>	western wheatgrass	Poaceae	0.001	6.25	0	0	0	0	<0.001	2.17
<i>Pedicularis centranthera</i>	dwarf lousewort	Scrophulariaceae	0.123	89.58	0.131	82.61	0.080	57.14	0.120	81.16
<i>Penstemon barbatus</i>	beardlip penstemon	Scrophulariaceae	0.017	18.75	0.003	4.35	0.001	28.57	0.008	13.04
<i>Penstemon virgatus</i>	upright blue pestemon	Scrophulariaceae	0.010	27.08	0.002	13.04	0	0	0.004	15.94
<i>Phacelia heterophylla</i>	variable-leaf scorpionweed	Hydrophyllaceae	0.014	22.92	<0.001	4.35	0.016	14.29	0.007	12.32
<i>Phlox austromontana</i>	mountain phlox	Polemoniaceae	0	0	<0.001	4.35	0	0	<0.001	2.17
<i>Poa fendleriana</i>	muttongrass	Poaceae	0.165	93.75	0.076	91.30	0.104	85.71	0.111	91.30
<i>Polygonum douglasii</i>	Douglas' knotweed	Polygonaceae	0.001	14.58	0.002	26.09	0.005	42.86	0.002	24.64
<i>Potentilla hippiana</i>	woolly cinquefoil	Rosaceae	<0.001	2.08	0.001	8.70	0.152	14.29	0.024	7.25
<i>Pseudocymopterus montanus</i>	alpine false springparsley	Apiaceae	0.008	39.58	0.005	56.52	0.052	42.86	0.013	48.55
<i>Pseudognaphalium macounii</i>	Macoun's cudweed	Asteraceae	0.003	16.67	0	0	0.003	14.29	0.002	7.97
<i>Pseudostellaria jamesiana</i>	tuber starwort	Caryophyllaceae	0.042	39.58	0.130	30.43	0.137	42.86	0.101	35.51
<i>Pteridium aquilinum</i>	western bracken fern	Dennstaedtiaceae	0.189	35.42	0.655	30.43	0.652	28.57	0.492	31.88
<i>Pterospora andromedea</i>	woodland pinedrops	Monotropaceae	<0.001	2.08	<0.001	4.35	0	0	<0.001	2.90
<i>Pyrola chlorantha</i>	green flowered wintergreen	Pyrolaceae	0.001	14.58	<0.001	4.35	<0.001	14.29	<0.001	9.42
<i>Pyrola picta</i>	white veined wintergreen	Pyrolaceae	0.005	27.08	0.002	17.39	0.006	28.57	0.003	22.46
<i>Robinia neomexicana</i>	New Mexico locust	Fabaceae	0.537	12.50	0.507	13.04	0.322	14.29	0.490	13.04
<i>Rosa woodsii</i>	Woods' rose	Rosaceae	0	0	0.013	13.04	0.006	14.29	0.008	8.70
<i>Rubus idaeus</i>	western red raspberry	Rosaceae	0.011	18.75	0.025	8.70	0.003	14.29	0.017	13.04
<i>Salix scouleriana</i>	Scouler's willow	Salicaceae	<0.001	2.08	0	0	0	0	<0.001	0.72
<i>Sambucus nigra</i>	black elderberry	Caprifoliaceae	0.001	4.17	0.021	8.70	0.003	14.29	0.012	7.97
<i>Senecio wootonii</i>	Wooton's ragwort	Asteraceae	0.002	14.58	<0.001	4.35	0	0	0.001	7.25
<i>Silene scouleri</i>	simple campion	Caryophyllaceae	0.002	27.08	0.004	34.78	<0.001	14.29	0.003	28.99
<i>Solidago</i> sp.	goldenrod	Asteraceae	0	0	0	0	0.003	14.29	<0.001	2.17
<i>Solidago velutina</i>	threenerve goldenrod	Asteraceae	0.045	12.50	0.005	13.04	0	0	0.018	10.87

Table B1 (continued)

Species	Common name	Family	Plot group A 2007–2009		Plot group B 2010		Plot group C 2011		All plots	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Solidago wrightii</i>	Wright's goldenrod	Asteraceae	0.019	6.25	0	0	0.008	14.29	0.008	4.35
<i>Sorbus dumosa</i>	Arizona mountain ash	Rosaceae	0.012	6.25	0.006	17.39	0.003	14.29	0.007	13.04
<i>Symphoricarpos oreophilus</i>	mountain snowberry	Caprifoliaceae	0.047	6.25	0.001	4.35	0	0	0.017	4.35
<i>Taraxacum officinale</i> ^a	common dandelion	Asteraceae	0.003	14.58	<0.001	8.70	0.036	14.29	0.007	11.59
<i>Thalictrum fendleri</i>	meadow-rue	Ranunculaceae	0.008	8.33	0.002	8.70	0.009	14.29	0.005	9.42
<i>Thlaspi montanum</i>	alpine pennycress	Brassicaceae	0.003	27.08	0.003	56.52	0	0	0.003	37.68
Unknown GRCA20070707_1			<0.001	6.25	0	0	0	0	<0.001	2.17

^aNonnative species.

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

Species	Common name	Family	Plot group A 2007		Plot group B 2010		Plot group C 2011		All plots	
			Basal area (m ² /ha) ^a	Plot frequency (%) ^b	Basal area (m ² /ha) ^a	Plot frequency (%) ^b	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	7.74	100.00	6.06	95.65
<i>Abies lasiocarpa</i>	subalpine fir	Pinaceae	1.25	56.25	0.51	65.22	1.61	42.86	0.94	58.70
<i>Picea engelmannii</i>	Engelmann spruce	Pinaceae	3.38	68.75	5.22	78.26	4.03	71.43	4.40	73.91
<i>Picea pungens</i>	Colorado blue spruce	Pinaceae	2.06	25.00	0.66	39.13	3.14	42.86	1.52	34.78
<i>Pinus ponderosa</i>	ponderosa pine	Pinaceae	9.44	87.5	9.78	86.96	6.94	85.71	9.23	86.96
<i>Populus tremuloides</i>	quaking aspen	Salicaceae	3.41	100.00	2.91	100.00	6.63	100.0	3.65	100.00
<i>Pseudotsuga menziesii</i>	Douglas fir	Pinaceae	2.87	75.00	2.57	82.61	2.68	100.0	2.69	82.61

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