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Integrated Upland Vegetation and Soils Monitoring for Petrified Forest National Park

2007 Summary Report

Natural Resource Data Series NPS/SCPN/NRDS—2009/005

ON THE COVER
Clayey Fan Ecological Site at Petrified Forest 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 2007 field crew consisted of Mare Nazaire and Jeff Organ.

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Introduction and Background

The National Park Service Vital Signs Monitoring Program was designed to monitor the status and trends in the condition of park natural resources, providing a strong scientific foundation for decision making and resource conservation for park managers. The Southern Colorado Plateau Network (SCPN) has selected upland vegetation and soils as indicators of the overall condition of upland ecosystems.

The upland ecosystems at Petrified Forest National Park (PEFO) face several threats. Exotic species pose a major threat to these grasslands/shrublands. Fifty-seven non-native species have been documented in the park (Thomas et al. 2004), including *Bromus tectorum* (cheatgrass), *Salsola* spp. (Russian thistle) and five noxious weeds (Hansen et al. 2003). Global climate change has the potential to alter the composition and structure of the grasslands. For example, increased droughts could cause a decrease in the cover of grasses, which in turn could cause an increase in soil erosion.

In 2007 the Integrated Upland Monitoring program of SCPN began upland monitoring at PEFO. The purpose of this report is to document monitoring activities in the 2007 field season, and summarize the data that were collected.

Methods

Sampling Frames

Our monitoring at PEFO is based on ecological sites developed by the US Natural Resources Conservation Service (NRCS). Ecological sites are based on soil survey data and represent landscapes with characteristic soils, hydrology, plant communities, and disturbance regimes and responses (Butler et al. 2003).

SCPN and park staff selected three ecological sites to be monitored at Petrified National Forest (PEFO): Clayey Fan, Loamy Upland, and Sandy Loam Upland. The three ecological sites comprise a large area of the park. The vegetation of these sites is largely composed of perennial grasses and shrubs.

Several modifications were made to the spatial coverages of the ecological sites using GIS, including the removal of roads, buildings and other infrastructure, and slopes greater than 20%. A set of spatially distributed sampling points was created using the Generalized Random-Tessellation Stratified (GRTS) design (Stevens and Olsen 2004) (see Figures 1 and 2). Park staff reviewed the sampling points, and rejected those points that landed within close proximity of archaeological sites. Before establishing a plot, the Integrated Upland crew conducted an ecological site assessment for each sampling point, and rejected the site if it did not fall within the ecological site, had a slope greater than 20%, or contained a major disturbance.

SCPN derived these three ecological sites from the 2002 NRCS soil survey. An updated survey was published in 2007 which merged the Sandy Loam Upland and Loamy Upland ecological sites into a single ecological site, designated Sandy Loam Upland. This change likely took place due to the fine scale mosaic pattern the two ecological sites display in the field and their similarity in soils and vegetation. In light of this change, SCPN decided after the 2007 field season to merge these two

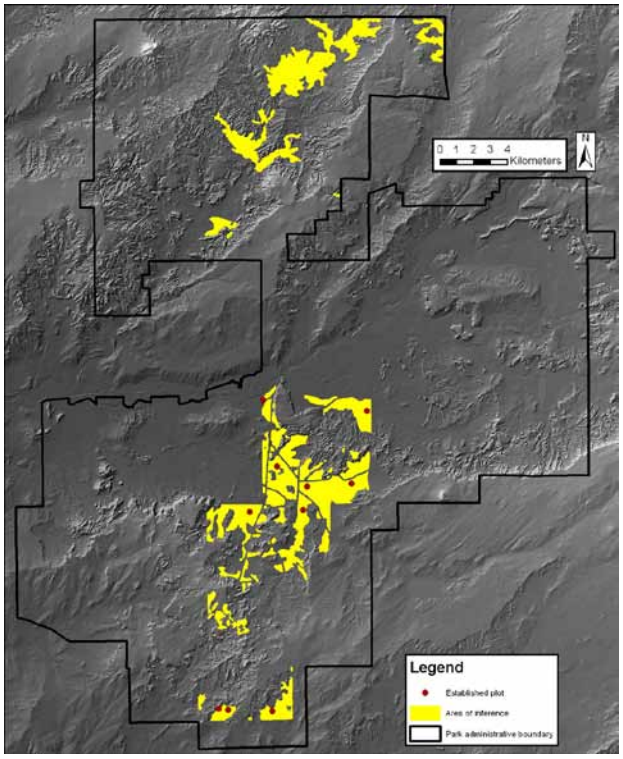

Figure 1. Sampling frame of Clayey Fan ecological site with the 10 plots established in 2007.

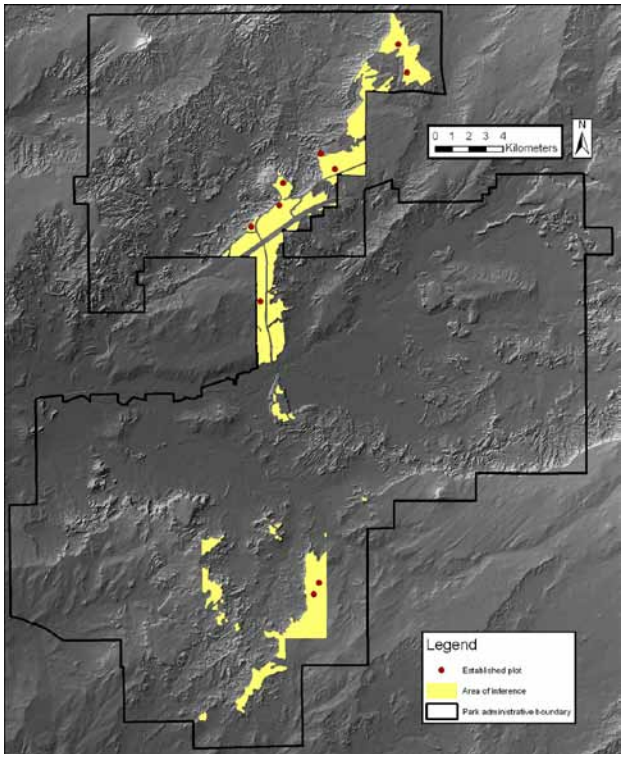

Figure 2. Sampling frame of Sandy Loam Upland ecological site with the 10 plots established in 2007.

ecological sites in our sampling frame in order to agree with the most recent soil survey data available.

Field Methods

The Southern Colorado Plateau Upland Monitoring crew implemented monitoring at PEFO in 2007 with the establishment of 10 plots in each of the three ecological sites. All plots were installed and read in mid September through early October.

With the merging of the Loamy Upland and the Sandy Loam Upland sites, it will only be necessary to resample 10 plots in this combined ecological site for pilot sampling. Although we sampled 10 plots in each of the two ecological sites in 2007, this report only presents data from 10 of these plots (the first 5 GRTS points from each of the original two sites) so these data will be comparable to subsequent years in the pilot sampling period.

Field methodology is provided in detail in the SCPN Integrated Upland Protocol (DeCoster et al., in review). Plots are 0.50 ha in size, measuring 71 m x 71 m. Data are collected on three 50 m transects, spaced 25 meters apart.

Shrub and Herbaceous Vegetation

Along each transect, shrub and herbaceous vegetation is sampled at 10 m intervals using five sets of nested quadrats. The largest quadrat size is 10 m^2 (2 m x 5 m) with three smaller quadrats nested

inside (0.01 m^2, 0.1 m^2, and 1 m^2). The presence of individual vascular species is recorded for each nested sub-quadrat. For each individual herbaceous and shrub species, percent cover is estimated in the 10 m^2 quadrat and recorded as one of 12 cover classes. Percent cover is also estimated for each functional group (e.g. graminoids, forbs, shrubs) in the largest quadrat and recorded as one of 12 cover classes.

Tree Overstory and Saplings

No tree species were observed in any of these plots.

Soil Stability and Hydrologic Function

Basal gaps are measured along each of the transects to provide a measure of the amount of bare soil. A soil aggregate stability test is conducted using 18 soil samples collected along the transects. Percent cover of soil surface features is estimated in the 1 m^2 quadrats in conjunction with the shrub and herbaceous data and recorded as one of 12 cover classes.

Data Summary

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

For herbaceous and shrub vegetation, cover and frequency are calculated for each species from the cover class midpoints. The mean cover is calculated for each plot, and the mean and standard deviation (SD) and range of cover (where that species occurs) are calculated for the ecological site. The species frequency is calculated for quadrats (mean percentage of quadrats per plot where the species occurs) and for plots (percentage of plots where the species occurs). The mean cover and SD of functional groups and surface features are calculated in a similar fashion.

1. Four diversity measures are calculated for herbaceous and shrub species (Magurran 1988). Calculations are made for all species in the site, and recalculated for native species only.
2. Species richness (S) is the number of species at a given spatial scale, and is calculated at all spatial scales (i.e. for each nested quadrat size, for the plot, and for the ecological site).
3. The Shannon Diversity Index (H') provides a measure of species diversity that takes into account the relative abundance of each species:

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

where p_i is the mean cover of each species.

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

$$H^r / \ln(S) \qquad (2)$$

4. Beta diversity ($ß_w$) is a measure of within-ecological site heterogeneity:

$$S_e / (S_p - 1) \qquad (3)$$

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.

Five calculations are made for the basal gaps data: (1) median basal gap size, (2) percentage of transects comprised by gaps, (3) percentage of transects comprised by gaps ≥ 50 cm, (4) number of gaps by size class, and (5) total number of gaps. The mean and SD are calculated for each metric.

The mean soil aggregate stability index is calculated along with the standard deviation. This index ranges between 1 and 6, where 1 indicates low aggregate stability and 6 indicates high stability. The index is also calculated separately for samples with vegetative cover and those without vegetative cover.

Results

Clayey Fan Ecological Site

Herbaceous and Shrub Vegetation

The herbaceous and shrub vegetation of the PEFO Clayey Fan ecological site is dominated by grasses. Table 1 lists the 15 most abundant species, and shows that 5 of the 6 most abundant species are grasses: *Sporobolus airoides* (alkali sacaton), *Pleuraphis jamesii* (James' galleta), *Bouteloua gracilis* (blue grama), *Sporobolus coromandelianus* (Madagascar dropseed), and *Bouteloua barbata* (sixweeks grama). The latter two are annual species, and are expected to vary annually. Common shrubs include *Atriplex obovata* (mound saltbush), and *Atriplex canescens* (fourwing saltbush). Several species of shrubs such as *Sarcobatus vermiculatus* (greasewood) and *Ephedra torreyana*, occur in few plots, but are locally abundant where they occur. Common forbs include *Salsola tragus* (prickly Russian thistle), and *Chamaesyce* spp Group A , a grouping of three species of annual sandmats that are difficult to distinguish in the field. High variation in species composition is indicated by large standard deviations (relative to their means), wide ranges in mean plot cover, and low quadrat and plot frequencies. A complete list of species found in the plots is located in Appendix A and includes common names, plant families, mean foliar cover and plot frequencies.

Three non-native species were found in the plots: *Salsola tragus* was the seventh most abundant species and occurred in all of the plots. In one plot its cover exceeds 5%. *Portulaca oleracea* is in low abundance, although it occurs in 60% of the plots and reaches a cover of 0.397% in one plot. *Bromus tectorum* is very sparse, and occurs in 40% of the plots.

The overall vegetative cover of the plots is rather low- 14.91% (Table 2). The covers of the functional groups confirm the dominance of grasses. Of the total vegetative cover, perennial grasses comprise 9.13%; shrubs comprise 3.05%; annual grasses comprise 2.31%; forbs comprise 1.50%; and cacti/succulents comprise 0.04%. Standing dead herbaceous cover is substantial (4.09%), while standing dead woody is relatively minor (0.86%). Standard deviations for total live vegetation and perennial grass cover are substantially lower (relative to their means) than those found for mean species cover.

Table 1. Cover and Frequency of Shrub and Herbaceous Species for the Clayey Fan Ecological Site. Foliar cover of the fifteen most abundant vascular species, expressed as a percentage. *Chamaesyce* spp. that are not identifiable in the field to species are placed in one of two groups. All non-native species are included, and are indicated by an asterisk. The range in foliar cover is provided for where the species occurs. (Many species do not occur in every plot of an ecological site; for these species, the minimum range of 0% is not provided).

Species	Foliar Cover (%)			Frequency (%)	
	Mean	SD	Range	Quadrat	Plot
Sporobolus airoides	6.181	6.117	0.773-22.087	92.00	100
Atriplex obovata	1.589	1.453	0.103-4.300	58.00	90
Pleuraphis jamesii	1.266	1.172	0.020- 3.800	54.67	100
Sporobolus coromandelianus	1.251	1.692	0.007-4.640	36.00	80
Bouteloua gracilis	1.210	1.588	0.050-4.257	50.67	90
Bouteloua barbata	1.062	1.240	0.003-2.797	55.33	90
*Salsola tragus**	0.973	1.618	0.087-5.367	60.67	100
Atriplex canescens	0.565	1.030	0.120-3.330	21.33	50
Sarcobatus vermiculatus	0.293	0.928	2.933-2.933	4.00	10
Chamaesyce spp. Group A	0.196	0.263	0.003-0.673	61.33	100
Achnatherum hymenoides	0.165	0.167	0.013-0.447	34.67	90
Atriplex confertifolia	0.150	0.276	0.153-0.883	6.00	40
Ericameria nauseosa	0.119	0.178	0.120-0.500	5.33	40
Gutierrezia sarothrae	0.089	0.165	0.093-0.527	19.33	40
Sphaeralcea hastulata	0.069	0.067	0.003-0.183	30.67	90
*Portulaca oleracea**	0.044	0.124	0.003-0.397	12.00	60
*Bromus tectorum**	0.004	0.008	0.003-0.023	5.33	40

Table 2. Cover of Functional Groups for the Clayey Fan Ecological Site. The cover of functional groups is expressed as a percentage. Components of total live vegetation are not strictly additive due to several factors: calculations are made from cover class midpoints, the various components may overlap, and the cover values are estimated independently.

Functional Group	Foliar Cover (%)		
	Mean	SD	Range
Total Live Vegetation	14.91	5.58	8.00-23.73
Perennial Grass	9.13	5.10	4.03-22.42
Annual Grass	2.31	2.74	0-7.01
Forbs	1.50	1.52	0.23-5.37
Shrubs, Dwarf Shrubs, Woody Vines	3.05	3.02	0.39-10.65
Cacti/ Succulents	0.04	0.03	0-0.09
Standing Dead Herbaceous	4.09	1.11	2.72-5.80
Standing Dead Woody	0.86	0.71	0.35-2.77

A total of 69 species are recorded in this ecological site, the highest recorded for any of the grasslands/shrublands sites the SCPN Upland Monitoring program has monitored to date. Mean species richness is 24.30 species per plot (Table 3a). Shannon diversity is 1.755, which is low—values generally fall between 1.5 and 3.5 (Margaleff 1972). The other diversity indices have moderate values. Evenness is 0.552: this index is bounded by 0 and 1, where a value of 1 indicates that all species are of equal abundance. Beta diversity is 2.961: high values (greater than 5) indicate large

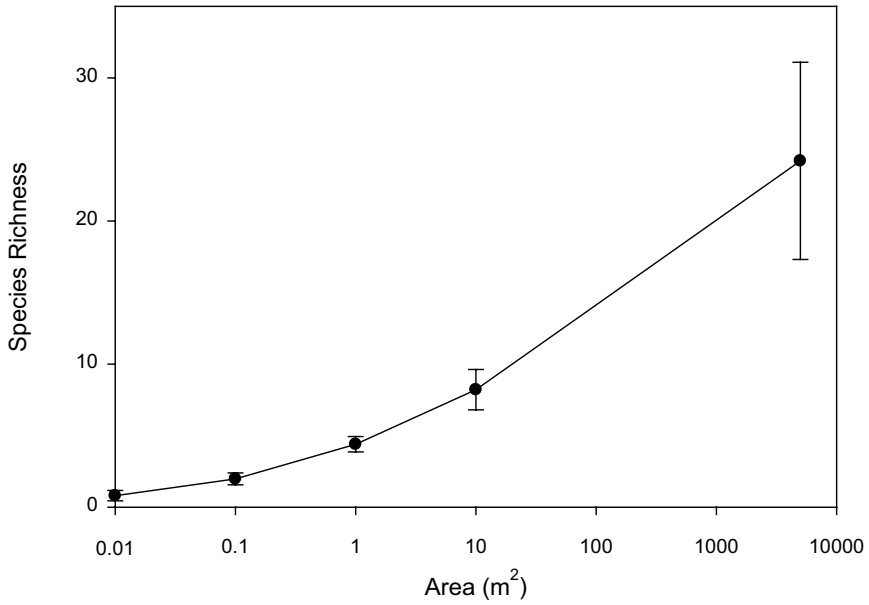

Figure 3. Mean Species Richness at 5 spatial scales for the Clayey Fan Ecological Site. Species richness is the number of vascular species in a given area. Estimates are based on 10 plots with 15 quadrats each. Error bars represent 1 standard deviation.

Table 3. Species Diversity for the Clayey Fan Ecological Site. Species diversity is expressed as mean, minimum and maximum species richness per plot, the total richness for the ecological site, Shannon-Weaver Diversity Index, Evenness Index and Beta Diversity. Metrics are presented for all species and only native species.

Table 3a. All Species				
Metric	**Plot**		**Ecological Site**	
	Mean (SD)	**Range**	**Metric**	
Richness	24.3 (7.1)	15 – 35	Richness	69
Shannon Diversity	1.755 (0.506)		ß Diversity	2.961
Evenness	0.557 (0.143)			
Table 3b. Native Species				
Metric	**Plot**		**Ecological Site**	
	Mean (SD)	**Range**	**Metric**	
Richness	22.3 (7.4)	12 – 34	Richness	66
Shannon Diversity	1.706 (0.503)		β Diversity	3.099
Evenness	0.554 (0.148)			

differences among plots, whereas low values (less than 1) indicate similar composition among plots (McCune and Grace 2002). All of the diversity indices are lowered by a small amount when only native species are examined, with the exception of beta diversity which increases slightly (Table 3b). The species area curve (Figure 3) illustrates how species accumulate with increased area. The shape of the curve is only slightly concave. This seems to indicate low diversity at finer spatial scales (less than 1 m^2), and is typical of grassland/shrublands in the region.

Soil Stability and Hydrologic Function

The amount of exposed soil is monitored in two ways: soil surface feature cover estimates in quadrats and basal gap intercepts. The cover of surface features (Table 4) shows that the majority of the soil surface is exposed, composed of undifferentiated crust (70.51%) and bare soil (14.68%). Live plant bases comprise 5.86%, dead herbaceous bases comprise 2.59%, and duff/litter comprises 6.26%. Biological crusts (moss and cyanobacteria), dead woody bases, and fine and coarse gravel comprise less than 1%. No lichen, cobble, stone or woody debris were observed.

The basal gap data (Table 5) show that 96.7% of transect length is gap; consequently 3.3% intersects plant bases. (Note that quadrat cover estimates yielded higher plant base cover values than basal gap intercept methods). The median gap size is 78.7 cm (Table 5).

The percentage of transects length consisting of gaps greater than 50 cm is somewhat lower (89.0%). The distribution of gaps sizes shows that the largest gap size class is the most abundant (Figure 4).

Soil aggregate stability provides a measurement of erodibility of soil (Table 6). The mean rating

Table 4. Surface Features Cover for the Clayey Fan Ecological Site. Cover of surface features is expressed as a percentage. Cover of surface features is estimated in 1 m^2 quadrats, and the plot mean is calculated from the cover class midpoints. The features do not add up to 100% because calculations were made from cover class midpoints, and estimations may have observer error.

Surface Feature	Cover (%)		
	Mean	SD	Range
Live Plant Base	5.86	2.51	2.82-10.95
Dead Woody Base	0.35	0.26	0.06-0.94
Dead Herbaceous Base	2.59	0.89	1.45-3.95
Bare Soil	14.68	7.16	2.32-27.72
Duff and Litter	6.26	3.65	3.14-15.60
Undifferentiated Crust	70.51	6.57	57.57-79.83
Moss	0.50	0.93	0-2.83
Lichen	0	0	0-0
Cyanobacteria	0.13	0.42	0-1.33
Fine Gravel (0.2 cm- 2cm)	0.78	1.28	0-3.94
Coarse Gravel (2cm – 7.5 cm)	0.14	0.22	0-0.54
Cobble (7.5 cm – 25 cm)	0	0	0-0
Stone, Boulder, Bedrock (>25 cm)	0	0	0-0
Woody Debris	0	0	0-0

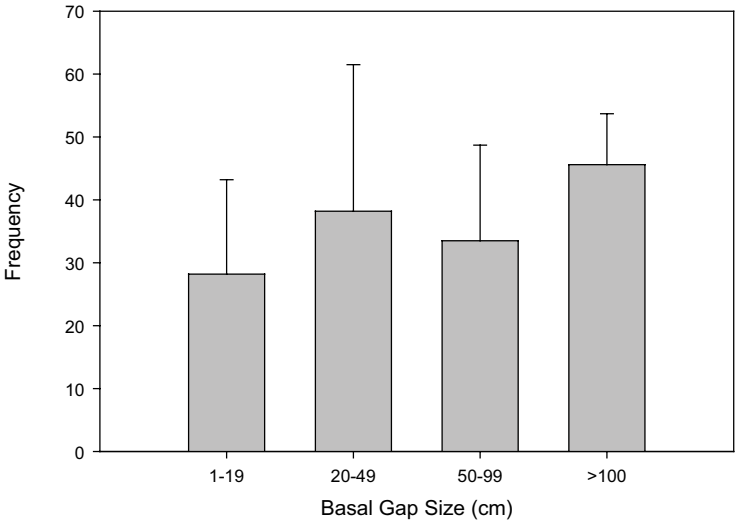

Figure 4. Basal Gap Size Distribution. The frequency of basal gaps is shown for 4 size classes. Error bars represent 1 standard deviation.

Table 5. Basal Gaps for the Clayey Fan Ecological Site. Basal gaps are measured along three 50 m transects in each plot. The mean and standard deviation of each metric is calculated for the 10 plots in the ecological site.

Metric	Mean	(SD)
Gap Number	119.0	(42.1)
Median Gap Size (cm)	78.7	(29.6)
Percent of Transect in Gaps	96.7	(1.3)
Percent of Transect in Gaps ≥ 50 cm	89.0	(4.8)

Table 6. Soil Stability for the Clayey Fan Ecological Site. Mean soil stability rating by cover. 18 points were measured in each of the10 plots. Ratings range from 1-6: 1 being the lowest stability and 6 being the highest

	Soil Stability Rating	
	Mean	(SD)
Cover	4.41	(0.67)
No Cover	3.67	(0.43)
Total	3.96	(0.42)

is 3.96, which is moderate. Soil occurring under vegetative cover has a higher stability rating than bare soil without cover: 4.41 compared to 3.67.

Sandy Loam Upland Ecological Site

Herbaceous and Shrub Vegetation

The herbaceous and shrub vegetation of the PEFO Sandy Loam Upland ecological site is dominated by a mixture grasses and shrubs. Table 7 lists the 15 most abundant species, and shows that the 3 most abundant species are grasses: *Bouteloua gracilis* (blue grama), *Sporobolus airoides* (alkali sacaton), and *Pleuraphis jamesii* (James' galleta).

The next three most abundant species are shrubs: *Gutierrezia sarothrae* (broom snakeweed), *Atriplex canescens* (fourwing saltbush) and *Artemesia filifolia* (sand sagebrush). Several species are patchily distributed, but often locally abundant where they occur. These include *Bouteloua eriopoda* (black grama), *Artemisia filifolia* (sand sagebrush) and *Bromus tectorum* (cheatgrass). *Salsola tragus* (prickly Russian thistle) is the only abundant forb. Species abundances are moderately variable as indicated by the high standard deviations (relative to the means), wide ranges in cover and low quadrat and plot frequencies. A complete list of species found in the plots is located in Appendix B and includes common names, plant families, mean foliar cover and plot frequencies.

There are four non-native species that occur in the Sandy Loam Upland plots. *Bromus tectorum* is

the seventh most abundant species, with a mean cover of 0.726%, and occurs in 60% of the plots. In one plot it has a cover if 6.98%. *Salsola tragus* is the eleventh most abundant species, and has a mean cover of 0.363%, and occurs in 70% of the plots. *Portulaca oleracea* (little hogweed) occur in one plot in very low abundance.

Table 7. Cover and Frequency of Shrub and Herbaceous Species for the Sandy Loam Upland Ecological Site. Foliar cover of the fifteen most abundant vascular species, expressed as a percentage. All non-native species are included and are indicated by an asterisk. The minimum range in foliar cover is provided for where the species occurs. (Many species do not occur in every plot of an ecological site; for these species, the minimum range of 0% is not provided)

Species	Foliar Cover %			Frequency (%)	
	Mean	SD	Range	Quadrat	Plot
Bouteloua gracilis	3.712	3.512	1.937- 11.753	65.33	80
Sporobolus airoides	2.622	4.457	0.040- 11.570	44.00	90
Pleuraphis jamesii	2.589	2.562	0.100- 8.633	75.33	100
Gutierrezia sarothrae	1.495	0.990	0.787-3.433	70.67	90
Atriplex canescens	1.085	1.092	0.070- 2.873	43.33	90
Chrysothamnus greenei	0.776	1.405	0.050-4.387	22.00	50
Artemisia filifolia	0.743	1.551	0.373- 4.567	14.67	30
*Bromus tectorum**	0.726	2.198	0.010- 6.980	20.67	60
Bouteloua eriopoda	0.714	1.735	0.040- 5.600	20.67	60
Achnatherum hymenoides	0.484	0.685	0.060- 2.233	50.00	90
Artemisia bigelovii	0.365	0.745	0.020- 2.323	13.33	30
*Salsola tragus**	0.363	0.783	0.233- 2.410	36.67	70
Ephedra torreyana	0.279	0.425	0.100- 1.350	12.00	60
Hesperostipa comata	0.256	0.403	0.007- 1.033	26.00	60
Atriplex obovata	0.224	0.709	2.243- 2.243	8.00	10
Sporobolus flexuosus	0.224	0.694	0.040- 2.200	6.67	20
*Portulaca oleracea**	0.002	0.006	0.020-0.020	0.67	10
*Polygonum aviculare**	<0.001	0.001	0.003-0.003	0.67	10

Overall vegetative cover is relatively low, comprising 18.58% (Table 8). The dominance of grasses and shrubs is confirmed: the cover perennial grass and graminoids is 11.21% and the cover of shrubs is 5.35%. The standard deviations and ranges of these groups show moderately low variability. Forb cover, cactus/ succulent cover and annual grass cover are less than 1%. Standing dead herbaceous cover is 5.01%, while standing dead woody cover is 1.23%.

A total of 63 species are recorded in this ecosite, with a mean species richness of 23.6 species per plot (Table 9a). Shannon diversity is 1.859, which is low. Values generally fall between 1.5 and 3.5 (Margalef 1972). Evenness is moderately high—0.586. The Evenness Index is bounded by 0 and 1, where a value of 1 indicates that all species are of equal abundance. Beta diversity is 2.788, which is moderate. High values (greater than 5) indicate large differences among plots, whereas low values

Table 8. Cover of Functional Groups for the Sandy Loam Upland Ecological Site. The cover of functional groups is expressed as a percentage. Components of total live vegetation are not strictly additive due to several factors: calculations are made from cover class midpoints, the various components may overlap, and the cover values are estimated independently.

Functional Group	Foliar Cover (%)		
	Mean	SD	Range
Total Live Vegetation	18.58	5.33	8.63-27.83
Perennial Grass, Graminoids	11.21	4.99	0.68-20.00
Annual Grass	0.71	2.03	0-6.48
Forbs	0.92	1.18	0.17-3.15
Shrubs, Dwarf Shrubs, and Woody Vines	5.35	2.92	2.22-10.30
Cacti, Succulents	0.15	0.15	0.003-0.52
Standing Dead Herbaceous	5.01	2.78	0.40-9.80
Standing Dead Woody	1.23	0.84	0.29-2.83

Table 9. Species Diversity for the Sandy Loam Upland Ecological Site. Species diversity is expressed as mean, minimum and maximum species richness per plot, the total richness for the ecosite, Shannon-Weaver Diversity Index and the Evenness index. Metrics are presented for all species and only native species.

Table 9a. All Species				
Metric	Plot		Ecological Site	
	Mean (SD)	Range	Metric	
Richness	23.6 (5.0)	11–30	Richness	63
Shannon Diversity	1.859 (0.482)		ß Diversity	2.788
Evenness	0.586 (0.125)			
Table 9b. Native Species				
Metric	Plot		Ecological Site	
	Mean (SD)	Range	Metric	
Richness	22.1 (4.8)	10–28	Richness	59
Shannon Diversity	1.804 (0.493)		ß Diversity	2.796
Evenness	0.581 (0.13)			

(less than 1) indicate similar composition among plots (McCune and Grace 2002). When these indices are recalculated using only native species, they do not change substantially (Table 9b). The species area curve in Figure 5 illustrates how species accumulate with increased area. The concave shape indicates low species richness at the finer spatial scales, and is typical for the grasslands and shrublands of the region.

Soil Stability and Hydrologic Function

The amount of exposed soil is monitored in two ways: soil surface feature cover estimates in quadrats and basal gaps intercepts. The cover of surface features (Table 10) shows that the majority of

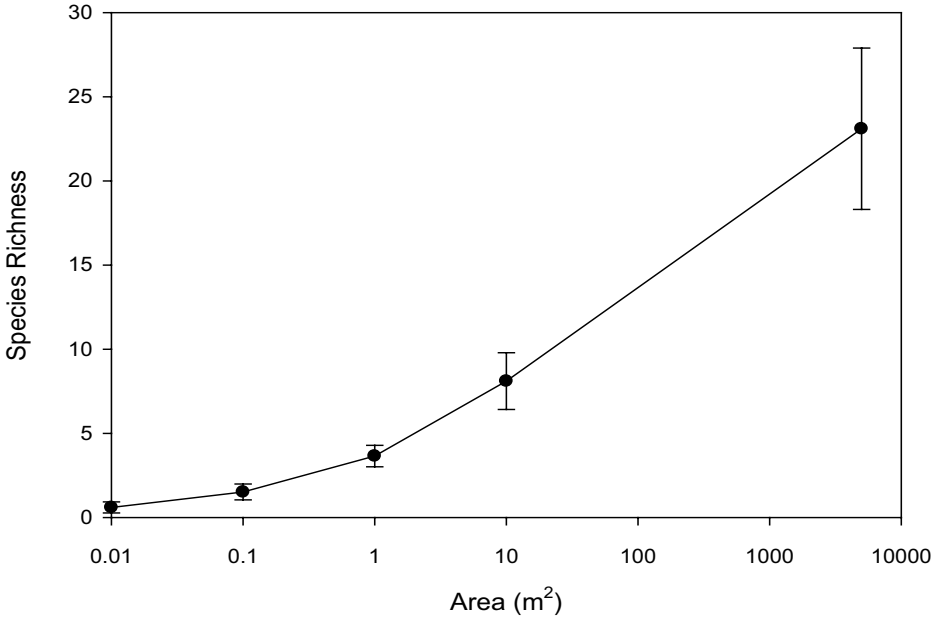

Figure 5. Mean Species Richness for the Sandy Loam Upland Ecological Site at 5 spatial scales. Estimates are based on 10 plots with 15 quadrats each. Error bars represent 1 standard deviation.

the soil surface is covered with undifferentiated crust (59.39%), and bare soil (19.91%), although these show high variability. Duff and litter comprise 7.00% cover, live plant base comprise 6.69%, dead herbaceous base comprises 3.00% and fine gravel comprises 1.93%. Dead woody base, cyano-bacteria, moss, coarse gravel, and woody debris all comprise less than 1%. Cobble, stone, or lichen cover were not observed.

The basal gap data (Table 11) show that 95.4% of total transect length is comprised of gap and consequently 4.6% intersects plant bases. (This is lower than the estimate of plant bases determined in the surface feature data). When the percentage of transect length is recalculated for gaps greater than 50 cm, the figure is reduced to 84.7%. There is a mean of 145.5 gaps per plot with a median gap size of 78.7 cm. There are a relatively similar number of gaps in the four gap size classes (Figure 6).

Soil aggregate stability provides a measurement of erodibility of soil (Table 12). The mean rating is 3.10, which is moderate. Soil occurring under vegetative cover has a higher stability rating than bare soil without cover: 3.66 compared to 2.70.

Discussion

These data represent the first year baseline of sampling for the Clayey Fan and Sandy Loam Upland ecological sites at PEFO. These sites are dominated by grasses, with moderate cover of shrubs. Both sites contain *Sporobolus airoides*, *Bouteloua gracilis, Pleuraphis jamesii*, and *Atriplex canscens*.

The Clayey Fan site is dominated by *Sporobolus airoides*, with abundant cover of *Atriplex obovata*, *Sporobolus coromandelianus and Bouteloua barbata (*figure 7). In contrast, the Sandy Loam Upland

Table 10. Surface Features Cover for the Sandy Loam Upland Ecological Site. Cover of surface features is expressed as a percentage. Cover of surface features is estimated in 1 m^2 quadrats, and the plot mean is calculated from the cover class midpoints. The features do not add up to 100% due to the fact that calculations are made from cover class midpoints, and that the estimations have observer error.

Surface Feature	Cover (%)		
	Mean	SD	Range
Live Plant Base	6.69	2.74	1.56-10.10
Dead Woody Base	0.28	0.34	0.02-0.89
Dead Herbaceous Base	3.00	1.61	0.28-5.47
Bare Soil	19.91	20.06	2.75-56.07
Duff and Litter	7.00	2.31	2.32-10.35
Undifferentiated Crust	59.39	20.18	19.57-82.83
Moss	0.10	0.29	0-0.93
Lichen	0	0	0-0
Cyanobacteria	0.50	1.58	0-5.00
Fine Gravel (0.2 cm-2 cm)	1.93	5.82	0-18.47
Coarse Gravel (2 cm-7.5 cm)	0.15	0.45	0-1.42
Cobble (7.5 cm-25 cm)	0	0	0-0
Stone, Boulder, Bedrock (>25 cm)	0	0	0-0
Woody Debris	0.52	1.31	0-4.17

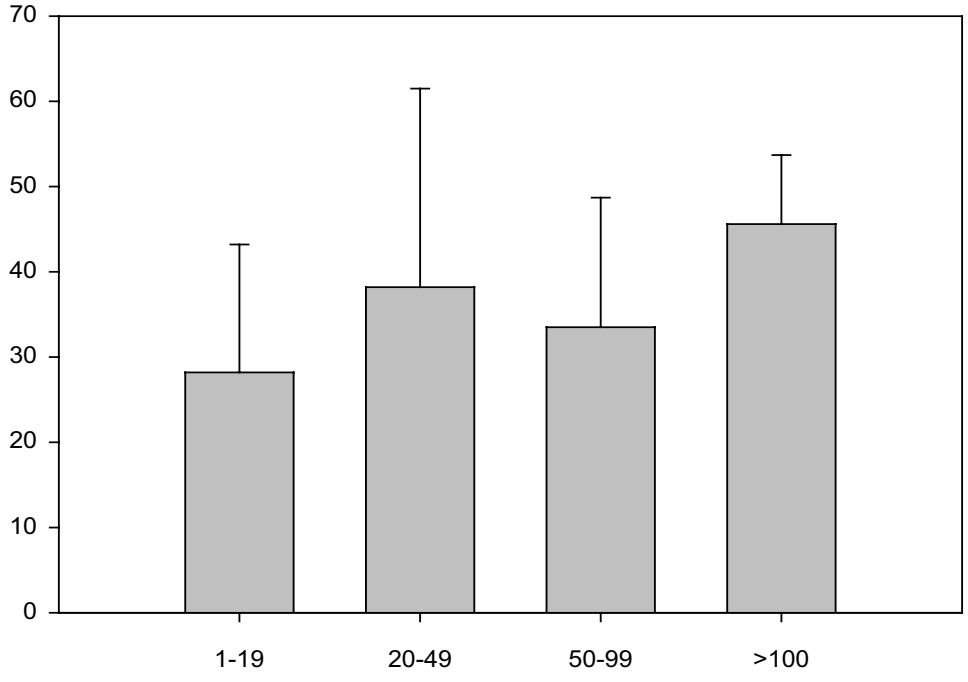

Figure 6. Basal Gap Size Distribution. The frequency of basal gaps is shown for 4 size classes. Error bars represent 1 standard deviation.

Table 11. Basal Gaps for the Sandy Loam Upland Ecological Site. Basal gaps are measured along three 50 m transects in each plot. The mean and standard deviation of each metric is calculated for the 10 plots in the ecosite.

Metric	Mean	(SD)
Gap Number	145.5	(51.3)
Median Gap Size (cm)	78.7	(61.2)
Percent of Transect in Gaps	95.5	(1.7)
Percent of Transect in Gaps ≥ 50 cm	84.7	(7.7)

Table 12. Soil Stability for the Sandy Loam Upland Ecological Site. Mean soil stability rating by cover. 18 points were measured in each of the10 plots. Ratings range from 1-6: 1 being the lowest stability and 6 being the highest.

	Soil Stability Rating	
	Mean	(SD)
Cover	3.66	(1.08)
No Cover	2.70	(0.96)
Total	3.10	(0.83)

Figure 7. Two photopoints from upland plots. The photo of the Clayey Fan Ecological Site (top) shows high cover of *Sporobolus airoides* in the foreground. The photo of the Sandy Loam Ecological Site (bottom) shows the high shrub cover typical for the site.

site demonstrates a co-dominance of the perennial grasses, and also contains moderate abundances of *Artemisia filifolia, Bouteloua eriopoda* and *Gutierrezia sarothrae*. The Sandy Loam Upland site has greater shrub cover, and consequently greater total live vegetative cover.

Several non-native species are present in each of the ecological sites. The two most abundant non-native species are *Bromus tectorum* and *Salsola tragus*, which occur in both sites. *Salsola tragus* is moderately abundant in both sites, while *Bromus tectorum* is only moderately abundant in the Sandy Loam Upland site.

Species diversity patterns are similar for both sites. Shannon diversity and evenness is greater for the Sandy Loam Upland site, while ecological site richness is greater for the Clayey Fan site. Species richness is higher in the Clayey Fan site at all spatial scales, particularly at the finer scales.

The soil aggregate stability and the amount of exposed soil are means by which to quantify the potential for the site for soil erosion. Soil aggregate stability corresponds with soil texture: the Clayey Fan site has greater stability than the Sandy Loam Upland site. Vegetative cover provides greater stability to the soil. The basal gap structure of the two sites is similar. Both sites have identical median gap sizes. The Clayey Fan site has a higher percentage of large gaps. This is likely the result of large areas where water pools that are either unvegetated or dominated by annuals. It is in the largest gaps sizes that soil is most susceptible to wind and water erosion. The Sandy Loam Upland site has less undifferentiated crust and more bare soil. Combined with the low soil stability rating, this suggests that Sandy Loam Upland site has the greatest susceptibility to soil erosion.

Our plan is to sample the quadrats and gap intercept transects annually for the next 3-5 years to determine the range of variability for key metrics. Power analysis will then be used to 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 previous year's data to demonstrate change in vegetation composition and structure, and change in hydrologic function and soil stability. More thorough trend analyses will be conducted once sufficient data have been collected.

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Appendix A

Complete species list for Clayey Fan Ecological Site with foliar cover and frequency values. Non-native species are indicated by an asterisk. *Chamaesyce* spp. that are not identifiable to species are placed in one of two groups.

Species	Common Name	Family	Foliar Cover (%)	Plot Frequency (%)
Achnatherum hymenoides	Indian ricegrass	Poaceae	0.165	90
Aristida adscensionis	sixweeks threeawn	Poaceae	<0.001	10
Artemisia bigelovii	Bigelow sage	Asteraceae	0.002	10
Artemisia filifolia	sand sagebrush	Asteraceae	0.005	10
Astragalus sp.	milkvetch	Fabaceae	0.017	60
Atriplex canescens	fourwing saltbush	Chenopodiaceae	0.565	50
Atriplex confertifolia	shadscale saltbush	Chenopodiaceae	0.150	40
Atriplex obovata	mound saltbush	Chenopodiaceae	1.589	90
Bouteloua barbata	sixweeks grama	Poaceae	1.062	90
Bouteloua eriopoda	black grama	Poaceae	0.050	10
Bouteloua gracilis	blue grama	Poaceae	1.210	90
*Bromus tectorum**	cheatgrass	Poaceae	0.004	40
Chaetopappa ericoides	rose heath	Asteraceae	0.009	50
Chamaesaracha coronopus	greenleaf five eyes	Solanaceae	0.014	30
Chamaesyce spp. Group A	annual sandmats	Euphorbiaceae	0.196	100
Chamaesyce spp. Group B	annual sandmats	Euphorbiaceae	0.021	40
Chenopodium leptophyllum	narrowleaf goosefoot	Chenopodiaceae	<0.001	10
Dalea candida	white prairie clover	Fabaceae	0.027	30
Elymus elymoides	squirreltail	Poaceae	0.006	20
Ephedra cutleri	Cutler's jointfir	Ephedraceae	0.015	20
Ephedra torreyana	Torrey's jointfir	Ephedraceae	0.110	20
Ephedra viridis	Mormon tea	Ephedraceae	0.050	10
Eragrostis pectinacea	desert lovegrass	Poaceae	0.031	10
Eriastrum diffusum	miniature woollystar	Polemoniaceae	<0.001	10
Ericameria nauseosa	rubber rabbitbrush	Asteraceae	0.119	40
Erigeron concinnus	Navajo fleabane	Asteraceae	0.001	10
Eriogonum deflexum	flatcrown buckwheat	Polygonaceae	0.007	40
Eriogonum divaricatum	divergent buckwheat	Polygonaceae	0.006	50
Gaillardia pinnatifida	red dome blanketflower	Asteraceae	<0.001	10
Gutierrezia sarothrae	broom snakeweed	Asteraceae	0.089	40
Heliomeris multiflora	showy goldeneye	Asteraceae	<0.001	10
Hymenopappus flavescens	collegeflower	Asteraceae	0.004	10
Ipomopsis sp.	gilia	Polemoniaceae	0.001	20
Isocoma drummondii	Drummond's goldenbush	Asteraceae	0.027	20
Krascheninnikovia lanata	winterfat	Chenopodiaceae	0.016	30
Machaeranthera canescens	hoary tansy-aster	Asteraceae	0.002	20

Appendix A *continued*

Species	Common Name	Family	Foliar Cover (%)	Plot Frequency (%)
Mentzelia albicaulis	whitestem blazingstar	Loasaceae	0.002	30
Monroa squarrosa	false buffalograss	Poaceae	0.030	80
Muhlenbergia pungens	sandhill muhly	Poaceae	0.009	20
Oenothera sp.	evening primrose	Onagraceae	0.019	40
Opuntia sp.	prickly pear	Cactaceae	0.011	40
Opuntia whipplei	Whipple's cholla	Cactaceae	0.007	20
Panicum hirticaule	Mexican panicgrass	Poaceae	0.001	10
Parryella filifolia	common dunebroom	Fabaceae	0.038	10
Pectis angustifolia	narrowleaf pectis	Asteraceae	0.008	20
Plantago patagonica	woolly plantain	Plantaginaceae	0.030	80
Pleuraphis jamesii	James' galleta	Poaceae	1.266	100
*Portulaca oleracea**	little hogweed	Portulacaceae	0.044	60
Psilostrophe tagetina	woolly paperflower	Asteraceae	0.001	10
*Salsola tragus**	prickly Russian thistle	Chenopodiaceae	0.973	100
Sanvitalia abertii	Albert's creeping zinnia	Asteraceae	0.012	20
Sarcobatus vermiculatus	greasewood	Chenopodiaceae	0.293	10
Schkuhria multiflora	many-flower false threadleaf	Asteraceae	0.001	20
Senecio flaccidus	threadleaf ragwort	Asteraceae	0.004	10
Sphaeralcea hastulata	spear globemallow	Malvaceae	0.069	90
Sporobolus airoides	alkali sacaton	Poaceae	6.181	100
Sporobolus contractus	spike dropseed	Poaceae	0.056	30
Sporobolus coromandelianus	Madagascar dropseed	Poaceae	1.251	80
Sporobolus cryptandrus	sand dropseed	Poaceae	0.008	40
Sporobolus flexuosus	mesa dropseed	Poaceae	0.020	20
Thelesperma megapotamicum	Hopi tea greenthread	Asteraceae	<0.001	10
Vulpia octoflora	sixweeks fescue	Poaceae	0.005	40
Yucca angustissima	narrowleaf yucca	Agavaceae	0.009	40
Unknown PEFO09172007-1			<0.001	10
Unknown PEFO09272007-2			0.007	10
Unknown PEFO10012007-1			<0.001	10
Unknown PEFO10022007-2			0.002	10
Unknown PEFO10022007-3			<0.001	10
Unknown PEFO10042007-2			0.001	10

Appendix B

Complete species list for Sandy Loam Upland Ecological Site with foliar cover and frequency values. Non-native species are indicated by an asterisk. Annual *Chamaesyce* spp. that are not identifiable to species in the field are placed in one of two groups

Species	Common Name	Family	Foliar Cover (%)	Plot Frequency (%)
Achnatherum hymenoides	Indian ricegrass	Poaceae	0.484	90
Amaranthus sp.	pigweed	Amaranthaceae	<0.001	10
Aristida purpurea	Fendler's threeawn	Poaceae	0.040	40
Artemisia bigelovii	Bigelow sage	Asteraceae	0.363	30
Artemisia filifolia	sand sagebrush	Asteraceae	0.743	30
Asclepias subverticillata	horsetail milkweed	Asclepiadaceae	<0.001	10
Astragalus sp.	milkvetch	Fabaceae	0.004	50
Atriplex canescens	fourwing saltbush	Chenopodiaceae	1.085	90
Atriplex confertifolia	shadscale saltbush	Chenopodiaceae	0.096	20
Atriplex obovata	mound saltbush	Chenopodiaceae	0.224	10
Bouteloua barbata	sixweeks grama	Poaceae	0.005	20
Bouteloua eriopoda	black grama	Poaceae	0.714	60
Bouteloua gracilis	blue grama	Poaceae	3.712	80
*Bromus tectorum**	cheatgrass	Poaceae	0.726	60
Chaetopappa ericoides	rose heath	Asteraceae	0.093	90
Chamaesaracha coronopus	greenleaf five eyes	Solanaceae	0.001	10
Chamaesyce spp. Group A	annual sandmats	Euphorbiaceae	0.042	80
Chamaesyce spp. Group B	annual sandmats	Euphorbiaceae	0.01	50
Chenopodium leptophyllum	narrowleaf goosefoot	Chenopodiaceae	0.002	10
Elymus elymoides	squirreltail	Poaceae	0.021	60
Ephedra cutleri	Cutler's jointfir	Ephedraceae	0.083	10
Ephedra torreyana	Torrey's jointfir	Ephedraceae	0.279	60
Ericameria nauseosa	rubber rabbitbrush	Asteraceae	0.028	20
Erigeron divergens	spreading fleabane	Asteraceae	0.005	10
Eriogonum corymbosum var. aureum	crispleaf buckwheat	Polygonaceae	<0.001	10
Eriogonum ericifolium	Yavapai buckwheat	Polygonaceae	0.002	10
Eriogonum jamesii	James' buckwheat	Polygonaceae	0.002	10
Escobaria vivipara	spinystar	Cactaceae	0.002	10
Evolvulus nuttallianus	shaggy dwarf morning-glory	Convolvulaceae	0.011	20
Gutierrezia sarothrae	broom snakeweed	Asteraceae	2.311	90
Hesperostipa comata	needle and thread	Poaceae	0.256	60
Hymenopappus flavescens	collegeflower	Asteraceae	0.003	20
Ipomopsis longiflora	whiteflower ipomopsis	Polemoniaceae	0.05	50
Krascheninnikovia lanata	winterfat	Chenopodiaceae	0.091	50
Machaeranthera canescens	hoary tansy-aster	Asteraceae	0.015	20

Appendix B *continued*

Species	Common Name	Family	Foliar Cover (%)	Plot Frequency (%)
Machaeranthera gracilis	slender goldenweed	Asteraceae	<0.001	10
Mentzelia albicaulis	whitestem blazingstar	Loasaceae	0.002	10
Monroa squarrosa	false buffalograss	Poaceae	0.019	40
Muhlenbergia pungens	sandhill muhly	Poaceae	0.038	20
Muhlenbergia torreyi	ring muhly	Poaceae	0.069	60
Oenothera caespitosa	tufted evening-primrose	Onagraceae	0.002	10
Opuntia sp.	prickly pear	Cactaceae	0.022	60
Opuntia whipplei	Whipple's cholla	Cactaceae	0.085	60
Plantago patagonica	woolly plantain	Plantaginaceae	0.035	80
Pleuraphis jamesii	James' galleta	Poaceae	2.589	100
*Polygonum aviculare**	prostrate knotweed	Polygonaceae	<0.001	10
*Portulaca oleracea**	little hogweed	Portulacaceae	0.002	10
*Salsola tragus**	prickly Russian thistle	Chenopodiaceae	0.365	70
Schkuhria multiflora	many-flower false threadleaf	Asteraceae	<0.001	10
Senecio flaccidus	threadleaf ragwort	Asteraceae	<0.001	10
Sphaeralcea hastulata	spear globemallow	Malvaceae	0.142	70
Sporobolus airoides	alkali sacaton	Poaceae	2.622	90
Sporobolus contractus	spike dropseed	Poaceae	0.039	10
Sporobolus coromandelianus	Madagascar dropseed	Poaceae	0.036	20
Sporobolus cryptandrus	sand dropseed	Poaceae	0.035	10
Sporobolus flexuosus	mesa dropseed	Poaceae	0.224	20
Verbena bracteata	bigbract verbena	Verbenaceae	0.023	10
Vulpia octoflora	sixweeks fescue	Poaceae	0.018	70
Yucca angustissima	narrowleaf yucca	Agavaceae	0.036	50
Yucca baccata	banana yucca	Agavaceae	0.002	10
Zinnia grandiflora	Rocky Mountain zinnia	Asteraceae	0.085	30
Unknown PEFO09122007-2			<0.001	10