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Integrated Upland Vegetation and Soils Monitoring for Mesa Verde National Park

2009 Summary Report

Natural Resource Data Series NPS/SCPN/NRDS—2011/172

ON THE COVER
Loamy Mesa Top Pinyon-Juniper ecological site at Mesa Verde National Park
Photograph by: Jim DeCoster

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

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Introduction and Background

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

SCPN and park staff selected the Loamy Mesa Top Pinyon-Juniper ecological site for long-term monitoring of upland vegetation and soils at Mesa Verde National Park (MEVE). 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 Loamy Mesa Top Pinyon-Juniper woodland is a unique ecosystem containing old-growth pinyon-juniper woodland. It faces numerous threats, including changing fire regimes, climate change, and invasion by nonnative species.

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

Methods

Sampling frame

We derived the sampling frame from the map of the Loamy Mesa Top Pinyon-Juniper ecological site, which was developed by the US Natural Resources Conservation Service (See Appendix A of DeCoster et al., in review). The sampling frame is the area from which we randomly select our sites, and hence the area to which statistical inferences can be made. To create the sampling frame, we modified the map of the ecological site using Geographical Information System (GIS) technology. These modifications were necessary to avoid areas that were

- outside of the target ecological site (roads, buildings and other infrastructure)
- expected to differ substantially from the norm, such as burned areas and mechanically treated areas, 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 ≥20%)
- containing arthropod monitoring sites (fig. 1).

We generated a set of spatially distributed sampling points using the Generalized Random Tessellation Stratified (GRTS) design (Stevens and Olsen 2004). Park staff reviewed the sampling points and rejected those points that landed too close to archaeological sites and other sensitive resources. Before establishing a plot, the Integrated Upland crew conducted an ecological site assessment for each sampling point and rejected sites that did not fall within the ecological site, had a slope greater than 20%, or contained a major disturbance. Twelve points were rejected. Park staff rejected nine points that were determined to be too close to archaeological sites. The Integrated Upland crew rejected one point that was located in the Shallow Loamy Mesa Top Pinyon-Juniper ecological site and two

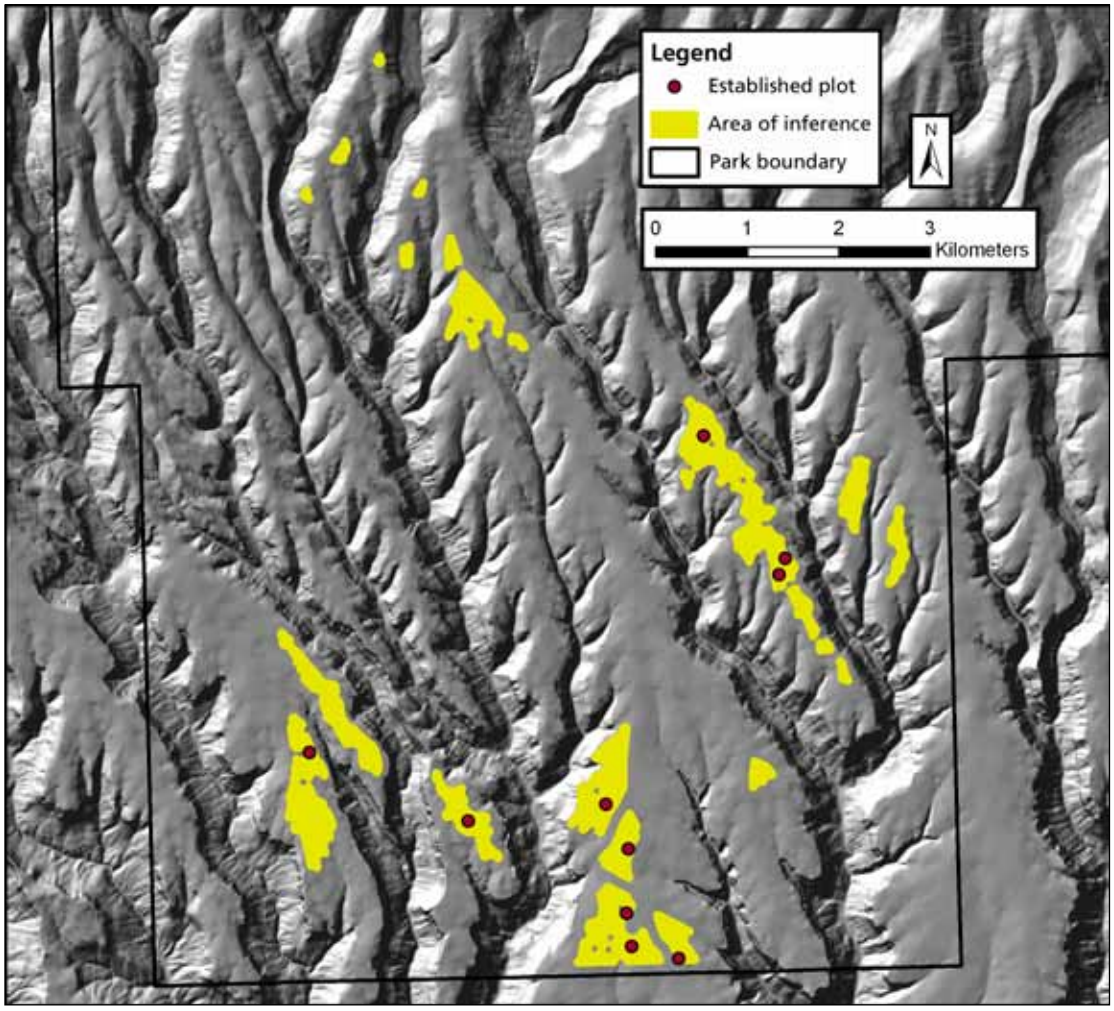

Figure 1. Sampling frame of the Loamy Mesa Top Pinyon-Juniper ecological site showing 10 plots sampled in 2007, 2008, and 2009

points located on the far north side of the ecological site that were distinctly different from the rest of the ecological site.

Field methods

In 2009, the SCPN Upland Monitoring crew sampled the same 10 plots that were established at MEVE in 2007. The plots were 0.50 ha in size, measuring 71 × 71 m. Shrub and herbaceous data and soil data were collected on three 50 m transects, spaced 25 m apart, within each plot. Overstory tree and sapling data were collected in subplots located between two of the transects. In all three years the crew collected the data from the plots in early August. Field methodology is provided in detail in the SCPN Integrated Upland Protocol (DeCoster et al., in review).

Shrub and herbaceous vegetation

The crew sampled shrub and herbaceous vegetation within five sets of nested quadrats at 10 m intervals along each transect. The largest quadrat size was 10 m^2 (2 × 5 m), with four smaller quadrats nested inside (0.01 m^2, 0.1 m^2, 1 m^2, 5 m^2). For each nested sub-quadrat we recorded the presence of individual vascular species. For each 10 m^2 quadrat we estimated percent cover for herbaceous

and shrub species and recorded it as one of 12 cover classes (e.g. 2%–5%, 5%–10%, etc.). We also estimated the percent cover for functional groups (e.g. perennial grasses, forbs, shrubs) in the 10 m^2 quadrats and recorded the cover class for each.

Overstory trees and saplings

We measured and mapped trees in 2007, but did not remeasure them in 2008 or 2009. However, we did assess tree canopy in 2008 and 2009. In 2008 we measured tree canopy closure with a hemispherical densiometer at five points along each transect; in 2009 a different aspect of tree canopy, canopy cover, was measured using the line intercept method along the transects.

Soil stability and hydrologic function

The crew estimated the percent cover of soil surface features in the 1 m^2 quadrats in conjunction with shrub and herbaceous data and recorded the cover in one of 12 cover classes. A soil aggregate stability test was conducted in 2007, using 18 soil samples collected along the transects. This procedure was not repeated in 2008 or 2009.

Data summary

The sample unit for summary and analysis is the plot; hence, we summarized data at the level of the plot. In order to calculate summary statistics for the ecological site, means and standard deviations were calculated from the plot means.

For herbaceous and shrub vegetation, cover was calculated for each species from the cover class midpoints, e.g. using 7.5% for cover class 5%–10%. The mean cover was calculated for each plot, and the mean and standard deviation (SD) were calculated for the ecological site from the plot means. Species frequency was calculated for quadrats (mean percentage of quadrats per plot where the species occurs) and for plots (percentage of plots where the species occurs). Mean cover and SD of functional groups and surface features were calculated in a similar fashion.

We calculated four diversity measures for herbaceous and shrub species (Magurran 1988), first for all species and then for native species only.

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

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

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

where p_i is the abundance of each species.

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

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

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

$$S_e / (S_p - 1)$$

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

Canopy closure and canopy cover were calculated by first deriving for the mean for each plot, and then the mean and standard deviation were calculated for the entire ecological site.

We made five calculations for the basal gaps data: median basal gap size, percentage of transects comprised by gaps and plant bases, percentage of transects comprised by each size class, and total number of gaps. Mean and SD were calculated for each metric.

Results

Shrub and herbaceous vegetation

Perennial grasses dominated herbaceous/shrub vegetation of the Loamy Mesa Top Pinyon-Juniper ecological site at MEVE (table 1 and fig. 2) with less cover of shrubs, forbs, and cacti/succulents. Total live vegetative cover showed a large decrease in 2008, from 14.17% to 10.05%. This change, however, is largely due to slight changes in methods: in 2007, tree foliar cover (< 2 m in height) was included in the estimation of total live vegetative cover, but tree cover was not included in 2008. Also, standing dead woody cover in 2007 included trees (< 2 m) and shrubs, but in 2008 and 2009 standing dead woody cover included only shrubs. While there were some changes in the cover of the other functional groups, most of these changes were small, particularly in light of the large among-plot variability, as indicated by the large standard deviations.

Table 1. Mean foliar cover of functional groups for 2007, 2008, and 2009

	Foliar cover (%)					
	2007		2008		2009	
Functional groups	Mean	(SD)	Mean	(SD)	Mean	(SD)
Total live foliar cover	14.17	(4.80)	10.05	(6.25)	9.46	(5.17)
Perennial grasses, graminoids	4.67	(3.12)	4.01	(2.38)	4.40	(2.73)
Annual grasses	<0.01	(0.01)	<0.01	(<.01)	<0.01	(<0.01)
Forbs	0.94	(0.77)	1.19	(0.66)	0.94	(0.47)
Shrubs	2.30	(2.61)	2.82	(3.50)	2.67	(2.87)
Cacti, succulents	1.29	(0.10)	1.17	(0.86)	1.26	(1.03)
Understory trees (<2 m height)	5.17	(2.56)	n/a	n/a	n/a	n/a
Standing dead herbaceous	2.28	(1.45)	1.34	(0.82)	0.99	(0.54
Standing dead woody	2.10	(1.02)	2.16	(2.18)	1.36	(1.165)

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

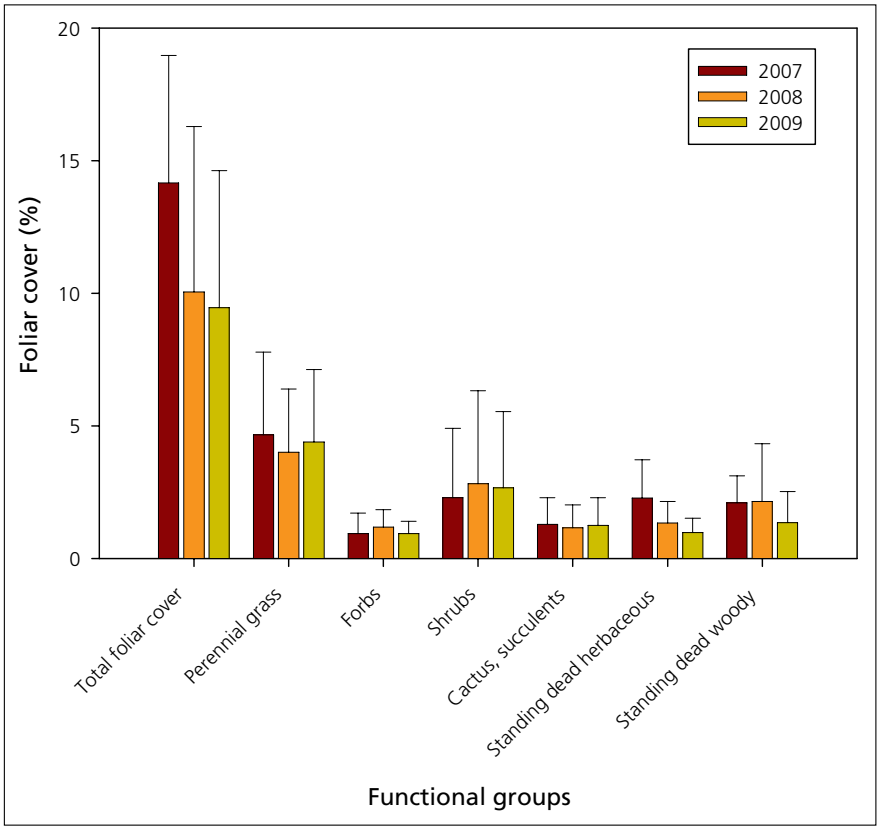

Figure 2. Mean cover of functional groups in 2007, 2008, and 2009. Note: means for total foliar and standing dead woody cover in 2007 include tree components. Error bars represent one standard deviation.

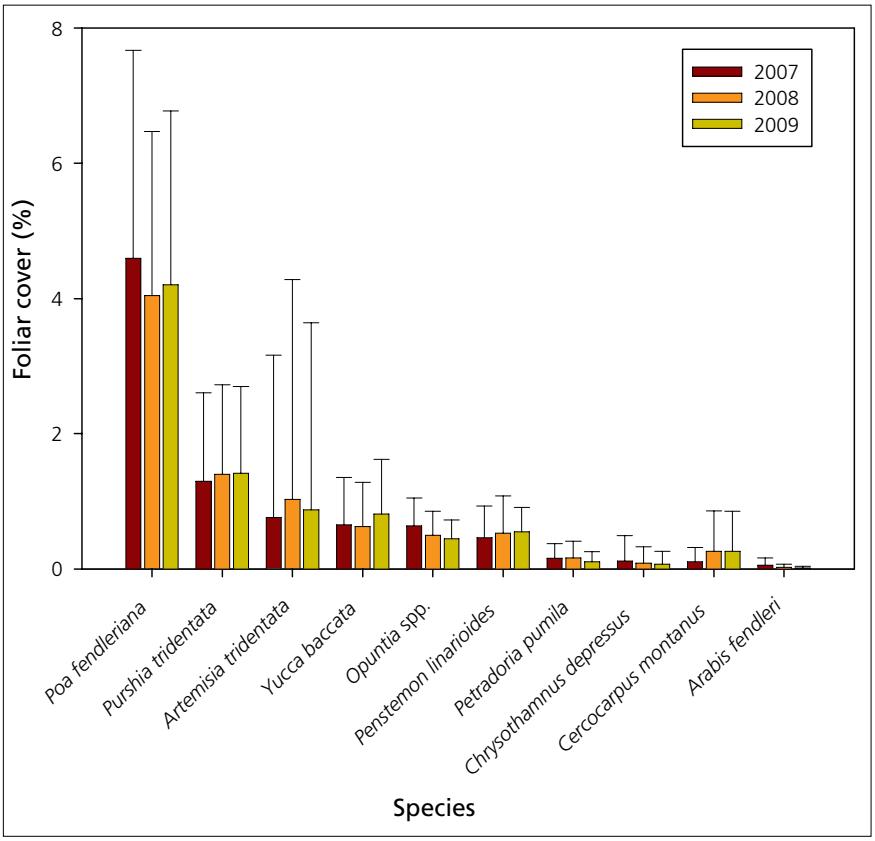

Figure 3. Mean foliar cover of the ten most abundant shrub and herbaceous species in 2007, 2008, and 2009. Error bars represent one standard deviation.

Table 2. Foliar cover and frequency of the fifteen most abundant vascular species and all nonnative species in 2007, 2008, and 2009

	2007				2008				2009			
Species	Mean cover (%)	SD	Quad freq	Plot freq	Mean cover (%)	SD	Quad freq	Plot freq	Mean cover (%)	SD	Quad freq	Plot freq
Poa fendleriana	4.596	3.077	96.67	100	4.042	2.427	96.00	100	4.202	2.572	96.67	100
Purshia tridentata	1.297	1.306	48.00	90	1.398	1.326	50.67	90	1.412	1.287	46.67	90
Artemisia tridentata	0.760	2.404	10.00	10	1.028	3.252	10.00	10	0.875	2.767	10.00	10
Yucca baccata	0.651	0.703	32.00	80	0.628	0.654	32.67	70	0.813	0.809	30.00	70
Opuntia spp.	0.636	0.415	50.67	90	0.496	0.359	51.33	90	0.448	0.277	49.33	90
Penstemon linarioides	0.462	0.468	78.67	100	0.527	0.555	83.33	100	0.551	0.361	82.00	100
Petradoria pumila	0.158	0.217	14.67	50	0.165	0.246	16.67	50	0.108	0.150	18.67	50
Chrysothamnus depressus	0.119	0.375	8.67	30	0.087	0.242	11.33	40	0.067	0.196	10.00	40
Cercocarpus montanus	0.104	0.214	10.00	30	0.261	0.596	10.67	30	0.261	0.593	9.33	30
Arabis fendleri	0.054	0.109	20.67	90	0.026	0.043	16.67	70	0.015	0.026	10.67	60
Phlox hoodii	0.031	0.062	10.67	40	0.030	0.051	14.00	40	0.037	0.062	14.67	40
Cordylanthus wrightii	0.029	0.033	27.33	80	0.080	0.087	33.33	90	0.059	0.083	46.00	90
Eriogonum racemosum	0.028	0.037	20.00	80	0.053	0.059	22.00	80	0.036	0.049	22.00	80
Gutierrezia sarothrae	0.021	0.065	4.00	10	0.023	0.073	4.67	10	0.017	0.051	5.33	30
Comandra umbellata	0.020	0.05	10.00	30	0.033	0.083	10.00	30	0.032	0.072	8.67	20
Descurainia sophia [a]	0.008	0.016	10.67	40	0	0	0	0	0	0	0	0
Bromus tectorum [a]	0.007	0.011	6.67	50	0.001	0.002	2.00	20	0.001	0.002	2.00	30
Ceratocephala testiculata [a]	0.005	0.009	10.00	50	0	0	0	0	0.001	0.004	2.67	10
Sisymbrium altissimum [a]	0.002	0.005	3.33	10	0.002	0.006	4.67	20	0.005	0.012	6.67	20
Carduus nutans [a]	0.001	0.002	2.00	30	0.001	0.002	2.67	40	0	0	0	0
Taraxacum officinale [a]	0.001	0.001	1.33	20	0	0	0	0	0	0	0	0
Erodium cicutarium [a]	<0.001	0.001	0.67	10	0	0	0	0	0	0	0	0
Tragopogon dubius [a]	0	0	0	0	0	0	0	0	<0.001	0.001	0.67	10

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

[a] Nonnative species.

The dominant grass was *Poa fendleriana* (muttongrass); the domninant shrubs were *Purshia tridentata* (antelope bitterbrush), *Chrysothamnus depressus* (longflower rabbitbrush) and *Cercocarpus montanus* (birchleaf mountain mahoghany); the dominant succulents were *Opuntia* spp. (prickly pear) and *Yucca baccata* (banana yucca); and the dominant forbs were *Penstemon linariodes* (toadflax penstemon) and *Petradoria pumila* (rock goldenrod). Like the functional groups, foliar cover of individual species differed among the three years, but most of these changes were quite small, especially considering the large standard deviations (table 2 and fig. 3). There was no overall pattern in cover changes among species; some species had their greatest cover in 2007, others had their greatest cover in 2008, and still others had their greatest cover in 2009.

Quadrat and plot frequencies did not change substantially between years, with a few exceptions: *Arabis fendleri* (Fendler rockcress) showed a gradual decrease in quadrat and plot frequency over the three years, and *Cordylanthus wrightii* (Wright bird's beak) showed an increase in quadrat and plot frequency over the three years. A number of species were not present in the plots in all three years. Some species were present in only one of the three years and are referred to here as unique species. Others were present in two of the three years. In 2007, there were nine unique species (not including the two unknowns), In 2008 there were two, and in 2009 there were five (See Appendix A).

In 2007, we found seven nonnative species in the plots. Only three of these species were found in 2008. Three nonnative species were also found in 2009, including one species not found previously: *Tragopogon dubius* (yellow salsify). Appendix A lists all species, along with common names, families, mean foliar covers, and plot frequencies by year.

Diversity indices varied among the three years (table 3). On the scale of the plot, species richness varied between 19.2 to 18.2 species per plot. Shannon diversity (which takes into account relative species abundance, and generally ranges between 1.5 and 3.5) ranged between 1.346 and 1.506, and evenness (the degree to which all species are of equal abundance, ranging from 0 to 1) ranged between 0.458 and 0.524 (Margalef 1972). On the scale of the ecological site, species richness ranged between 57 and 49 species, and beta diversity (a measure of within site heterogeneity, generally ranging between 1 and 5) ranged between 2.849 and 3.132 (McClune and Grace 2002). When these

Table 3. Species diversity metrics for all species and for native species only

	2007		2008		2009	
	Mean	(SD)	Mean	(SD)	Mean	(SD)
All species						
Plot						
Plot richness	19.2	(5.1)	18.2	(4.2)	18.4	(5.0)
Shannon diversity	1.346	(0.347)	1.506	(0.264)	1.443	(0.238)
Evenness	0.458	(0.101)	0.524	(0.092)	0.501	(0.069)
Ecological site						
Ecological site richness	57		49		51	
Beta diversity						
Native species						
Plot						
Plot richness	17.1	(4.8)	17.3	(4.0)	17.7	(4.9)
Shannon diversity	1.324	(0.334)	1.500	(0.262)	1.435	(0.233)
Evenness	0.469	(0.101)	0.531	(0.093)	0.505	(0.073)
Ecological site						
Ecological site richness	50		45		47	
Beta diversity	3.106		2.761		2.814	

indices were recalculated using only native species, all indices were slightly lower, except evenness, which was higher.

Trees

Tree diameters were not remeasured in 2008 or 2009, but tree canopy was assessed in both years. To help determine the best way to measure canopy we used a different methodology each year. In 2008 we measured canopy closure using a hemispherical densiometer. Mean canopy closure was 50.8% with a standard deviation of 15.6. In 2009, we measured canopy cover using the line intercept method, measuring the amount of canopy cover intersecting the three transects. Mean canopy cover was 37.4% with a standard deviation of 9.2%. 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).

Soil stability and hydrologic function

The crew monitored the amount of exposed soil in two ways: cover estimates of soil surface features in quadrats and measurements of basal gaps along transects. These measurements were undertaken in all three years. As expected, most changes in the surface features were relatively small (table 4 and fig. 4). However, three features—undifferentiated crust, bare soil and cyanobacteria—showed large variation among years: (table 4 and fig. 4). The basal gap data is difficult to interpret due to a change in protocol. In 2007 we did not include gaps < 20 cm in our measurement, hence the percentage of plant bases along the transect includes both plant bases and these small gaps (table 5 and fig. 5).

Table 4. Cover of soil surface features

	2007		2008		2009	
Surface feature	Mean (%)	(SD)	Mean (%)	(SD)	Mean (%)	(SD)
Live plant base	3.02	(1.81)	3.34	(1.62)	3.22	(1.68)
Dead woody base	0.28	(0.39)	1.04	(1.73)	0.46	(0.68)
Dead herbaceous base [a]	0	(0)	0.75	(0.44)	0.53	(0.31)
Bare soil	0.84	(0.74)	1.14	(1.08)	5.43	(4.66)
Duff and litter	58.16	(13.62)	56.72	(9.31)	60.65	(7.63)
Undifferentiated crust	18.46	(12.86)	26.83	(10.27)	20.79	(11.22)
Moss	2.11	(1.69)	1.47	(1.54)	0.72	(0.67)
Lichen	0.15	(0.26)	0.14	(0.19)	0.16	(0.24)
Cyanobacteria	8.65	(4.65)	3.71	(4.72)	3.26	(3.99)
Fine gravel (0.2–2 cm)	0.01	(0.01)	0.02	(0.03)	0.01	(0.03)
Coarse gravel (2–7.5 cm)	0.06	(0.10)	0.06	(0.11)	0.07	(0.09)
Cobble (7.5–25 cm)	0.14	(0.42)	0.02	(0.04)	0.02	(0.03)
Stone, bedrock (>25 cm)	0	(0)	0	(0)	0.12	(0.34)
Woody debris	1.42	(0.76)	1.80	(0.90)	2.06	(1.02)

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

[a]Dead herbaceous base was not measured in 2007.

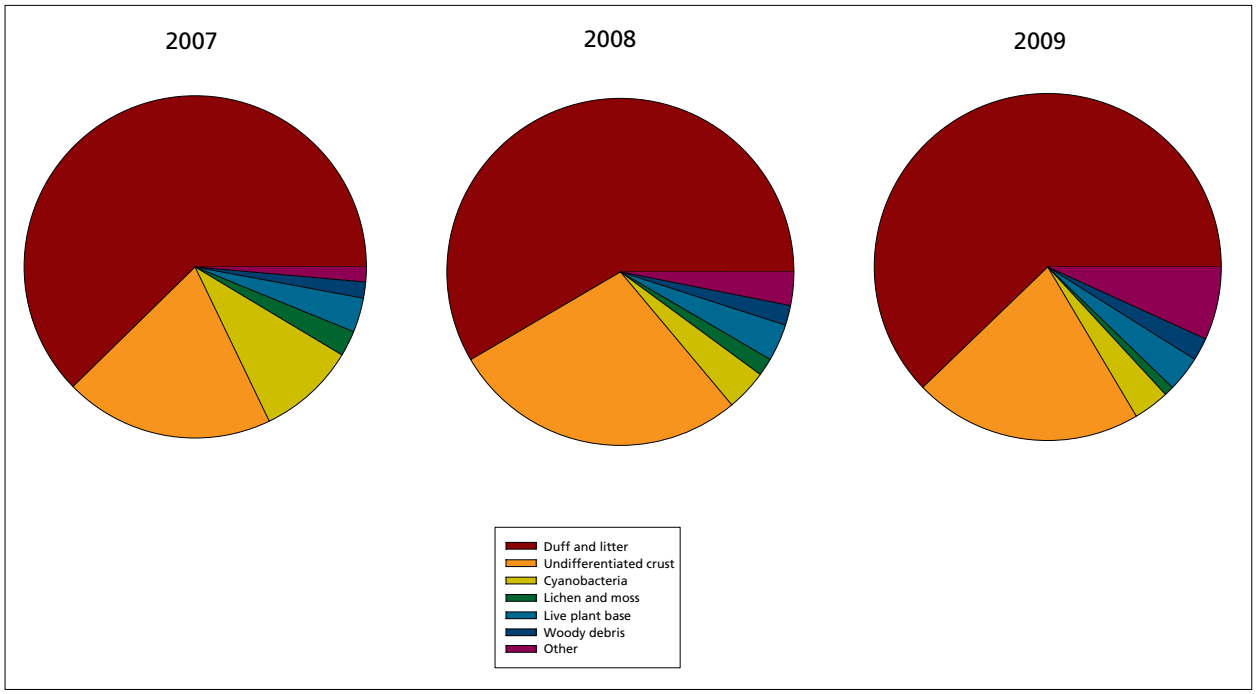

Figure 4. Mean cover of soil surface features in 2007, 2008, and 2009

Table 5. Number of basal gaps, median gap size, and percentage of transect in different gap size classes in 2007, 2008, and 2009

	2007		2008		2009	
Metric	Mean	(SD)	Mean	(SD)	Mean	(SD)
Number of gaps	51.60	(20.48)	124.1	(52.8)	94.1	(43.8)
Median gap size (cm)	194.20	(106.23)	83.0	(59.8)	94.8	(37.6)
Percent of transect in gaps 0–19 cm	n/a	n/a	1.86	(1.18)	1.14	(0.94)
Percent of transect in gaps 20–49 cm	1.87	(1.26)	5.78	(3.31)	4.49	(3.13)
Percent of transect in gaps 50–99 cm	5.14	(2.66)	12.25	(7.34)	9.28	(5.08)
Percent of transect in gaps ≥100 cm	90.46	(4.48)	76.87	(12.62)	81.70	(10.03)
Percent of transect in gaps	97.46	(1.43)	96.75	(1.62)	96.61	(1.75)
Percent of transect in plant bases	2.54	n/a	3.25	(1.62)	3.39	(1.76)

Note: Gaps were measured slightly differently in 2007. Gaps <20 cm were not measured and are included with plant bases.

There is substantial among year variation in some of the metrics.

Discussion

The data presented here indicate relatively small variation in the vegetation and surface features in the Loamy Mesa Top Pinyon-Juniper ecological site among the years 2007, 2008, and 2009. Variation in functional group cover and species cover and frequencies were minor, especially considering the

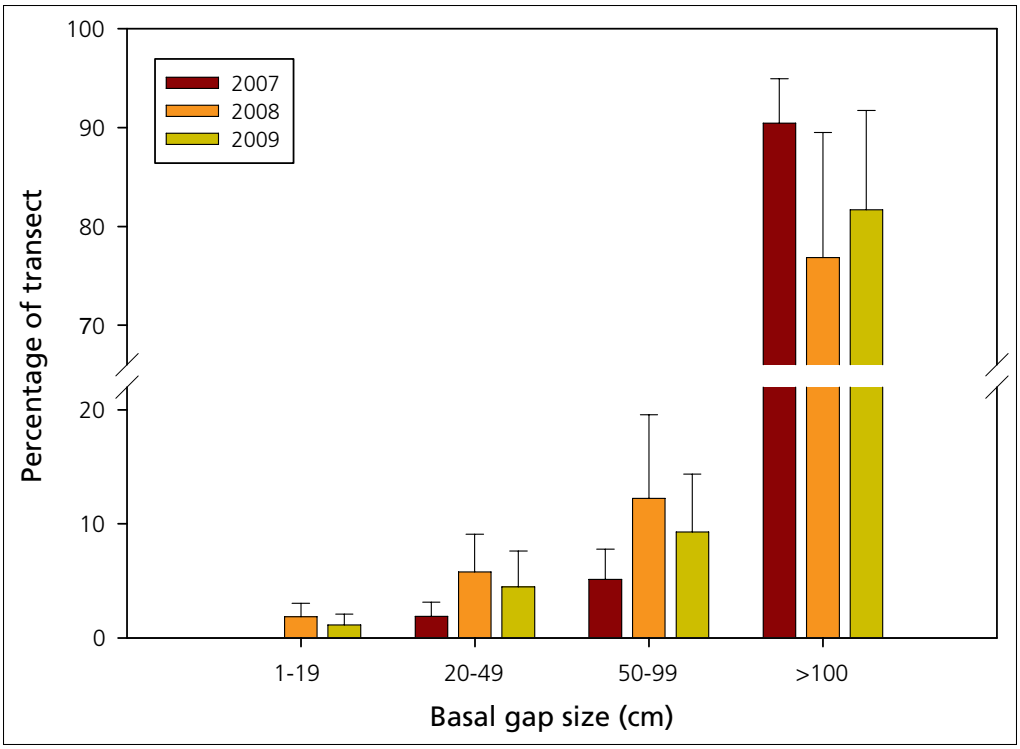

Figure 5. Percentage of transect in different gap sizes in 2007, 2008, and 2009. Note: In 2007 basal gaps <20 cm were not measured. Error bars represent one standard deviation.

high variability among plots. Similarly, the species diversity indices showed small among-year variation. The variation that did occur is, in part, attributable to variation in precipitation. 2008 had an extremely wet winter, and 2007 and 2008 had strong summer monsoons. 2009, on the other hand, was generally drier, rising above the long term precipitation average only slightly in April and June (fig. 6). The timing and the amount of precipitation differentially influences germination, growth, and flowering of species. Annual species and perennial forbs seem to be influenced the most by the climatic variation. Seven nonnative species were found in the plots in 2007, but three of these species were not found in 2008 and 2009. One new species was found in 2009. The large number of nonnative species in 2007 may have been a result of the large amount of precipitation. All but *Taraxacum officinale* and *Carduus nutans* were annuals.

Cover of soil surface features showed variation, particularly in undifferentiated crust, bare soil, and cyanobacteria. These variations may be attributable to how soil surface features appear in wet conditions versus dry conditions. When the ground surface is wet, cyanobacteria are much more visible, and undifferentiated crust becomes more difficult to distinguish from bare soil. In addition, physical crust is formed by raindrop impact and decreases with increasing time since the last rainfall. As a result of the particularly wet August in 2007, many of the plots were sampled during or shortly after precipitation events, which may have caused the crew to incorrectly estimate the cover of soil surface features.

We stress that the differences noted between years are not indicative of any trend, since trends cannot be determined with only three years of sampling. Nor should they be interpreted as being ecologically significant. Differences are due to ecological variability, such as annual climatic fluctuation or sampling errors inherent in the field sampling process. Cover estimation may vary among individuals (and crews), species may be mis-identified, slight differences between observers in applying sampling methods may go unnoticed, and the location of transects and quadrats vary slightly from

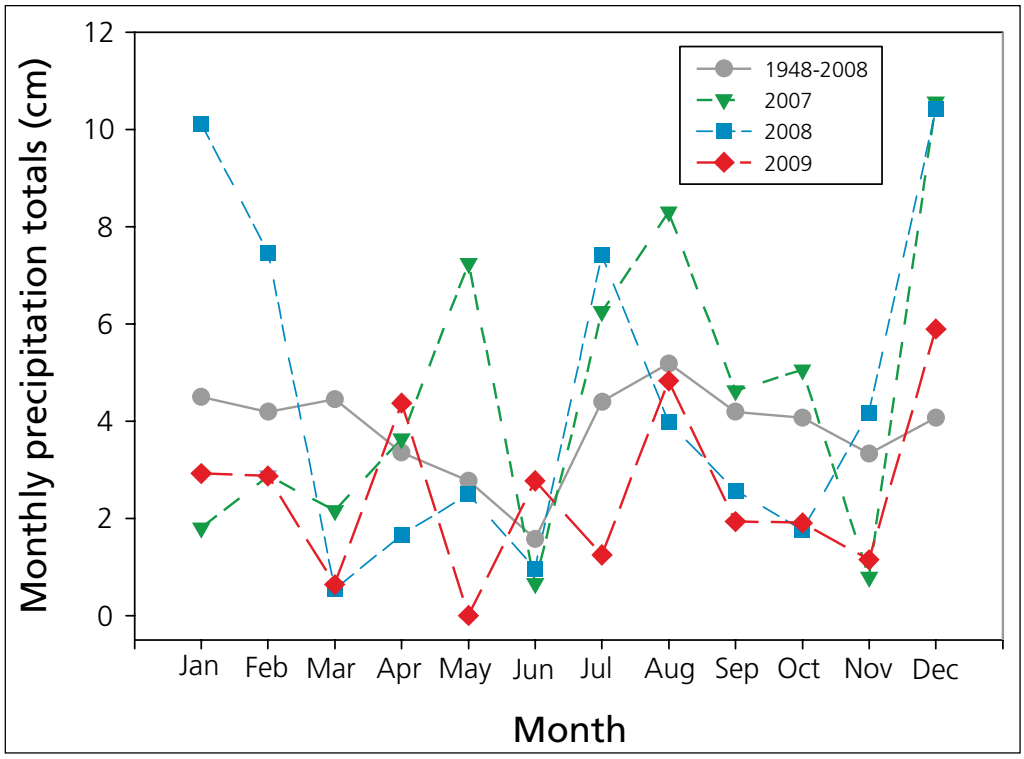

Figure 6. Total monthly precipitation for 2007, 2008, and 2009 with the mean monthly totals for 1948 through 2009 (WRCC 2010)

year to year. We strive to minimize these errors by ensuring that transect lines are as straight as possible, quadrats are placed correctly, and field crews are thoroughly trained on methods and species identification and remain calibrated on cover estimation.

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

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Appendix A

Complete species list for the Loamy Mesa Top Pinyon-Juniper ecological site with mean foliar cover and frequency for species in 2007, 2008, and 2009

			2007		2008		2009	
Species	Common name	Family	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
Achnatherum hymenoides	Indian ricegrass	Poaceae	0.009	10	0.017	20	0.016	20
Amelanchier utahensis	Utah serviceberry	Rosaceae	0.002	10	0.002	10	0.025	20
Androsace septentrionalis	pygmy rock jasmine	Primulaceae	<0.001	10	0	0	0	0
Antennaria parvifolia	small leaf pussytoes	Asteraceae	<0.001	0	0	0	<0.001	10
Antennaria rosea	rosy pussytoes	Asteraceae	<0.001	10	<0.001	10	0.000	0
Arabis fendleri	Fendler's rockcress	Brassicaceae	0.054	90	0.026	70	0.015	60
Arabis holboellii	Holboell's rockcress	Brassicaceae	<0.001	10	<0.001	10	0	0
Artemisia tridentata	basin big sagebrush	Asteraceae	0.760	10	1.028	10	0.875	10
Astragalus	milkvetch	Fabaceae	0.008	50	0.044	70	0.030	70
Astragalus pattersonii	Patterson's milkvetch	Fabaceae	0	0	0	0	0.010	20
Bromus tectorum [a]	cheatgrass	Poaceae	0.007	50	0.001	20	0.001	30
Calochortus flexuosus	winding mariposa lily	Liliaceae	0	0	0	0	0.002	10
Carduus nutans [a]	nodding thistle	Asteraceae	0.001	30	0.001	40	0.000	0
Carex rossii	Ross' sedge	Cyperaceae	0	0	0	0	<0.001	10
Ceratocephala testiculata [a]	curveseed butterwort	Ranunculaceae	0.005	40	0	0	0.001	10
Cercocarpus montanus	birchleaf mountain mahogany	Rosaceae	0.104	30	0.261	30	0.261	30
Chenopodium album	lambsquarters	Chenopodiaceae	0.004	50	0.002	40	0.001	30
Chenopodium leptophyllum	narrowleaf goosefoot	Chenopodiaceae	0	0	0.001	10	0.001	20
Chrysothamnus depressus	longflower rabbitbrush	Asteraceae	0.119	30	0.087	40	0.067	40
Comandra umbellata	bastard toadflax	Santalaceae	0.020	30	0.033	30	0.032	20
Cordylanthus wrightii	Wright's bird's beak	Scrophulariaceae	0.029	80	0.080	90	0.059	90
Cryptantha sp.	cryptantha	Boraginaceae	0	0	0	0	<0.001	10
Dalea sp.	prairie clover	Fabaceace	0.001	10	0	0	0	0
Delphinium sp.	larkspur	Ranunculaceae	0	0	0	0	<0.001	10

Appendix A *continued.*

Species	Common name	Family	2007		2008		2009	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
Descurainia sophia [a]	herb sophia	Brassicaceae	0.008	40	0	0	0	0
Draba reptans	Carolina draba	Brassicaceae	0.017	60	0	0	<0.001	10
Echinocereus sp.	hedgehog cactus	Cactaceae	0.000	10	0	0	0	0
Elymus elymoides	squirreltail	Poaceae	0.019	40	0.022	40	0.011	50
Erigeron divergens	spreading fleabane	Asteraceae	0.006	10	0.011	20	0.002	30
Eriogonum racemosum	redroot buckwheat	Polygonaceae	0.028	80	0.053	80	0.036	80
Eriogonum umbellatum	sulphur-flowered buckwheat	Polygonaceae	0.002	30	0.007	30	0.007	20
Erodium cicutarium [a]	stork's bill	Geraniaceae	<0.001	10	0	0	0	0
Escobaria vivipara	spinystar	Cactaceae	<0.001	10	<0.001	10	<0.001	10
Gutierrezia sarothrae	broom snakeweed	Asteraceae	0.021	10	0.023	10	0.017	30
Hesperostipa comata	needle and thread	Poaceae	0	0	0.013	10	0.098	10
Heterotheca villosa	hairy false goldenaster	Asteraceae	0.001	20	0.002	10	0.002	10
Ipomopsis aggregata	scarlet gilia	Polemoniaceae	<0.001	10	0	0	0	0
Iris missouriensis	western blue flag	Iridaceae	0	0	<0.001	10	0	0
Koeleria macrantha	prairie junegrass	Poaceae	0.013	30	0.035	40	0.008	20
Lappula occidentalis	flatspine stickseed	Boraginaceae	0.001	10	0	0	0	0
Lepidium montanum	mountain pepperweed	Brassicaceae	0.001	10	0	0	0	0
Lesquerella rectipes	straight bladderpod	Brassicaceae	0.004	10	0.011	20	0.005	30
Lupinus ammophilus	sand lupine	Fabaceae	0.002	40	0.165	70	0.032	80
Lupinus argenteus	silvery lupine	Fabaceae	<0.001	10	0.006	40	<0.001	10
Machaeranthera canescens	hoary tansyaster	Asteraceae	0.009	60	0.020	70	0.007	80
Opuntia spp.	prickly pear	Cactaceae	0.636	90	0.496	90	0.448	90
Packera multilobata	lobeleaf groundsel	Asteraceae	<0.001	10	<0.001	10	<0.001	10
Pedicularis centranthera	dwarf lousewort	Scrophulariaceae	0.001	20	0.024	30	0.043	40
Penstemon barbatus	beardlip penstemon	Scrophulariaceae	0.017	60	0.016	70	0.014	60
Penstemon linarioides	toadflax penstemon	Scrophulariaceae	0.462	100	0.527	100	0.551	100
Peraphyllum ramosissimum	squaw apple	Rosaceae	0.002	10	0.002	10	0.007	10
Petradoria pumila	rock goldenrod	Asteraceae	0.158	50	0.165	50	0.108	50

Appendix A *continued.*

Species	Common name	Family	2007		2008		2009	
			Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
Phlox gracilis	slender phlox	Polemoniaceae	0.009	20	0	0	0.006	10
Phlox hoodii	Hood's phlox	Polemoniaceae	0.031	40	0.030	40	0.037	40
Phlox longifolia	longleaf phlox	Polemoniaceae	0.002	10	0.003	20	0.006	30
Phoradendron juniperinum	juniper mistletoe	Viscaceae	0	0	0.002	10	0	0
Poa fendleriana	muttongrass	Poaceae	4.596	100	4.042	100	4.202	100
Polygonum douglasii	Douglas' knotweed	Polygonaceae	0.013	100	0.019	100	0.015	100
Purshia tridentata	antelope bitterbrush	Rosaceae	1.297	90	1.398	90	1.412	90
Quercus gambelii	Gambel oak	Fagaceae	0.005	10	0.010	10	0.010	10
Sisymbrium altissimum [a]	tumblemustard	Brassicaceae	0.002	10	0.002	20	0.005	20
Sphaeralcea coccinea	scarlet globemallow	Malvaceae	0.001	10	0.003	10	0.005	10
Sporobolus cryptandrus	sand dropseed	Poaceae	0	0	<0.001	10	0	0
Streptanthus cordatus	heartleaf twistflower	Brassicaceae	<0.001	10	<0.001	10	0	0
Taraxacum officinale [a]	common dandelion	Asteraceae	0.001	20	0	0	0	0
Tragopogon dubius [a]	yellow salsify	Asteraceae	0	0	<0.001	10	<0.001	10
Yucca baccata	banana yucca	Agavaceae	0.651	80	0.628	70	0.813	70
Unknown MEVE08032007-1			<0.001	10	0	0	0	0
Unknown MEVE08032007-2			<0.001	10	0	0	0	0

[a] Nonnative species