



Integrated Upland Vegetation and Soils Monitoring for Petrified Forest National Park

2012–2014 Summary Report

Natural Resource Data Series NPS/SCPN/NRDS—2016/1040



ON THE COVER
Clayey Fan ecological site at Petrified Forest National Park
Photography by: SCPN

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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Contents

- Figures v
- Tables v
- 1 Introduction 1
- 2 Methods 1
 - 2.1 Sampling frame 1
 - 2.2 Field methods 2
 - 2.2.1 Shrub and herbaceous vegetation 2
 - 2.2.2 Soils 3
 - 2.3 Panel design and implementation 4
 - 2.4 Initial sampling: 2007-2010 4
 - 2.5 Data summary 6
 - 2.5.1 Shrub and herbaceous species, functional groups and soil surface features 6
 - 2.5.2 Species diversity 6
 - 2.5.3 Soil stability 7
- 3 Results 8
 - 3.1 Clayey Fan ecological site 8
 - 3.1.1 Shrub and herbaceous vegetation 8
 - 3.1.2 Soil stability and hydrologic function 13
 - 3.2 Sandy Loam Upland ecological site 15
 - 3.2.1 Shrub and herbaceous vegetation 15
 - 3.2.2 Soil stability and hydrologic function 22
- 4 Discussion 23
- 5 Literature cited 23
- Appendix A: Foliar cover of functional groups in the Clayey Fan ecological site at Petrified Forest National Park, 2007–2014 A1
- Appendix B: Plant species list for the Clayey Fan ecological site at Petrified Forest National Park, 2007-2014 A2
- Appendix C. Cover of soil surface features in the Clayey Fan ecological site at Petrified Forest National Park, 2007–2014 A10
- Appendix D. Soil stability ratings for the Clayey Fan ecological site at Petrified Forest National Park, 2007–2014 A11
- Appendix E: Foliar cover of functional groups in the Sandy Loam Upland ecological site at Petrified Forest National Park, 2007–2013 A12
- Appendix F: Plant species list for the Sandy Loam Upland ecological site at Petrified Forest National Park, 2007-2013 A13

Contents (continued)

Appendix G. Cover of soil surface features in the Sandy Loam Upland ecological site at Petrified Forest National Park, 2007–2013	A18
Appendix H. Soil stability ratings for the Sandy Loam Upland ecological site at Petrified Forest National Park, 2007–2013	A19

Figures

Figure 1. Sampling frame of Clayey Fan ecological site at Petrified Forest NP	2
Figure 2 Sampling frame of Sandy Loam Upland ecological site at Petrified Forest NP	3
Figure 3. Sampling year and panel assignment for plots used in the panel design for integrated upland vegetation and soils monitoring at Petrified Forest NP, 2007–2014.	5
Figure 4. Mean percent foliar cover of functional groups for all 20 plots in panels A&B, combined, in 2012 (a) and all 20 plots in panels B&C, combined, in 2014 (b) in the Clayey Fan ecological site at Petrified Forest NP.	8
Figure 5. Mean percent foliar cover of functional groups, by panel, in 2012, 2014, and for the initial sampling year (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP.	9
Figure 6. Mean percent foliar cover of the 10 most abundant shrub and herbaceous species for all 20 plots in panels A&B in 2012 (a) and all 20 plots in panels B&C in 2014 (b) in the Clayey Fan ecological site at Petrified Forest NP.	9
Figure 7. Number of species in each plot frequency class for (a) 20 plots in panels A&B in 2012, and (b) 20 plots in panels B&C in 2014 in the Clayey Fan ecological site at Petrified Forest NP.	11
Figure 8. Mean percent foliar cover of the most abundant shrub and herbaceous species in 2012, 2014, and for the initial sampling year (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP.	12
Figure 9. Mean quadrat frequency of shrub and herbaceous species with foliar cover >0.5%, by panel, in 2012, 2014, and for the initial sampling year (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP.	13
Figure 10. Diversity indices for all species, by panel, in 2012, 2014, and for the initial sampling year (2007–2010) in the Clayey Fan ecological site in Petrified Forest NP.	14
Figure 11. Mean cover of soil surface features, by panel, for 2012, 2014, and for the initial sampling period (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP.	15
Figure 12. Mean soil stability ratings for all samples and for samples under and not under vegetative cover, by panel, for 2012, 2014, and the initial sampling period (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP.	16
Figure 13. Mean percent foliar cover of functional groups for all 20 plots in panels A&B in the Sandy Loam Upland ecological site at Petrified Forest NP in 2013.	16
Figure 15. Mean percent foliar cover of the 12 most abundant shrub and herbaceous species for all 20 plots in panels A&B in the Sandy Loam Upland ecological site at Petrified Forest NP in 2013.	17
Figure 16. Number of species in each plot frequency class for all 20 plots in panels A&B in the Sandy Loam Upland ecological site at Petrified Forest NP in 2013.	17
Figure 17. Mean percent foliar cover for the most abundant shrub and herbaceous species, by panel, for 2013 and for the initial sampling period (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP.	19
Figure 18. Mean quadrat frequency of shrub and herbaceous species with foliar cover >0.3%, by panel, for 2013 and for the initial sampling period (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP.	20
Figure 19. Diversity indices by panel, for 2013, and for the initial sampling period (2007–2010) in the Sandy Loam Upland ecological site in Petrified Forest NP.	20
Figure 20. Mean percent cover of soil surface features, by panel, for 2013, and for the initial sampling period (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP.	21

Figures (continued)

Figure 21. Mean soil stability ratings for all samples and for samples under and not under vegetative cover, by panel, for 2013, and for the initial sampling period (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP.	22
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Tables

Table 1. Panel design for resampling monitoring plots in the Clayey Fan and Sandy Loam Upland ecological sites at Petrified Forest NP.	4
Table 2. Foliar cover and frequency of shrub and herbaceous species in the Clayey Fan ecological site at Petrified Forest NP, by panel, in 2012, 2014, and for the initial sampling year (2007–2010).	10
Table 3. Species diversity metrics for all species, and for native species only, by panel, for 2012, 2014, and for the initial sampling period (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP.	14
Table 4. Foliar cover and frequency of shrub and herbaceous species, by panel, for 2013, and the initial year of sampling (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP.	18
Table 5. Species diversity metrics for all species and for native species only, by panel, for 2013, and the initial year of sampling (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP.	21

1 Introduction

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 for making decisions and working with other agencies and the public to protect park ecosystems. 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 Clayey Fan and Sandy Loam Upland ecological sites for long-term monitoring of upland vegetation and soils at Petrified Forest National Park (PEFO). 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). These two ecological sites comprise a large area of the upland grassland ecosystem at PEFO. They face numerous threats, including soil erosion, climate change, and invasion by nonnative species.

Between 2007 and 2010 we established and sampled 30 plots in the Clayey Fan ecological site, and 30 plots in the Sandy Loam Upland ecological site. In 2012, we implemented a panel design incorporating these plots, sampling panels A&B in the Clayey Fan ecological site in 2012 and panels B&C in 2014; and panels A&B in the Sandy Loam Upland ecological site in 2013.

In this report we document monitoring activities in the Clayey Fan and Sandy Loam Upland ecological sites during the 2012, 2013 and 2014 field seasons, and report these data in the context of the first year of data for the plots collected during the 2007 to 2011 establishment period. For the complete set of data collected at PEFO from 2007–2011, see the data summary reports, available from the SCPN website (<http://science.nature.nps.gov/im/units/scpn/publications.cfm?tab=2>)

2 Methods

2.1 Sampling frame

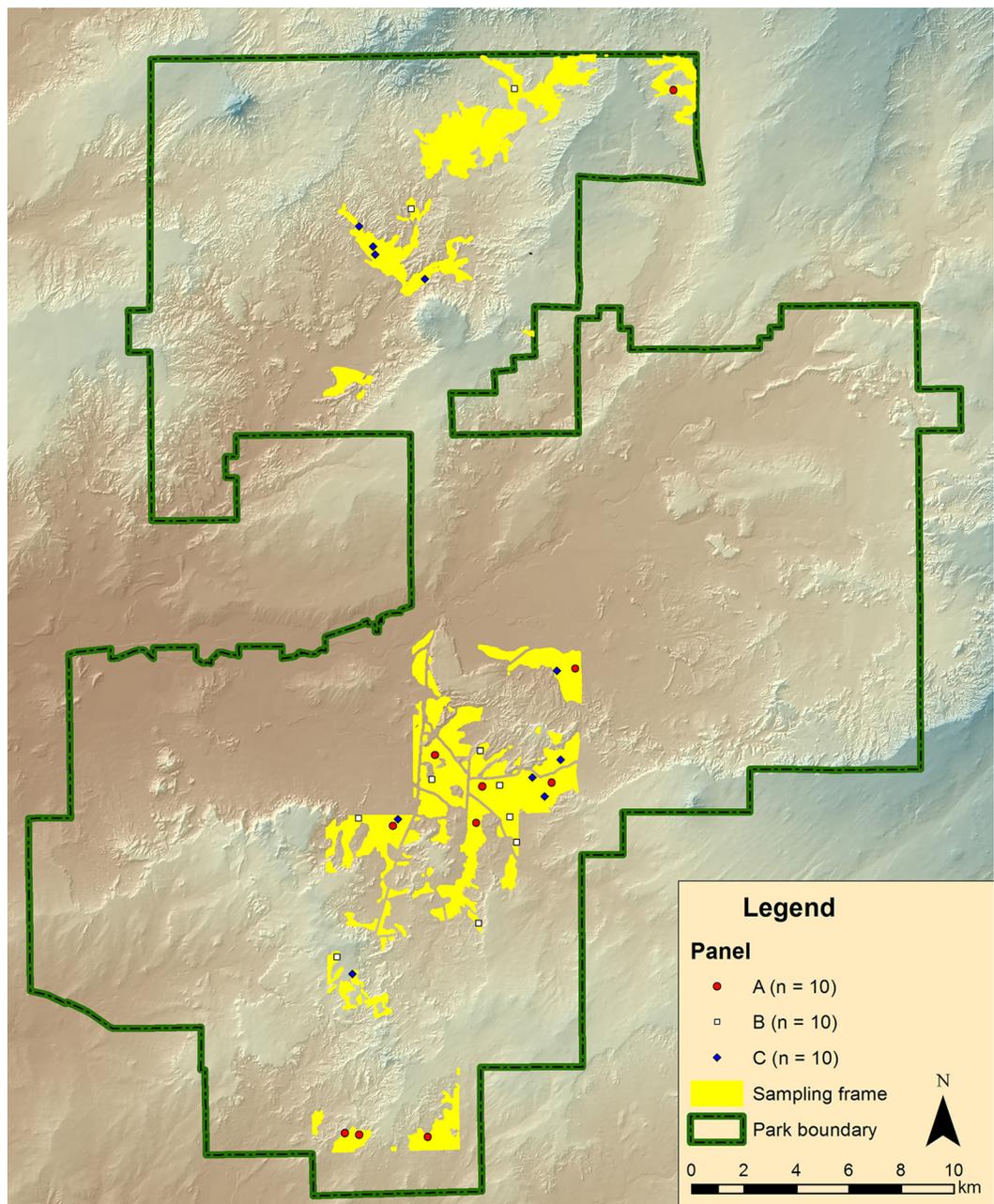
We derived our base sampling frames for the Clayey Fan ecological site (Figure 1) and the Sandy Loam Upland ecological site (Figure 2) from SSURGO soils maps, which were developed by the U.S. Natural Resources Conservation Service (see Appendix A of DeCoster et al. 2012). The sampling frame is the area from which we randomly select our sites, and hence the area to which statistical inferences can be made.

In making final adjustments to our sampling frames, we modified the maps of the ecological site using Geographical Information System (GIS) technology by removing areas

- outside of the target ecological site (i.e., roads, buildings)
- at risk for erosion as a result of sampling (slopes $\geq 20\%$)

We generated a set of spatially distributed sampling points for each of the sites 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. The integrated upland crew visited the first series of GRTS points for each ecological site and assessed each point, rejecting those that deviated substantially from the ecological site description, had a slope greater than 20%, or contained a major disturbance. We rejected 58 points in the Clayey Fan ecological site—56 points deviated substantially from the ecological site description and 2 points exceeded our hiking time limit of 2 hours. We rejected 6 points in the Sandy Loam Upland ecological site—3 points were in proximity to archeological sites, one point was in proximity to a road, one point deviated substantially from the ecological site description and one point was within 200 m of an existing plot.

Figure 1. Sampling frame of Clayey Fan ecological site at Petrified Forest NP showing the 10 plots in each panel.



2.2 Field methods

Integrated upland monitoring plots are 0.50 ha in size (measuring 71 × 71 m) and consist of 3 parallel 50 m transects spaced 25 m apart. We collected data for shrub and herbaceous species cover and frequency, functional group cover, soil surface feature cover, soil stability, and basal gap data in the 3 transects within each plot. Detailed field methodology is provided in the SCPN integrated upland monitoring protocol (DeCoster et al. 2012). Generally, we conducted our work in October of each year, except for 2007, when we began our field sampling in late September, and 2013, when field sampling occurred in early November.

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

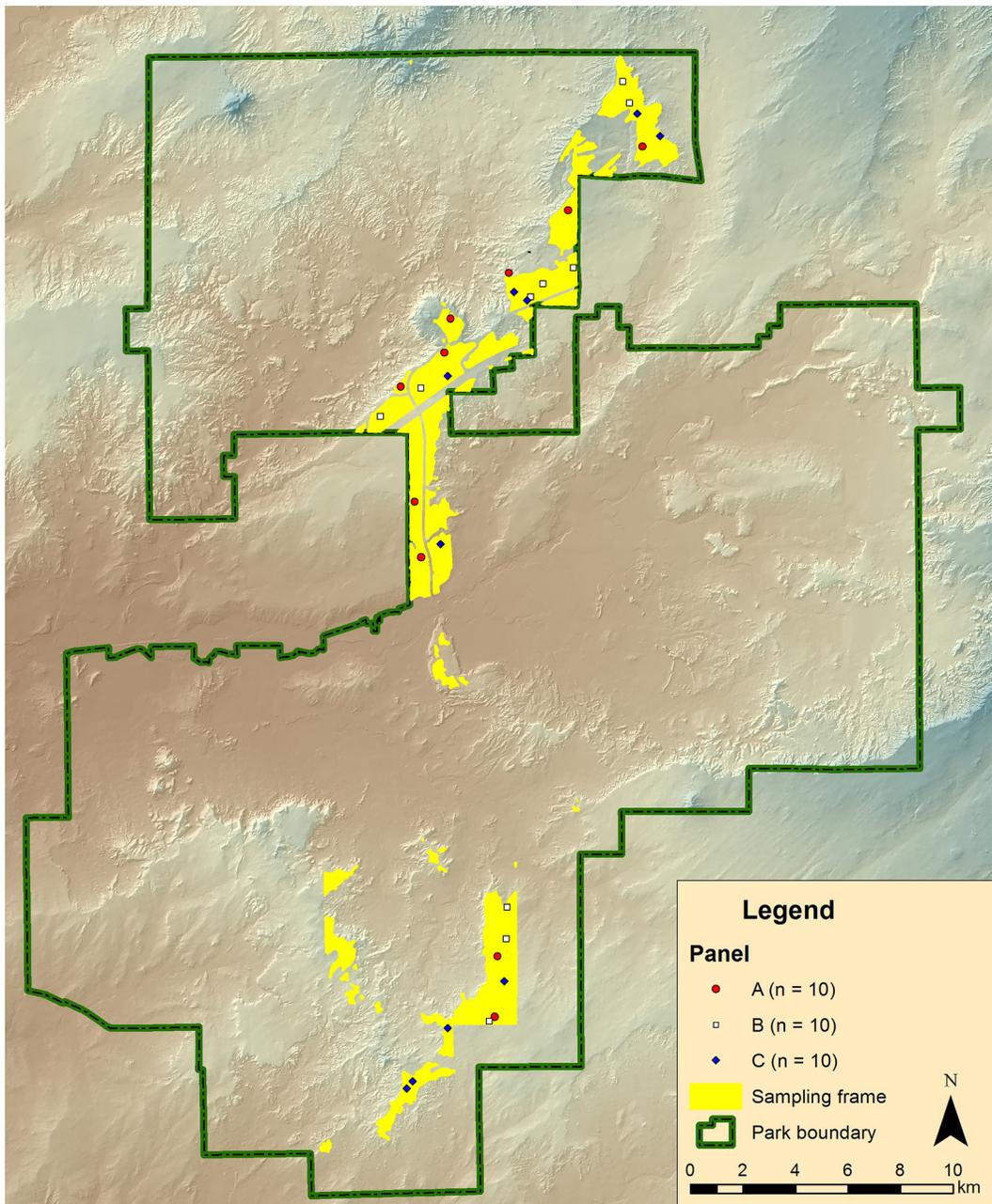


Figure 2 Sampling frame of Sandy Loam Upland ecological site at Petrified Forest NP showing the 10 plots in each panel.

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 Soils

We estimated the percent cover of soil surface features in the 1 m² quadrats along transects, and recorded cover in 1 of 12 cover classes. We measured basal gaps as the distance between plant bases of perennial plants along each transect. However, we are not reporting these data in this report. We conducted soil stability tests during plot establishment on 18 samples for each plot, and again during the 2012-2013 field sampling periods. If soils were wet, however, we did not collect the data, as results are not accurate under those conditions.

2.3 Panel design and implementation

A rotating panel design is a sampling strategy sometimes used when estimates are produced regularly over time. Under such a design, equally sized sets of plots, or ‘panels’, are brought in and out of the sample through time in some specified pattern. In essence, this approach seeks to reduce monitoring costs by optimizing the balance between two desirable but competing monitoring qualities—frequent enough sampling to detect temporal change, and a sufficient sample size to capture the spatial heterogeneity of the target ecosystem. The overlap of panel sampling allows for an estimate of change for every pair of years included in the sample; this is termed a “temporally connected” sampling design and provides greater power to detect trends through time.

SCPN developed and began using a rotating panel design for integrated upland monitoring at PEFO in 2012. The 30 monitoring plots within each ecological site are partitioned into 3 panels (n=10), with 2 of the 3 panels sampled every other year (Table 1). To maintain spatial balance, plots were assigned to panels according to their GRTS numbers; i.e. the plots with the 10 lowest GRTS numbers were assigned to Panel A; the 10 next highest GRTS numbers were assigned to Panel B, etc.

In 2012, we implemented the panel design and collected data in 20 plots representing panels A&B in the Clayey Fan ecological site. In 2014 we collected data in 20 plots representing panels B&C. Panel A consists of the 9 plots we established in 2007 and 1 plot that was established in 2010. Panel B consists of 10 plots we established in 2010. Panel C consists of 9 plots established in 2010 and 1 plot established in 2014 (Figure 3).

In 2013, we collected data in 20 plots representing panels A&B in the Sandy Loam Upland ecological site. For this ecological site, Panel A consists of 7 plots that were established in 2007 and 3 plots established in 2010; panel B consists of 4 plots established in 2007 and 6 plots established in 2010; panel C consists of 6 plots established in 2007 and 4 plots established in 2010.

2.4 Initial sampling: 2007-2010

Because we are implementing upland monitoring across 15 ecological sites in 10 parks, plot establishment for upland vegetation and soils monitoring in SCPN parks has occurred over several years. At PEFO, we established 10 plots in Clayey Fan ecological site in 2007 and sampled them for 3 consecutive years in 2007, 2008 and 2009. In 2010 we established 20 additional plots (Figure 3). In 2012 we decommissioned one of plots established in 2007, as it deviated substantially from the ecological site description, and established a replacement plot.

The Sandy Loam Upland ecological site was originally sampled as two ecological sites in 2007—Sandy Loam Upland and Loamy Upland ecological sites. Following our sampling in 2007, the NRCS published an updated soil survey that merged the Sandy Loam Upland and Loamy Upland ecological sites into a single ecological site,

Table 1. Panel design for resampling monitoring plots in the Clayey Fan and Sandy Loam Upland ecological sites at Petrified Forest NP. Each panel comprises 10 plots for a total of 30 plots across 3 panels for each ecological site. A “-” indicates that no resampling was conducted for that panel during that year.

Panel	Year											
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Clayey Fan ecological site												
A	10	-	-	-	10	-	10	-	-	-	10	-
B	10	-	10	-	-	-	10	-	10	-	-	-
C	-	-	10	-	10	-	-	-	10	-	10	-
Total	20	0	20	0	20	0	20	0	20	0	20	0
Sandy Loam Upland ecological site												
A	-	10	-	-	-	10	-	10	-	-	-	10
B	-	10	-	10	-	-	-	10	-	10	-	-
C	-	-	-	10	-	10	-	-	-	10	-	10
Total	0	20	0	20	0	20	0	20	0	20	0	20

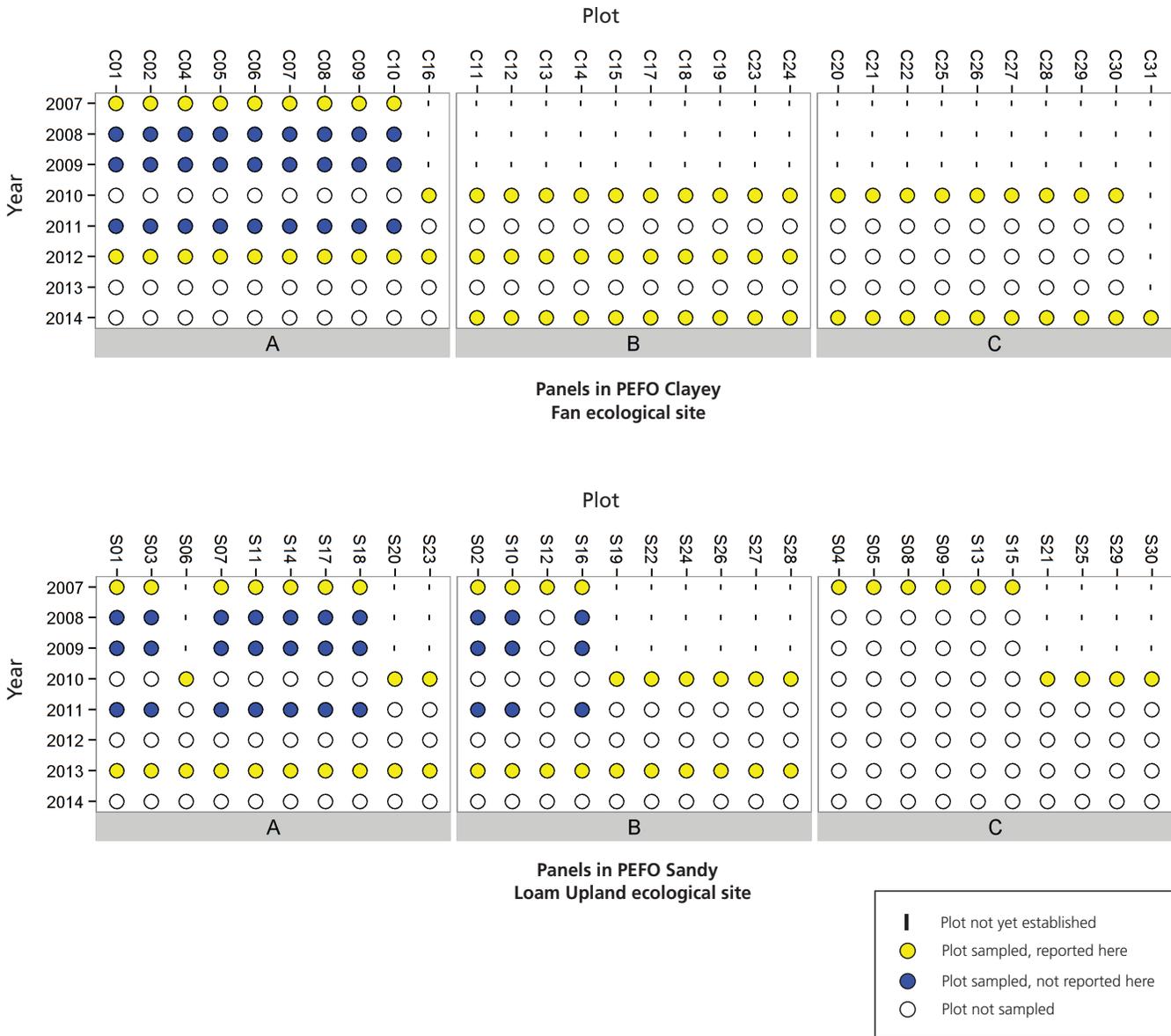


Figure 3. Sampling year and panel assignment for plots used in the panel design for integrated upland vegetation and soils monitoring at Petrified Forest NP, 2007-2014. First year of sampling is the year the plot was established.

designated Sandy Loam Upland. As a result, we subsequently merged the sampling frames for these two original ecological sites (weighted equally). In 2010, we established 13 additional plots from those that had been initially rejected in 2007 because they contained a combination of the two ecosites. We decommissioned 3 established plots based on GRTS number order. This brought the total number of plots for the ecological site to 30.

In this report we present data from 2007–2010 to provide context for the data collected between 2012 and 2014. We emphasize that data presented from the establishment period were collected over the course of 4 years and therefore do not represent a single sampling event. The full benefit of the panel design will not be realized until we have collected data through several cycles of the design.

2.5 Data summary

We first summarized data at the level of the plot, which is the sample unit, and then calculated the mean and the standard deviation for most metrics from the plot means for each panel and time period (initial sampling year, 2012, 2013, and 2014). Three metrics—plot frequency, site richness and beta diversity—were calculated across all plots and were therefore not calculated by averaging plot values.

For the Clayey Fan ecological site, we present data from panels A&B in 2012 and panels B&C in 2014, along with data from the initial sampling of all 3 panels (2007–2010) for context. For the Sandy Loam Upland ecological site, we present data from panels A & B in 2013, along with data from the initial sampling of all 3 panels.

2.5.1 *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 year, and then the mean and standard deviation calculated for each panel and time period. Mean cover and standard deviation of functional groups and soil surface features were calculated in a similar fashion.

For each panel and time period, we calculated both mean quadrat frequency and plot frequency for each species. Quadrat frequency is the percentage of 10 m² quadrats per plot in which a species occurs. Plot frequency is the percentage of plots in which the species occurs. We also combined and summarized species and functional group foliar cover for panels A&B in 2012 and 2013, and panels B&C in 2014 to provide a summary of the status for each year.

2.5.2 *Species diversity*

We calculated four diversity measures (Magurran 1988) for herbaceous and shrub species for each panel and time period— first for all species and then for native species only.

(1) Species richness (S) is the number of species at a given spatial scale. This was calculated at both the level of the plot and at the level of the site (i.e. all plots within the panel).

(2) The Shannon Diversity Index (H') provides a measure of species diversity that takes into account the relative abundance of each species and generally falls between 1.5 and 3.5:

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

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, and ranges between 0 and 1:

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

(4) Beta diversity (β) is a measure of within-site heterogeneity and ranges between 1 and 5:

$$\beta = S_e / (S_p - 1)$$

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

We calculated plot richness, Shannon diversity, and evenness for each plot and year, and the mean and standard deviation were then calculated for the panel and time period. Site richness and beta diversity, which are not based on plot means, were calculated for the site for each panel and time period.

We calculated plot richness, Shannon diversity, and evenness for each plot and year, and the mean and standard deviation were then calculated for the panel and time period. Site richness and beta diversity, which are not based on plot means, were calculated for the site for each panel and time period.

2.5.3 Soil stability

We calculated mean soil aggregate stability index for each plot and year, and then calculated the mean and standard deviation for each panel and time period. The stability index ranges from 1 to 6, where 1 indicates low aggregate stability and 6 indicates high aggregate stability. The stability index was also calculated separately for samples with vegetative cover and for samples without perennial vegetative cover.

3 Results

3.1 Clayey Fan ecological site

3.1.1 Shrub and herbaceous vegetation

We examine foliar cover of functional groups, foliar cover and frequency of species, and species diversity, presenting the 2014 and 2012 data in the context of the data from the first year of sampling.

3.1.1.1 Functional group cover

Foliar cover of functional groups indicates broad patterns in cover for shrub and herbaceous vegetation. Perennial grasses dominated the Clayey Fan ecological site, providing over 75% of the total live cover. In 2012, for panels A&B combined, the mean total live foliar cover for all plots in both panels was 8.00%, and the mean foliar cover of perennial grass was 6.16% (Figure 4). Mean foliar cover of shrubs was 1.20%. The mean foliar covers of forbs, cacti/ succulents and annual grasses were all less than 1%. Standard deviations, indicating among-plot variability, were large for many of the functional groups.

In 2014, the mean total live foliar cover of all plots in both panels was 13.20% and the mean foliar cover of perennial grass was 10.82% (Figure 4). Mean foliar cover of shrubs was 1.84%. The mean foliar covers of forbs, cacti/ succulents and annual grasses were again small components. Standard deviations, indicating among-plot variability, were large for many of the functional groups. Figure 5 presents the mean foliar cover of each functional group by panel for both 2012 and 2014, and the initial sampling period (2007–2010). Appendix A summarizes functional group cover data by sampling period and panel.

3.1.1.2 Species foliar cover and frequency

Examination of foliar cover and frequency of individual species allows for more thorough understanding of the structure and dynamics of the vegetation in the Clayey Fan ecological site. In 2012, for panels A&B combined, the 3 species with the greatest foliar cover were perennial grasses: *Sporobolus airoides* (alkali sacaton), *Hilaria jamesii* (James' galleta) and *Bouteloua gracilis* (blue grama) (Figure 6). Other abundant perennial grasses included

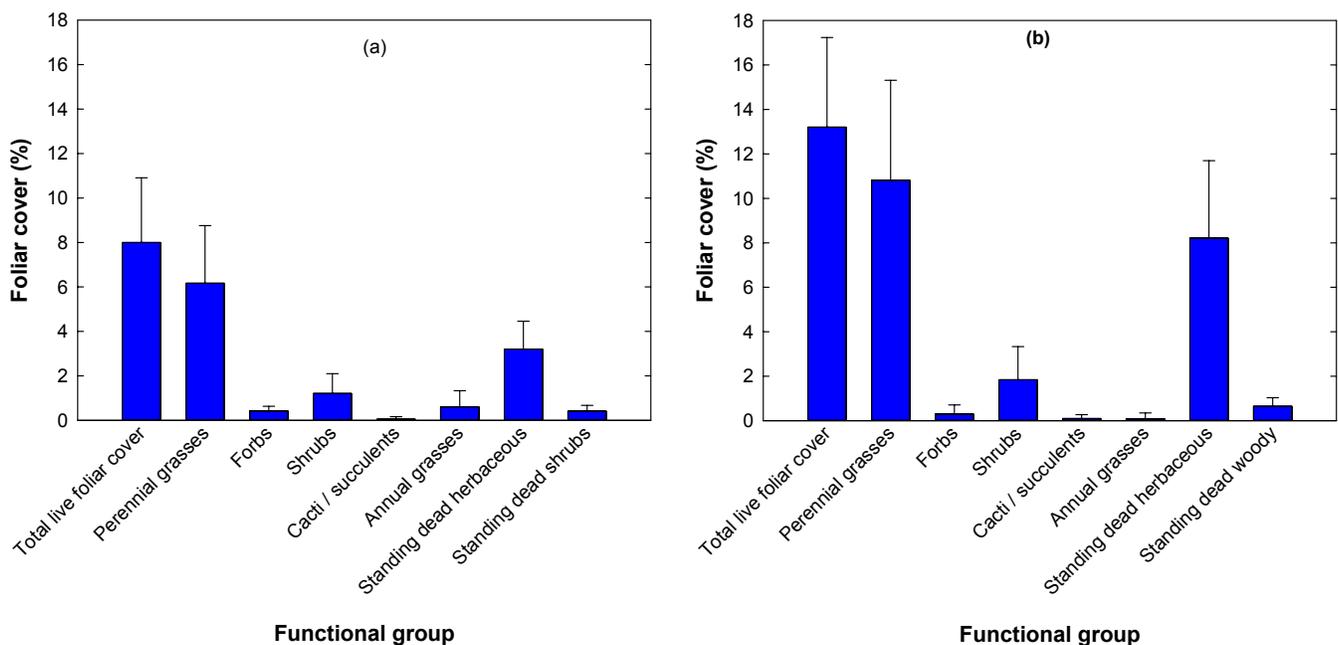


Figure 4. Mean percent foliar cover of functional groups for all 20 plots in panels A&B, combined, in 2012 (a) and all 20 plots in panels B&C, combined, in 2014 (b) in the Clayey Fan ecological site at Petrified Forest NP. Error bars represent 1 standard deviation.

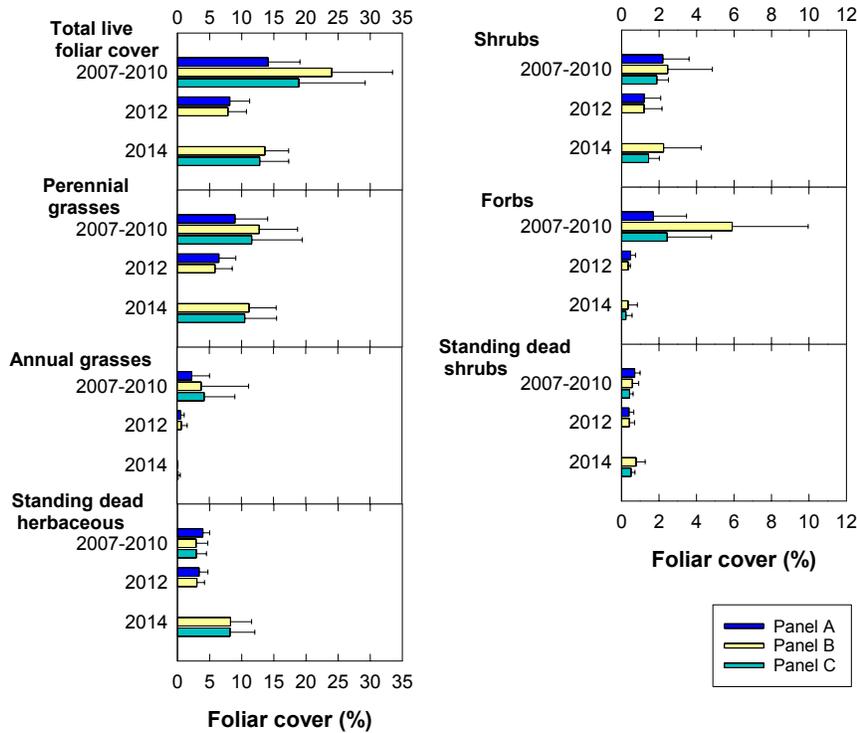


Figure 5. Mean percent foliar cover of functional groups, by panel, in 2012, 2014, and for the initial sampling year (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP. Error bars represent 1 standard deviation. Note the scales are different on the 2 columns. For panels A and C in 2007–2010, n=9; for all other panels and time periods, n=10.

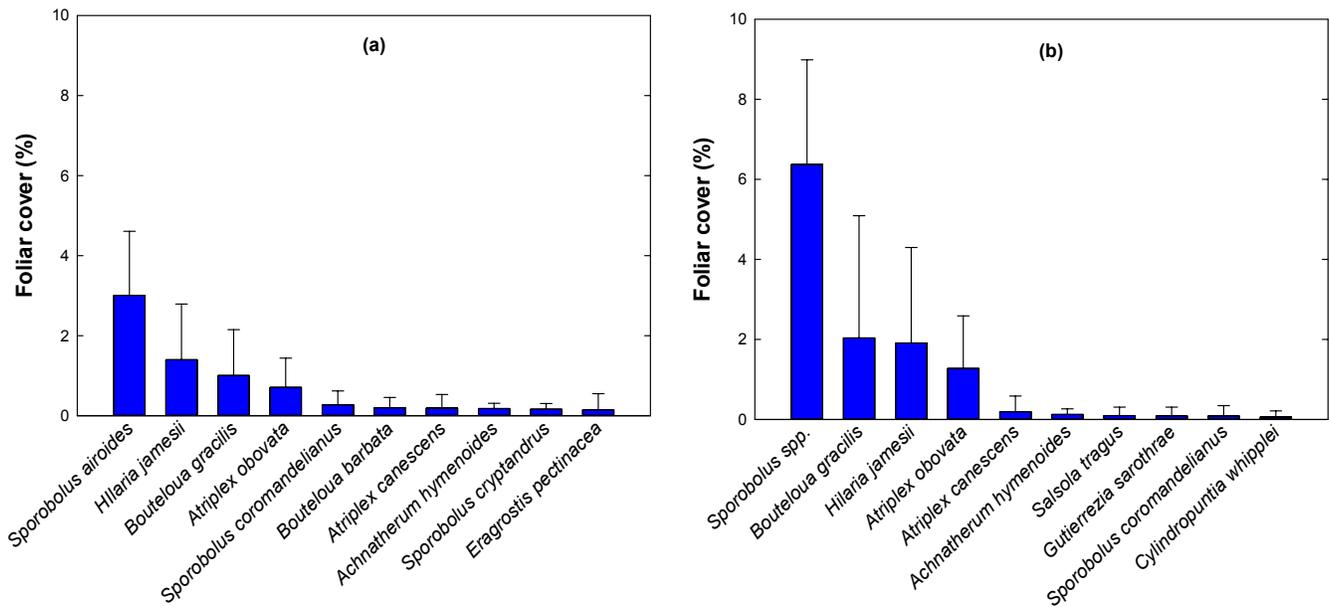


Figure 6. Mean percent foliar cover of the 10 most abundant shrub and herbaceous species for all 20 plots in panels A&B in 2012 (a) and all 20 plots in panels B&C in 2014 (b) in the Clayey Fan ecological site at Petrified Forest NP. Error bars represent 1 standard deviation.

Table 2. Foliar cover and plot frequency of shrub and herbaceous species in the Clayey Fan ecological site at Petrified Forest NP, by panel, in 2012, 2014, and for the initial sampling year (2007–2010). This table includes only species with a mean foliar cover >0.3% in any of the panels, as well as all nonnative species. Species are arranged in descending order based on their mean foliar values in 2014 for both panels combined.

Abundant species	Initial sampling year between 2007 and 2010						2012				2014			
	Panel A, n=9		Panel B, n=10		Panel C, n=9		Panel A, n=10		Panel B, n=10		Panel B, n=10		Panel C, n=10	
	Mean cover (%)	Plot frequency (%)	Mean cover (%)	Plot frequency (%)	Mean cover (%)	Plot frequency (%)	Mean cover (%)	Plot frequency (%)	Mean cover (%)	Plot frequency (%)	Mean cover (%)	Plot frequency (%)	Mean cover (%)	Plot frequency (%)
<i>Sporobolus</i> spp.	0	0	0	0	0	0	0	0	0	0	6.290	100	6.455	100
<i>Bouteloua gracilis</i>	1.278	100	1.260	70	1.663	55.6	1.31	100	0.697	70	1.311	70	2.758	60
<i>Hilaria jamesii</i>	1.295	100	2.219	100	1.272	77.8	1.449	100	1.347	100	2.780	100	1.037	80
<i>Atriplex obovata</i>	1.229	90	1.483	80	1.571	100	0.673	100	0.74	90	1.352	90	1.196	100
<i>Atriplex canescens</i>	0.232	40	0.375	50	0.093	33.3	0.131	40	0.249	50	0.323	50	0.062	40
<i>Achnatherum hymenoides</i>	0.221	100	0.194	80	0.09	66.7	0.217	100	0.14	80	0.182	80	0.068	50
<i>Salsola tragus</i>	1.101	100	1.936	100	0.545	100	0.11	80	0.045	90	0.124	70	0.070	60
<i>Sporobolus coromandelianus</i>	1.249	80	2.509	50	1.403	66.7	0.307	90	0.24	60	0.035	40	0.132	40
<i>Euphorbia</i> spp.	0.209	100	1.490	100	0.604	88.9	0.125	100	0.080	90	0.022	80	0.019	90
<i>Eriogonum cernuum</i>	0.005	10	0.548	30	0.006	11.1	0.019	50	0.008	30	0.011	20	0	0
<i>Bouteloua barbata</i>	1.062	100	0.494	80	2.227	100	0.196	90	0.202	100	0.005	30	0.005	20
<i>Eragrostis pectinacea</i>	0	0	0.609	30	0.427	33.3	0.088	40	0.207	40	0.004	20	0	0
<i>Xanthium strumarium</i>	0	0	1.263	20	<0.001	11.1	0	0	0.011	20	0.003	20	0	0
<i>Sporobolus airoides</i>	5.696	100	8.926	100	8.079	100	2.754	100	3.262	100	<0.001	10	0	0
Nonnative species														
<i>Salsola tragus</i>	1.101	100	1.936	100	0.545	100	0.110	80	0.045	90	0.124	70	0.070	60
<i>Halogeton glomeratus</i>	0	0	0	0	0.002	11.1	0	0	0	0	0	0	0.055	20
<i>Portulaca oleracea</i>	0.004	50	0.085	70	0.069	44.4	0.008	40	0.014	40	0.003	40	0.005	30
<i>Bromus tectorum</i>	0.004	30	<0.001	10	0.002	11.1	0.001	20	0.001	20	0	0	0.002	10
<i>Erodium cicutarium</i>	0	0	0.002	10	0	0	0	0	0	0	<0.001	10	<0.001	10
<i>Mollugo cerviana</i>	0	0	0.002	10	0.231	33.3	0	0	<0.001	10	0	0	0	0
<i>Thinopyrum ponticum</i>	0	0	0.033	10	0	0	0	0	0.006	10	0	0	0	0

Achnatherum hymenoides (Indian ricegrass), and *Sporobolus cryptandrus* (sand dropseed). Abundant shrubs included *Atriplex obovata* (mound saltbush) and *Atriplex canescens* (fourwing saltbush). Common annual grasses included *Eragrostis pectinacea* (tufted lovegrass), *Sporobolus coromandelianus* (Madagascar dropseed) and *Bouteloua barbata* (sixweeks grama).

Seven nonnative species occurred in the plots (Table 2). In 2012 there were 5 nonnative species. *Salsola tragus* (prickly Russian thistle) was the most abundant, with mean foliar covers of 0.110% and 0.045%, and plot frequencies of 80% and 90% for panels A&B, respectively. *Portulaca oleracea* (little hogweed) occurred in 40% of the plots in each of the panels. *Bromus tectorum* (cheatgrass), *Mollugo cerviana* (threadstem carpetweed) and *Thinopyrum ponticum* (tall wheatgrass) occurred in trace amounts.

In 2014, we grouped all perennial species of *Sporobolus* by genus. For panels B&C combined, the 3 species with the greatest foliar cover were *Sporobolus* spp. (dropseed), *Hilaria jamesii* and *Bouteloua gracilis* (Figure 6). *Achnatherum hymenoides* was another abundant perennial. Common shrubs included *Atriplex obovata*, *Atriplex canescens*, and *Gutierrezia sarothrae* (broom snakeweed). Other common species in 2014 included the annual grass *Sporobolus coromandelianus*, the nonnative forb *Salsola tragus* and *Cylindropuntia whipplei* (Whipple’s cholla).

Salsola tragus was also the most abundant nonnative species in 2014, with mean foliar covers of 0.124% and 0.070%, and quadrat frequencies of 70% and 60% for panels B&C, respectively. *Halogeton glomeratus* (saltlover) occurred in 20% of the plots in panel C with a mean foliar cover of 0.55%. *Portulaca oleracea*, *Bromus tectorum* and *Erodium cicutarium* (stork’s bill) occurred in trace amounts.

The number of species in each plot frequency class provides another means to understand the community composition of the vegetation. Most plant communities are dominated by a small number of species, with the majority of the species having low abundances, which translates into few species having high plot frequencies, and the majority of species having low abundances. The Clayey Fan ecological site at PEFO follows this pattern. In 2012, the majority of the species had low plot frequencies—half of species occurred in 15% or less of the plots and only 3 species occurred in all of the plots. In 2014, half of the species occurred in 10% or less of the plots and only 1 species occurred in all of the plots (Figure 7).

Figure 8 and Table 2 present mean foliar cover of the most abundant species in the Clayey Fan ecological site for the 3 sampling periods by panel. Most species had moderately large standard deviations, indicating large among-plot variability. Figure 9 and Table 3 present plot frequency of the most abundant species for the 3 sampling pe-

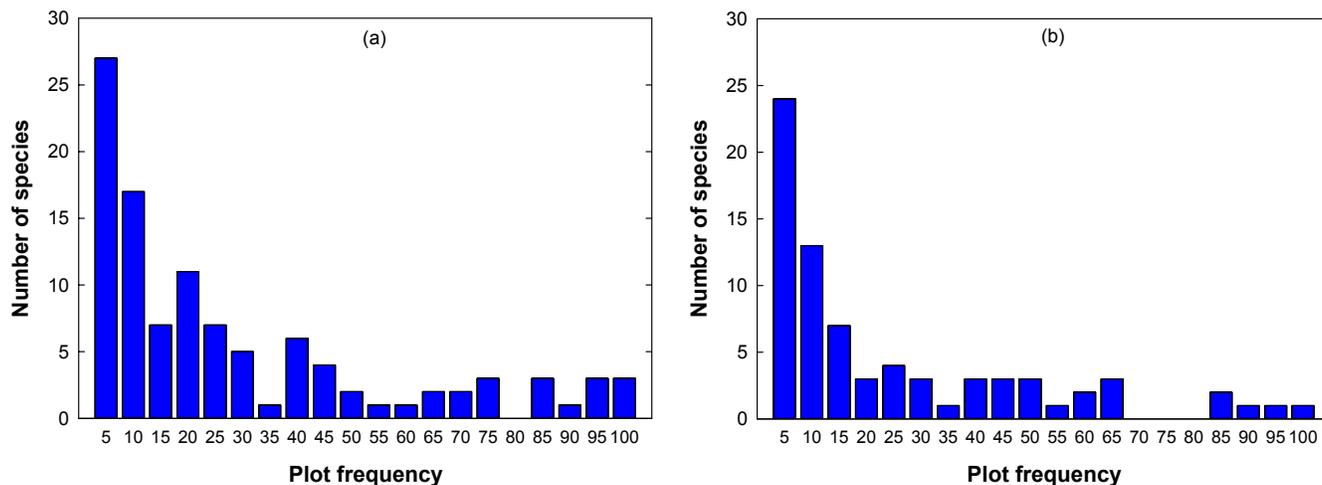


Figure 7. Number of species in each plot frequency class for (a) 20 plots in panels A&B in 2012, and (b) 20 plots in panels B&C in 2014 in the Clayey Fan ecological site at Petrified Forest NP.

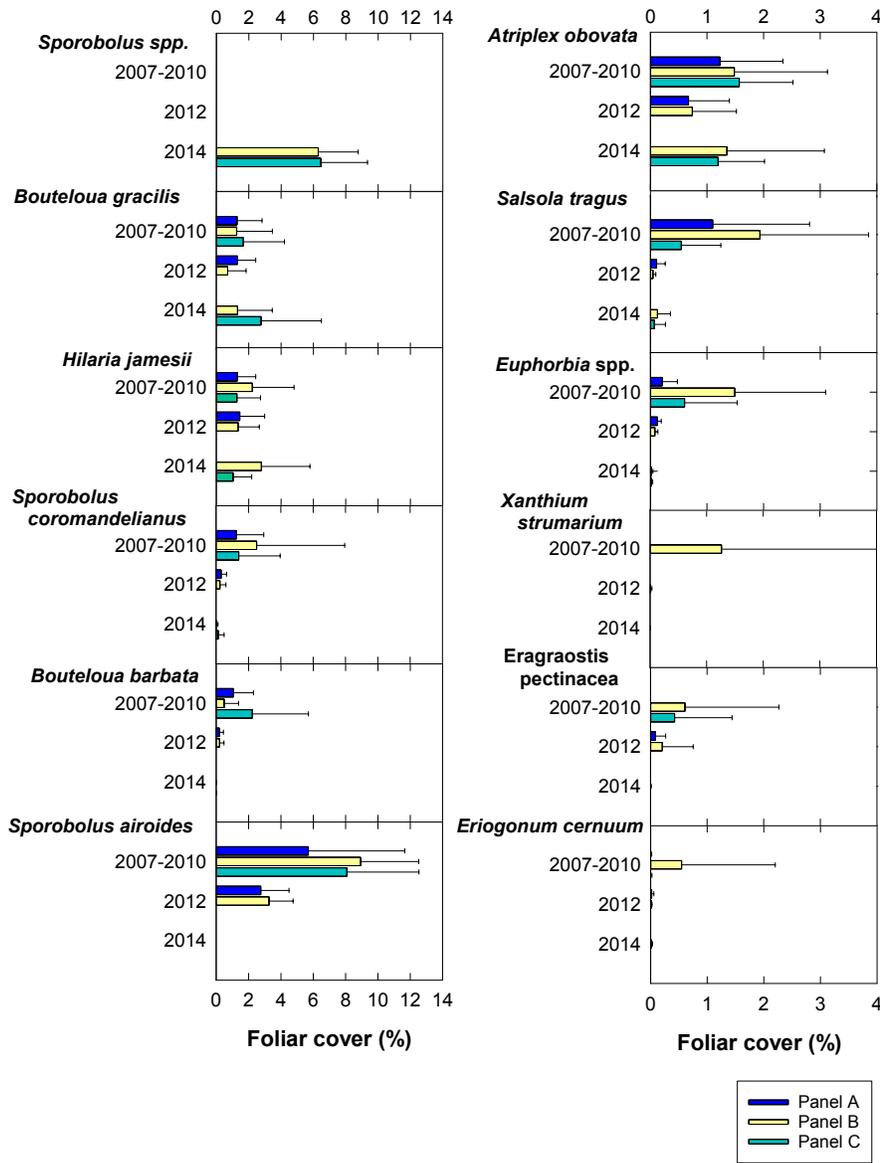


Figure 8. Mean percent foliar cover of the most abundant shrub and herbaceous species in 2012, 2014, and for the initial sampling year (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP. Species with a mean foliar cover > 0.5% in at least one panel are included. Note scales are different for each column. Error bars represent 1 standard deviation. For panels A and C in 2007-2010, n=9; for all other panels and time periods, n=10.

riods by panel. Appendix B lists all species that occurred in the ecological site with common names, mean foliar cover, and plot frequencies by panel and sampling period.

3.1.1.3 Species diversity

For 2012, the species diversity indices indicated moderate diversity on the scale of the plot and moderately high diversity on the scale of the site (Table 3 and Figure 10). On the scale of the plot, mean plot richness was 31.9 for panel A, and 27.0 for panel B. Shannon diversity was 2.03 for panel A, and 1.84 for panel B. Evenness values were 0.59 and 0.56. On the scale of the panel, species richness values were 81 and 79 species. For panels A&B combined, a total of 96 species were detected in 2012. When we recalculated the metrics using only native species, the metrics showed small changes.

In 2014, mean plot richness was 19.7 for panel B, and 17.7 for panel C. Shannon diversity was 1.35 and 1.13 for panels B&C respectively. Evenness values were 0.45 and 0.39. Richness values were 66 species for panel B, and 47 species for panel C. For panels B&C combined, there were a total of 76 species in 2014. When we recalculated the metrics using only native species, the metrics showed small changes.

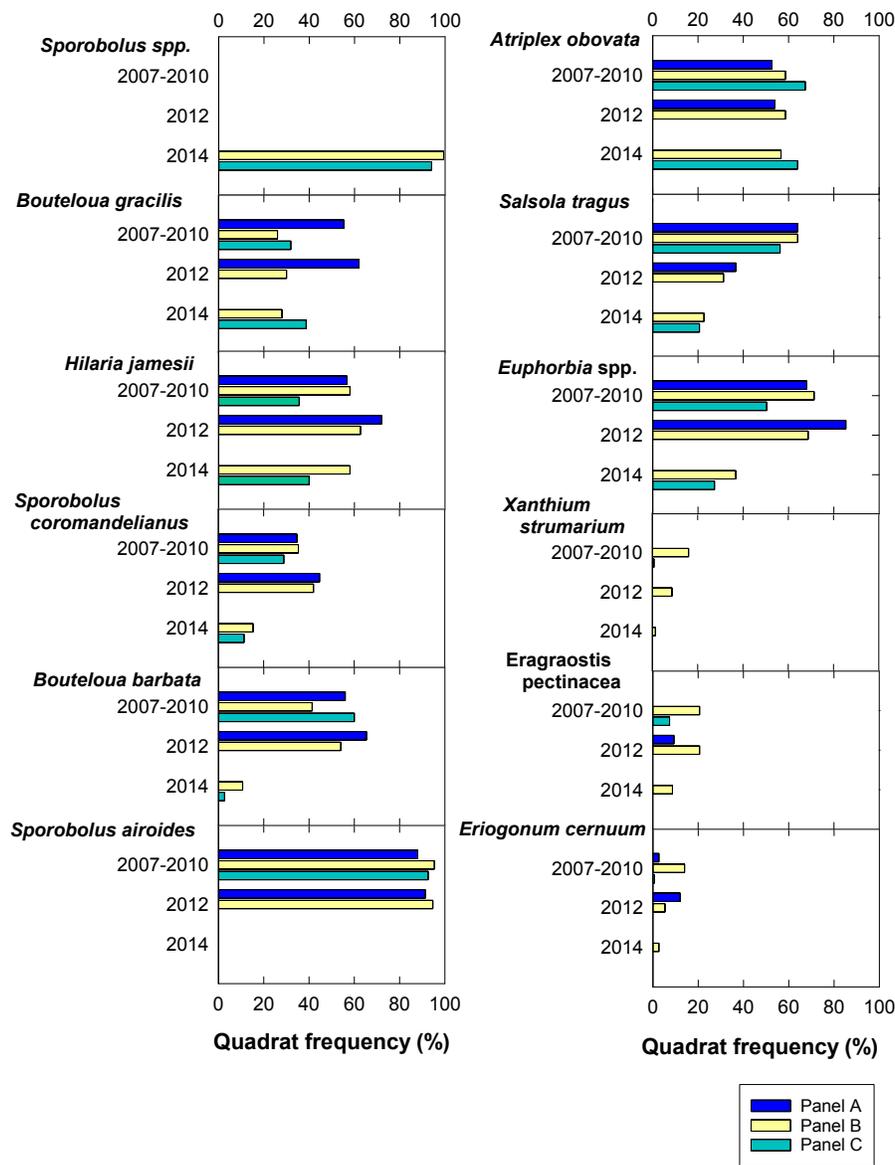


Figure 9. Mean quadrat frequency of shrub and herbaceous species with foliar cover >0.5%, by panel, in 2012, 2014, and for the initial sampling year (2007-2010) in the Clayey Fan ecological site at Petrified Forest NP. For panels A and C in 2007-2010, n=9; for all other panels and time periods, n=10.

3.1.2 Soil stability and hydrologic function

We measured the amount of soil surface at risk for soil erosion using cover estimates of soil surface features. We measured the stability of the surface layer of soil using the soil aggregate stability test.

Undifferentiated crust (including both non-biologic physical crust and undifferentiated biological crusts) and bare soil were the dominant soil features in the Clayey Fan ecological site. Because these two features are hard to distinguish from each other in wet conditions, combining them allows for easier interpretation of the data. In 2012, when combined, mean covers of these 2 features were consistent across the two panels, 87.7% for panel A and 87.6% for panel B. (Figure 11). We summarize the remaining categories here but not all are individually distinguished or displayed in Figure 11. Dead herbaceous base and dead woody base combined were also very similar across the panels, with mean covers of 4.9% and 5.4%. All other soil surface features had mean covers of less than 4%.

For 2014, undifferentiated crust and bare soil combined had mean covers of 85.0% for panel B and 81.8% for panel C (Figure 11). Rock components (including fine gravel, coarse gravel, cobble and stone) had mean covers of 2.1% and 5.6% for panels B&C respectively. All other soil surface features had mean covers of less than 4%. Data values are available in Appendix C.

Table 3. Species diversity metrics for all species, and for native species only, by panel, for 2012, 2014, and for the initial sampling period (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP. SD = standard deviation. Note: richness and diversity values from the initial sampling period (2007–2011) were calculated using slightly different species groupings than were used for the 2012 and 2014 sampling periods. Therefore reported values from the initial period are not directly comparable to the later values. This discrepancy will be resolved in future reports.

All species	Initial sampling year between 2007 and 2010						2012				2014				
	Panel A, n=9		Panel B, n=10		Panel C, n=9		Panel A, n=10		Panel B, n=10		Panel B, n=10		Panel C, n=10		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Plot richness	26.1	10.1	26.2	5.7	22.4	10.7	31.9	7.7	27.0	6.2	19.7	4.6	17.7	6.5	
Shannon diversity	1.84	0.56	1.76	0.26	1.53	0.57	2.03	0.45	1.84	0.26	1.35	0.33	1.13	0.38	
Evenness	0.57	0.15	0.54	0.06	0.49	0.12	0.59	0.11	0.56	0.07	0.45	0.09	0.39	0.09	
Native species															
Plot richness	24.3	10.5	24.2	5.3	20.4	10.1	30.5	7.4	25.4	6.5	18.5	4.4	16.4	6.2	
Shannon diversity	1.80	0.55	1.62	0.30	1.42	0.57	1.99	0.43	1.81	0.25	1.31	0.30	1.08	0.39	
Evenness	0.57	0.15	0.51	0.08	0.47	0.13	0.58	0.10	0.57	0.07	0.45	0.08	0.39	0.09	

All species	Initial sampling year between 2007 and 2010			2012		2014	
	Panel A, n=9	Panel B, n=10	Panel C, n=9	Panel A, n=10	Panel B, n=10	Panel B, n=10	Panel C, n=10
	Panel richness ^a	77	82	62	81	79	66
Beta diversity ^a	3.07	3.25	2.89	2.62	3.04	3.53	2.81
Native species							
Panel richness ^a	74	77	57	78	75	63	42
Beta diversity ^a	3.18	3.32	2.93	2.64	3.07	3.60	2.73

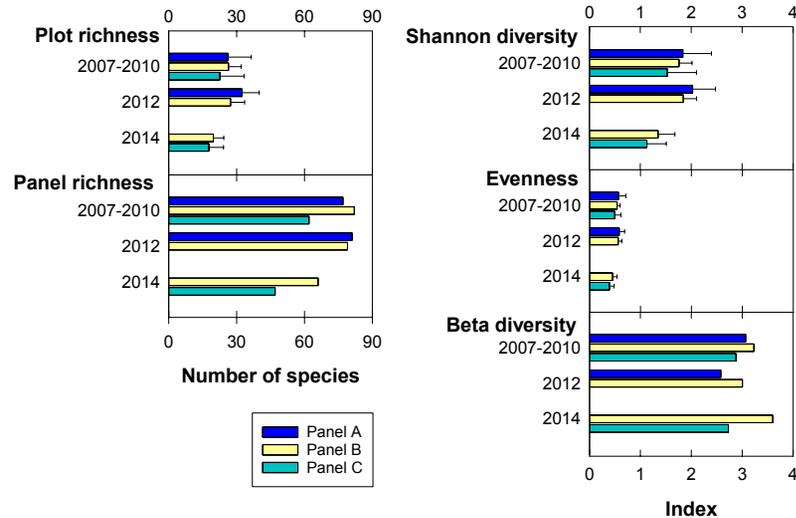


Figure 10. Diversity indices for all species, by panel, in 2012, 2014, and for the initial sampling year (2007–2010) in the Clayey Fan ecological site in Petrified Forest NP. For panels A&C in 2007–2010, n=9; for all other panels and time periods, n=10. Panel richness and beta diversity are not calculated from plot means and therefore do not have standard deviations.

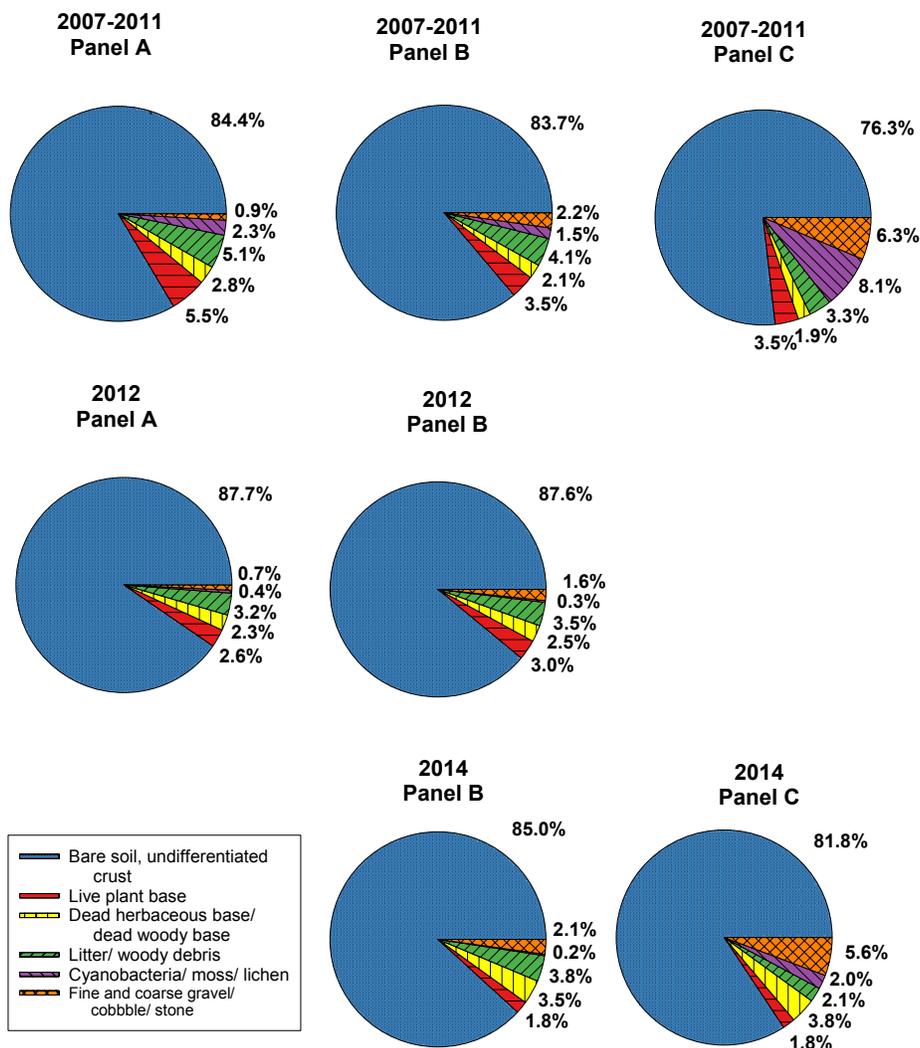


Figure 11. Mean cover of soil surface features, by panel, for 2012, 2014, and for the initial sampling period (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP. Soil surface features do not add up to 100% because the calculations were made from cover class midpoints, and the estimations have observer error. For panels A&C in 2007–2010, n=9; for all other panels and time periods, n=10.

In 2012, mean soil stability ratings for all samples in a plot had values of 2.8 and 4.1 for panels A&B respectively in (Figure 12). Ratings were greater for samples under perennial vegetative cover than those without cover. Standard deviations, indicating among-plot variation, were moderate.

In 2014 mean soil stability ratings for all samples in a plot had values of 2.8 and 3.7 for panels B&C respectively (Figure 12). Ratings were greater for samples under perennial vegetative cover than those without cover. Standard deviations, indicating among-plot variation, were moderate. All data values corresponding to Figure 12 are available in table format in Appendix D.

3.2 Sandy Loam Upland ecological site

3.2.1 Shrub and herbaceous vegetation

We examined foliar cover of functional groups, foliar cover and frequency of species, and species diversity.

3.2.1.1 Functional group cover

Foliar cover of functional groups indicates broad patterns in cover for shrub and herbaceous vegetation. Perennial grasses dominate the Sandy Loam Upland ecological site. In 2013, for panels A&B combined, the mean total live foliar cover of all plots in was 20.63%, and the mean foliar cover of perennial grass was 16.70% (Figure 13). Mean foliar cover of shrubs was 3.42%; mean foliar cover of cacti and yucca, annual grasses and forbs were all

Figure 12. Mean soil stability ratings for all samples and for samples under and not under vegetative cover, by panel, for 2012, 2014, and the initial sampling period (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP. Error bars represent 1 standard deviation. Ratings range from 1 to 6, with 1 being the lowest stability and 6 being the highest. For panels A&C in 2007–2010, n=9; for all other panels and time periods, n=10.

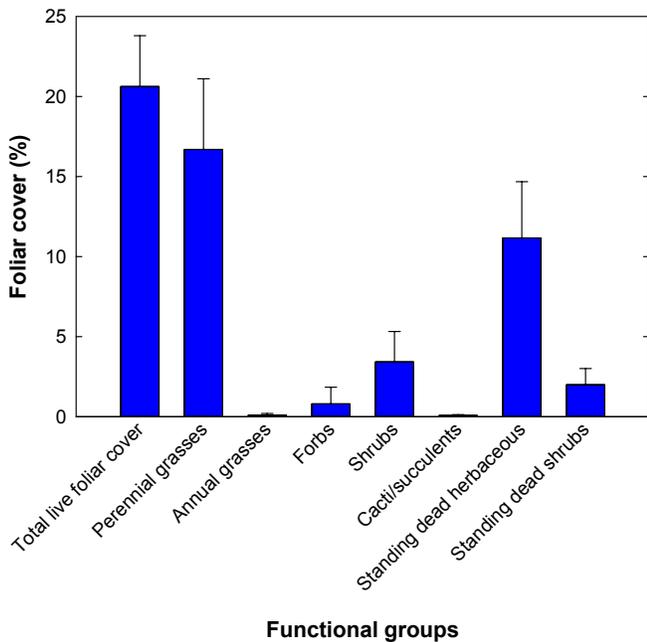
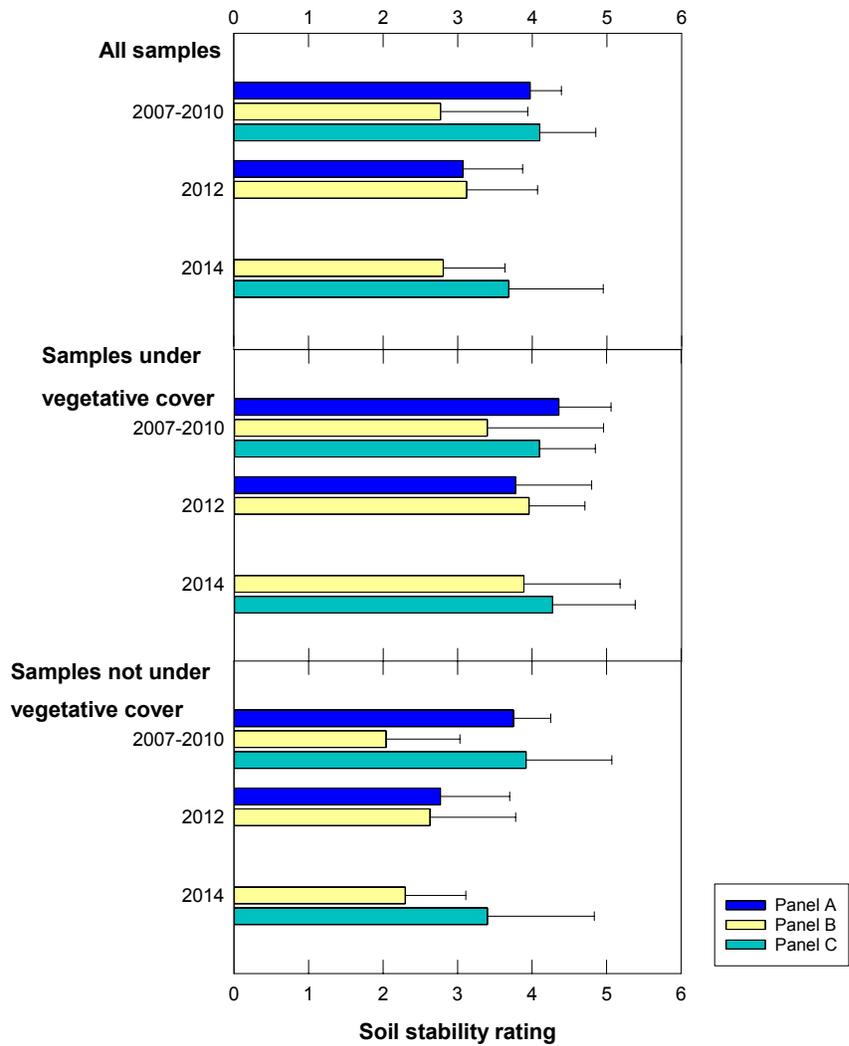


Figure 13. Mean percent foliar cover of functional groups for all 20 plots in panels A&B in the Sandy Loam Upland ecological site at Petrified Forest NP in 2013. Annual grasses are not shown due to low cover. Error bars represent 1 standard deviation.

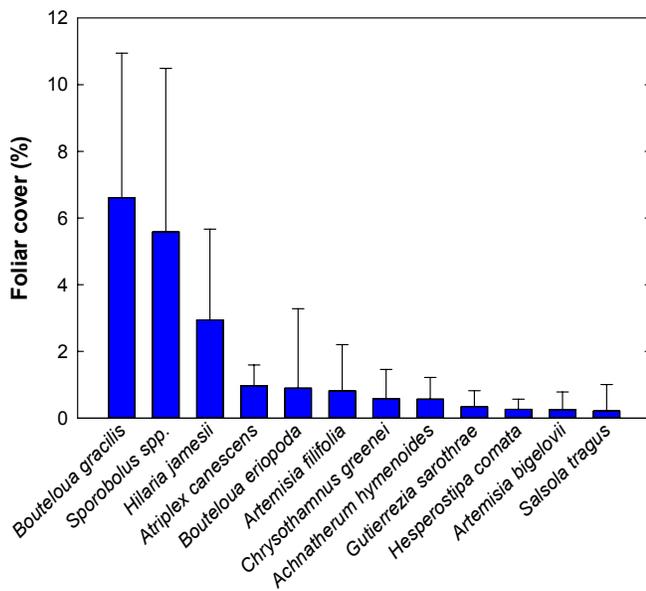


Figure 15. Mean percent foliar cover of the 12 most abundant shrub and herbaceous species for all 20 plots in panels A&B in the Sandy Loam Upland ecological site at PEFO in 2013. Error bars represent 1 standard deviation.

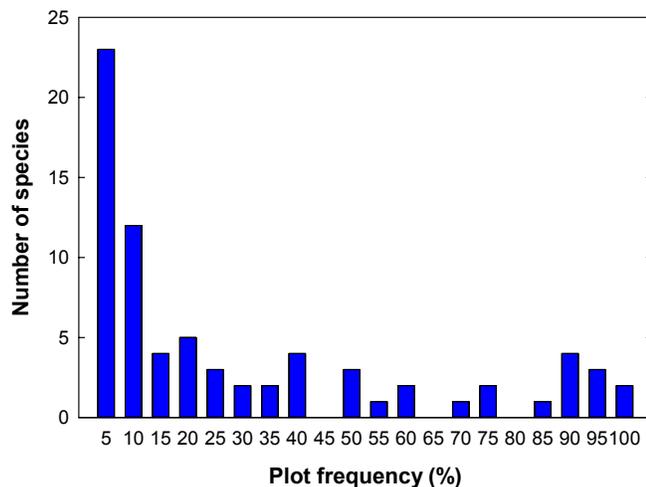


Figure 16. Number of species in each plot frequency class for all 20 plots in panels A&B in the Sandy Loam Upland ecological site at Petrified Forest NP in 2013.

less than 1%. Standard deviations, indicating among-plot variability, were large for many of the functional groups.

Figure 14 presents the mean foliar cover of each functional group by panel for both 2013 and the initial sampling period (2007-2010). Appendix E summarizes functional group cover data by sampling period and panel.

3.2.1.2 Species foliar cover and frequency

Foliar cover and frequency of individual species provides an indication of the structure and dynamics of the vegetation in the Sandy Loam Upland ecological site. In 2013, for panels A&B combined, the 3 species with the greatest foliar cover were perennial grasses—*Bouteloua gracilis*, *Sporobolus spp.* (alkali sacaton) and *Hilaria jamesii* (Figure 15). Other abundant perennial grasses included *Achnatherum hymenoides* and *Hesperostipa comata* (needle and thread). Abundant shrubs included *Atriplex canescens*, *Artemisia filifolia* (sand sage), *Chrysothamnus Greenei* (Greene’s rabbitbrush), *Gutierrezia sarothrae* and *Artemisia bigelovii* (Bigelow’s sage). *Salsola tragus* was the most abundant forb.

The distribution the plot frequencies of species provides another means to understand the community composition of the vegetation. Most plant communities are dominated by a small number of species, with the majority of the species having low abundances, which translates into few species having high plot frequencies, and the majority of species having low plot frequencies. The Sandy Loam Upland ecological site at PEFO follows this pattern. For the 20 plots in 2013, the majority of the species had low plot frequencies—50% of the 74 species occurred in 15% or less of the plots, 23 species only occurred in one plot, and only 2 species occurred in all of the plots (Figure 16).

Five nonnative species were found in the plots in 2013 (Table 4). *Salsola tragus* was the most abundant in 2013 with mean foliar covers of 0.416% and 0.013%, and quadrat frequencies of 28.0% and 3.3% for panels A&B, respectively. *Portulaca oleracea* and *Kochia scoparia* (Mexican burning bush) had mean foliar covers ranging from .028% to .064% and quadrat frequencies ranging from 4.7% to 8.7%. *Salsola collina* (slender Russian thistle) and *Mollugo cerviana* (threadstem carpetweed) occurred in trace amounts.

Table 4. Foliar cover and plot frequency of shrub and herbaceous species, by panel, for 2013, and the initial year of sampling (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP. This table includes only species with a mean foliar cover >0.2% in panels A&B combined during the initial year of sampling, or in 2013, as well as all nonnative species. Species are arranged in descending order based on their mean foliar values in 2013 for both panels combined.

Abundant species	Initial sampling year between 2007 and 2010						2013			
	Panel A, n=10		Panel B, n=10		Panel C, n=10		Panel A, n=10		Panel B, n=10	
	Mean cover (%)	Plot frequency (%)	Mean cover (%)	Plot frequency (%)	Mean cover (%)	Plot frequency (%)	Mean cover (%)	Plot frequency (%)	Mean cover (%)	Plot frequency (%)
<i>Bouteloua gracilis</i>	3.478	80	6.430	100	6.876	100	5.371	80	7.852	100
<i>Sporobolus</i> spp.	3.465	100	4.188	100	1.223	100	5.546	100	5.630	100
<i>Hilaria jamesii</i>	3.649	100	2.192	100	4.501	100	3.695	100	2.189	100
<i>Atriplex canescens</i>	1.154	90	1.249	100	1.558	90	0.946	90	0.991	100
<i>Bouteloua eriopoda</i>	0.746	60	0.224	50	1.519	70	1.383	50	0.409	50
<i>Artemisia filifolia</i>	0.747	40	1.062	30	0.857	50	0.852	40	0.781	30
<i>Chrysothamnus Greenei</i>	0.311	40	0.986	40	0	0	0.347	60	0.813	50
<i>Achnatherum hymenoides</i>	0.435	90	0.829	90	0.508	100	0.516	90	0.620	90
<i>Gutierrezia sarothrae</i>	1.037	80	0.859	100	2.524	100	0.408	90	0.283	90
<i>Hesperostipa comata</i>	0.212	60	0.261	70	0.491	70	0.225	90	0.301	100
<i>Artemisia bigelovii</i>	0.264	20	0.252	40	0.083	10	0.268	20	0.236	40
<i>Salsola tragus</i>	0.506	90	0.202	60	0.765	60	0.416	70	0.013	50
<i>Euphorbia</i> spp.	0.276	80	0.721	80	0.364	60	0.173	90	0.226	100
<i>Sphaeralcea hastulata</i>	0.256	60	0.202	80	0.079	80	0.024	70	0.037	80
<i>Bromus tectorum</i>	0.027	40	0.762	40	0.129	50	0	0	0	0
Nonnative species										
<i>Salsola tragus</i>	0.506	90	0.202	60	0.765	60	0.416	70	0.013	50.00
<i>Portulaca oleracea</i>	0.023	30	0.090	30	0.042	30	0.064	40	0.045	40.00
<i>Kochia scoparia</i>	0	0	<0.001	10	0	0	0.028	40	0.031	10.00
<i>Salsola collina</i>	0	0	0	0	0	0	0	0	0.002	10.00
<i>Mollugo cerviana</i>	0.003	20	0.004	10	0.029	30	<0.001	10	<0.001	10.00
<i>Bromus tectorum</i>	0.027	40	0.762	40	0.129	50	0	0	0	0
<i>Polygonum aviculare</i>	0	0	<0.001	10	0	0	0	0	0	0

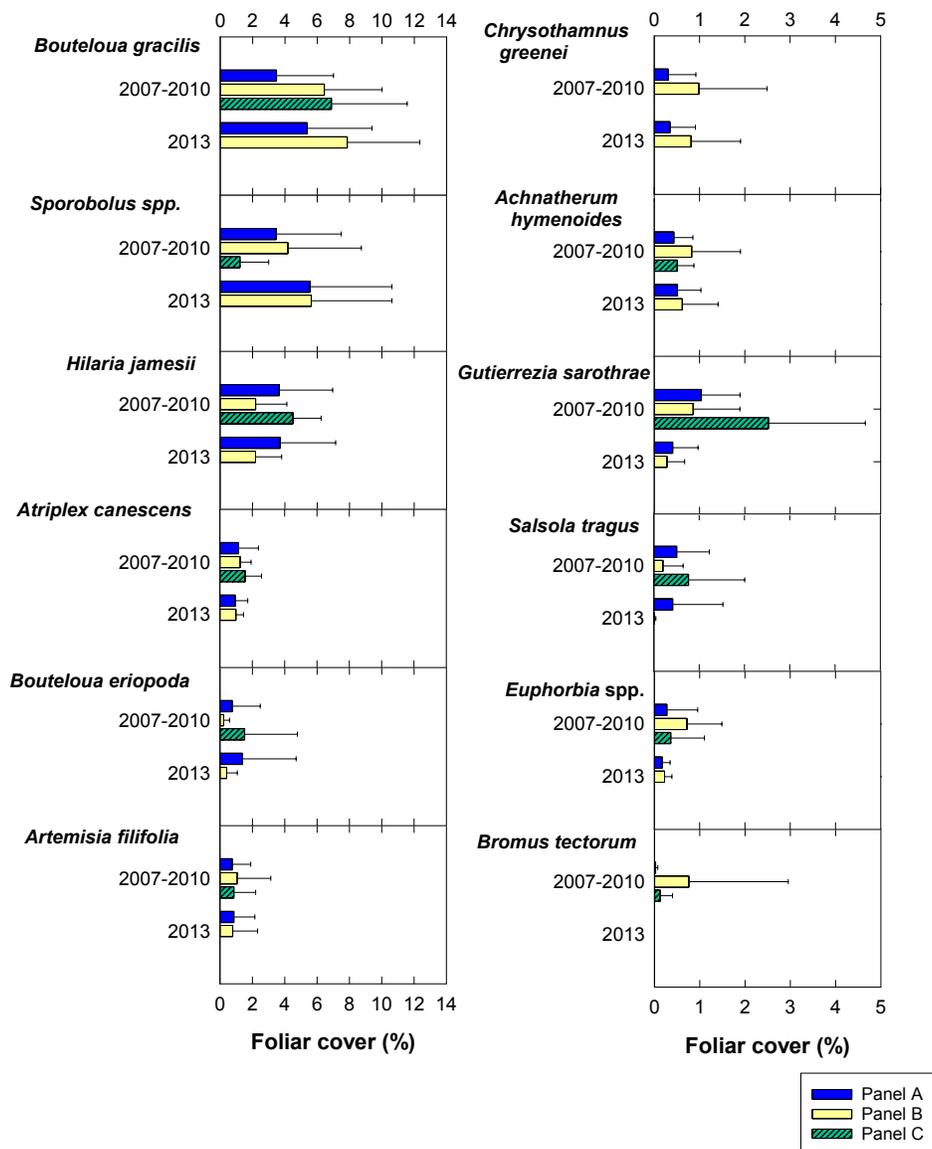


Figure 17. Mean percent foliar cover for the most abundant shrub and herbaceous species, by panel, for 2013 and for the initial sampling period (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP. Includes species with a foliar cover >0.3% in at least one panel. Note that scales are different for each column. Error bars represent 1 standard deviation. For each panel and sampling period, n = 10.

Figure 17 and Table 4 present mean foliar cover of the most abundant species for the 2 sampling periods by panel. Most species had moderately large standard deviations, indicating large among-plot variability. Figure 18 and Table 4 present quadrat frequency of the most abundant species for the 2 sampling periods by panel. Appendix F lists all species that occurred in the ecological site with common names, families, mean foliar cover, and plot frequencies by panel and sampling period.

3.2.1.3 Species diversity

The species diversity indices indicate moderate diversity on the scale of the plot and moderately high diversity on the scale of the site (Table 5 and Figure 19). On the scale of the plot, mean plot richness was 22.0 for panel A and 22.7 for panel B. Shannon diversity (which takes the relative abundance of each species into account and generally ranges between 1.5 and 3.5) was the same, 1.64, for both panels. Evenness was also the same—0.53 for both panels. Species richness was 62 species for panel A and 59 species for panel B. For panels A&B combined, there were a total of 74 species in 2013. When we recalculated the metrics using only native species, the metrics showed small changes.

Figure 18. Mean quadrat frequency of shrub and herbaceous species with foliar cover >0.3%, by panel, for 2013 and for the initial sampling period (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP. For each panel and sampling period, n = 10.

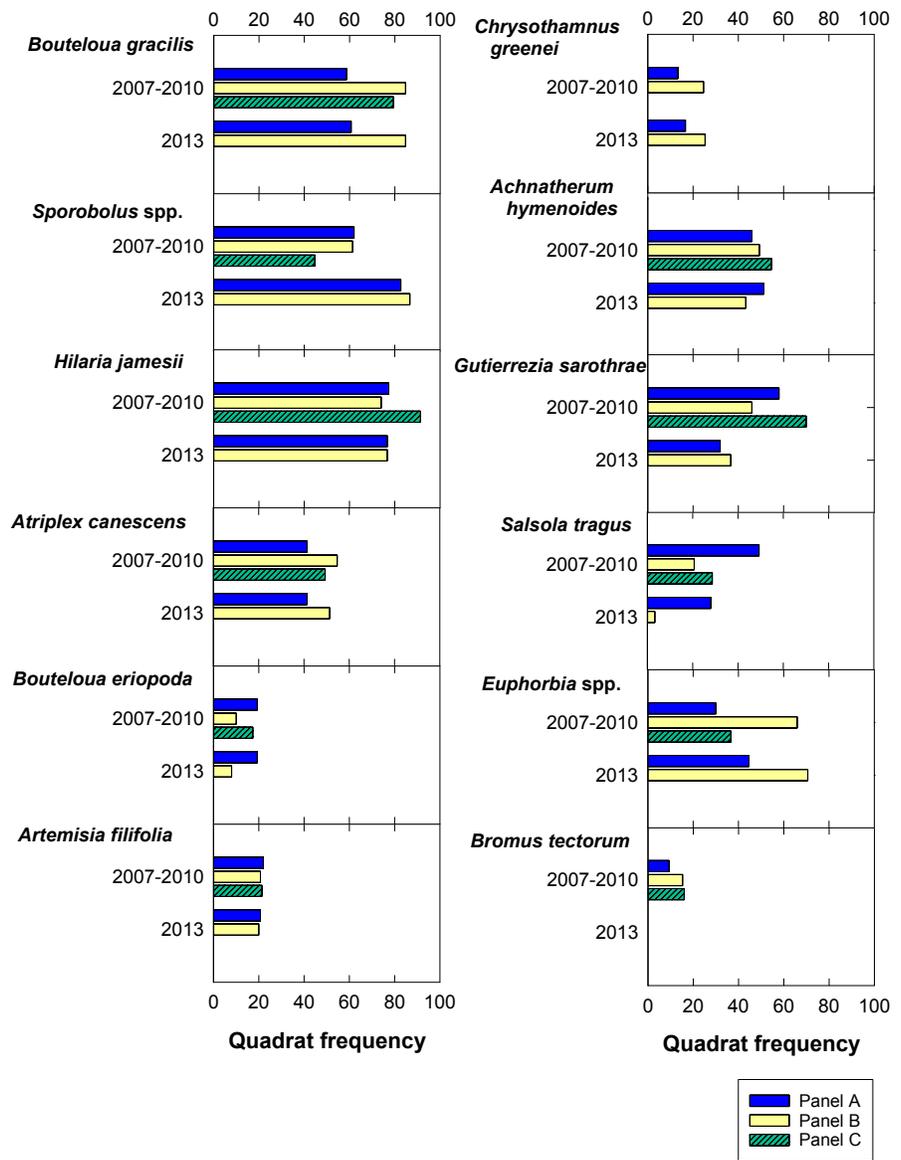


Figure 19. Diversity indices by panel, for 2013, and for the initial sampling period (2007–2010) in the Sandy Loam Upland ecological site in Petrified Forest NP. Panel richness and beta diversity are not calculated from plot means and therefore do not have standard

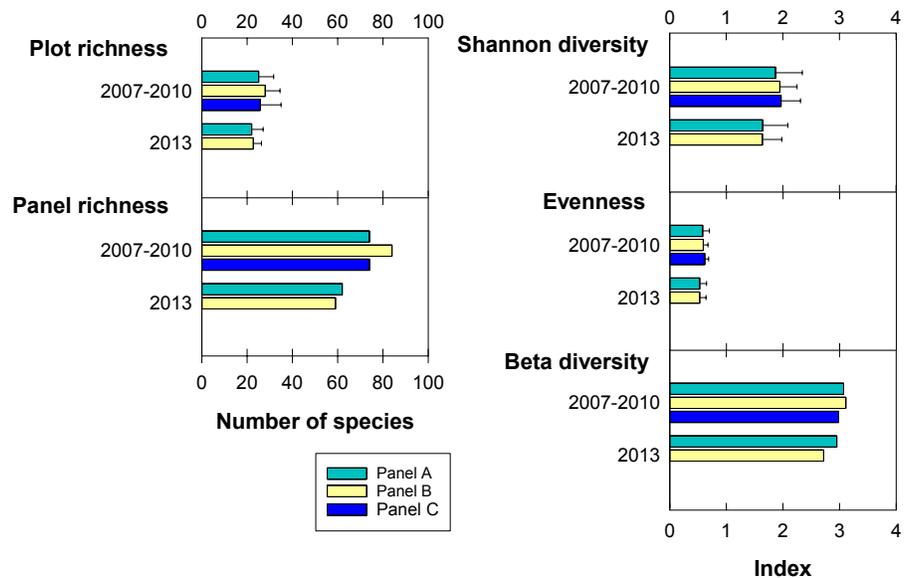


Table 5. Species diversity metrics for all species and for native species only, by panel, for 2013, and the initial year of sampling (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP. SD = standard deviation. Note: richness and diversity values from the initial sampling period (2007–2011) were calculated using slightly different species groupings than were used for the 2012 and 2014 sampling periods. Therefore, reported values from the initial period are not directly comparable to the later values. This discrepancy will be resolved in future reports.

	Initial sampling year between 2007 and 2010						2013			
	Panel A, n=10		Panel B, n=10		Panel C, n=10		Panel A, n=10		Panel B, n=10	
All species	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Plot richness	25.1	6.6	28.0	6.5	25.8	9.2	22.0	5.1	22.7	3.6
Shannon diversity	1.87	0.47	1.95	0.30	1.97	0.34	1.64	0.44	1.64	0.34
Evenness	0.58	0.12	0.59	0.08	0.62	0.07	0.53	0.12	0.53	0.11
Native species										
Plot richness	23.3	6.1	26.4	6.2	24.1	8.9	20.4	4.6	21.5	3.0
Shannon diversity	1.81	0.47	1.88	0.32	1.90	0.34	1.61	0.44	1.62	0.35
Evenness	0.58	0.12	0.58	0.09	0.61	0.07	0.53	0.12	0.53	0.11

	Initial sampling year between 2007 and 2010			2013	
	Panel A, n=10	Panel B, n=10	Panel C, n=10	Panel A, n=10	Panel B, n=10
All species					
Panel richness	74	84	74	62	59
Beta diversity	3.07	3.11	2.98	2.95	2.72
Native species					
Panel richness	70	78	70	58	54
Beta diversity	3.14	3.07	3.03	2.99	2.63

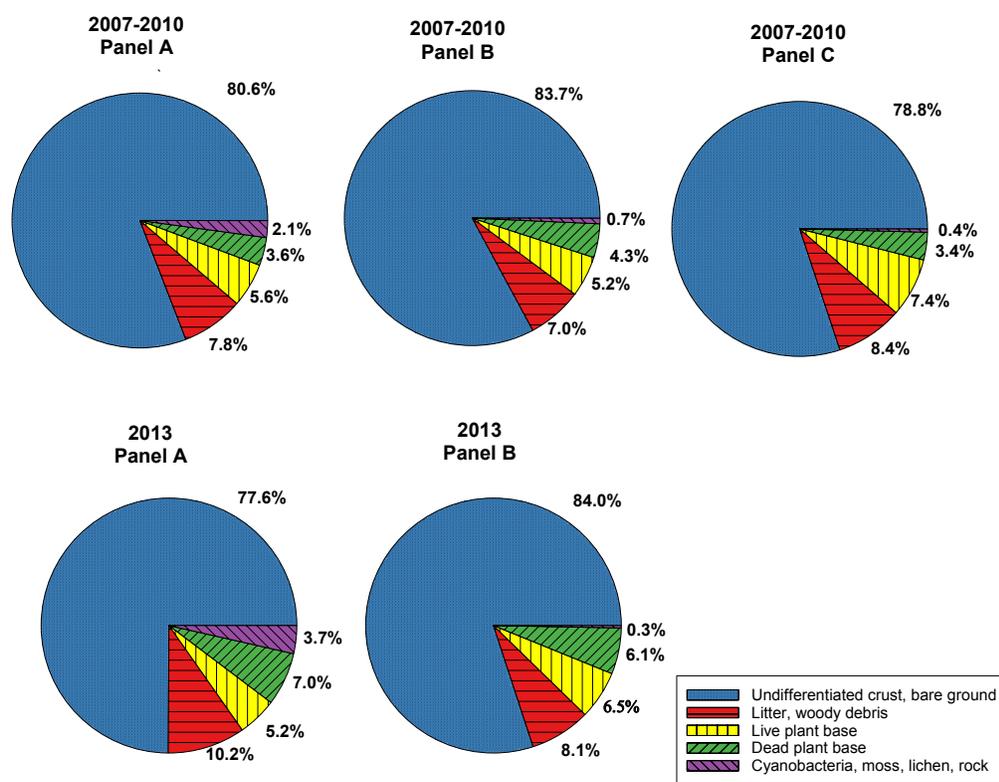
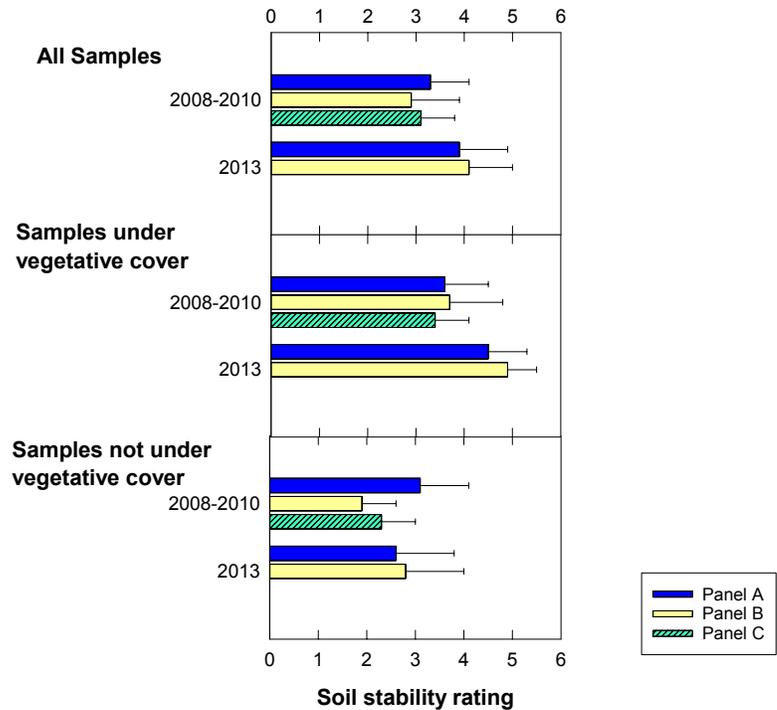


Figure 20. Mean percent cover of soil surface features, by panel, for 2013, and for the initial sampling period (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP. Soil surface features do not add up to 100% because the calculations were made from cover class midpoints. For all panels, n = 10.

Figure 21. Mean soil stability ratings for all samples and for samples under and not under vegetative cover, by panel, for 2013, and for the initial sampling period (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP. Error bars represent 1 standard deviation. Ratings range from 1 to 6, with 1 being the lowest stability and 6 being the highest. For each panel and sampling period, n = 10.



3.2.2 Soil stability and hydrologic function

We measure the amount of soil surface potentially subject to soil erosion through cover estimates of soil surface features. We measure stability of the surface layer of soil using the soil aggregate stability test.

Undifferentiated crust (including both non-biologic physical crust and undifferentiated biological crusts) and bare soil were the dominant soil features in 2013. Because these two features are hard to distinguish from each other in wet conditions, combining them allows for easier interpretation of the data. When combined, these 2 features were approximately 77.6 % and 84.0% for panels A&B respectively, in 2013 (Figure 20). We summarize the remaining categories here but not all are individually distinguished or displayed in Figure 20. Live plant base, litter/woody debris and dead herbaceous base/ dead woody base ranged in cover between 5% and 11%. Biological soil crust components (cyanobacteria, moss and lichen), and rock components (fine gravel, coarse gravel and cobble) had values of 3.7% and 0.3% for panels A&B in 2013. Data values are available in Appendix G.

Mean soil stability ratings for all samples in a plot had values of 3.9 and 4.1 in 2013 for panels A&B, respectively (Figure 21). Ratings were greater for samples under perennial vegetative cover than those without cover. Standard deviations, indicating among-plot variation, were moderate. All data values corresponding to Figure 21 are available in Appendix H.

4 Discussion

The data summarized in this report represent the first panel-based sampling of vegetation and soils in the Clayey Fan and Sandy Loam Upland ecological sites at PEFO. The shrub and herbaceous data demonstrate that these ecological sites are examples of diverse and relatively undisturbed grassland, with a shrub component. In the Clayey Loam ecological site, 5 nonnative species occurred in the plots in 2012 and in 2014; in the Sandy Loam Upland ecological site, 5 nonnative species occurred in 2013. *Salsola tragus* was moderately abundant in both sites, and the remaining species had low to sparse abundances.

Species diversity was moderately high both on the plot scale and at the landscape scale. The soils data from both sites indicate that there is some potential for erosion. The majority of the soil surface was comprised of bare soil and undifferentiated crust, and the cover of biological soil crust (cyanobacteria, lichen and moss) was low. However, soil stability ratings were moderately high.

We stress that while we present data for 3 time periods, one must be careful in making comparisons and interpreting differences as signs of change based on only a few data points, particularly in light of the annual variability in species abundance.

Data from our repeat sampling of 10 plots at each of these sites between 2007 and 2009 (data not reported here) demonstrated moderate variation in species foliar cover and frequency from year to year that appeared to be at least partially the result of variation in precipitation over those years (DeCoster and Swan 2011). Annual variation in herbaceous species abundance suggests that data from multiple points in time are needed in order to identify meaningful vegetation trends.

According to the SCPN panel design, we will visit one ecological site every year, sampling 2 panels (20 plots) on each visit. The Clayey Fan site will be sampled in even years and the Sandy Loam Upland site in odd years. As we collect more data over a longer time period, we will begin to examine trends in the condition of vegetation and soils for the Clayey Fan and the Sandy Loam Upland ecological sites at PEFO.

5 Literature cited

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Appendix A: Foliar cover of functional groups in the Clayey Fan ecological site at Petrified Forest National Park, 2007–2014

Table A-1. Foliar cover of functional groups by panel in the Clayey Fan ecological site at Petrified Forest NP for 2012 and 2014, and for the initial sampling year for all plots (2007–2010). The means for 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.

Functional group	Initial sampling year between 2007 and 2010						2012				2014			
	Panel A, n=9		Panel B, n=10		Panel C, n=9		Panel A, n=10		Panel B, n=10		Panel B, n=10		Panel C, n=10	
	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Total live foliar cover	14.10	4.96	24.00	9.45	18.88	10.33	8.14	3.09	7.87	2.87	13.60	3.69	12.81	4.51
Perennial grasses	8.97	5.09	12.73	5.98	11.57	7.85	6.47	2.61	5.85	2.69	11.15	4.22	10.48	4.96
Annual grasses	2.27	2.76	3.74	7.38	4.19	4.78	0.56	0.53	0.65	0.91	0.04	0.09	0.14	0.36
Forbs	1.70	1.77	5.91	4.05	2.44	2.37	0.48	0.26	0.36	0.12	0.35	0.49	0.24	0.33
Shrubs	2.20	1.40	2.46	2.38	1.88	0.62	1.21	0.88	1.20	0.95	2.24	2.00	1.44	0.58
Cacti/succulents	0.04	0.03	0.21	0.47	0.07	0.09	0.04	0.04	0.07	0.16	0.10	0.22	0.09	0.11
Standing dead herbaceous	3.95	1.05	2.90	1.81	2.93	1.58	3.37	1.38	3.03	1.18	8.24	3.29	8.19	3.85
Standing dead shrubs	0.70	0.29	0.58	0.34	0.43	0.19	0.40	0.25	0.42	0.29	0.78	0.48	0.51	0.20

Appendix B: Plant species list for the Clayey Fan ecological site at Petrified Forest National Park, 2007-2014

Table B-1. Plant species list with mean foliar cover and plot frequency, by panel, for 2012, 2014, and for the initial sampling period (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP.

Species	Common name	Initial sampling year between 2007 and 2010						2012				2014			
		Panel A, n=9		Panel B, n=10		Panel C, n=9		Panel A, n=10		Panel B, n=10		Panel B, n=10		Panel C, n=10	
		Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Achnatherum hymenoides</i>	Indian ricegrass	0.221	100	0.194	80	0.09	66.7	0.217	100	0.14	80	0.182	80	0.068	50
<i>Allium macropetalum</i>	largeflower onion	0.001	10	0	0	<0.001	11.1	0.001	10	0	0	<0.001	10	0.001	10
<i>Amaranthus</i> spp.	pigweed	0	0	0.002	20	0	0	0.001	10	0	0	0	0	0	0
<i>Ambrosia</i> spp.	ragweed	0	0	0	0	0	0	0	0	0	0	0.002	10	0	0
<i>Aristida adscensionis</i>	sixweeks threeawn	0	0	0	0	0.013	11.1	0.004	30	0.011	20	<0.001	10	0	0
<i>Aristida purpurea</i>	Fendler's threeawn	0.001	20	0.024	20	0.04	22.2	0.001	20	0.011	20	0.023	10	0.039	20
<i>Artemisia bigelovii</i>	Bigelow sage	0.051	20	0.004	10	0.084	11.1	0.024	30	0.007	10	0.004	10	0.078	10
<i>Artemisia filifolia</i>	sand sagebrush	0.005	10	0.188	30	0	0	0	0	0.079	30	0.102	30	0	0
<i>Artemisia ludoviciana</i>	white sagewort	0	0	0	0	0	0	0.006	10	0	0	0	0	0	0
<i>Astragalus amphioxys</i>	Crescent milkvetch	0.017	70	0.025	70	0.016	55.6	0.025	80	0.01	50	0.010	50	0.003	30
<i>Astragalus ceramicus</i>	painted milkvetch	0	0	0.002	20	0	0	0.002	20	0	0	0	0	0	0
<i>Astragalus mollissimus</i>	wooly locoweed	0	0	0.002	10	0	0	0	0	0.001	10	0	0	0	0
<i>Astragalus</i> spp.	milkvetch	0	0	0	0	<0.001	11.1	0	0	0	0	0	0	0	0
<i>Atriplex canescens</i>	fourwing saltbush	0.232	40	0.375	50	0.093	33.3	0.131	40	0.249	50	0.323	50	0.062	40
<i>Atriplex confertifolia</i>	shadscale saltbush	0.152	50	0.011	30	0.045	22.2	0.073	80	0.036	50	0.030	40	0.016	20
<i>Atriplex obovata</i>	mound saltbush	1.229	90	1.483	80	1.571	100	0.673	100	0.74	90	1.352	90	1.196	100
<i>Atriplex saccaria</i>	sack saltbush	0	0	<0.001	10	0.013	11.1	0	0	0	0	0	0	0	0

a Nonnative species

Table B-1. (continued) Plant species list with mean foliar cover and plot frequency, by panel, for 2012, 2014, and for the initial sampling year (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP.

Species	Common name	Initial sampling year between 2007 and 2010						2012				2014			
		Panel A, n=9		Panel B, n=10		Panel C, n=9		Panel A, n=10		Panel B, n=10		Panel B, n=10		Panel C, n=10	
		Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Bouteloua barbata</i>	sixweeks grama	1.062	100	0.494	80	2.227	100	0.196	90	0.202	100	0.005	30	0.005	20
<i>Bouteloua eriopoda</i>	black grama	0.05	10	0	0	0	0	0.01	10	0	0	0	0	0	0
<i>Bouteloua gracilis</i>	blue grama	1.278	100	1.26	70	1.663	55.6	1.31	100	0.697	70	1.311	70	2.758	60
<i>Bromus tectorum</i> ^a	cheatgrass	0.004	30	<0.001	10	0.002	11.1	0.001	20	0.001	20	0	0	0.002	10
<i>Calochortus aureus</i>	golden mariposa lily	0	0	0	0	0	0	0.006	20	0.003	30	0.011	30	0.009	20
<i>Chaetopappa ericoides</i>	rose heath	0.011	60	0.004	30	<0.001	11.1	0.022	50	0.01	50	0.007	20	0	0
<i>Chamaesaracha coronopus</i>	greenleaf five eyes	0.003	20	0.064	60	0.039	33.3	0.01	30	0.019	50	0.003	50	0.008	40
<i>Chenopodium</i> spp.	goosefoot	0	0	0.179	30	0.019	33.3	0	0	0	0	0	0	0	0
<i>Chrysothamnus Greenei</i>	Greene's rabbitbrush	0.033	10	0.003	20	0.011	11.1	0.01	10	0.006	20	0.004	20	0.010	10
<i>Comandra umbellata</i>	bastard toadflax	0.007	10	0	0	0	0	0.002	10	0	0	0	0	0	0
<i>Cordylanthus wrightii</i>	Wright's bird's beak	<0.001	10	0.002	10	0	0	0	0	0	0	0	0	0	0
<i>Corispermum americanum</i>	American bugseed	0.019	10	0.007	10	0	0	<0.001	10	0	0	<0.001	10	0	0
<i>Cryptantha flava</i>	Brenda's yellow cryptantha	0	0	0	0	0	0	0	0	0	0	<0.001	10	0	0
<i>Cryptantha</i> spp.	cryptantha	<0.001	10	0.005	30	0.009	33.3	0.012	20	0.004	40	<0.001	10	0	0
<i>Cylindropuntia whipplei</i>	Whipple cholla	0.007	20	0.05	30	0.05	44.4	0.005	30	0.053	30	0.065	50	0.060	50
<i>Dalea candida</i>	white prairieclover	0.027	30	0.01	10	0	0	0.014	20	0	0	0	0	0	0
<i>Dalea lanata</i>	woolly prairieclover	0	0	0	0	0	0	0	0	0.002	10	0	0	0	0

^a Nonnative species

Table B-1. (continued) Plant species list with mean foliar cover and plot frequency, by panel, for 2012, 2014, and for the initial sampling year (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP.

Species	Common name	Initial sampling year between 2007 and 2010						2012				2014			
		Panel A, n=9		Panel B, n=10		Panel C, n=9		Panel A, n=10		Panel B, n=10		Panel B, n=10		Panel C, n=10	
		Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Descurainia pinnata</i>	western tansymustard	0	0	0	0	<0.001	11.1	0.004	60	0.004	30	<0.001	10	0.002	40
<i>Dieteria canescens</i>	hoary tansyaster	0.035	30	0.005	10	0	0	0.017	20	0.002	10	<0.001	10	0	0
<i>Dimorphocarpa wislizeni</i>	spectacle pod	0.002	10	0.006	10	<0.001	11.1	<0.001	10	0.003	10	0.002	10	<0.001	10
<i>Draba cuneifolia</i>	wedgeleaf draba	0	0	0.007	30	0	0	<0.001	10	<0.001	10	0.002	30	0.001	10
<i>Echinocereus triglochidiatus</i>	kingcup cactus	0	0	0	0	0	0	0	0	0	0	<0.001	10	0	0
<i>Elymus elymoides</i>	squirreltail	<0.001	10	<0.001	10	0	0	0.005	30	<0.001	10	0.002	10	0	0
<i>Enneapogon desvauxii</i> ^a	nineawn pappusgrass	0	0	0	0	<0.001	11.1	0	0	<0.001	10	0.000	0	<0.001	10
<i>Ephedra cutleri</i>	Cutler's jointfir	0.005	10	0	0	0	0	0.023	10	0	0	0	0	0	0
<i>Ephedra torreyana</i>	Torrey's jointfir	0.093	40	0	0	0	0	0.051	50	0	0	0	0	0	0
<i>Ephedra viridis</i>	Mormon tea	0.05	10	0	0	0	0	0	0	0	0	0	0	0	0
<i>Eragrostis pectinacea</i>	desert lovegrass	0	0	0.609	30	0.427	33.3	0.088	40	0.207	40	0.004	20	0.000	0
<i>Eriastrum diffusum</i>	miniature woollystar	<0.001	10	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ericameria nauseosa</i>	rubber rabbitbrush	0.095	40	0.057	20	0	0	0.014	40	0.007	20	0.033	20	0.083	10
<i>Erigeron</i> spp.	fleabane	<0.001	10	0	0	0.024	22.2	0	0	0	0	0	0	0	0
<i>Erigeron concinnus</i>	Navajo fleabane	0.003	20	0	0	0	0	0.005	20	0.009	40	0	0	0	0
<i>Erigeron divergens</i>	spreading fleabane	0	0	0.04	10	0	0	0.001	10	<0.001	10	0	0	0	0
<i>Eriogonum cernuum</i>	nodding buckwheat	0.005	10	0.548	30	0.006	11.1	0.019	50	0.008	30	0.011	20	0	0
<i>Eriogonum deflexum</i>	flatcrown buckwheat	0.007	40	<0.001	10	0	0	0.004	20	0	0	0	0	0	0

^a Nonnative species

Table B-1. (continued) Plant species list with mean foliar cover and plot frequency, by panel, for 2012, 2014, and for the initial sampling year (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP.

Species	Common name	Initial sampling year between 2007 and 2010						2012				2014			
		Panel A, n=9		Panel B, n=10		Panel C, n=9		Panel A, n=10		Panel B, n=10		Panel B, n=10		Panel C, n=10	
		Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Eriogonum divaricatum</i>	divergent buckwheat	0.009	60	0.018	40	0.012	66.7	0.011	70	0.019	20	0.044	30	0.009	30
<i>Eriogonum leptocladon</i>	sand buckwheat	0.027	10	0.03	10	0	0	0.01	10	0.014	10	0.060	10	0	0
<i>Erodium cicutarium</i> ^a	stork's bill	0	0	0.002	10	0	0	0	0	0	0	<0.001	10	<0.001	10
<i>Erysimum capitatum</i>	sanddune wallflower	0	0	0	0	0	0	0	0	0.002	10	0	0	0	0
<i>Escobaria vivipara</i>	spynstar	0	0	<0.001	10	<0.001	11.1	<0.001	10	0.001	10	0.001	20	0.002	20
<i>Euphorbia albomarginata</i>	whitemargin sandmat	0	0	0.002	10	0	0	0	0	0	0	0	0	0	0
<i>Euphorbia fendleri</i>	Fendler's sandmat	0	0	0.022	40	0.031	22.2	0	0	0	0	0	0	0	0
<i>Euphorbia</i> spp.	annual sandmats	0.209	100	1.49	100	0.604	88.9	0.125	100	0.08	90	0.022	80	0.019	90
<i>Evolvulus nuttallianus</i>	shaggy dwarf morning-glory	0	0	0	0	0.037	22.2	0	0	0	0	0	0	0.015	20
<i>Gaillardia pinnatifida</i>	red dome blanketflower	0.002	10	0	0	0	0	0.002	10	0	0	0	0	0	0
<i>Gutierrezia sarothrae</i>	broom snakeweed	0.171	50	0.1	50	0.014	33.3	0.156	70	0.132	80	0.179	60	0	0
<i>Halogeton glomeratus</i> ^a	saltlover	0	0	0	0	0.002	11.1	0	0	0	0	0	0	0.055	20
<i>Helianthus annuus</i>	common sunflower	0	0	<0.001	10	0	0	0	0	0	0	0	0	0	0
<i>Heliomeris multiflora</i>	showy goldeneye	<0.001	10	0.002	10	0	0	0	0	0	0	<0.001	10	0	0
<i>Heliotropium curassavicum</i>	salt heliotrope	0	0	<0.001	10	0	0	0	0	0	0	0	0	0	0
<i>Hesperostipa comata</i>	needle and thread	0.039	10	0.012	20	0.002	11.1	0.036	20	0.004	30	0.041	30	0.015	20
<i>Hilaria jamesii</i>	James' galleta	1.295	100	2.219	100	1.272	77.8	1.449	100	1.347	100	2.780	100	1.037	80

a Nonnative species

Table B-1. (continued) Plant species list with mean foliar cover and plot frequency, by panel, for 2012, 2014, and for the initial sampling year (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP.

Species	Common name	Initial sampling year between 2007 and 2010						2012				2014			
		Panel A, n=9		Panel B, n=10		Panel C, n=9		Panel A, n=10		Panel B, n=10		Panel B, n=10		Panel C, n=10	
		Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Hymenopappus filifolius</i>	fineleaf hymenopappus	0	0	0.001	20	0.001	11.1	0.001	30	0.001	30	<0.001	10	0.000	0
<i>Hymenopappus flavescens</i>	collegeflower	0.002	10	0	0	0	0	0.001	20	0.004	20	0	0	0	0
<i>Hymenoxys richardsonii</i>	Colorado rubberweed	0	0	0.002	10	0	0	0	0	0.001	10	0	0	0	0
<i>Ipomopsis gunnisonii</i>	sanddune ipomopsis	0.001	20	0.002	10	0.001	11.1	0	0	0	0	0	0	0	0
<i>Ipomopsis longiflora</i>	whiteflower ipomopsis	0.007	10	0.002	10	0.006	11.1	<0.001	10	0	0	0	0	0	0
<i>Ipomopsis multiflora</i>	manyflowered ipomopsis	0	0	0	0	0	0	0.003	30	0.001	20	0	0	0	0
<i>Isocoma rusbyi</i>	Rusby's goldenbush	0.027	20	0.059	10	0	0	0.009	20	0.02	10	0.064	10	0	0
<i>Kallstroemia parviflora</i>	warty caltrop	0	0	0	0	0.003	11.1	0	0	0	0	0	0	0	0
<i>Krascheninnikovia lanata</i>	winterfat	0.016	30	0	0	0	0	0.017	20	0	0	0	0	0	0
<i>Laennecia coulteri</i>	Coulter's horseweed	0	0	0	0	0	0	0	0	<0.001	10	0	0	0	0
<i>Lappula occidentalis</i>	flatspine stickseed	0	0	0	0	0.006	11.1	0.004	60	0.001	20	0	0	0.002	30
<i>Linum aristatum</i>	bristle flax	0	0	0	0	0	0	0	0	0	0	<0.001	10	0	0
<i>Linum</i> spp.	flax	0.001	10	0.001	20	0.001	11.1	0.001	30	0.003	10	0	0	0	0
<i>Machaeranthera canescens</i>	hoary tansyaster	0.035	30	0.005	10	0	0	0.017	20	0.002	10	0	0	0	0
<i>Menodora scabra</i>	rough menodora	<0.001	10	0	0	0	0	0	0	0	0	0	0	0	0
<i>Mentzelia albicaulis</i>	whitestem blazingstar	0.018	40	0	0	0	0	0.001	20	0.001	10	0	0	0	0
<i>Mentzelia multiflora</i>	Adonis blazingstar	0.002	10	0.005	20	0	0	0.001	20	0	0	0	0	0	0

a Nonnative species

Table B-1. (continued) Plant species list with mean foliar cover and plot frequency, by panel, for 2012, 2014, and for the initial sampling year (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP.

Species	Common name	Initial sampling year between 2007 and 2010						2012				2014			
		Panel A, n=9		Panel B, n=10		Panel C, n=9		Panel A, n=10		Panel B, n=10		Panel B, n=10		Panel C, n=10	
		Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Mollugo cerviana</i> ^a	threadstem carpetweed	0	0	0.002	10	0.231	33.3	0	0	<0.001	10	0	0	0	0
<i>Muhlenbergia pungens</i>	sandhill muhly	0.034	30	0	0	0	0	0.01	30	0	0	0	0	0	0
<i>Munroa squarrosa</i>	false buffalograss	0.028	70	0.048	80	0.067	77.8	0.032	60	0.028	80	0.002	40	0.003	60
<i>Nama hispida</i>	bristly nama	0	0	0.002	30	0.001	33.3	0	0	0.001	10	0	0	0	0
<i>Oenothera albicaulis</i>	whitest evening primrose	0	0	0	0	0	0	0	0	0	0	0.004	30	0.022	60
<i>Oenothera</i> spp.	evening primrose	0.017	40	0.05	60	0.234	66.7	0.015	70	0.014	70	0.017	80	0.007	40
<i>Opuntia</i> spp.	prickly pear	0.011	30	0.009	40	0.013	44.4	0.008	60	0.005	40	0.005	30	0.021	70
<i>Panicum hirticaule</i>	Mexican panicgrass	0.001	10	0	0	0	0	0.001	20	0	0	0	0	0	0
<i>Parryella filifolia</i>	common dunebroom	0.062	20	0.016	20	0	0	0.011	20	0.016	20	0.024	20	0	0
<i>Pascopyrum smithii</i>	western wheatgrass	0	0	0	0	0	0	<0.001	10	0.005	10	0.006	10	0	0
<i>Pectis angustifolia</i>	lemonscent	0.008	20	0.005	30	0.234	33.3	0.005	20	0.005	10	0	0	0.004	10
<i>Phacelia</i> spp.	scorpionweed	<0.001	10	0.001	20	0	0	0	0	<0.001	10	0	0	0.002	10
<i>Phemeranthus parviflorus</i>	sunbright	0	0	0.003	10	0	0	0	0	<0.001	10	0	0	0	0
<i>Plantago patagonica</i>	woolly plantain	0.028	70	0.009	70	0.026	88.9	0.014	80	0.017	60	0.001	20	0.008	90
<i>Portulaca oleracea</i> ^a	little hogweed	0.004	50	0.085	70	0.069	44.4	0.008	40	0.014	40	0.003	40	0.005	30
<i>Portulaca pilosa</i>	kiss me quick	0	0	0.017	10	0.182	22.2	0.004	20	0.008	20	0	0	0.013	20
<i>Psilostrophe tagetina</i>	woolly paperflower	0.001	10	0	0	0	0	0.002	10	0	0	0	0	0	0
<i>Quincula lobata</i>	Chinese lantern	0	0	0.006	20	0	0	0	0	<0.001	10	0	0	0	0

a Nonnative species

Table B-1. (continued) Plant species list with mean foliar cover and plot frequency, by panel, for 2012, 2014, and for the initial sampling year (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP.

Species	Common name	Initial sampling year between 2007 and 2010						2012				2014			
		Panel A, n=9		Panel B, n=10		Panel C, n=9		Panel A, n=10		Panel B, n=10		Panel B, n=10		Panel C, n=10	
		Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Salsola tragus</i> ^a	prickly Russian thistle	1.101	100	1.936	100	0.545	100	0.11	80	0.045	90	0.124	70	0.070	60
<i>Sanvitalia abertii</i>	Abert's creeping zinnia	0.012	20	0.001	10	0.021	11.1	0.026	30	<0.001	10	0.001	10	0.001	20
<i>Sarcobatus vermiculatus</i>	greasewood	0	0	0	0	0.016	11.1	0	0	0	0	0	0	0	0
<i>Schkuhria multiflora</i>	many-flower false threadleaf	0.001	20	0.001	30	0.004	11.1	0.006	30	0.008	20	0	0	0	0
<i>Senecio flaccidus</i>	threadleaf ragwort	0.004	10	0	0	0	0	0.007	10	<0.001	10	0	0	0	0
<i>Sphaeralcea hastulata</i>	spear globemallow	0	0	0	0	0	0	0	0	0	0	0.007	40	0.004	40
<i>Sphaeralcea parvifolia</i>	small-leaf globemallow	0	0	0	0	0	0	0	0	0	0	0.005	30	0	0
<i>Sphaeralcea</i> spp.	globemallow	0.056	90	0.101	100	0.112	100	0.063	90	0.108	100	0.065	70	0.019	100
<i>Sporobolus airoides</i>	alkali sacaton	5.696	100	8.926	100	8.079	100	2.754	100	3.262	100	<0.001	10	0	0
<i>Sporobolus contractus</i>	spike dropseed	0.084	40	0.071	40	0.056	33.3	0.076	70	0.163	50	0	0	0	0
<i>Sporobolus coromandelianus</i>	Madagascar dropseed	1.249	80	2.509	50	1.403	66.7	0.307	90	0.24	60	0.035	40	0.132	40
<i>Sporobolus cryptandrus</i>	sand dropseed	0.02	50	0.065	60	0.02	33.3	0.165	100	0.16	100	0.004	10	0.000	0
<i>Sporobolus flexuosus</i>	mesa dropseed	0.161	30	0.019	10	0	0	0.124	20	0.01	30	0	0	0	0
<i>Sporobolus giganteus</i>	giant dropseed	0	0	0	0	0	0	0	0	0.002	10	0.002	10	0	0
<i>Sporobolus</i> spp.	dropseed	0	0	0	0	0	0	0	0	0	0	6.290	100	6.455	100
<i>Stephanomeria pauciflora</i>	brownplume wirelettuce	0.002	10	0	0	0	0	0	0	0	0	0	0	0	0
<i>Suaeda nigra</i>	seepweed	0	0	0	0	0	0	0	0	0	0	0	0	0.014	20

a Nonnative species

Table B-1. (continued) Plant species list with mean foliar cover and plot frequency, by panel, for 2012, 2014, and for the initial sampling year (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP.

Species	Common name	Initial sampling year between 2007 and 2010						2012				2014			
		Panel A, n=9		Panel B, n=10		Panel C, n=9		Panel A, n=10		Panel B, n=10		Panel B, n=10		Panel C, n=10	
		Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Thelesperma megapotamicum</i>	Hopi tea greenthread	0.005	20	0.012	20	0	0	0.006	20	0.005	20	0.002	10	0	0
<i>Thinopyrum ponticum</i> ^a	tall wheatgrass	0	0	0.033	10	0	0	0	0	0.006	10	0	0	0	0
<i>Townsendia annua</i>	annual Townsend daisy	0.005	10	0.012	40	0.036	100	0.009	80	0.014	70	0.013	30	0.074	90
<i>Verbena bracteata</i>	bigbract verbena	0	0	0.04	20	0	0	0	0	0	0	0	0	0	0
<i>Verbesina encelioides</i>	golden crownbeard	0	0	<0.001	10	0	0	0	0	0.002	10	0	0	0	0
<i>Vulpia octoflora</i>	sixweeks fescue	0.004	30	0	0	0	0	0	0	0	0	0	0	0	0
<i>Xanthium strumarium</i>	rough cocklebur	0	0	1.263	20	<0.001	11.1	0	0	0.011	20	0.003	20	0	0
<i>Yucca angustissima</i>	narrowleaf yucca	0.014	50	0.021	30	0.001	22.2	0.012	60	0.01	50	0.024	20	0.002	20
<i>Yucca baccata</i>	banana yucca	0	0	0	0	0	0	0	0	0	0	<0.001	10	0	0
PEFO20141104_1	unknown species	0	0	0	0	0	0	0	0	0	0	<0.001	10	0	0

a Nonnative species

Appendix C. Cover of soil surface features in the Clayey Fan ecological site at Petrified Forest National Park, 2007–2014

Table C-1. Cover of soil surface features, by panel, for 2012 and 2014, and for the initial sampling year for all plots (2007–2010) in the Clayey Fan ecological site in Petrified Forest NP. The soil surface features do not add up to 100% as the calculations were made from cover class midpoints. Standard deviation = SD.

Soil surface feature	Initial sampling year between 2007 and 2010						2012				2014			
	Panel A, n=9		Panel B, n=10		Panel C, n=9		Panel A, n=10		Panel B, n=10		Panel B, n=10		Panel C, n=10	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Live plant base	5.54	2.81	3.46	2.18	3.49	1.82	2.64	1.03	2.96	0.99	1.80	1.21	1.79	0.82
Dead woody base	0.30	0.28	0.16	0.24	0.02	0.03	0.12	0.08	0.14	0.08	0.07	0.08	0.08	0.05
Dead herbaceous base	2.46	0.76	1.95	1.33	1.86	0.89	2.18	0.75	2.33	0.79	3.41	2.22	3.67	2.32
Bare soil	15.86	5.72	14.57	11.13	10.91	9.27	6.39	3.98	9.65	6.34	3.63	5.40	2.14	1.47
Litter	5.12	1.64	4.14	2.34	3.33	1.30	3.21	1.83	3.46	1.65	3.75	2.00	2.11	1.07
Undifferentiated crust	68.59	7.80	69.11	11.98	65.35	11.16	81.32	4.43	77.90	7.52	81.38	7.44	79.62	5.35
Moss	0.52	0.93	0.02	0.04	1.16	1.67	0.20	0.33	0.11	0.28	0.07	0.18	0.56	0.57
Lichen	0	0	0	0	0.12	0.34	<0.01	0.01	<0.01	0.01	0	0	0	0
Cyanobacteria	1.76	5.10	1.52	3.19	6.77	8.87	0.22	0.43	0.16	0.27	0.15	0.24	1.46	1.36
Fine gravel (0.2 to <2 cm)	0.81	1.27	1.95	3.30	6.18	7.23	0.46	0.75	1.01	1.35	1.39	2.38	4.60	4.89
Coarse gravel (2.0 to <7.5 cm)	0.14	0.21	0.24	0.44	0.09	0.08	0.28	0.68	0.62	1.25	0.73	1.72	0.94	1.35
Cobble (7.5 to < 25 cm)	0	0	0	0	0.01	0.02	0	0	0.01	0.04	0.01	0.02	0.01	0.03
Stone, bedrock (≥25 cm)	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.03
Woody debris	0	0	0	0	0	0	<0.01	<0.01	0.02	0.05	0.01	0.03	0	0

Appendix D. Soil stability ratings for the Clayey Fan ecological site at Petrified Forest National Park, 2007–2014

Table D-1. Soil stability ratings for all samples, and for samples under and not under vegetative cover, by panel, for 2012, 2014, and for the initial sampling period (2007–2010) in the Clayey Fan ecological site at Petrified Forest NP. Ratings range from 1 to 6 with 1 being the lowest stability and 6 being the highest. Sample sizes were reduced in panel C in 2014 because soils were too wet to conduct the test.

Sample	Initial sampling year between 2007 and 2010						2012				2014			
	Panel A, n=9		Panel B, n=10		Panel C, n=9		Panel A, n=10		Panel B, n=10		Panel B, n=10		Panel C, n=10	
	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
All samples	4.0	0.4	2.8	1.2	4.1	0.8	3.1	0.8	3.1	0.9	2.8	0.8	3.7	1.3
Samples under vegetative cover	4.4	0.7	3.4	1.6	4.1	0.8	3.8	1.0	4.0	0.9	3.9	1.3	4.3	1.1
Samples not under vegetative cover	3.8	0.5	2.0	1.0	3.9	1.2	2.8	0.9	2.6	1.2	2.3	0.8	3.4	1.4

Appendix E: Foliar cover of functional groups in the Sandy Loam Upland ecological site at Petrified Forest National Park, 2007–2013

Table E-1. Foliar cover of functional groups by panel in the Sandy Loam Upland ecological site at Petrified Forest NP for 2013, and for the initial sampling year for all plots (2007–2010). The means for 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.

Foliar cover type	Initial sampling year between 2007 and 2010						2013			
	Panel A, n=10		Panel B, n=10		Panel C, n=10		Panel A, n=10		Panel B, n=10	
	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Total live foliar cover	18.88	5.56	21.12	3.21	25.12	5.73	20.39	3.83	20.87	2.55
Perennial grasses	12.82	6.19	14.14	3.17	15.98	6.65	16.48	5.71	16.92	2.92
Annual grasses	0.20	0.27	1.04	2.09	0.68	1.50	0.09	0.16	0.07	0.05
Forbs	1.76	1.57	1.95	2.03	2.07	1.85	0.96	1.38	0.63	0.58
Shrubs	4.27	1.94	4.81	3.28	7.01	3.02	3.57	1.88	3.26	2.01
Cacti/succulents	0.09	0.08	0.19	0.16	0.12	0.16	0.08	0.05	0.06	0.07
Standing dead herbaceous	5.44	2.72	4.42	1.73	4.93	1.23	12.07	4.28	10.27	2.45
Standing dead shrubs	1.64	0.99	1.97	1.78	1.90	1.37	2.08	1.02	1.90	1.05

Appendix F: Plant species list for the Sandy Loam Upland ecological site at Petrified Forest National Park, 2007-2013

Table F-1. Plant species list with mean foliar cover and plot frequency, by panel, for 2013, and for the initial sampling period (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP.

Species	Common name	Initial sampling year between 2007 and 2010						2013			
		Panel A, n=10		Panel B, n=10		Panel C, n=10		Panel A, n=10		Panel B, n=10	
		Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Achnatherum hymenoides</i>	Indian ricegrass	0.435	90	0.829	90	0.508	100	0.516	90	0.620	90
<i>Amaranthus acanthochiton</i>	greenstripe	0	0	0	0	0.004	10	0	0	0	0
<i>Amaranthus</i> spp.	pigweed	<0.001	10	0.056	20	0.006	10	0.010	10	0	0
<i>Aristida adscensionis</i>	sixweeks threeawn	0	0	0	0	0	0	0	0	<0.001	10
<i>Aristida purpurea</i>	Fendler's threeawn	0.038	30	0.020	60	0.039	50	0.024	30	0.018	40
<i>Artemisia bigelovii</i>	Bigelow sage	0.264	20	0.252	40	0.083	10	0.268	20	0.236	40
<i>Artemisia filifolia</i>	sand sagebrush	0.747	40	1.062	30	0.857	50	0.852	40	0.781	30
<i>Asclepias involucreata</i>	dwarf milkweed	0	0	0	0	0.002	10	0	0	0	0
<i>Asclepias subverticillata</i>	western whorled milkweed	<0.001	10	0	0	0	0	0	0	0	0
<i>Astragalus amphioxys</i>	Crescent milkvetch	0.006	40	0.007	60	0.023	30	0.000	10	0.001	10
<i>Astragalus ceramicus</i>	painted milkvetch	<0.001	10	0	0	<0.001	10	0	0	0	0
<i>Astragalus mollissimus</i>	wooly locoweed	0.033	30	0.017	40	0.049	20	0	0	0	0
<i>Astragalus</i> spp.	milkvetch	<0.001	10	0.002	10	0.001	20	0	0	0	0
<i>Atriplex canescens</i>	fourwing saltbush	1.154	90	1.249	100	1.558	90	0.946	90	0.991	100
<i>Atriplex confertifolia</i>	shadscale saltbush	0.096	20	0	0	0	0	0.151	20	0	0
<i>Atriplex obovata</i>	mound saltbush	0.224	10	0	0	0	0	0.187	10	0	0
<i>Atriplex saccaria</i>	sack saltbush	0	0	0	0	0	0	0	0	<0.001	10
<i>Boerhavia</i> spp.	spiderling	0	0	0	0	0	0	0	0	0.008	10
<i>Bouteloua barbata</i>	sixweeks grama	0.014	40	0.017	50	0.101	40	0.018	70	0.010	70
<i>Bouteloua eriopoda</i>	black grama	0.746	60	0.224	50	1.519	70	1.383	50	0.409	50
<i>Bouteloua gracilis</i>	blue grama	3.478	80	6.430	100	6.876	100	5.371	80	7.852	100

a Nonnative species

Table F-1. (continued) Plant species list with mean foliar cover and plot frequency, by panel, for 2013, and for the initial sampling year (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP.

Species	Common name	Initial sampling year between 2007 and 2010						2013			
		Panel A, n=10		Panel B, n=10		Panel C, n=10		Panel A, n=10		Panel B, n=10	
		Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Bromus tectorum</i> ^a	cheatgrass	0.027	40	0.762	40	0.129	50	0	0	0	0
<i>Chaetopappa ericoides</i>	rose heath	0.085	80	0.062	100	0.152	100	0.048	70	0.040	100
<i>Chamaesaracha coronopus</i>	greenleaf five eyes	0.015	30	0.069	50	0.001	30	0.007	10	0.024	30
<i>Chenopodium leptophyllum</i>	narrowleaf goosefoot	0.002	10	0.072	30	0.077	20	0.003	20	0.028	20
<i>Chenopodium leptophyllum</i>	narrowleaf goosefoot	0.002	10	0.072	30	0.077	20	0.003	20	0.028	20
<i>Chenopodium</i> spp.	goosefoot	0.052	20	0.152	40	0.096	40	0.001	10	0.000	0
<i>Chrysothamnus Greenei</i>	Greene's rabbitbrush	0.311	40	0.986	40	0.000	0	0.347	60	0.813	50
<i>Comandra umbellata</i>	bastard toadflax	0	0	0.060	30	0.015	20	<0.001	10	0.027	30
<i>Cryptantha</i> spp.	cryptantha	0.002	10	0.020	20	0.005	30	<0.001	10	0	0
<i>Cylindropuntia whipplei</i>	Whipple's cholla	0.035	50	0.114	80	0.059	30	0.029	40	0.042	60
<i>Dalea candida</i>	white prairieclover	0	0	0.003	20	0.006	20	0	0	0	0
<i>Dalea lanata</i>	woolly prairieclover	0	0	0.002	10	0	0	0	0	0	0
<i>Dasyochloa pulchella</i>	low woollygrass	0	0	0	0	0	0	0.006	10	0	0
<i>Dieteria canescens</i>	hoary tanyaster	0.089	20	0.044	30	0.036	60	<0.001	10	0.006	10
<i>Dimorphocarpa wislizeni</i>	spectacle pod	0	0	<0.001	10	0.010	30	0	0	0	0
<i>Echinocereus</i> spp.	kingcup cactus	0	0	0.002	10	0	0	<0.001	10	0.002	10
<i>Elymus elymoides</i>	squirreltail	0.015	50	0.024	60	0.030	40	0.006	10	0.004	20
<i>Enneapogon desvauxii</i> ^a	nineawn pappusgrass	0	0	0	0	0	0	<0.001	10	0	0
<i>Ephedra cutleri</i>	Cutler's jointfir	0	0	0	0	0.271	10	0	0	0	0
<i>Ephedra torreyana</i>	Torrey's jointfir	0.207	50	0.186	30	0.485	40	0.191	50	0.137	30
<i>Ephedra viridis</i>	Mormon tea	0	0	0	0	0.062	10	0	0	0	0
<i>Eragrostis pectinacea</i>	desert lovegrass	0.000	10	0.225	10	0.200	10	0.049	10	0.012	40
<i>Ericameria nauseosa</i>	rubber rabbitbrush	0.023	10	0.005	10	0	0	0.023	10	0.005	10
<i>Erigeron divergens</i>	spreading fleabane	0.023	10	0.008	20	0	0	0	0	0	0
<i>Eriogonum cernuum</i>	nodding buckwheat	0	0	0.021	20	0	0	0	0	0	0

^a Nonnative species

Table F-1. (continued) Plant species list with mean foliar cover and plot frequency, by panel, for 2013, and for the initial sampling year (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP.

Species	Common name	Initial sampling year between 2007 and 2010						2013			
		Panel A, n=10		Panel B, n=10		Panel C, n=10		Panel A, n=10		Panel B, n=10	
		Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Eriogonum corymbosum</i>	crispleaf buckwheat	<0.001	10	0	0	0	0	0.002	10	0	0
<i>Eriogonum deflexum</i>	flatcrown buckwheat	0	0	0	0	0	0	0	0	<0.001	10
<i>Eriogonum divaricatum</i>	divergent buckwheat	0.002	10	0.007	10	0.005	10	0	0	0	0
<i>Eriogonum jamesii</i>	James' buckwheat	0.002	10	0	0	0	0	0	0	0	0
<i>Eriogonum leptocladon</i>	sand buckwheat	0	0	0.004	10	0.002	10	0	0	0.002	10
<i>Eriogonum pulchrum</i>	Meteor Crater wild buckwheat	0.002	10	0	0	0	0	0.002	10	0	0
<i>Erysimum capitatum</i>	sanddune wallflower	0	0	0	0	0	0	0.002	10	0	0
<i>Escobaria vivipara</i>	spiny star	<0.001	10	0	0	<0.001	10	0.001	30	0	0
<i>Euphorbia fendleri</i>	Fendler's sandmat	0	0	0.025	10	0.093	10	0	0	0	0
<i>Euphorbia revoluta</i>	threadstem sandmat	0.009	20	0	0	<0.001	10	0	0	0	0
<i>Euphorbia serpyllifolia</i>	thymeleaf sandmat	0.012	20	0	0	0	0	0	0	0	0
<i>Euphorbia</i> spp.	sandmat	0.276	80	0.721	80	0.364	60	0.173	90	0.226	100
<i>Evolvulus nuttallianus</i>	shaggy dwarf morning-glory	0.009	30	0.014	30	0.019	40	0.006	30	0.011	20
<i>Gutierrezia sarothrae</i>	broom snakeweed	1.037	80	0.859	100	2.524	100	0.408	90	0.283	90
<i>Hesperostipa comata</i>	needle and thread	0.212	60	0.261	70	0.491	70	0.225	90	0.301	100
<i>Hilaria jamesii</i>	James' galleta	3.649	100	2.192	100	4.501	100	3.695	100	2.189	100
<i>Hymenopappus filifolius</i>	fineleaf hymenopappus	0.002	10	0.001	10	0.003	10	0.000	10	0.001	20
<i>Hymenopappus flavescens</i>	collegeflower	0.002	10	0.001	10	0.004	10	0	0	0	0
<i>Ipomopsis longiflora</i>	whiteflower ipomopsis	0.072	80	0.010	20	0.047	50	0.003	30	<0.001	10
<i>Ipomopsis pumila</i>	dwarf ipomopsis	0	0	0.001	10	0	0	0	0	0	0
<i>Kallstroemia parviflora</i>	warty caltrop	0	0	0	0	0	0	<0.001	10	0.010	10
<i>Kochia scoparia</i> ^a	Mexican burningbush	0	0	<0.001	10	0	0	0.028	40	0.031	10
<i>Krascheninnikovia lanata</i>	winterfat	0.076	40	0.029	30	0.902	40	0.134	40	0.053	40
<i>Laennecia coulteri</i>	Coulter's horseweed	0	0	0	0	0	0	0	0	0.035	10
<i>Linum lewisii</i>	prairie flax	0	0	<0.001	10	0	0	0	0	<0.001	10

a Nonnative species

Table F-1. (continued) Plant species list with mean foliar cover and plot frequency, by panel, for 2013, and for the initial sampling year (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP.

Species	Common name	Initial sampling year between 2007 and 2010						2013			
		Panel A, n=10		Panel B, n=10		Panel C, n=10		Panel A, n=10		Panel B, n=10	
		Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Lycium pallidum</i>	pale desert-thorn	0	0	0	0	<0.001	10	0	0	0	0
<i>Mentzelia albicaulis</i>	whitestem blazingstar	0.003	20	0	0	0	0	0	0	0	0
<i>Mentzelia multiflora</i>	Adonis blazingstar	0	0	0	0	0	0	0.002	10	0.002	10
<i>Mentzelia</i> spp.	blazingstar	0	0	0.003	10	<0.001	10	0	0	0	0
<i>Mollugo cerviana</i> ^a	threadstem carpetweed	0.003	20	0.004	10	0.029	30	<0.001	10	<0.001	10
<i>Muhlenbergia pungens</i>	sandhill muhly	0.005	10	0.033	10	0.025	10	0.010	10	0.052	10
<i>Muhlenbergia torreyi</i>	ring muhly	0.046	50	0.086	50	0.043	30	0.048	50	0.078	50
<i>Munroa squarrosa</i>	false buffalograss	0.054	60	0.037	60	0.045	60	0.026	90	0.029	90
<i>Nama dichotoma</i>	wishbone fiddleleaf	0	0	0.003	10	0	0	0	0	0	0
<i>Nama hispida</i>	bristly nama	0.005	20	0.008	30	0.011	20	0	0	0.015	10
<i>Oenothera albicaulis</i>	whitest evening-primrose	0.020	20	0.023	50	0.035	30	0	0	0	0
<i>Oenothera caespitosa</i>	tufted evening-primrose	0.002	10	0	0	0	0	<0.001	10	0.056	30
<i>Oenothera pallida</i>	pale evening-primrose	0.002	10	0.042	10	0	0	<0.001	10	0	0
<i>Oenothera</i> spp.	evening-primrose	<0.001	10	<0.001	10	<0.001	10	0	0	0	0
<i>Opuntia</i> spp.	prickly pear	0.017	60	0.021	50	0.018	70	0.015	90	0.007	60
<i>Parryella filifolia</i>	common dunebroom	0.050	10	0.050	10	0	0	0.023	10	0.023	10
<i>Pectis angustifolia</i>	lemonscent	0	0	0.001	20	0.005	20	<0.001	10	0	0
<i>Phacelia integrifolia</i>	gypsum phacelia	0	0	0.003	10	0	0	0	0	0	0
<i>Phacelia ivesiana</i>	Ive's phacelia	0.001	10	0	0	0	0	0	0	0	0
<i>Plantago patagonica</i>	woolly plantain	0.030	70	0.008	40	0.015	70	0	0	0	0
<i>Polygonum aviculare</i> ^a	prostate knotweed	0	0	<0.001	10	0	0	0	0	0	0
<i>Pomaria jamesii</i>	James' holdback	0.005	10	0.005	10	0.002	10	0	0	0	0
<i>Portulaca oleracea</i> ^a	little hogweed	0.023	30	0.090	30	0.042	30	0.064	40	0.045	40
<i>Portulaca pilosa</i>	kiss me quick	0.005	10	0	0	0.002	10	0.004	10	<0.001	10
<i>Salsola collina</i> ^a	slender Russian thistle	0	0	0	0	0	0	0	0	0.002	10
<i>Salsola tragus</i> ^a	prickly Russian thistle	0.506	90	0.202	60	0.765	60	0.416	70	0.013	50
<i>Sanvitalia abertii</i>	Abert's creeping zinnia	0.011	10	0.085	20	0.010	10	0.015	20	0.027	40

a Nonnative species

Table F-1. (continued) Plant species list with mean foliar cover and plot frequency, by panel, for 2013, and for the initial sampling year (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP.

Species	Common name	Initial sampling year between 2007 and 2010						2013			
		Panel A, n=10		Panel B, n=10		Panel C, n=10		Panel A, n=10		Panel B, n=10	
		Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)	Foliar cover (%)	Plot frequency (%)
<i>Schkuhria multiflora</i>	many-flower false threadleaf	0	0	0.006	20	0	0	0	0	0	0
<i>Senecio flaccidus</i>	threadleaf ragwort	0	0	<0.001	10	0	0	0	0	0.008	20
<i>Solanum jamesii</i>	wild potato	0	0	0.002	10	0	0	0	0	0	0
<i>Sphaeralcea ambigua</i>	desert globemallow	0	0	0.006	10	0	0	0	0	0	0
<i>Sphaeralcea hastulata</i>	spear globemallow	0.256	60	0.202	80	0.079	80	0.024	70	0.037	80
<i>Sphaeralcea parvifolia</i>	small-leaf globemallow	0	0	0	0	0.005	10	0	0	0	0
<i>Sphaeralcea</i> spp.	globemallow	0.001	10	0.005	20	0.013	30	0	0	<0.001	10
<i>Sporobolus coromandelianus</i>	Madagascar dropseed	0.105	30	0.036	40	0.146	10	0.003	20	0.015	60
<i>Sporobolus</i> spp.	dropseed	3.465	100	4.188	100	1.223	100	5.546	100	5.630	100
<i>Stephanomeria pauciflora</i>	brownplume wirelettuce	0	0	0.009	10	<0.001	10	0	0	0	0
<i>Townsendia annua</i>	annual Townsend daisy	0.005	20	0.001	30	0.013	20	0	0	0	0
<i>Verbena bracteata</i>	bigbract verbena	0	0	0.023	10	0	0	0	0	0	0
<i>Vulpia octoflora</i>	sixweeks fescue	0.012	50	0.032	30	0.019	40	0	0	0	0
<i>Xanthisma gracile</i>	slender goldenweed	0	0	<0.001	10	0.006	10	0	0	0	0
<i>Xanthisma spinulosum</i>	lacy tansyaster	0	0	0.033	10	0.008	20	0	0	0.002	10
<i>Xanthium strumarium</i>	rough cocklebur	0	0	<0.001	10	0	0	0	0	0	0
<i>Yucca angustissima</i>	narrowleaf yucca	0.039	70	0.047	60	0.033	60	0.033	70	0.032	50
<i>Yucca baccata</i>	banana yucca	0.002	10	0.010	10	0.020	10	0.010	10	0	0
<i>Zinnia grandiflora</i>	Rocky Mountain zinnia	0.085	30	0	0	0	0	0.067	30	0	0

a Nonnative species

Appendix G. Cover of soil surface features in the Sandy Loam Upland ecological site at Petrified Forest National Park, 2007–2013

Table G-1. Cover of soil surface features, by panel, for 2013, and for the initial sampling year for all plots (2007–2010) in the Sandy Loam Upland ecological site in Petrified Forest NP. The soil surface features do not add up to 100% as the calculations were made from cover class midpoints. Standard deviation = SD.

	Initial sampling year between 2007 and 2010						2013			
	Panel A, n=10		Panel B, n=10		Panel C, n=9		Panel A, n=10		Panel B, n=10	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Live plant base	5.56	2.56	5.24	2.38	7.36	3.76	5.16	2.49	6.46	1.55
Dead woody base	0.32	0.36	0.34	0.38	0.50	0.66	0.44	0.59	0.15	0.09
Dead herbaceous base	3.23	1.79	4.00	1.54	2.94	1.03	6.56	3.37	5.99	1.90
Bare soil	19.42	18.56	19.04	23.29	24.36	19.53	8.44	10.50	12.95	19.97
Litter	7.31	2.56	7.02	2.22	8.22	2.90	10.16	3.46	8.04	2.67
Undifferentiated crust	61.15	20.00	64.66	24.41	54.44	21.40	69.14	13.49	71.02	19.52
Moss	0.01	0.02	0.17	0.33	0	0	0.01	0.01	0.08	0.19
Lichen	0	0	0	0	0	0	0	0	0.02	0.07
Cyanobacteria	0.05	0.16	0.51	1.58	0.18	0.58	0.08	0.17	0.15	0.29
Fine gravel (0.2 to <2 cm)	1.92	5.82	0.02	0.04	0.14	0.22	3.55	10.88	0.04	0.11
Coarse gravel (2.0 to <7.5 cm)	0.15	0.45	0.01	0.01	0.06	0.10	0.04	0.10	0.02	0.05
Cobble (7.5 to < 25 cm)	0	0	0	0	0.02	0.04	<0.01	0.01	0	0
Stone, bedrock (≥25 cm)	0	0	0	0	0	0	0	0	0	0
Woody debris	0.53	1.31	0.01	0.03	0.15	0.46	0.01	0.02	0.02	0.03

Appendix H. Soil stability ratings for the Sandy Loam Upland ecological site at Petrified Forest National Park, 2007–2013

Table H-1. Soil stability ratings for all samples, and for samples under and not under vegetative cover, by panel, for 2013, and for the initial sampling period (2007–2010) in the Sandy Loam Upland ecological site at Petrified Forest NP. Ratings range from 1 to 6 with 1 being the lowest stability and 6 being the highest. Sample size was reduced in panel B in 2013 because the soils were too wet to conduct the test.

	Initial sampling year between 2007 and 2010						2013			
	Panel A, n=10		Panel B, n=9		Panel C, n=8		Panel A, n=10		Panel B, n=9	
	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
All samples	3.3	0.8	2.9	1.0	3.1	0.7	3.9	1.0	4.1	0.9
Samples under vegetative cover	3.6	0.9	3.7	1.1	3.4	0.7	4.5	0.8	4.9	0.6
Samples not under vegetative cover	3.1	1.0	1.9	0.7	2.3	0.7	2.6	1.2	2.8	1.2

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