



Integrated Upland Monitoring in Arches National Park

Annual Report 2010 (Non-sensitive Version)

Natural Resource Technical Report NPS/NCPN/NRTR—2012/525.N



ON THE COVER

Grassland, Arches National Park. NPS photo.

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Prepared by

Dana Witwicki
Northern Colorado Plateau Network
National Park Service
P.O. Box 848
Moab, UT 84532

Editing and Design

Alice Wondrak Biel
Northern Colorado Plateau Network
National Park Service
P.O. Box 848
Moab, UT 84532

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Executive Summary

The goal of the Northern Colorado Plateau Network (NCPN) integrated upland monitoring effort is to provide park managers with status and trend information on vegetation and soil attributes. This information is intended to determine natural variability of upland resources and provide early warning of resource degradation.

This report summarizes NCPN upland monitoring in Arches National Park (NP) in 2010. This report also outlines goals and objectives of NCPN upland monitoring, methods of the upland monitoring protocol, and procedures for defining and mapping target populations for monitoring, and describes the results of this year's efforts and plans for future monitoring.

Upland monitoring was initiated at Arches NP in 2010. Based on discussions with park resource staff, blackbrush shrublands, pinyon-juniper (PJ) and blackbrush shrublands, and grasslands were selected for monitoring. The sampling frame was delineated using the soils map units where each ecological site type occurred in the park. Eight plots were established and monitored in each ecological site type in 2010.

Early monitoring data describe status of ecological site types. Interpretation will be limited until additional data are acquired and more rigorously analyzed. In this report, measures were summarized for each ecological site type. The only analysis performed was an ordination of species and biological soil crust cover. Results of this ordination indicated good separation between the grassland sites and the other two ecological site types. There was some overlap between the deep blackbrush and PJ/blackbrush sites; this was expected, because blackbrush (*Coleogyne ramosissima*) was a dominant species at both sites, and soil properties were more important in distinguishing these ecological site types. In addition, grassland sites were split into two distinct clusters, which correlated well with alternative ecosystem states of the Semidesert Sandy Loam (fourwing saltbush) ecological site.

1 Introduction

Uplands represent the vast majority of land area in national park units of the Northern Colorado Plateau Network (NCPN). These upland areas include rock outcrops, badlands, shrublands, grasslands, woodlands, forests, and subalpine meadows, with local vegetation determined by soil type and depth, topography, climate, and disturbance history. Upland vegetation supplies most regional primary productivity, which translates to energy for other trophic levels. The condition of upland vegetation influences soil stability and nutrient cycling, which in turn determines potential above-ground production of native plant species and the propensity for invasion by non-native species. Vegetation also provides habitat for various organisms. The ability of uplands to retain soil and nutrients, absorb and release water, and buffer high-runoff precipitation events also influences conditions in riparian areas.

Upland ecosystems of the Colorado Plateau, where the majority of NCPN park units are located, tend to be dominated by shrubs, perennial grasses, and small trees. Although these life forms play an integral role in defining the structure and function of Colorado Plateau ecosystems (Whitford 2002), it is the highly pinnacled biological soil crusts that make these these dryland systems unique. Biological soil crusts are biotic communities composed of cyanobacteria, algae, micro-fungi, mosses, and lichens that occur on and within the upper few millimeters of the soil surface (Belnap et al. 2003). Their presence stabilizes the soil surface and reduces susceptibility to wind and water erosion (Williams et al. 1995). They also contribute to nutrient cycling by fixing C (Lange 2003) and N (Evans and Lange 2003; Belnap 2002) and affect the availability of nutrients to plants (Harper and Belnap 2001). Biological soil crusts are particularly sensitive to disturbances that affect the soil surface, such as trampling and off-road vehicle use (Rosentreter and Belnap 2003).

In the basins neighboring the Colorado Plateau, where several NCPN park units are located, biological soil crusts also play an important role but are less dramatically pin-

nacled. In the forests, shrublands, and meadows of the mountain regions surrounding the Colorado Plateau, where numerous NCPN park units are located, the role of biological soil crusts is less important because much of the soil surface is covered by vegetation and litter.

Many upland ecosystems of the region are characterized by low resistance and resilience. Even moderate disturbances can affect vegetative composition and structure, and recovery to pre-disturbance conditions can be relatively slow. Natural disturbance regimes of the region include extreme climatic events; fire, insect and disease outbreaks; herbivory; and trampling (Miller 2005). Grazing, which has been a traditional land use throughout much of the plateau, has resulted in shifts in vegetation composition (Harris et al. 2003) and ecological states (Miller et al. 2011) that may persist for many decades or longer. Fire-regime alteration (Whelan 1995) and invasion of exotic plants (Bock et al. 1986) have additionally contributed to these shifts. Increasing recreational use and unauthorized social trailing threatens the integrity of upland systems through soil surface disturbance and resulting increases in soil erosion by water and wind. Additional pressure inside parks may also result from land use in adjacent areas.

Global climate change is expected to change levels and seasonality of dominant precipitation events (Garfin et al. 2010), and we are only beginning to understand the implications for plateau ecosystems (Munson et al. 2011a,b). Additional information on characteristics of Colorado Plateau ecosystems and ecological threats to the region is provided in Miller (2005).

The overall goal of the NCPN integrated upland monitoring program is to determine long-term trends in vegetation, soil stability, and hydrologic function in the context of changes in other ecological drivers, stressors, and processes. Monitoring will increase fundamental understanding of upland systems and provide managers with early warning of undesirable change and information for management decisions. Specific objectives of the integrated upland monitoring protocol are described below.

Determine status and trends in plant communities, including:

- overall species richness
- cover of vegetation by dominant species and life form
- density of shrubs by size class
- basal area and density of tree species
- canopy closure
- fuel volume and litter/duff depth
- frequency of exotic invasive species

Determine status and trends in soil stability, including:

- cover of biological soil crusts by morphological group (cyanobacteria, lichen, moss, and undifferentiated crust)
- cover of other surface features (litter, rock, bare ground, etc.)

- soil aggregate stability
- canopy-gap size (as an indicator of wind erosion potential)

Determine status and trends in hydrologic function, including:

- basal-gap size

Evaluation of upland monitoring data relative to other vital signs will help us to identify drivers and distinguish “natural” from anthropogenic change. Local weather-station data can be used to interpret responses, and remote sensing can be used to determine change in vegetation at larger scales caused by land use or climate change. Historical upland monitoring data sets may be integrated with data collected by NCPN to allow earlier detection of trends.

2 Methods

2.1 Integrated Upland Monitoring in Arches National Park

2.1.1 Resource issues driving upland monitoring

Discussion with Southeast Utah Group (SEUG) resource management staff identified grasslands and shrublands as the highest priority for long-term upland monitoring. Managers were concerned about potential system degradation due to trampling of physical and biological crust, and subsequent increases in wind and water erosion of soil. Both NCPN and SEUG staff agreed that it was best to monitor (1) dominant vegetation types in the park (blackbrush, pinyon-juniper [PJ], and grasslands), and (2) some of the same ecological site types in Arches NP as are currently monitored by the NCPN in Canyonlands NP. For ecological sites that occur in both parks, this will provide a larger dataset that could help detect trends more quickly. The goal of upland monitoring at Arches National Park (NP) is to provide information on the natural variability of upland resources, as well as early warning of system degradation.

2.1.2 Mapping and selecting target populations

2.1.2.1 Accessibility

Areas that posed safety threats, were inaccessible within budgetary limitations, and/or were anthropogenic in nature were filtered out of the sampling frame. Areas located on slopes of $\geq 50\%$ and/or isolated by steep slopes were eliminated. Accessibility and slope features were generated using the Landscape Accessibility Model (<http://science.nature.nps.gov/im/units/ncpn/Tools.cfm>). Eighty-seven percent of the park was deemed accessible.

2.1.2.2 Selection of target ecological-site types

NCPN upland monitoring uses survey designs and ecological sites (SRM 1989, 1995) to define target populations. An ecological site is defined by a combination of soil properties (texture, depth, water-holding capacity), geology, landform, climatic regime, and

potential vegetation. The spatial extent of ecological sites is largely determined by soil map units within the soil survey, although the location of an ecological site within a soil map unit is not explicit. Using a new draft Arches Soil Survey (USDA NRCS unpublished), ecological sites associated with blackbrush, PJ, and grasslands were determined.

At Canyonlands NP and other NCPN parks, ecological sites have been lumped into broader groups with similar vegetation, precipitation, and soil depth that we call ecological site types. Ecological site types were also used at Arches NP to group similar ecological sites in the soil survey (see Table 2-1). After further discussion with SEUG resource staff, three ecological site types were selected for monitoring at Arches NP: deep blackbrush, PJ/blackbrush, and grassland.

Deep blackbrush. The deep blackbrush ecological site type is characterized by blackbrush (*Coleogyne ramosissima*) on deep eolian sands and sandy loams. Deep blackbrush was selected as a priority ecological site type at Arches NP due to its large spatial extent in the park and because the network is not currently monitoring it at Canyonlands NP. Although a substantial area of this ecological site type exists in Canyonlands NP, it was not recognized in the old soil survey, and was therefore not included in the Canyonlands upland monitoring design. In Arches NP, the deep blackbrush ecological site type includes two ecological sites (see Table 2-1 and Figure 2-1).

PJ/Blackbrush. The PJ/blackbrush ecological site type is characterized by blackbrush and Utah juniper (*Juniperus osteosperma*) on shallow sandy soils. At both Canyonlands and Arches NPs, there is one target ecological site, 236-Semidesert Shallow Sandy Loam (Utah juniper/blackbrush), in the PJ/blackbrush ecological site type (see Table 2-1 and Figure 2-1). Although a second ecological site, 19-Shallow Sand Rock Pocket, was mapped in the draft Arches Soil Survey, it contains too much bedrock to depict trends in vegetation as defined by our monitoring criteria. Additionally, it was not included in the old Canyonlands Soil Survey, which was used to develop the NCPN upland monitoring design at that park.

Table 2-1. Description of ecological sites selected for monitoring, Arches National Park.

Ecological site type	Ecological site name notation / No.	Soil series	Soil properties	Geological properties	Vegetative properties	Disturbance-mediated alternative states
Shrubland						
Deep blackbrush	Semidesert Sand (blackbrush) SDS210 / 210	Mido	Deep sands on dunes and sand sheets	Eolian deposits derived from sandstone	Dominated by blackbrush	<i>Description currently n/a</i>
	Semidesert Sandy Loam (blackbrush) SDSL218 / 218	Milok	Deep sandy loams on mesas and hills	Alluvium and eolian deposits derived from sandstone	Dominated by blackbrush	<i>Description currently n/a</i>
PJ / Blackbrush	Semidesert Shallow Sandy Loam (Utah juniper/blackbrush) SDSSL236 / 236	Arches, Crosscan, Reef, Simel	Shallow sandy loams on benches, mesas, and hillslopes	Residuum, colluvium and/or eolian deposits from sandstone	Dominated by blackbrush, juniper, and pinyon pine	Decreased bunchgrass and increased juniper, blackbrush, and prickly pear. Cheatgrass and annual forbs may invade.
Herbaceous						
Grassland	Semidesert Sand (fourwing saltbush) SDS212 / 212	Mido	Deep sands on dunes and sand sheets	Eolian deposits derived from sandstone	Dominated by Indian ricegrass, fourwing saltbush, and Mormon tea	Decreased bunchgrass and saltbush and increased snakeweed, prickly pear, juniper, and sand sage. Russian thistle may invade.
	Semidesert Sandy Loam (fourwing saltbush) SDSL215 / 215	Begay, Milok	Deep sandy loams on mesas and valleys	Alluvium and eolian deposits derived mainly from sandstone	Dominated by Indian ricegrass, needle and thread, fourwing saltbush, and Mormon tea	Decreased bunchgrass and increased snakeweed, Mormon tea, and prickly pear. Cheatgrass and Russian thistle may invade.

Grassland. The grassland ecological site type is characterized by native perennial bunchgrasses on deep sandy soils. The two grassland ecological sites at Arches NP are the same ecological sites that the NCPN monitors at Canyonlands NP (see Table 2-1 and Figure 2-1). Two additional grassland ecological sites (115-Desert Sand and 118-Desert Sandy Loam) were included in the Canyonlands sampling design, but it is expected that these will be combined with the semidesert grassland ecological sites in the new version of the Canyonlands Soil Survey, which should be completed within the next few years.

Although a shallow blackbrush ecological site type has substantial area in Arches NP, it was not selected for monitoring due to the limitations of our affordable effort and the park's

preference to monitor deep blackbrush. This ecological site type is currently monitored at Canyonlands NP.

The estimated area of target ecological sites in Arches NP is 6921.9 ha (see Table 2-2). The area of each ecological site in the park is calculated using the estimated percentage of that ecological site within each of the soil map units where it is predicted to occur; therefore, it is often substantially less than the area shown on the soil map.

2.1.2.3 Mapping of target ecological site types

Because the draft Arches Soil Survey provided a good estimate of locations of target ecological sites, we did not explicitly map ecological sites for Arches NP in the way we did for Canyonlands NP. Instead, we



A) Semidesert Sand (blackbrush)



B) Semidesert Sandy Loam (blackbrush)



C) Semidesert Shallow Sandy Loam (Utah juniper/blackbrush)



D) Semidesert Sand (fourwing saltbush)



E) Semidesert Sandy Loam (fourwing saltbush)

Figure 2-1. Examples of the ecological sites selected for upland monitoring at Arches National Park. See Table 2-1 for descriptions.

Table 2-2. Area (ha) of each ecological site type included in the sampling frame for upland monitoring, Arches National Park.

Ecological site type	Area (ha)*	Predicted target area**
Deep blackbrush	4,375	49.3%
PJ/blackbrush	3,871	62.2%
Grassland	2,509	94.1%
Total sampling frame	10,755	64.4%

* Based on the accessible area within a 10-km hiking distance.

**Predicted amount of target ecological site in the sampling frame

developed a predictive map of deep blackbrush, PJ/blackbrush, and grassland ecological site types using the soil map units associated with the target ecological sites (Figure 2-2). All soil map units that contained >10% of a soil component associated with a target ecological site were included in the sampling frame.

The area of the sampling frame is larger than the predicted area of each ecological site (Table 2-2) because all soil map units used to make the map contained some non-target areas. The sampling frame area represents 34.7% of the total park area and 40.1% of accessible area. Before site selection, the sampling frame was buffered by 25 m to prevent plots from crossing roads, trails, the park boundary, non-target vegetation, or inaccessible areas.

2.1.3 Selection of monitoring locations

Monitoring plots were selected using the Reversed Randomized Quadrant Recursive Raster (RRQRR) method (Theobald et al. 2007) to create a spatially balanced design within the sampling frame. RRQRR provides an ordered list of centroids for all possible monitoring plots in the sampling frame. Points were then assigned a predicted ecological site type based on the areas shown in Figure 2-2. Within each ecological site type, plots were established in ascending order of plot number. If a plot was rejected (e.g., due to incorrect vegetation type, crossing a road, trail, park unit boundary, or cliff), the next sequentially ordered plot was used.

2.1.4 Revisit design

A rotating-panel revisit design (Figure 2-3) was created that samples 8 plots each year

for a total of 28 plots over 7 years for each of the 3 priority ecological site types. A total of 84 plots are sampled among all ecological site types. Plots are sampled two years in a row (in order to detect annual variation due to temperature, precipitation, etc.) and rested for five years. The sampling scheme repeats itself every seven years. The number of plots in each ecological site should approximately represent the area of each ecological site in the sampling frame. This revisit strategy maximizes the ability to detect trends and minimizes the impact on biological soil crusts in the park.

2.2 Integrated Upland Monitoring Procedures

2.2.1 Response design

The response design (methods used to collect observations) for integrated upland monitoring in NCPN parks is based largely on rangeland monitoring procedures recommended by Herrick and colleagues (2005). All measures recorded along transects are sub-samples scaled to the plot level. The plot-level measures are the primary values used in summaries and statistical analyses.

At each plot, observations are recorded along three parallel, 50-m transects spaced 25 m apart (Figure 2-4). At the origin of each transect, a photo is taken down the length of the transect toward the end point. Photos of biological soil crusts are also taken at a specified point along each transect. A point-intercept method is used to record percent cover of plant species and ground-cover attributes at 0.5-m intervals along each transect. Density of shrubs (by species and height class) and exotic perennials (by species) is recorded in a 1-m belt upslope of each transect. Canopy and basal-gap measures are acquired along each of the transects using line-intercept methods. Six surface-soil samples are taken along each of the transects to assess soil-aggregate stability. Disturbances observed on and around the site are also recorded.

2.3 Database

All observations recorded in the field are stored in an NCPN Access database. Quality assurance and quality control (QA/QC) procedures include domain checking in

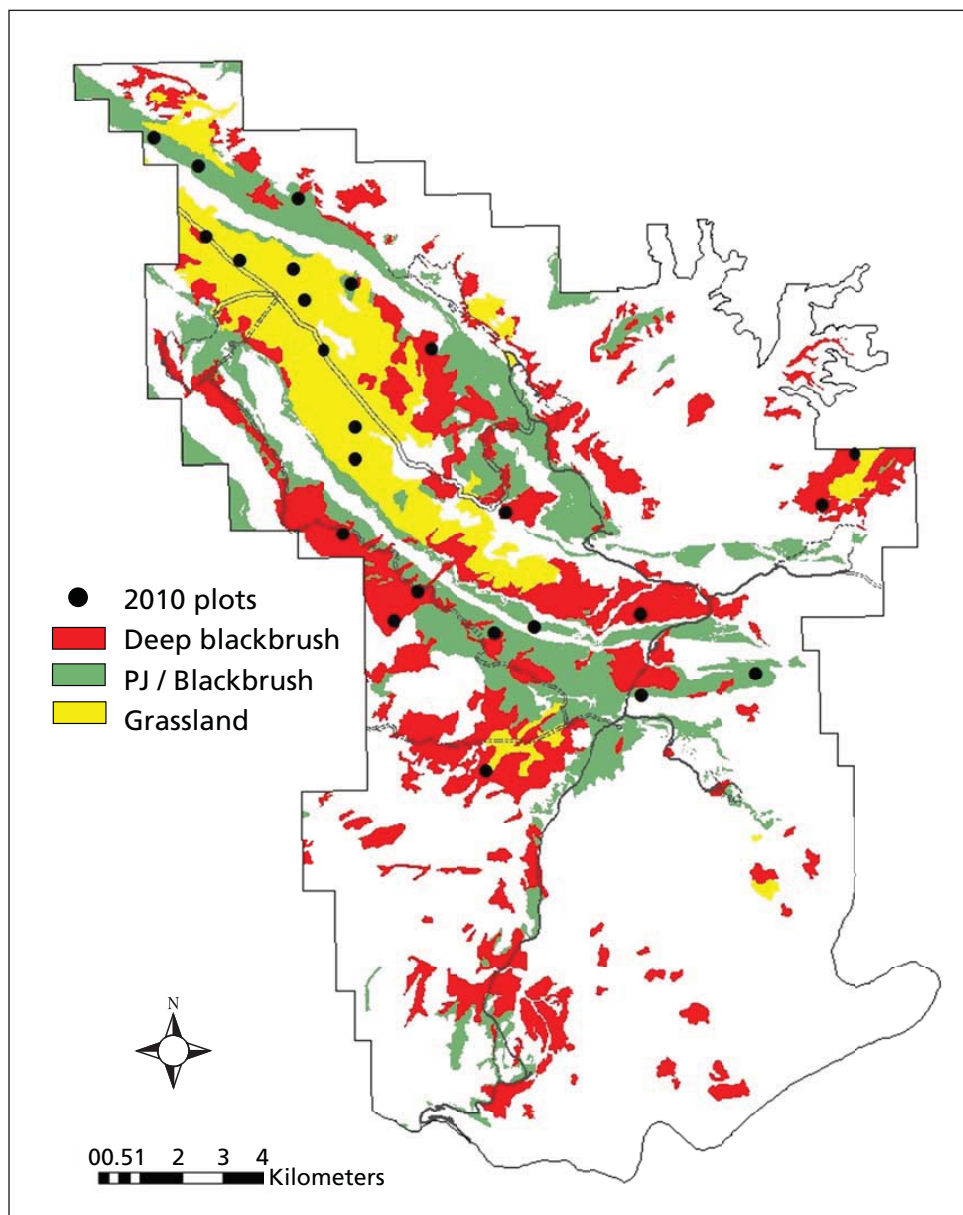


Figure 2-2. Sampling frame and location of monitoring plots in Arches National Park, 2010.

Panel	Year									
	1	2	3	4	5	6	7	8	9	10
1	4	4						4	4	
2		4	4						4	4
3			4	4						4
4				4	4					
5					4	4				
6						4	4			
7	4						4	4		

Figure 2-3. Number of plots sampled each year per ecological site type based on 7-year rotating panel revisit design for long-term upland monitoring at Arches National Park.

data-entry procedures, checks for missing values, and logic checks. All spatial data used in selecting monitoring locations, the sampling frame, and the RRQRR -generated

sampling locations are GIS-ArcMap shape files and are stored with the Access database on NCPN servers.

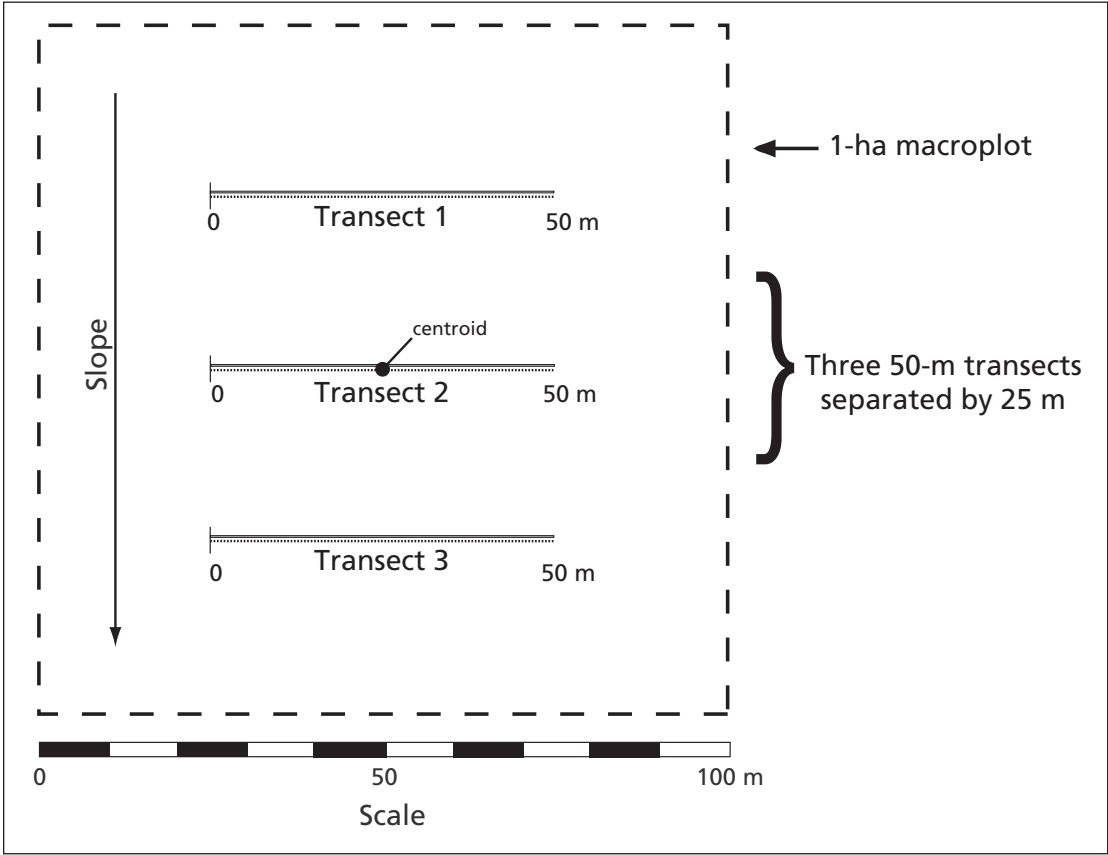


Figure 2-4. Plot layout for upland monitoring of grasslands and shrublands.

3 Results

3.1 Monitored Plots

In September and October 2010, twenty-four plots were established and monitored as part of the long-term revisit design, including 8 deep blackbrush, 8 PJ/blackbrush, and 8 grassland plots (see Figure 2-2). Table 3-1 summarizes plot visits by ecological site. Each plot was sampled using the suite of measures appropriate for that vegetation type (tables begin on page 11).

3.2 Ecological Site Type Summaries

Status and trend assessments are more meaningful after many years of monitoring, and as the number of monitoring plots increases. More intensive evaluation of monitoring data is slated to commence after five full years of monitoring.

For this annual report, plot-level summaries of the measures listed in Chapter 1 were generated for each monitoring plot, then summarized by ecological site type. Summaries are simply a mean and the range (minimum, maximum) for a measured attribute. Given the limited data, measures were not statistically compared among ecological site types. The reader is cautioned not to draw wide-reaching conclusions from this initial set of results.

The only analysis provided is a multivariate assessment of the similarity of vegetative and biological soil crust conditions within and among ecological site types (see Section 3.2.9). Data from 2010 were ordinated using NMS (non-metric multidimensional scaling), which involves scaling plots on the basis of similarity (or dissimilarity) of species and biological soil crust cover. Plots are distributed in multivariate space, typically along 1–3 axes, and within this space, plots with similar composition are located closer together and correlated with dominant species or biological soil crust.

3.2.1 Species richness

Species richness by life form is reported in Table 3-2. Recorded species were compared to the NPSpecies database to determine first-time observations in Arches NP. One new

species, nodding wild buckwheat (*Eriogonum cernuum*), was detected in the park in 2010. A voucher was created for this species.

No threatened or endangered species were found on any plots in 2010. Threatened and endangered plant species are not common in the areas of Arches NP monitored by the network, and the NCPN does not specifically monitor them in this park.

3.2.2 Cover by life form and dominant species

Percent cover of live and total vegetation by life form is shown in Table 3-3. Live cover includes photosynthetic and live woody tissue. Total cover additionally includes dead plants, dead parts of live plants, and senesced tissue that was alive earlier in the growing season.

Live and total percent cover of dominant species for each ecological site type are shown in Table 3-4. Dominant species were selected using species predicted by ecological site descriptions and species frequently detected in plots. The percent cover of all species recorded for each plot is included in an electronic appendix that accompanies this report (arch10_species.xls).

3.2.3 Shrub density

Density of shrub species for each ecological site type is shown in Table 3-5.

3.2.4 Exotic species

Cover of exotic plant species is shown in Table 3-6. When exotic species were detected, cover was summarized for all plots in the ecological site type.

Russian thistle (*Salsola tragus*) was detected at all grassland plots, with cover as high as 63.3%. Cheatgrass (*Bromus tectorum*) was also detected at grassland sites, but cover was less than 3%. These same two exotic species were detected at deep blackbrush plots, but cover was low (<2%). Exotic species were not detected in PJ/blackbrush plots, and no exotic perennial species were detected during upland monitoring at Arches NP.

In 2010, NCPN upland sampling methods did not include an invasive species walk;

therefore, lack of detection does not mean that other exotic species were not present in plots. In 2011, methods will be added to include early detection of exotics.

3.2.5 *Biological soil crust and surface features*

Biological soil crust and surface-feature cover are shown in Table 3-7.

3.2.6 *Canopy and basal gaps*

Canopy- and basal-gap sizes are shown in Table 3-8. The distribution of gaps by size class is illustrated in Figures 3-1 and 3-2 (figures begin on page 15).

3.2.7 *Soil aggregate stability*

Measures of soil aggregate stability are reported in Table 3-9. Soil stability numbers range from 1 (least stable) to 6 (most stable) and are correlated with current erosion resistance and soil biotic integrity. They also usually reflect hydrologic function because stable soils are less likely to disperse and clog soil pores during rainstorms. The numbers are affected by soil texture, so it is important to limit comparisons to similar soils that have comparable amounts of sand, silt, and clay. Extremely sandy soils may not have maximum soil stability values of 6.

3.2.8 *Plot ordinations*

Non-metric multidimensional scaling (NMS) ordination was performed using species with relative cover values of $\geq 10\%$ and absolute biological soil crust cover (Figure 3-3). Relative cover is the percent cover of the species divided by the total vegetation cover on a plot. This requirement was imposed to emphasize dominant species. Biological soil crust cover was calculated by combining cover of dark cyanobacteria, lichen, and moss. The direction and relative magnitude of correlations of species and biological soil crust are shown in the graph. The species/biological soil crust vector from the origin shows the direction of positive correlation.

The ordination illustrates the separation of grassland ecological site types from the other two ecological site types. In addition, grassland sites are split into two distinct clusters. Most grassland sites were characterized by a mix of perennial bunchgrasses and shrubs, but three of the sites were dominated by high cover of Russian thistle. There was some separation between deep blackbrush and PJ/blackbrush sites, although overlap is understandable because both were dominated by blackbrush. Soil properties not included in the ordination were more important for distinguishing these two ecological site types (see Table 2-1).

Table 3-1. Number of plots by ecological site type and ecological site monitored, Arches National Park, 2010.

Ecological site type	Ecological site	# of plots
Deep blackbrush	Semidesert Sand	8
	Semidesert Sandy Loam	0
PJ / blackbrush	Semidesert Shallow Sandy Loam	8
Grassland	Semidesert Sand	1
	Semidesert Sandy Loam	7

See Table 2-1 for description of ecological sites.

Table 3-2. Mean (range) number of plant species detected per monitoring plot by life form and ecological site type, Arches National Park, 2010.

Ecological site type	Number of species detected					
	Total	Tree	Shrub	Perennial grass	Annual grass	Forb/ Herb
Deep blackbrush	8.4 (4–13)	0.6 (0–1)	4.8 (2–7)	0.5 (0–2)	0.3 (0–1)	2.3 (0–4)
PJ / blackbrush	7.0 (6–8)	1.5 (1–2)	5.1 (4–6)	0	0	0.4 (0–1)
Grassland	10.5 (4–18)	0	2.0 (0–4)	3.3 (1–7)	0.8 (0–1)	4.5 (2–10)

Table 3-3. Mean (range) percent cover by life form for each ecological site type, Arches National Park, 2010.

Total		Tree		Shrub		Perennial grass		Annual grass		Forb/Herb	
Live	Total	Live	Total	Live	Total	Live	Total	Live	Total	Live	Total
Deep blackbrush											
17.0 (11.0–23.0)	25.2 (19.7–33.7)	1.5 (0–6.3)	1.7 (0–7.0)	14.7 (9.0–18.7)	21.8 (13.7–32.0)	0.2 (0–1.7)	0.5 (0–2.7)	0	0.1 (0–0.7)	0.7 (0–2.0)	1.5 (0–3.0)
PJ / blackbrush											
15.3 (10.7–19.7)	20.8 (13.7–29.0)	3.5 (1.0–6.7)	4.1 (1.3–8.0)	11.5 (4.3–18.0)	16.4 (5.7–26.0)	0	0.04 (0–0.3)	0	0	0.4 (0–1.7)	0.4 (0–1.7)
Grassland											
16.8 (10.0–26.7)	40.3 (27.3–66.3)	0	0	6.1 (0–13.0)	8.2 (0–18.3)	1.9 (0–5.0)	9.4 (2.0–17.0)	0	1.1 (0–2.7)	9.1 (0.3–23.0)	24.0 (2.3–64.3)

Table 3-4. Mean (range) percent cover of dominant species by ecological site type, Arches National Park, 2010.

Scientific name	Common name	Life form	Duration	Nativity	Percent cover	
					Live	Total
Deep blackbrush						
<i>Artemisia filifolia</i>	sand sagebrush	Shrub	Perennial	Native	0.9 (0–2.3)	1.4 (0–4.3)
<i>Coleogyne ramosissima</i>	blackbrush	Shrub	Perennial	Native	9.5 (4.3–15.3)	15.0 (6.3–24.3)
<i>Ephedra viridis</i>	Mormon tea	Shrub	Perennial	Native	2.0 (0–8.0)	2.2 (0–8.0)
<i>Gutierrezia sarothrae</i>	broom snakeweed	Dwarf Shrub	Perennial	Native	0.3 (0–2.3)	0.4 (0–2.3)
<i>Juniperus osteosperma</i>	Utah juniper	Tree	Perennial	Native	1.5 (0–6.3)	1.7 (0–7.0)
<i>Opuntia</i> sp.	pricklypear	Dwarf Shrub	Perennial	Native	0.6 (0–1.3)	0.9 (0–2.0)
<i>Quercus welshii</i>	Havard oak	Shrub	Perennial	Native	0.4 (0–1.7)	0.7 (0–1.7)
PJ / blackbrush						
<i>Coleogyne ramosissima</i>	blackbrush	Shrub	Perennial	Native	8.0 (2.3–12.7)	11.3 (2.7–19.7)
<i>Ephedra viridis</i>	Mormon tea	Shrub	Perennial	Native	0.7 (0–1.7)	1.0 (0–2.3)
<i>Juniperus osteosperma</i>	Utah juniper	Tree	Perennial	Native	2.8 (1.0–4.3)	3.3 (1.3–5.0)
<i>Opuntia species</i>	pricklypear	Dwarf Shrub	Perennial	Native	0.7 (0–3.0)	0.9 (0–4.3)
<i>Pinus edulis</i>	two-needle pinyon	Tree	Perennial	Native	0.8 (0–2.3)	0.9 (0–3.0)
Grassland						
<i>Artemisia filifolia</i>	sand sagebrush	Shrub	Perennial	Native	0.5 (0–2.7)	1.2 (0–8.0)
<i>Ephedra viridis</i>	Mormon tea	Shrub	Perennial	Native	3.2 (0–8.0)	4.1 (0–9.3)
<i>Gutierrezia sarothrae</i>	broom snakeweed	Dwarf Shrub	Perennial	Native	0.04 (0–0.3)	0.04 (0–0.3)
<i>Hilaria jamesii</i>	galleta	Graminoid	Perennial	Native	0.5 (0–1.3)	2.9 (0–7.3)
<i>Krascheninnikovia lanata</i>	winterfat	Shrub	Perennial	Native	2.3 (0–7.3)	2.5 (0–8.0)
<i>Opuntia species</i>	pricklypear	Dwarf Shrub	Perennial	Native	0.1 (0–0.3)	0.3 (0–1.3)
<i>Salsola tragus</i>	Russian thistle	Forb	Annual	NonNative	8.3 (0.3–23.0)	20.1 (0.3–63.3)
<i>Sporobolus cryptandrus</i>	sand dropseed	Graminoid	Perennial	Native	0.4 (0–1.0)	2.8 (0.7–5.7)
<i>Stipa comata</i>	needle and thread	Graminoid	Perennial	Native	0.3 (0–1.3)	0.5 (0–2.3)
<i>Stipa hymenoides</i>	Indian ricegrass	Graminoid	Perennial	Native	0.5 (0–2.0)	2.4 (0–7.0)

Table 3-5. Density of shrub species per hectare by ecological site type, Arches National Park, 2010.

Scientific name	Common name	No. of plots with species present*	Density (number of shrubs/ha)		
			Mean	Minimum	Maximum
Deep blackbrush					
<i>Artemisia filifolia</i>	sand sagebrush	4	217	0	1,000
<i>Atriplex canescens</i>	fourwing saltbush	1	8	0	67
<i>Coleogyne ramosissima</i>	blackbrush	8	4,383	1,200	6,800
<i>Ephedra viridis</i>	Mormon tea	4	367	0	1,600
<i>Eriogonum leptocladon</i>	sand wild buckwheat	4	283	0	1,133
<i>Juniperus osteosperma</i>	Utah juniper	3	33	0	133
<i>Poliomintha incana</i>	purple sage	2	83	0	467
<i>Purshia mexicana</i>	cliffrose	1	8	0	67
<i>Quercus welshii</i>	Havard oak	1	192	0	1,533
PJ / blackbrush					
<i>Cercocarpus intricatus</i>	dwarf mountain mahogany	1	8	0	67
<i>Chrysothamnus nauseosus</i>	rubber rabbitbrush	1	8	0	67
<i>Chrysothamnus viscidiflorus</i>	green rabbitbrush	3	67	0	200
<i>Coleogyne ramosissima</i>	blackbrush	8	5,450	1,333	9,000
<i>Ephedra torreyana</i>	Torrey's jointfir	4	100	0	267
<i>Ephedra viridis</i>	Mormon tea	5	342	0	1,267
<i>Eriogonum corymbosum</i>	crisp-leaf wild buckwheat	2	25	0	133
<i>Eriogonum microthecum</i>	slender wild buckwheat	1	17	0	133
<i>Fraxinus anomala</i>	singleleaf ash	2	25	0	133
<i>Juniperus osteosperma</i>	Utah juniper	8	158	67	333
<i>Pinus edulis</i>	two-needle pinyon	2	25	0	133
<i>Purshia mexicana</i>	cliffrose	5	183	0	733
<i>Quercus welshii</i>	Havard oak	1	17	0	133
Grassland					
<i>Artemisia filifolia</i>	sand sagebrush	2	175	0	867
<i>Atriplex canescens</i>	fourwing saltbush	1	33	0	267
<i>Eriogonum leptocladon</i>	sand wild buckwheat	1	25	0	200
<i>Krascheninnikovia lanata</i>	winterfat	6	2,192	0	7,067

* A total of 8 plots were monitored in each ecological site type in 2010.

Table 3-6. Mean (range) cover and density of exotic plant species detected by ecological site type, Arches National Park, 2010.

Scientific name	Common name	Life form	Duration	No. of plots with exotic species detected*	Percent cover**		Density (# of exotic perennials/ha)
					Live	Total	
Deep blackbrush							
<i>Bromus tectorum</i>	cheatgrass	Graminoid	Annual	2	0	0.1 (0–0.3)	na
<i>Salsola tragus</i>	Russian thistle	Forb	Annual	3	0.3 (0–1.3)	0.3 (0–1.7)	na
PJ / blackbrush				0	0	0	na
Grassland							
<i>Bromus tectorum</i>	cheatgrass	Graminoid	Annual	5	0	1.1 (0–2.7)	na
<i>Salsola tragus</i>	Russian thistle	Forb	Annual	8	8.3 (0.3–23.0)	20.1 (0.3–63.3)	na

* A total of 8 plots were monitored in each ecological site type in 2010.

** Mean and range are based on all plots within a vegetation type where an exotic species was detected.

Table 3-7. Mean (range) percent cover of surface features by ecological site type, Arches National Park, 2010.

Ecological site type	Crust, undifferentiated	Cyano-bacteria	Lichen	Moss	Bare soil	Litter	Woody debris	Small rock	Large rock	Bedrock
Deep blackbrush	62.8 (29.3–79.3)	1.7 (0–7.0)	0.04 (0–0.3)	3.1 (0–6.3)	10.8 (0–43.3)	18.0 (10.3–24.3)	0.04 (0–0.3)	1.9 (0–8.3)	0	0
PJ / blackbrush	51.0 (37.3–67.7)	6.0 (0–18.3)	0.5 (0–1.7)	3.6 (1.0–7.7)	0.7 (0–1.7)	14.3 (10.0–18.0)	0.2 (0–0.3)	15.8 (1.0–40.3)	1.5 (0–2.7)	4.8 (0.3–19.3)
Grassland	52.8 (29.3–71.3)	0.4 (0–2.3)	0	1.8 (0–5.7)	0.3 (0–1.3)	38.6 (16.7–66.3)	0	0.4 (0–2.7)	0	0

Table 3-8. Mean (range) canopy- and basal-gap size by ecological site type, Arches National Park, 2010.

Ecological site type	Canopy gap (cm)	Basal gap (cm)
Deep blackbrush	169 (130–202)	345 (257–639)
PJ / blackbrush	203 (138–310)	503 (223–930)
Grassland	227 (82–701)	331 (136–1065)

Table 3-9. Mean (range) soil-aggregate stability measures by ecological site type, Arches National Park, 2010.

Ecological site type	Total	Protected*	Unprotected*
Deep blackbrush	3.3 (2.0–4.6)	4.0 (1.3–6.0)	2.8 (1.4–4.0)
PJ / blackbrush	3.5 (2.1–4.6)	4.4 (3.5–5.4)	3.2 (1.6–4.9)
Grassland	3.0 (1.1–4.3)	4.6 (4.0–5.5)	2.6 (1.1–4.2)

Numbers range from 1 (least stable) to 6 (most stable).

*Protected are samples collected under vegetation; unprotected are samples collected in the open.

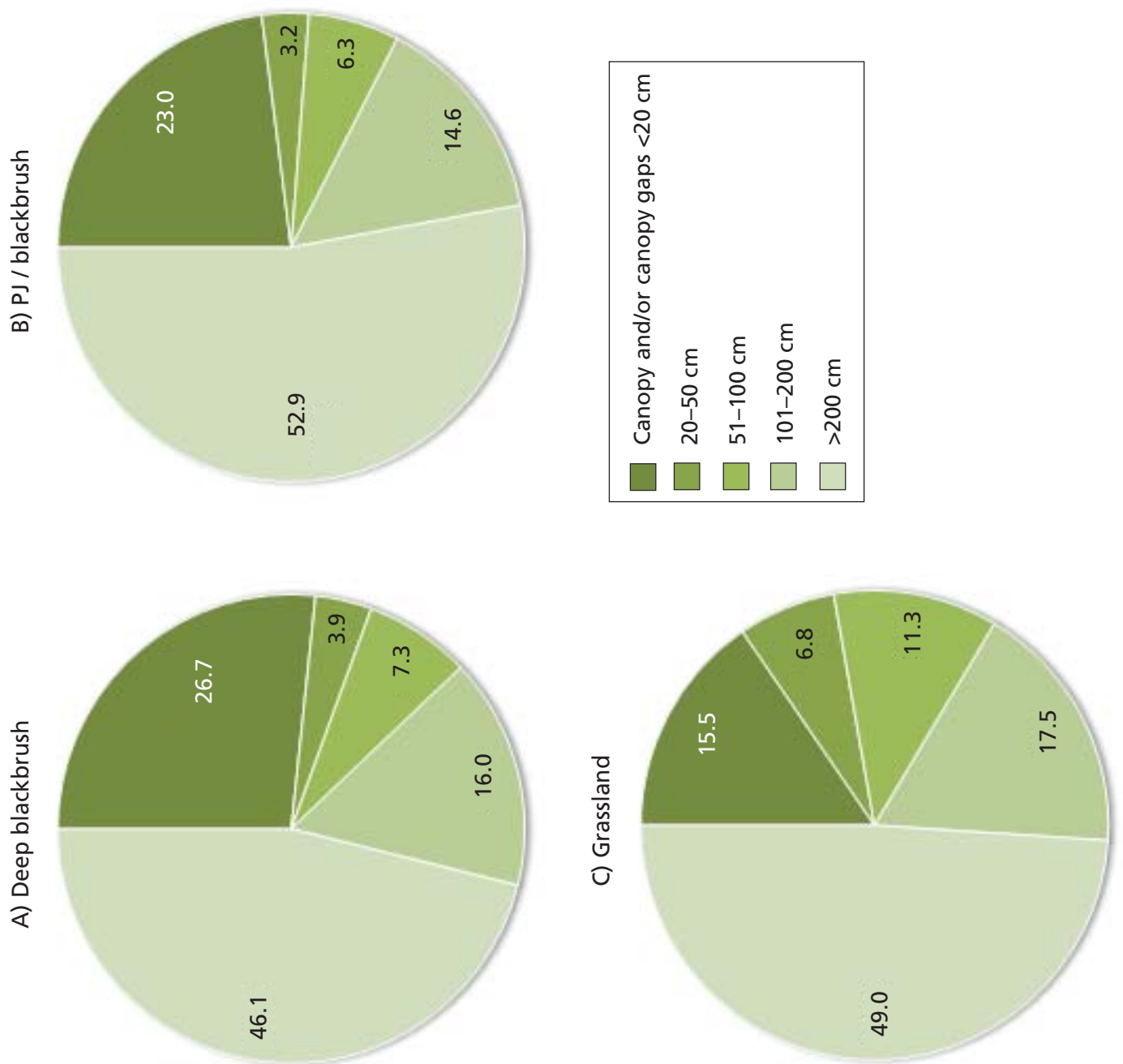
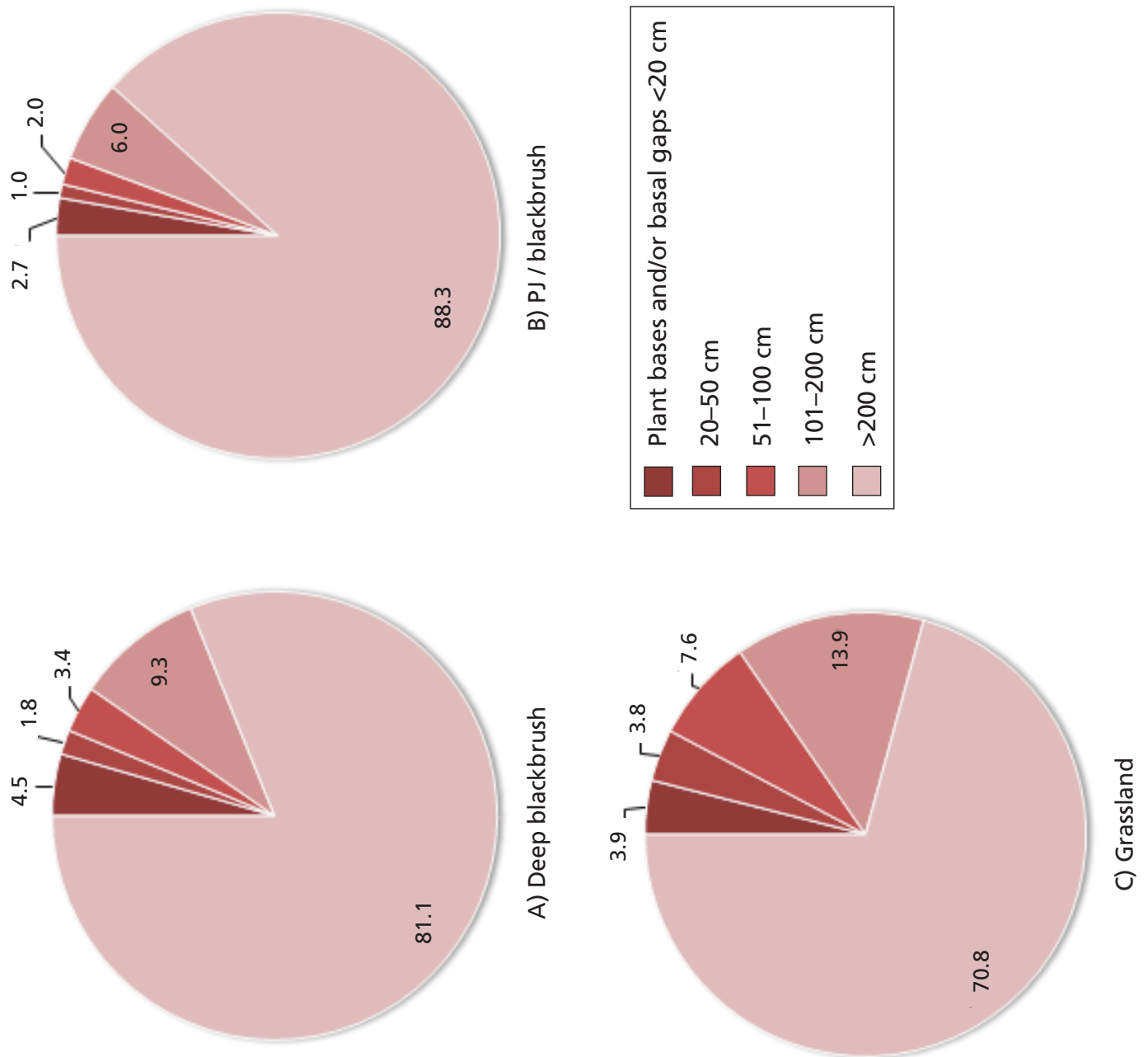


Figure 3-1. Distribution of canopy gaps for a) deep blackbrush, b) PJ/blackbrush, and c) grassland sites in Arches National Park, 2010.

Figure 3-2. Distribution of basal gaps for a) deep blackbrush, b) PJ/blackbrush, and c) grassland sites in Arches National Park, 2010.



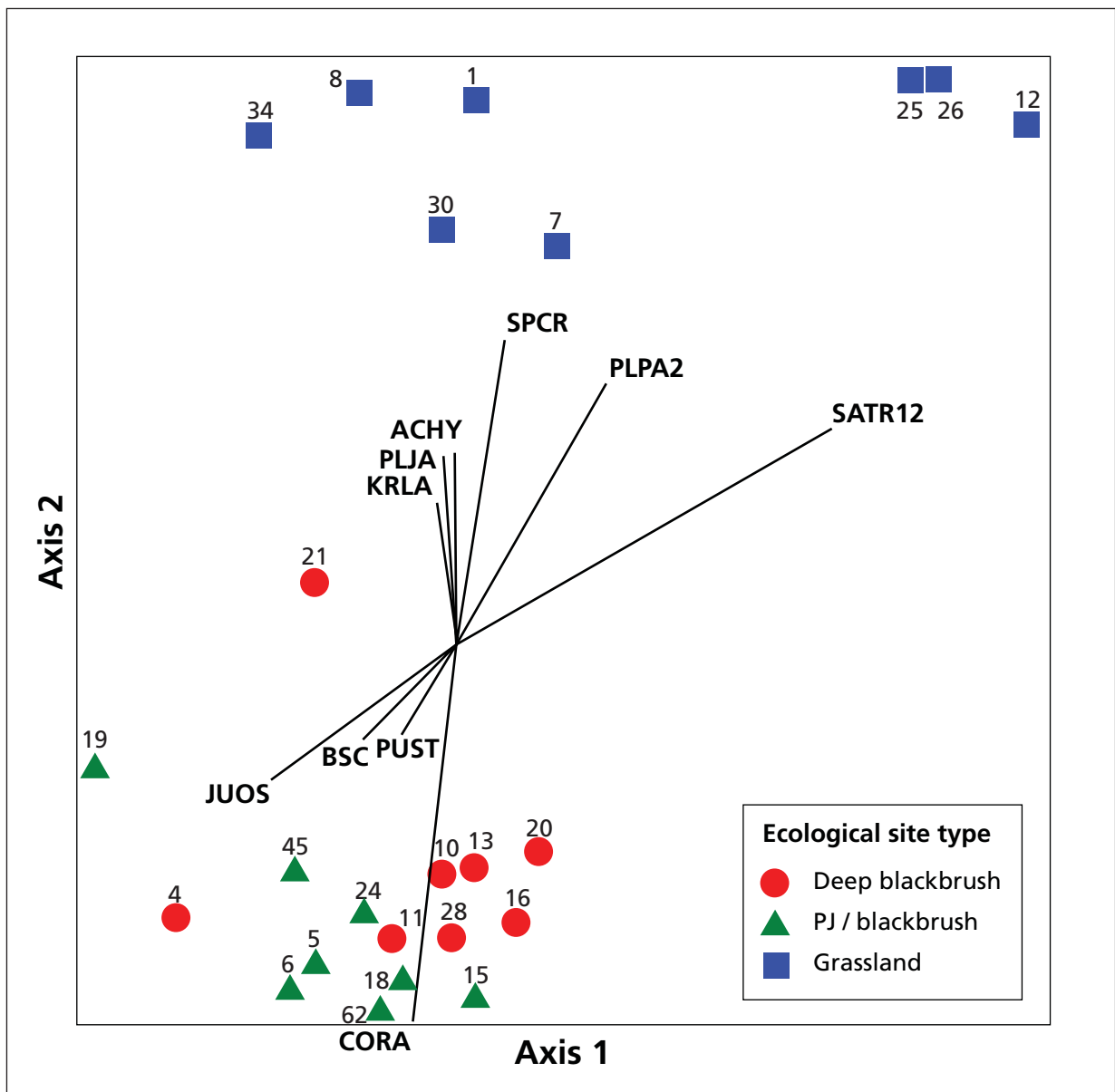


Figure 3-3. Non-metric multidimensional scaling (NMS) ordination of plots from the three ecological site types monitored at Arches National Park in 2010. Points are labeled by Plot ID.

Species codes

ACHY = *Stipa hymenoides* (Indian ricegrass)
 CORA = *Coleogyne ramosissima* (blackbrush)
 JUOS = *Juniperus osteosperma* (Utah juniper)
 KRLA = *Krascheninnikovia lanata* (winterfat)
 PLJA = *Hilaria jamesii* (galleta)

PLPA2 = *Plantago patagonica* (woolly plantain)
 PUST = *Purshia mexicana* (cliffrose)
 SATR12 = *Salsola tragus* (Russian thistle)
 SPCR = *Sporobolus cryptandrus* (sand dropseed)
 BSC = biological soil crust (cyanobacteria, lichen, and moss)

4 Discussion

This was the first year of monitoring at Arches NP. Early monitoring data, which describe status and conditions of sites inside the park, may be useful in understanding park ecosystems in an alternative-state framework, which recognizes that “Ecosystems can shift between alternative states characterized by persistent differences in structure, function, and capacity to provide ecosystem services valued by society” (Miller et al. 2011). Alternative states of an ecological site can be detected through ordination of plot species and biological soil crust data. Miller and others (2011) used this concept to define three current ecosystem states of the Semidesert Sandy Loam (fourwing saltbush) ecological site. The three states were:

- 1) ***Biological soil crust-invaded (biocrust)***. characterized by well-developed biological soil crust (dominated by cyanobacteria, lichen, and moss), native perennial grasses, and palatable native shrubs. These areas have never had major soil surface disturbance from livestock grazing, but invasive annual plant species are present.
- 2) ***Invaded grassland state (grass-bare)***. characterized by native perennial grasses and palatable native shrubs, but lacking well-developed biological soil crusts. These areas have current or previous livestock grazing, and invasive annual plant species are present.
- 3) ***Annualized state (annualized-bare)***—. invasive annuals are the dominant plant species. Lower cover of native perennial species is associated with previous livestock grazing and, in some cases, persistent drought.

Seven of the eight deep grassland plots monitored in Arches NP in 2010 (all plots except 30), belong to this ecological site and can be examined in this framework.

The two clusters of deep grassland plots in our ordination appear to fit well into the two ecosystem states with previous livestock grazing (grass-bare and annualized-bare). The three plots associated with Russian thistle (12, 25, and 26), are likely in the annualized-bare ecosystem state, while the other four plots in this ecological site (1, 7, 8, and 34) are most similar to the grass-bare state. Miller and others (2011) found lower cover of perennial grass and palatable shrub cover in the annualized-bare state than in the grass-bare state, and our data followed this pattern, as well (see Appendix A). One of the other main differences between these two ecosystem states was higher cover of annual forbs in the annualized-bare state, which clearly occurred at our monitoring plots, as well (see Appendix A).

None of the Semidesert Sandy Loam plots at Arches NP fit into the biocrust ecosystem state. This was expected, because all plots monitored by NCPN were previously grazed. Miller and others (2011) found that biological soil crust (i.e., cyanobacteria, lichen, and moss) had a mean cover of 34.1% and standard error of 3.0 in this ecosystem state, which is much higher than the biological soil crust cover at any of the NCPN plots (see Appendix A).

In 2011, we plan to monitor 24 plots according to the full operational monitoring design. One-half of the plots visited in 2010 will be revisited, and the remaining plots will be established. In addition, plots will be visited in mid-April, so that timing of NCPN upland monitoring coincides with the timing of historic SEUG long-term vegetation monitoring. Further discussion will occur with park resource staff to ensure that park expectations and needs are satisfied by NCPN integrated upland monitoring. A status and trend report will be produced after five full years of monitoring have been completed.

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Appendix A. Supplemental Information

Table A. Cover of biological soil crust and vegetation characteristics of Semidesert Sandy Loam (fourwing saltbrush) upland monitoring plots in Arches National Park, 2010, in alternative ecosystem states defined in Miller and others (2011).

Ecosystem state	Plot ID	Biological soil crust*	Native		Exotic	
			Shrub	Perennial grass	Annual grass	Annual forb
Grass-bare	1	1.3	14.7	17.0	2.7	10.0
	7	6.3	18.3	10.0	0	8.0
	8	0.7	9.0	14.0	0	2.0
	34	2.3	13.7	10.7	2.7	0.3
Annualized-bare	12	0	0	2.0	0.7	63.3
	25	0	0.7	8.0	0.3	37.3
	26	0	0	4.0	2.3	35.3

* Biological soil crust consists of cyanobacteria, lichen, and moss.

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