



Integrated Upland Monitoring in Zion National Park

Annual Report 2011 (Non-Sensitive Version)

Natural Resource Technical Report NPS/NCPN/NRTR—2013/663.N



ON THE COVER

Gambel oak shrubland, Zion National Park. NPS photo.

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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 provide early warning of resource degradation and determine natural variability of upland resources.

This report summarizes NCPN upland monitoring in Zion National Park (NP) during 2011. It 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 Zion NP in 2011. Based on discussions with park resource staff, one Gambel oak (*Quercus gambelii*) and three singleleaf pinyon (*Pinus monophylla*) / Utah juniper (*Juniperus osteosperma*) (pinyon-juniper; PJ) ecological site types were selected for monitoring. The sampling frame was delineated using the soil map units where each ecological site type occurred in the park. Twenty-four PJ and 12 Gambel oak plots were established and monitored in 2011.

In this report, measures were summarized for each ecological site type. The only analysis performed was an ordination of species cover. Results of this ordination indicated a high degree of overlap between the three PJ site types and separation between PJ and Gambel oak sites. Early monitoring data describe status of ecological site types, and interpretation is limited until additional data are acquired and more rigorously analyzed after at least five years of monitoring are complete.

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1 Introduction

Uplands represent the vast majority of land area in national park units of the 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 that, 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 dryland systems unique. Biological soil crusts are biotic communities composed of cyanobacteria, algae, microfungi, 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) (Figure 1-1).

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 pinnacled. In the forests, shrublands, and meadows of the mountain regions surrounding the

Colorado Plateau, where numerous NCPN park units are located, biological soil crusts do not play an important role since 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 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



Figure 1-1. Example of damage caused to biological soil crust by off-road vehicle use, Arches National Park.

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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
- fuel loading
- 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 (e.g., litter, rock, bare ground)
- soil aggregate stability

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

2 Methods

2.1 Integrated upland monitoring in Zion National Park

2.1.1 Resource issues driving upland monitoring

Park resource management staff identified singleleaf pinyon (*Pinus monophylla*) and Utah juniper (*Juniperus osteosperma*) woodlands (hereafter referred to as pinyon-juniper [PJ]) and Gambel oak (*Quercus gambelii*) shrublands as high priorities for long-term monitoring. PJ woodlands occur at middle elevations on the south and east sides of the park and vary depending on elevation, aspect, and soil properties. Gambel oak and mixed montane shrubs are the dominant vegetation types at the highest elevations of the park.

One goal of selecting these vegetation types is to collect data on vegetation not well-represented in plots sampled by the fire-effects monitoring program at Zion National Park (NP). Another concern relative to PJ woodlands is the potential for stand-replacing fires and the resulting influence on watersheds. The overall goal of monitoring is to provide information on possible elevational shifts in vegetation from a warming climate, natural variability of upland resources, and 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 $\geq 40\%$ 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>). After additional discussion with park resource staff, the Dakota Hills area, which would require a 3–5 mile hike to the park boundary, was excluded from the accessible area. Thirty-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 the Washington County Soil Survey (USDA NRCS 1977), ecological sites associated with PJ and Gambel oak were determined. These ecological sites were evaluated, and two of the PJ ecological sites were determined not to be suitable for NCPN integrated upland monitoring due to their small area within the park and steep slopes unsuitable for our response design (unpublished report available on request). After further discussion with park staff, the remaining PJ and Gambel oak ecological sites were selected for upland monitoring (see Table 2-1 and Figure 2-1).

When ecological sites are found to have similar vegetation, precipitation, and soil depth, the NCPN may lump them into broader groups called ecological site types. Ecological site types were used at Zion NP to group the two similar Gambel oak ecological sites (Mountain Loam [Oak] and Mountain Stony Loam [Oak]) into a single ecological site type for the sampling frame (Table 2-1). Due to large differences between soil characteristics of the PJ ecological sites, these three ecological sites were kept as separate ecological site types in the sampling frame (PJ-Upland Sand, PJ-Upland Shallow Loam, and PJ-Upland Stony Loam; Table 2-1).

2.1.2.3 Mapping of target ecological site types

Because the Washington County Soil Survey provided a good estimate of locations of target ecological sites, we did not explicitly map ecological sites for Zion NP. Instead, a predictive map of each PJ and Gambel oak ecological site type was developed using the soil map units associated with the target

Table 2-1. Description of ecological sites selected for upland monitoring in Zion National Park, by ecological site type.

Ecological site Notation / No.	Soil properties	Geological properties	Vegetative properties	Disturbance-mediated alternative states
Pinyon-juniper				
Upland Sand (Juniper-Pinyon) US324 / 324	Deep sands on plateau slopes and valleys	Eolian deposits derived from sandstone	Dominated by Utah juniper and singleleaf pinyon pine	Decreased Indian ricegrass and squirreltail and increased pinyon, juniper, sandhill muhly, and snakeweed from overgrazing. Pinyon, juniper, and some shrubs may decrease temporarily after fire. Annual forbs and grasses are most likely to invade.
Upland Shallow Loam (Pinyon-Utah juniper) USHL315 / 315	Shallow sandy loams on mesas	Residuum weathered from conglomerate or sandstone	Dominated by Utah juniper and singleleaf pinyon pine	Decreased bunchgrass and increased pinyon, juniper, snakeweed, and prickly pear from overgrazing. Pinyon, juniper, and some shrubs may decrease temporarily after fire.
Upland Stony Loam (Pinyon-Utah juniper) USL321 / 321	Deep, very stony loamy sands and sandy loams on mesas and mountain slopes	Residuum, alluvium, and colluvium derived from sandstone, siltstone, and shale	Dominated by Utah juniper and two-needle or singleleaf pinyon pine	Decreased grass and bitterbrush and increased pinyon and juniper from overgrazing. Decreased pinyon and juniper and increased grass, forbs, Gambel oak, and manzanita from fire. Cheatgrass is likely to invade.
Gambel oak				
Mountain Loam (Oak) MLO	Deep sandy loams on mesa tops, valleys, and mountain side slopes	Material weathered from limestone and some sandstone	Dominated by Gambel oak, snowberry, and mountain big sagebrush	Decreased grasses and forbs and increased Gambel oak and less palatable shrubs from overgrazing.
Mountain Stony Loam (Oak) MStL463 / 436	Deep stony and cobbly silt and sandy loams on mountain side slopes and mesa tops	Residuum and slope alluvium weathered from shale, limestone, and sandstone	Dominated by Gambel oak	<i>Description currently N/A</i>



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

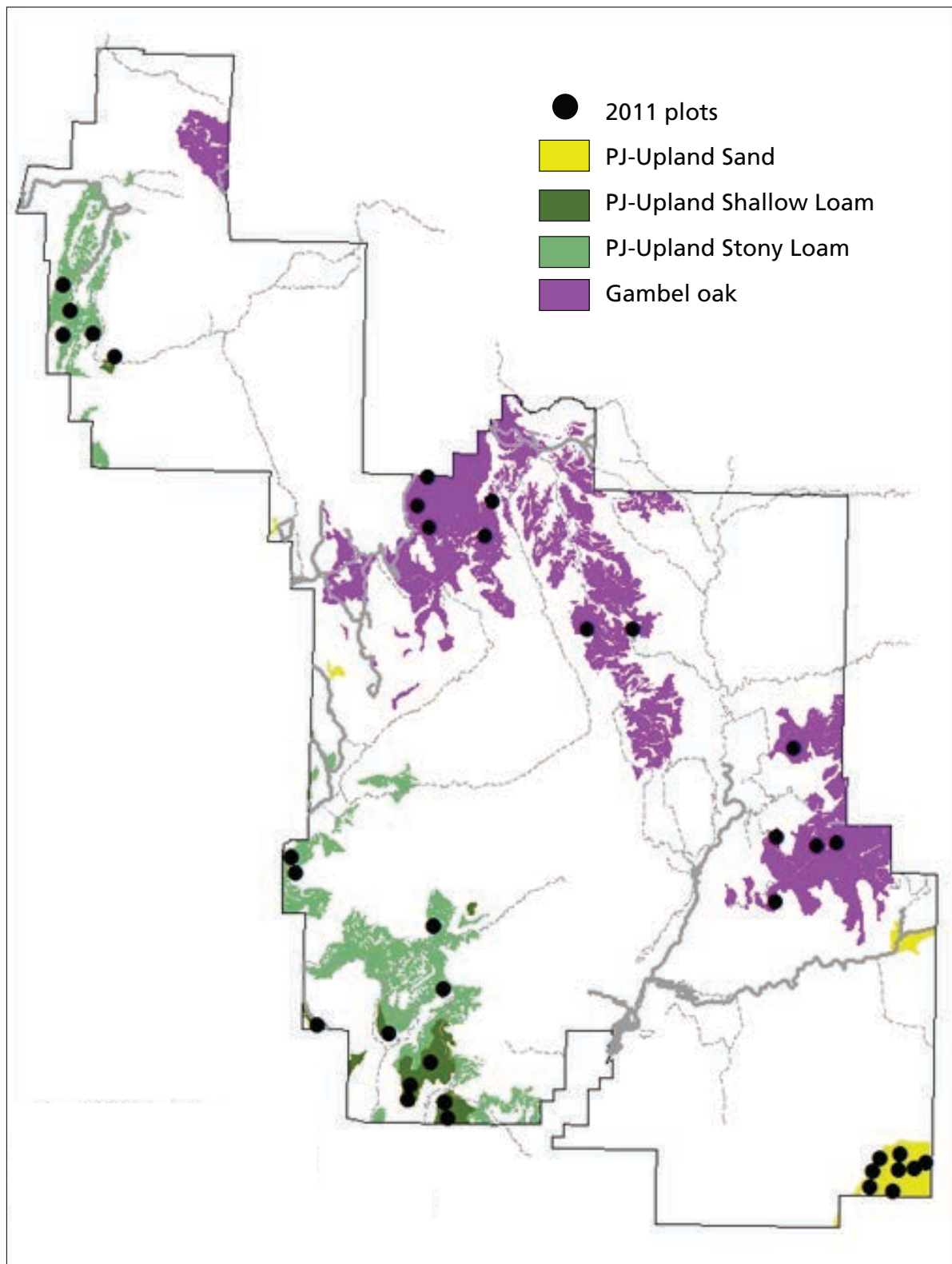


Figure 2-2. Sampling frame and location of monitoring plots in Zion National Park, 2011.

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 for all target ecological site types (8,892 ha vs. 5,426 ha) because all soil map units used to make the map contain some non-target areas (Table 2-2). The sampling frame area represents 14.9% of the total park area and 39.6% of accessible area. Before site selection, the sampling frame was buffered by 65 m to prevent plots from crossing roads, trails, buildings, campsites, the park boundary, riparian areas (perennial streams, springs, and wetlands), and 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 being too close to an established plot, incorrect vegetation type, crossing a road, trail, park unit boundary, or cliff), the next sequentially ordered plot was used.

2.1.4 Revisit design

Each year, 24 PJ plots (8 in each ecological site type) and 12 Gambel oak plots are monitored (Figure 2-3). A total of 90 plots are sam-

a) Pinyon-juniper

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	4				4	4
5	4				4	4				4

b) Gambel oak

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

Figure 2-3. Number of (a) pinyon-juniper (PJ) plots in each ecological site type and (b) Gambel oak plots sampled each year, based on a five-year rotating panel revisit design for long-term upland monitoring at Zion National Park. In each PJ ecological site type (Upland Sand, Upland Shallow Loam, and Upland Stony Loam), 8 plots are sampled each year, and 20 unique plots are sampled over five years. In the Gambel oak ecological site type, 12 plots are sampled each year, and 30 unique plots are sampled over five years.

pled among all ecological site types (see Table 2-2). Plots are sampled for two consecutive years (in order to detect year-to-year differences due to temperature, precipitation, or other factors) and rested for three years. Every five years, the sampling scheme repeats itself. 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.

Table 2-2. Area of the sampling frame and number of plots sampled in each ecological site type for upland monitoring, Zion National Park.

Ecological site type	Area of sampling frame (ha)	Predicted percent target area	Predicted area of target ecological sites in sampling frame (ha)	# plots sampled/ year	Total # of plots sampled
PJ-Upland Sand	499	85%	424	8	20
PJ-Upland Shallow Loam	511	85%	434	8	20
PJ-Upland Stony Loam	2,514	60%	1,507	8	20
Gambel oak	5,368	57%	3,061	12	30
Total	8,892		5,426	36	90

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) and standard forest, woodland, and fuels procedures (USDI 2003; Brown 1974). Specific measurements taken at each plot depend on the vegetation type (see the response design column in Table 2-3).

2.2.1.1 Pinyon-juniper woodlands

At each plot, observations are recorded along three parallel, 50-m transects spaced 25 m apart (Figure 2-4). Photos are taken from the origin and end of each transect. Photos of the soil surface 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. Exotic-species frequency is recorded using 1 × 1-m quadrats placed every 5 m along each transect.

Density of shrubs (by species and height class) and tree seedlings (by species) is recorded in a 1-m belt upslope of each transect. Saplings (2.5–15 cm diameter) are identified to species, and density is tallied in a 5-m belt transect centered on Transect 2. All overstory trees (>15 cm diameter) in Quadrant 1 are identified to species, tagged with unique numbers, and measured for diameter. Diameter of trees is typically measured at breast height (dbh), except for woodland species that typically have multi-stem growth forms (e.g., pinyon pines and Utah juniper), which are measured at the root crown (drc).

Fuels are measured using Brown's planar method (Brown 1974) along four 50-ft transects that extend beyond the plot on two corners. Counts of fine woody fuels, diameters of coarse woody fuels, and depth of litter and duff are recorded to derive fuel loading of each fuel class. Disturbances and exotic plants observed on and around the site are also recorded.

2.2.1.2 Gambel oak/mixed montane shrublands

Gambel oak/mixed montane shrub systems are structurally different from other vegetation types on the Colorado Plateau, and their dense, tall vegetation is not easily sampled using standard upland methods. This vegetation type is sampled using three 20-m transects (Figure 2-5), with photos taken at the origin and end of each transect. Point-intercept cover is collected at 0.25-m intervals, and exotic-species frequency is collected at smaller intervals along transects. Within the 20 × 20-m plot, species and diameter are recorded for all mature trees and exceptionally large individuals of Gambel oak. Fuel measurements and density of shrubs and trees are not recorded in this vegetation type. Disturbances and exotic plants on and around the monitoring plot are recorded using the same methods as the other vegetation types.

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 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.

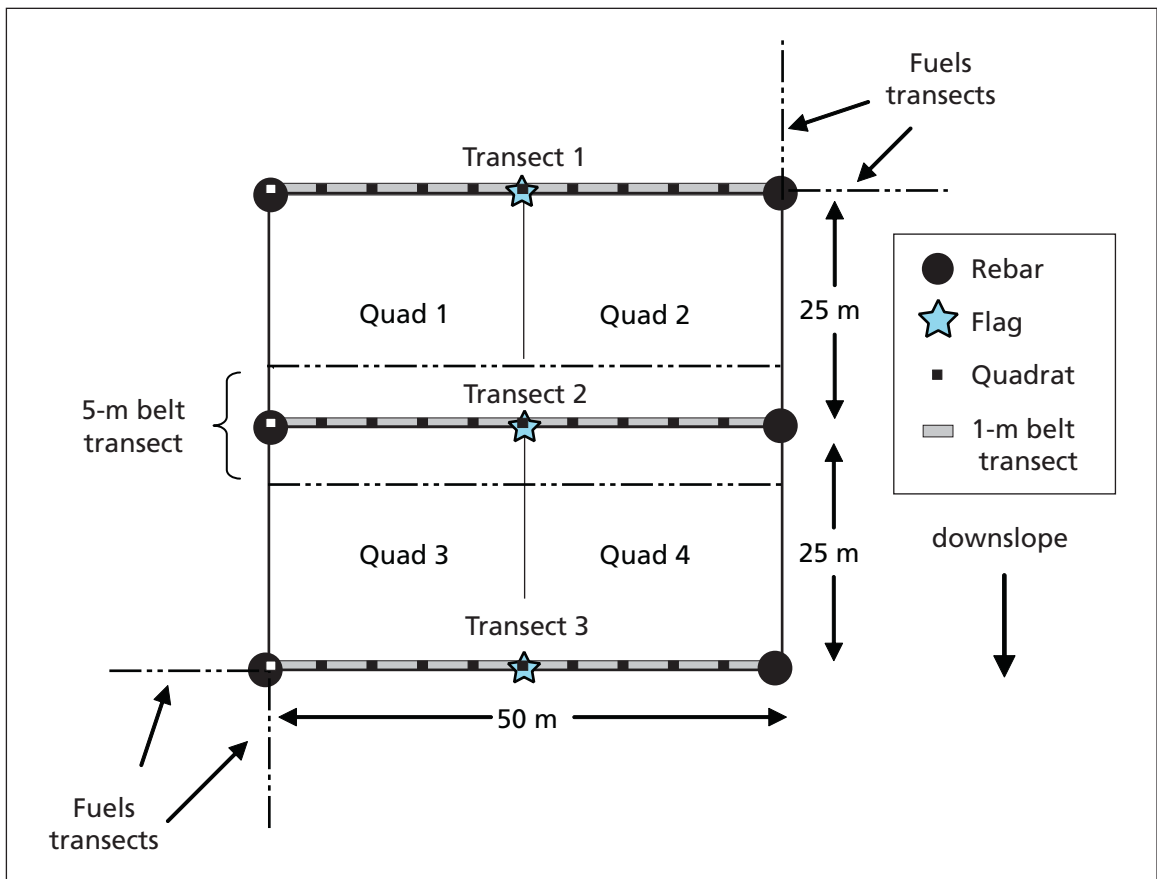


Figure 2-4. Plot layout for upland monitoring of pinyon-juniper woodlands.

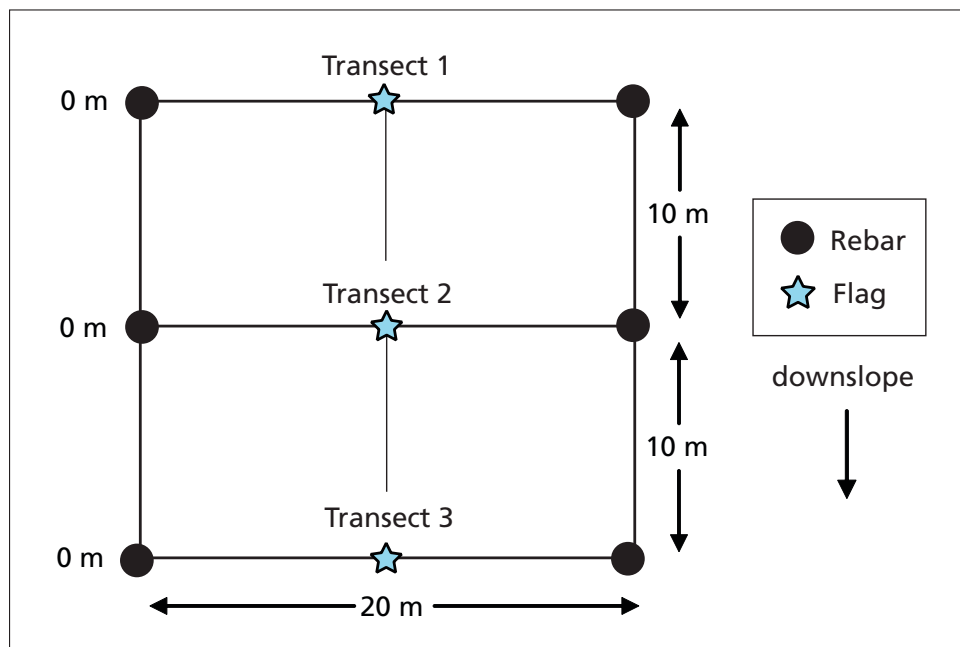


Figure 2-5. Plot layout for upland monitoring of Gambel oak/mixed montane shrublands.

3 Results

3.1 Monitored plots

In September and October 2011, thirty-six plots were established and monitored as part of the long-term revisit design, including 24 PJ and 12 oak plots (see Figure 2-2). The 24 PJ plots were divided evenly among the three ecological site types. Table 3-1 summarizes plot visits by vegetation type and ecological site (tables begin on page 13). Each plot was sampled using the suite of measures appropriate for that vegetation type (see response-design column in Table 3-1).

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 are complete.

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 statistical analysis provided is a multivariate assessment of the similarity of vegetative conditions within and among ecological site types (see Section 3.2.9). Data were ordinated using non-metric multidimensional scaling (NMS), which involves scaling plots on the basis of similarity (or dissimilarity) of species composition and 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.

3.2.1 Species richness

A total of 117 species were detected in Zion NP in 2011. Species richness by life form is reported in Table 3-2 for all ecological site

types. Recorded species were compared to the NPSpecies database to determine first-time observations in Zion NP. No new species were detected in 2011.

Although Zion NP only has populations of one federally listed threatened or endangered plant species within its borders, at least 189 plants of special conservation concern exist within the park (Fertig and Alexander 2009). Five of these species, Davidson's wild buckwheat (*Eriogonum davidsonii*), kidney-shaped wild buckwheat (*Eriogonum subreniforme*), Mohave datil (*Yucca vespertina*), silktassel (*Garrya flavescens*), and Zion golden-aster (*Chrysopsis zionensis*), were detected in PJ plots in 2011.

3.2.2 Cover by life form and dominant species

Total vegetation by life form is shown in Table 3-3 for all ecological site types. 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 is shown in Table 3-4 for all ecological site types. 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 (zion11_species.xls).

3.2.3 Shrub density

Density of shrub species is shown in Table 3-5 for PJ ecological site types. Big sagebrush (*Artemisia tridentata*) had the highest density in Upland Sand, and this species was found at all plots in this ecological site. Although big sagebrush also had the highest density at Upland Stony Loam, it was detected at only three plots. Shrub species varied widely by plot in this ecological site. Big sagebrush and blackbrush (*Coleogyne ramosissima*) had the highest densities at Upland Shallow Loam plots.

Greenleaf manzanita (*Arctostaphylos patula*), Mexican manzanita (*Arctostaphylos pungens*), turbinella live-oak (*Quercus turbinella*), Utah serviceberry (*Amelanchier*

utahensis), and Whipple's cholla (*Opuntia whipplei*) are common in the pinyon-juniper ecological sites monitored at Zion NP but are not counted in our shrub density counts. Their sprawling or multi-stemmed lifeform makes it extremely difficult to distinguish individuals, and measuring density of these shrubs is not repeatable. Cover can alternatively be used to assess the status of these species.

3.2.4 Tree density

Density of live seedlings, saplings, and overstory trees is shown in Table 3-6 for all ecological site types. Density and diameter for all overstory trees >15 cm diameter are shown in Table 3-7 for all ecological site types. Utah juniper was detected at all PJ plots, and singleleaf pinyon was detected at nearly all PJ plots. Utah juniper tended to have the highest densities for larger diameter trees, while singleleaf pinyon had the highest densities for seedlings and smaller-diameter saplings. Gambel oaks with a diameter greater than 10 cm occurred at one-third of the Gambel oak plots monitored.

3.2.5 Exotic species

Percent cover and frequency of detection of exotic plant species are shown in Table 3-8 for all ecological site types. When exotic species were detected, cover was summarized for all plots in the ecological site type.

In 2011, nine exotic plant species were detected through cover and frequency sampling at Zion NP. Exotic plant species were detected in all ecological site types. They tended to be annual species in PJ plots and a mix of annual and perennial species in Gambel oak plots. Cheatgrass (*Bromus tectorum*) was detected at all but one PJ plot. Cover of cheatgrass was low at Upland Sand and Upland Shallow Loam plots and higher at some Upland Stony Loam plots. Red brome (*Bromus rubens*) had higher cover and frequency of detection than cheatgrass at Upland Shallow Loam plots.

Beginning in 2011, NCPN upland sampling methods also included an "exotic plant walk" to search for other exotic plants present in plots. A list of all exotic plant species detected, and descriptions of the number of

plants, size of invasions, and approximate locations, are included in an electronic appendix that accompanies this report (zion11_exotics.xls).

3.2.6 Biological soil crust and surface features

Biological soil crust and surface-feature cover are shown in Table 3-9 for all ecological site types. Surface cover at PJ plots was mainly litter and undifferentiated crust. Substantial amounts of rock cover also occurred at Upland Shallow Loam and Upland Stony Loam ecological sites. Litter was the dominant surface cover for Gambel oak plots.

3.2.7 Soil aggregate stability

Measures of soil aggregate stability are reported in Table 3-10 for all PJ ecological site types. 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. Because the numbers are affected by soil texture, 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 Fuels

Fuel loading of downed woody material, litter, and duff is reported in Table 3-11 for all PJ ecological site types. In general, PJ plots were characterized by low fuel volumes. Fuel loading in the Upland Sand ecological site was similar to that in Upland Stony Loam. Fuel loading was higher in those ecological sites than in Upland Shallow Loam.

3.2.9 Plot ordinations

Non-metric multidimensional scaling (NMS) ordination was performed using species with relative cover values of $\geq 10\%$ (Figures 3-1). 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. The direction and relative magnitude of correlations of species are shown in the graphs for

each combination of axes. The species vector from the origin shows the direction of positive correlation.

The ordination illustrates the separation of Gambel oak from the PJ sites and the high degree of overlap between the three PJ site types. Gambel oak sites were strongly cor-

related with Gambel oak and mountain snowberry (*Symphoricarpos oreophilus*). In addition to Utah juniper and singleleaf pinyon, there were numerous shrubs and annual grasses correlated with PJ sites. Upland Sand was the most tightly grouped PJ site, especially in axes 1 vs. 2 and 2 vs. 3.

Table 3-1. Response design and number of plots by dominant vegetation and ecological site monitored in Zion National Park, 2011.

Dominant vegetation	Response design	Ecological site*	Number of plots
Pinyon-juniper	Woodland	Upland Sand	8
		Upland Shallow Loam	8
		Upland Stony Loam	8
Gambel oak	Oak	Mountain Loam	3
		Mountain Stony Loam	9
Total			36

* See Table 2-1 for description of ecological sites and vegetation types.

Table 3-2. Mean (range) number of plant species detected per monitoring plot by life form and ecological site type, Zion National Park, 2011.

Ecological site	Number of species detected					
	Total	Tree	Shrub	Perennial grass	Annual grass	Forb/ Herb
PJ-Upland Sand	13.4 (10–18)	2.4 (2–3)	4.6 (3–6)	2.4 (1–4)	1.8 (1–2)	2.3 (1–4)
PJ-Upland Shallow Loam	11.6 (10–16)	1.9 (1–3)	5.3 (3–8)	0.5 (0–1)	2.5 (1–4)	1.5 (0–5)
PJ-Upland Stony Loam	15.9 (7–22)	1.9 (1–2)	5.9 (2–9)	2.0 (0–4)	2.1 (1–3)	4.0 (1–6)
Gambel oak	15.5 (12–21)	1.3 (0–3)	4.8 (3–6)	2.8 (0–5)	0.4 (0–1)	6.2 (2–12)

Table 3-3. Mean (range) percent cover of vegetation by life form for each ecological site type, Zion National Park, 2011.

Ecological site type	Total		Tree		Shrub		Perennial grass		Annual grass		Forb/Herb	
	Live	Total	Live	Total	Live	Total	Live	Total	Live	Total	Live	Total
PJ-Upland	43.1	51.3	25.3	27.2	18.3	22.8	2.8	4.8	0.2	2.3	1.8	4.5
Sand	(35.7–49.7)	(43.3–57.7)	(18.7–32.7)	(20.7–34.7)	(7.3–28.0)	(10.3–35.7)	(0.3–6.7)	(0.3–8.3)	(0–0.7)	(0–6.7)	(0.3–2.7)	(0.7–7.7)
PJ-Upland	31.0	41.6	14.3	15.5	16.8	23.9	0.04	0.3	0.4	6.3	0.7	2.4
Shallow Loam	(21.0–43.0)	(31.7–48.3)	(0–27.3)	(2.3–29.0)	(4.0–27.0)	(10.7–34.7)	(0–0.3)	(0–1.0)	(0–1.3)	(0–20.7)	(0–3.0)	(0.7–8.0)
PJ-Upland	43.2	54.5	17.5	19.0	23.3	27.9	2.6	5.1	2.0	7.5	2.7	5.3
Stony Loam	(20.3–70.3)	(36.0–75.0)	(0.3–47.7)	(2.3–49.3)	(5.0–43.3)	(5.7–51.0)	(0–7.3)	(0–12.7)	(0–11.0)	(0.7–30.7)	(0–6.3)	(0.3–12.3)
Gambel oak	56.2	66.5	4.1	6.6	45.3	48.1	5.5	7.7	0	3.0	7.8	13.0
	(22.5–88.8)	(32.1–95.8)	(0–20.4)	(0–28.3)	(21.3–76.3)	(22.1–83.8)	(0–16.3)	(0–21.3)		(0–14.6)	(0.8–16.3)	(1.7–30.4)

Table 3-4. Mean (range) percent cover of dominant species by ecological site type, Zion National Park, 2011.

Scientific name	Common name	Life form	Duration	Nativity	No. of plots with species present*	Percent cover	
						Live	Total
PJ-Upland Sand							
<i>Artemisia tridentata</i>	big sagebrush	Shrub	Perennial	Native	8	1.3 (0–5.3)	3.1 (1.0–10.0)
<i>Ephedra viridis</i>	Mormon tea	Shrub	Perennial	Native	7	1.4 (0–4.7)	1.8 (0–7.3)
<i>Juniperus osteosperma</i>	Utah juniper	Tree	Perennial	Native	8	10.3 (5.0–18.3)	11.5 (5.3–19.7)
<i>Muhlenbergia pungens</i>	sandhill muhly	Graminoid	Perennial	Native	5	1.9 (0–6.7)	2.4 (0–8.0)
<i>Pinus monophylla</i>	singleleaf pinyon	Tree	Perennial	Native	8	14.5 (4.0–23.7)	15.2 (4.0–23.7)
<i>Poa fendleriana</i>	muttongrass	Graminoid	Perennial	Native	5	0.7 (0–2.3)	1.5 (0–4.3)
<i>Quercus gambelii</i>	Gambel oak	Shrub	Perennial	Native	8	12.3 (1.7–18.7)	14.1 (3.0–22.3)
PJ-Upland Shallow Loam							
<i>Artemisia tridentata</i>	big sagebrush	Shrub	Perennial	Native	6	0.8 (0–2.7)	2.5 (0–7.0)
<i>Coleogyne ramosissima</i>	blackbrush	Shrub	Perennial	Native	3	5.8 (0–19.3)	7.6 (0–27.0)
<i>Gutierrezia sarothrae</i>	broom snakeweed	Dwarf shrub	Perennial	Native	4	2.6 (0–17.3)	3.0 (0–19.7)
<i>Juniperus osteosperma</i>	Utah juniper	Tree	Perennial	Native	8	9.5 (0–17.3)	10.4 (1.3–18.3)
<i>Opuntia</i> sp.	pricklypear species	Dwarf shrub	Perennial	Native	6	0.8 (0–2.0)	2.0 (0–4.7)
<i>Pinus monophylla</i>	singleleaf pinyon	Tree	Perennial	Native	5	4.8 (0–12.3)	5.0 (0–13.3)
PJ-Upland Stony Loam							
<i>Amelanchier utahensis</i>	Utah serviceberry	Shrub	Perennial	Native	6	1.4 (0–7.0)	2.0 (0–10.0)
<i>Gutierrezia sarothrae</i>	broom snakeweed	Dwarf Shrub	Perennial	Native	6	2.1 (0–6.0)	2.5 (0–7.7)
<i>Juniperus osteosperma</i>	Utah juniper	Tree	Perennial	Native	8	12.0 (0.3–39.3)	13.4 (1.3–42.0)
<i>Pinus monophylla</i>	singleleaf pinyon	Tree	Perennial	Native	7	6.0 (0–14.7)	6.1 (0–15.0)
<i>Poa fendleria</i>	muttongrass	Graminoid	Perennial	Native	6	1.6 (0–5.7)	3.2 (0–11.3)
<i>Quercus gambelii</i>	Gambel oak	Shrub	Perennial	Native	4	6.0 (0–34.7)	6.7 (0–37.7)
Gambel oak							
<i>Amelanchier utahensis</i>	Utah serviceberry	Shrub	Perennial	Native	10	2.7 (0–7.9)	2.8 (0–8.3)
<i>Artemisia tridentata</i>	big sagebrush	Shrub	Perennial	Native	3	1.0 (0–9.2)	1.4 (0–12.5)
<i>Poa fendleriana</i>	muttongrass	Graminoid	Perennial	Native	7	1.3 (0–7.1)	2.3 (0–13.3)
<i>Quercus gambelii</i>	Gambel oak	Graminoid	Perennial	Native	12	39.3 (12.9–67.9)	41.5 (13.3–76.7)
<i>Symphoricarpos oreophilus</i>	mountain snowberry	Graminoid	Perennial	Native	9	4.7 (0–16.3)	5.3 (0–17.9)
<i>Vicia americana</i>	American vetch	Forb	Perennial	Native	10	0.7 (0–2.5)	2.9 (0–5.4)

* In 2011, eight plots were monitored in each ecological site type, except Gambel oak, which had 12 plots.

Table 3-5. Density of shrub species per hectare by ecological site type, Zion National Park, 2011.

Scientific name	Common name	No. of plots with species present*	Density (number of shrubs/ha)		
			Mean	Minimum	Maximum
PJ-Upland Sand					
<i>Artemisia tridentata</i>	big sagebrush	8	708	67	2,867
<i>Chrysothamnus nauseosus</i>	rubber rabbitbrush	4	50	0	200
<i>Chrysothamnus viscidiflorus</i>	green rabbitbrush	1	25	0	200
<i>Ephedra viridis</i>	Mormon tea	7	392	0	1,733
<i>Purshia tridentata</i>	antelope bitterbrush	2	25	0	133
PJ-Upland Shallow Loam					
<i>Artemisia tridentata</i>	big sagebrush	5	300	0	867
<i>Cercocarpus montanus</i>	alder-leaf mountain mahogany	1	83	0	667
<i>Chrysothamnus nauseosus</i>	rubber rabbitbrush	1	8	0	67
<i>Coleogyne ramosissima</i>	blackbrush	4	1,525	0	4,867
<i>Ephedra nevadensis</i>	Nevada ephedra	3	158	0	600
<i>Ephedra viridis</i>	Mormon tea	2	92	0	667
<i>Garrya flavescens</i>	silktassel bush	1	17	0	133
<i>Purshia mexicana</i>	cliffrose	2	283	0	1,533
<i>Rhus aromatica</i>	skunkbush sumac	1	8	0	67
PJ-Upland Stony Loam					
<i>Artemisia tridentata</i>	big sagebrush	3	1,533	0	10,000
<i>Atriplex canescens</i>	fourwing saltbush	1	17	0	133
<i>Cercocarpus montanus</i>	alder-leaf mountain mahogany	2	125	0	933
<i>Chrysothamnus depressus</i>	dwarf rabbitbrush	2	150	0	1,067
<i>Chrysothamnus nauseosus</i>	rubber rabbitbrush	1	17	0	133
<i>Chrysothamnus viscidiflorus</i>	green rabbitbrush	1	8	0	67
<i>Ephedra nevadensis</i>	Nevada ephedra	1	8	0	67
<i>Ephedra torreyana</i>	Torrey's mormon tea	1	8	0	67
<i>Eriogonum microthecum</i>	slender wild buckwheat	2	67	0	400
<i>Fraxinus anomala</i>	singleleaf ash	1	17	0	133
<i>Garrya flavescens</i>	silktassel bush	2	25	0	133
<i>Psoralea fremontii</i>	Fremont's indigo-bush	1	8	0	67
<i>Purshia tridentata</i>	antelope bitterbrush	3	33	0	133
<i>Rhus aromatica</i>	skunkbush sumac	1	8	0	67

* In 2011, eight plots were monitored in each PJ ecological site type.

Table 3-6. Mean (range) density of live seedlings, saplings, and overstory trees by ecological site type, Zion National Park, 2011.

Scientific name	Common name	No. of plots with species detected ^a	Density of live trees by diameter ^b class (no. of trees/ha)				
			Seedling	Sapling			Tree
			<2.5 cm	2.5–5.0 cm	5.1–10.0 cm	10.1–15.0 cm	>15 cm ^c
PJ-Upland Sand							
<i>Juniperus osteosperma</i>	Utah juniper	8	17 (0–67)	40 (0–160)	55 (0–160)	25 (0–160)	136 (48–240)
<i>Pinus edulis</i>	two-needle pinyon	3	8 (0–67)	15 (0–80)	20 (0–160)	10 (0–80)	8 (0–48)
<i>Pinus monophylla</i>	singleleaf pinyon	8	258 (0–533)	110 (0–240)	155 (0–360)	45 (0–80)	108 (0–288)
PJ-Upland Shallow Loam							
<i>Juniperus osteosperma</i>	Utah juniper	8	33 (0–67)	25 (0–120)	45 (0–200)	65 (0–160)	114 (0–160)
<i>Pinus edulis</i>	two-needle pinyon	1	0	0	0	0	2 (0–16)
<i>Pinus monophylla</i>	singleleaf pinyon	6	133 (0–600)	50 (0–360)	55 (0–400)	45 (0–240)	28 (0–80)
PJ-Upland Stony Loam							
<i>Juniperus osteosperma</i>	Utah juniper	8	175 (0–1133)	50 (0–160)	85 (0–240)	35 (0–80)	122 (0–368)
<i>Pinus monophylla</i>	singleleaf pinyon	7	367 (0–1267)	70 (0–160)	35 (0–160)	60 (0–200)	42 (0–144)
Gambel oak							
<i>Abies concolor</i>	white fir	1	na	na	na	na	1 (0–16)
<i>Juniperus osteosperma</i>	Utah juniper	4	na	na	na	na	4 (0–48)
<i>Juniperus scopulorum</i>	Rocky Mountain juniper	1	na	na	na	na	4 (0–48)
<i>Pinus edulis</i>	two-needle pinyon	5	na	na	na	na	3 (0–32)
<i>Quercus gambelii</i>	Gambel oak	4	na	na	na	na	36 (0–304)

^a In 2011, eight plots were monitored in each ecological site type, except Gambel oak, which had 12 plots.

^b Diameter was measured at root crown for Utah juniper, singleleaf pinyon, and two-needle pinyon, and at breast height for all other species.

^c This category also includes Gambel oak >10 cm dbh.

Table 3-7. Mean (range) density and diameter for all trees >15 cm and Gambel oak >10 cm diameter by ecological site type, Zion National Park, 2011.

Scientific name	Common name	No. of plots with species detected*	Density (no. of trees/ha)	Diameter** (cm)	% dead
PJ-Upland Sand					
<i>Juniperus osteosperma</i>	Utah juniper	8	138 (48–256)	26.1 (21.9–30.5)	1 (0–6)
<i>Pinus edulis</i>	two-needle pinyon	2	8 (0–48)	26.6 (20.2–32.9)	0
<i>Pinus monophylla</i>	singleleaf pinyon	7	108 (0–288)	27.2 (22.1–37.8)	0
PJ-Upland Shallow Loam					
<i>Juniperus osteosperma</i>	Utah juniper	8	138 (80–176)	22.7 (17.6–27.3)	18 (0–100)
<i>Pinus edulis</i>	two-needle pinyon	1	2 (0–16)	26.2	0
<i>Pinus monophylla</i>	singleleaf pinyon	6	36 (0–80)	20.5 (15.5–24.8)	17 (0–100)
PJ-Upland Stony Loam					
<i>Juniperus osteosperma</i>	Utah juniper	6	136 (0–384)	22.6 (17.3–28.0)	19 (0–100)
<i>Pinus monophylla</i>	singleleaf pinyon	5	42 (0–144)	24.1 (18.6–30.4)	0
Gambel oak					
<i>Abies concolor</i>	white fir	1	1 (0–16)	17.1	0
<i>Juniperus osteosperma</i>	Utah juniper	4	17 (0–64)	26.5 (25.9–26.9)	81 (25–100)
<i>Juniperus scopulorum</i>	Rocky Mountain juniper	1	4 (0–48)	21.4	0
<i>Pinus edulis</i>	two-needle pinyon	5	16 (0–80)	19.1 (16.1–22.8)	87 (33–100)
<i>Quercus gambelii</i>	Gambel oak	4	81 (0–544)	15.1 (12.4–22.1)	49 (0–100)

* In 2011, eight plots were monitored in each ecological site type, except Gambel oak, which had 12 plots.

** Diameter was measured at root crown for Utah juniper, singleleaf pinyon, and two-needle pinyon, and at breast height for all other species.

Table 3-8. Mean (range) percent cover and frequency of exotic plant species detected by ecological site type in Zion National Park, 2011.

Scientific name	Common name	Life form	Duration	No. of plots with exotic species detected*	Percent cover		Frequency of detection (%)
					Live	Total	
PJ-Upland Sand							
<i>Bromus tectorum</i>	cheatgrass	Graminoid	Annual	7	0.1 (0–0.7)	1.2 (0–5.7)	12.5 (0–30.0)
PJ-Upland Shallow Loam							
<i>Bromus rubens</i>	red brome	Graminoid	Annual	7	0.2 (0–1.0)	5.1 (0–19.7)	54.6 (0–100)
<i>Bromus tectorum</i>	cheatgrass	Graminoid	Annual	8	0	0.7 (0–2.7)	30.0 (13.3–70.0)
<i>Lactuca serriola</i>	prickly lettuce	Forb	Annual	2	0	0.04 (0–0.3)	1.3 (0–10.0)
<i>Salsola tragus</i>	Russian-thistle	Forb	Annual	1	0	0.2 (0–1.7)	0.4 (0–3.3)
<i>Sisymbrium altissimum</i>	tumble mustard	Forb	Annual	1	0	0.4 (0–3.0)	5.0 (0–40.0)
<i>Tragopogon dubius</i>	yellow salsify	Forb	Biennial	1	0	0	0.4 (0–3.3)
PJ-Upland Stony Loam							
<i>Bromus rubens</i>	red brome	Graminoid	Annual	5	0.04 (0–0.3)	0.7 (0–2.3)	14.2 (0–40.0)
<i>Bromus tectorum</i>	cheatgrass	Graminoid	Annual	8	1.9 (0–10.3)	6.0 (0.3–28.0)	47.1 (16.7–96.7)
<i>Lactuca serriola</i>	prickly lettuce	Forb	Annual	5	0.8 (0–4.0)	1.4 (0–7.7)	19.2 (0–83.3)
<i>Sisymbrium altissimum</i>	tumble mustard	Forb	Annual	1	0	0	0.8 (0–6.7)
Gambel oak							
<i>Bromus inermis</i>	smooth brome	Graminoid	Perennial	1	0.03 (0–0.4)	0.03 (0–0.4)	0.3 (0–3.3)
<i>Bromus tectorum</i>	cheatgrass	Graminoid	Annual	5	0	3.0 (0–14.6)	19.7 (0–73.3)
<i>Lactuca serriola</i>	prickly lettuce	Forb	Annual	2	0.2 (0–1.7)	1.1 (0–7.9)	14.7 (0–93.3)
<i>Poa pratensis</i>	Kentucky bluegrass	Graminoid	Perennial	6	1.3 (0–5.8)	1.9 (0–6.7)	23.3 (0–86.7)
<i>Taraxacum officinale</i>	common dandelion	Forb	Perennial	1	0	0	0.6 (0–6.7)
<i>Tragopogon dubius</i>	yellow salsify	Forb	Biennial	5	0	0.03 (0–0.4)	6.4 (0–33.3)

* In 2011, eight plots were monitored in each ecological site type, except Gambel oak, which had 12 plots.

Table 3-9. Mean (range) percent cover of surface features by ecological site type, Zion National Park, 2011.

Ecological site type	Crust, undifferentiated	Cyanobacteria	Lichen	Moss	Bare soil	Litter	Woody debris	Small rock	Large rock	Bedrock
PJ-Upland Sand	27.6 (11.3–44.0)	1.2 (0–3.0)	0.2 (0–0.7)	1.5 (0–6.3)	2.3 (0–12.0)	62.3 (52.0–73.7)	0.9 (0–2.3)	0.04 (0–0.3)	0	0.5 (0–4.0)
PJ-Upland Shallow Loam	27.2 (10.3–57.0)	0.5 (0–2.3)	0.3 (0–1.0)	4.7 (0.7–17.3)	3.6 (0–10.3)	41.2 (23.0–59.0)	0.5 (0–1.7)	13.0 (1.3–26.7)	3.1 (0–8.7)	2.2 (0–7.3)
PJ-Upland Stony Loam	22.8 (4.7–58.3)	0.9 (0–6.7)	0.1 (0–0.3)	0.9 (0–2.3)	1.1 (0–3.7)	52.6 (23.7–81.3)	0.4 (0–1.3)	7.8 (1.3–11.7)	9.2 (0–33.7)	0.2 (0–1.3)
Gambel oak	10.7 (0–25.0)	0	0	0.1 (0–0.8)	0.4 (0–0.8)	75.1 (45.8–96.3)	1.0 (0–6.7)	5.1 (0–31.7)	4.2 (0–24.6)	0.1 (0–1.3)

Table 3-10. Mean (range) soil-aggregate stability measures by PJ ecological site type, Zion National Park, 2011. Numbers range from 1 (least stable) to 6 (most stable).

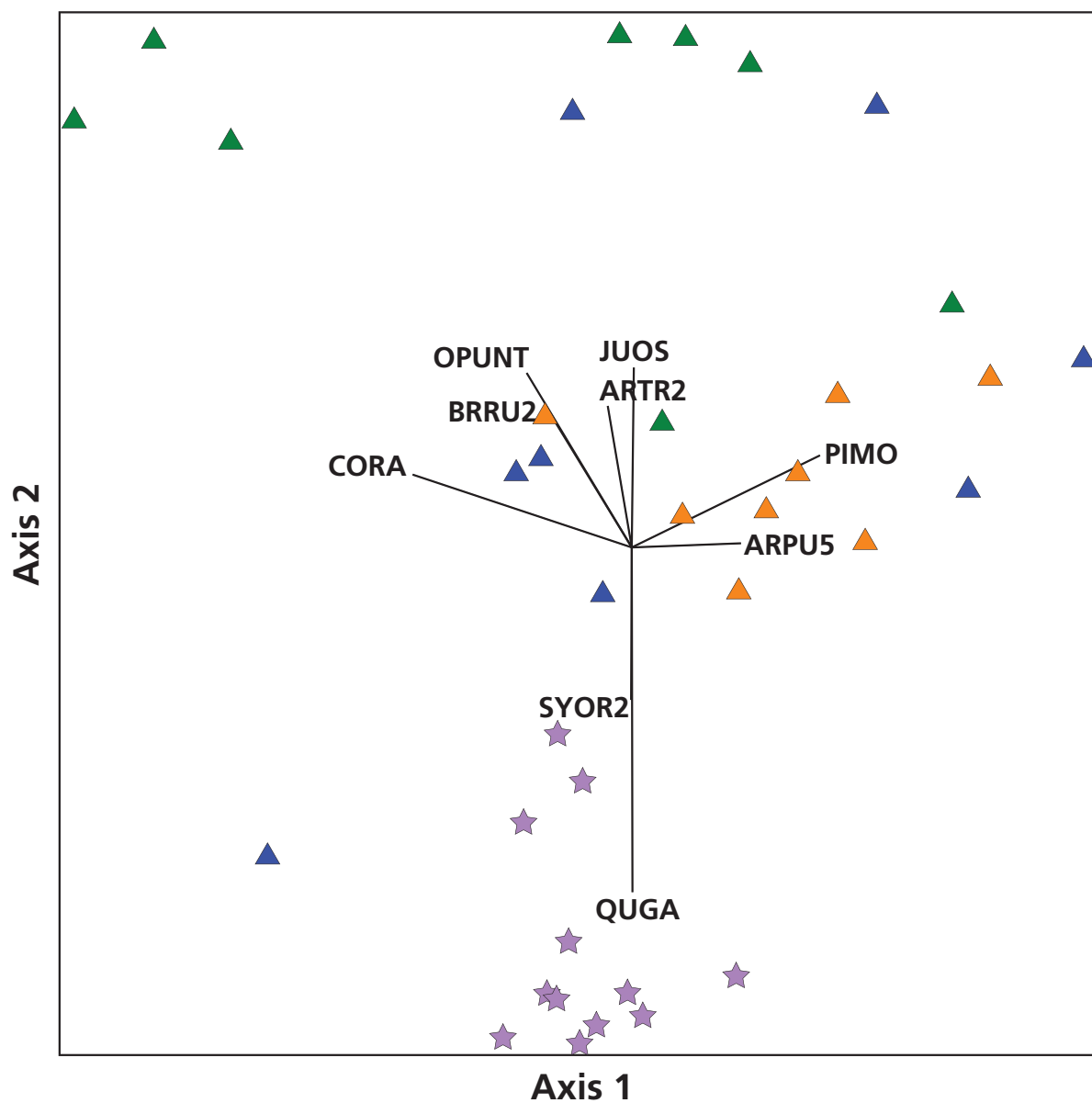
Ecological site type	Total	Protected*	Unprotected*
PJ-Upland Sand	3.3 (2.3–4.4)	3.8 (2.7–4.9)	2.9 (1.7–3.9)
PJ-Upland Shallow Loam	3.9 (3.1–4.9)	4.7 (3.4–5.9)	3.3 (2.6–4.0)
PJ-Upland Stony Loam	3.8 (3.1–5.4)	4.0 (3.1–5.3)	3.6 (2.4–5.6)

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

Table 3-11. Mean (range) fuel loading of downed woody material (1-hr, 10-hr, 100-hr, and 1,000-hr fuels), litter, and duff in PJ ecological site types, Zion National Park, 2011.

Ecological site type	Fuel loading (tons/acre)							
	Total	1-hr	10-hr	100-hr	1,000-hr		Litter	Duff
					Sound*	Rotten*		
PJ-Upland Sand	6.4 (3.4–10.6)	0.3 (0.03–0.6)	0.9 (0.1–2.6)	0.1 (0–0.4)	0.05 (0–0.4)	0	4.9 (3.1–6.6)	0.2 (0–0.5)
PJ-Upland Shallow Loam	3.4 (1.0–7.3)	0.1 (0.03–0.3)	0.5 (0–0.9)	0.3 (0–0.8)	0.1 (0–0.9)	0	2.2 (0.1–5.6)	0.2 (0–0.6)
PJ-Upland Stony Loam	7.0 (3.4–9.3)	0.3 (0.05–0.5)	0.8 (0.2–1.6)	0.3 (0–0.4)	0.5 (0–3.6)	0.1 (0–0.3)	4.2 (1.0–7.1)	0.9 (0–1.6)

*A piece of fuel is rotten when it is obviously punky or can be easily kicked apart at the intersection point; otherwise it is considered sound.



Ecological site type

▲ PJ - Upland Sand

▲ PJ - Upland Shallow Loam

▲ PJ - Upland Stony Loam

★ Gambel oak

Figure 3-1a. Non-metric multidimensional scaling (NMS) ordination of plots from the four ecological site types monitored in Zion National Park in 2011: Axes 1 and 2.

Species codes

ARPU5 = *Arctostaphylos pungens* (Mexican manzanita)

ARTR2 = *Artemisia tridentata* (big sagebrush)

BRRU2 = *Bromus rubens* (red brome)

CORA = *Coleogyne ramosissima* (blackbrush)

JUOS = *Juniperus osteosperma* (Utah juniper)

OPUNT = *Opuntia species* (pricklypear)

PIMO = *Pinus monophylla* (singleleaf pinyon)

QUGA = *Quercus gambelii* (Gambel oak)

SYOR2 = *Symphoricarpos oreophilus* (mountain snowberry)

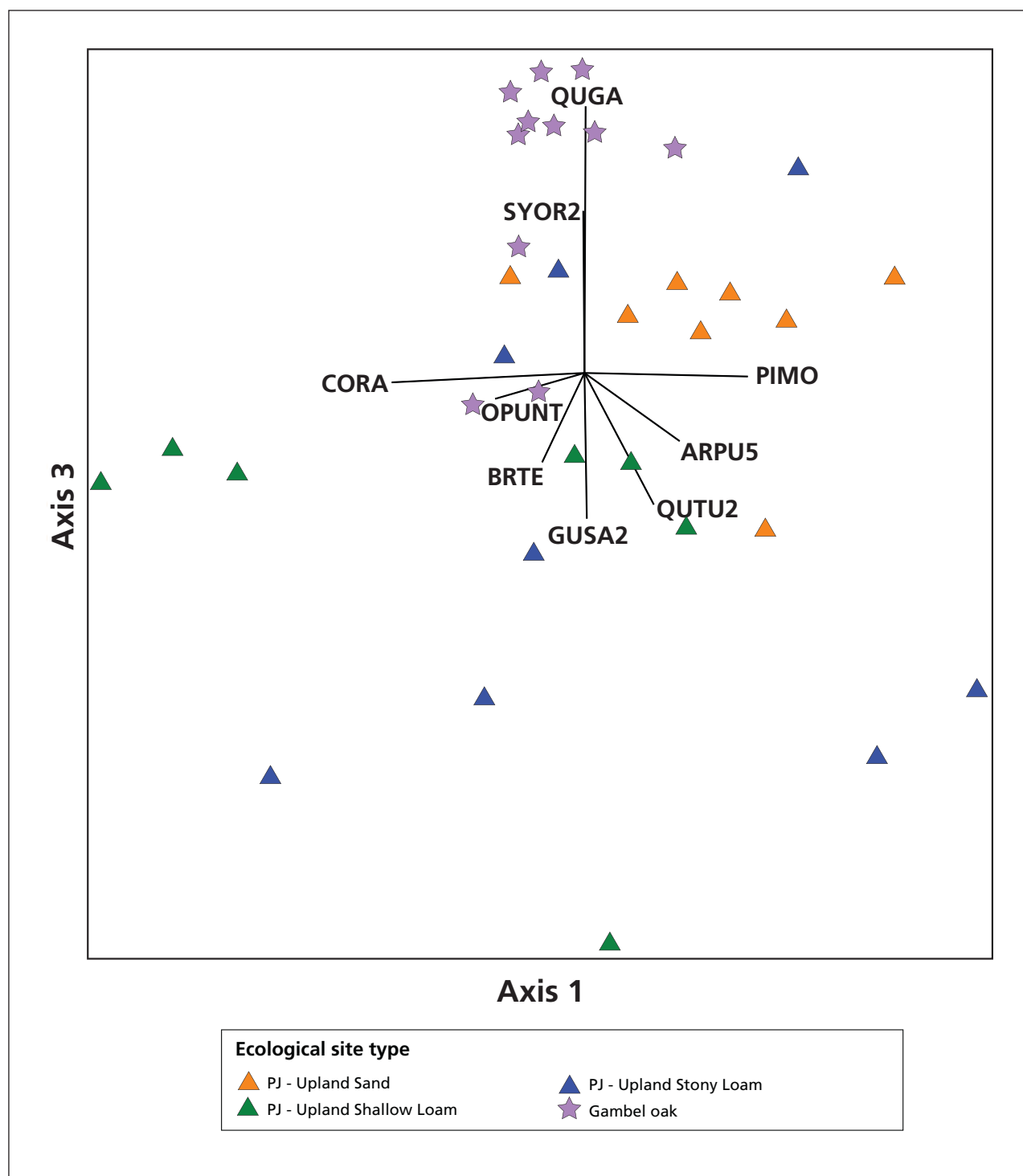


Figure 3-1b. Non-metric multidimensional scaling (NMS) ordination of plots from the four ecological site types monitored in Zion National Park in 2011: Axes 1 and 3.

Species codes

ARPU5 = *Arctostaphylos pungens* (Mexican manzanita)
 BRTE = *Bromus tectorum* (cheatgrass)
 CORA = *Coleogyne ramosissima* (blackbrush)
 GUSA2 = *Gutierrezia sarothrae* (broom snakeweed)

OPUNT = *Opuntia species* (pricklypear)
 PIMO = *Pinus monophylla* (singleleaf pinyon)
 QUGA = *Quercus gambelii* (Gambel oak)
 QUTU2 = *Quercus turbinella* (turbinella live-oak)
 SYOR2 = *Symphoricarpos oreophilus* (mountain snowberry)

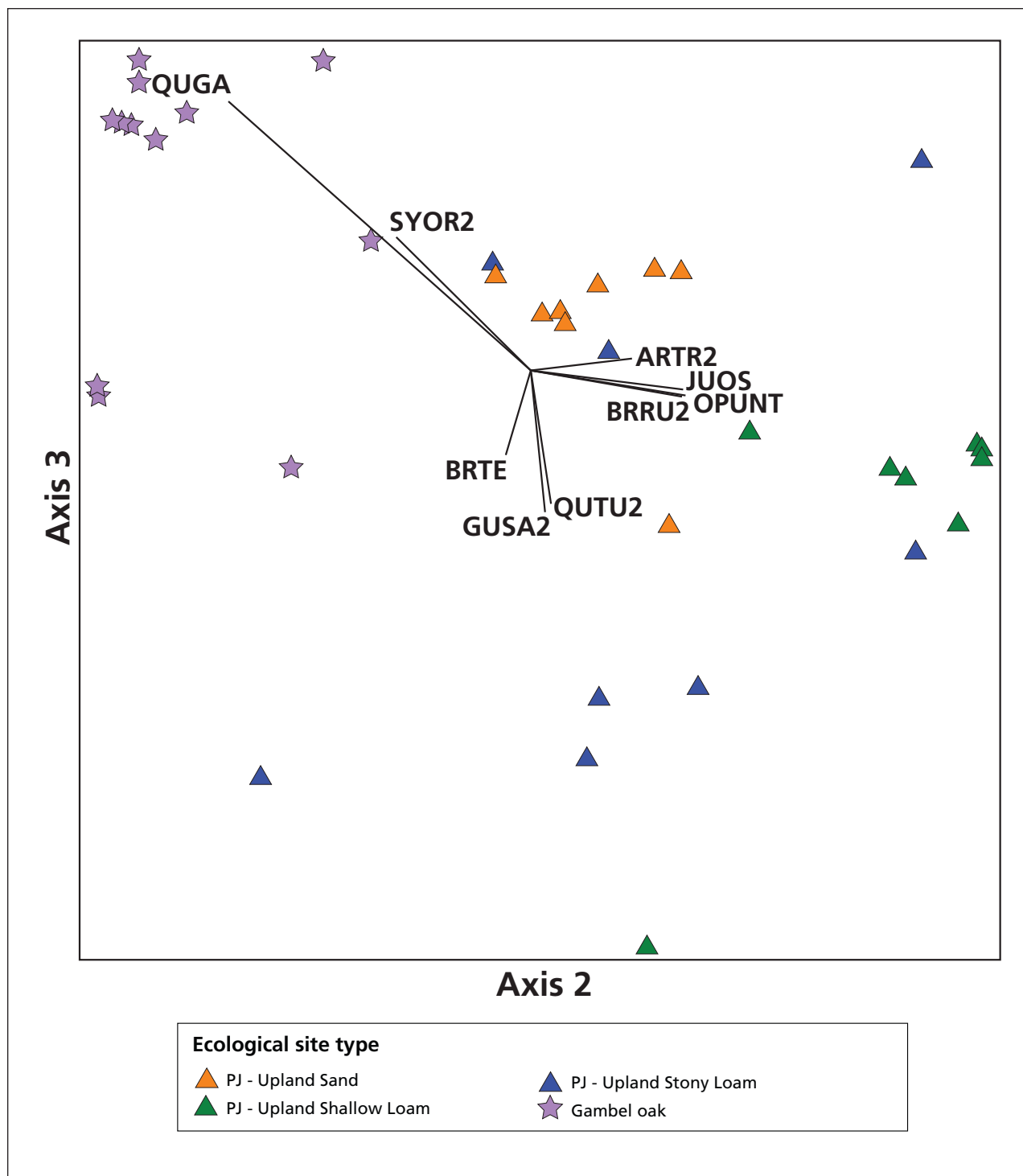


Figure 3-1c. Non-metric multidimensional scaling (NMS) ordination of plots from the four ecological site types monitored in Zion National Park in 2011: Axes 2 and 3.

4 Discussion

This was the first year of monitoring at Zion NP. Early monitoring data, which describe status and conditions of sites inside the park, were used to characterize ecological site types monitored in the park based on a cursory review of the data. In the NMS ordination, Gambel oak plots were vegetatively very similar despite including two ecological sites in this site type. Although all PJ sites were dominated by Utah juniper and single-leaf pinyon, the ecological site types differed in numerous ways. Upland Sand sites had higher cover and density of singleleaf pinyon than the other PJ sites. In the NMS ordination, PJ sites had a wide range of vegetation among the ecological site types. Upland Shallow Loam and Upland Stony Loam sites had an especially high amount of overlap. This may be due, in part, to the fact that some plots in each of these ecological site types were burned, which drastically changed the dominant vegetation at the site. Exotic plant species were less frequently detected at Upland Sand plots than the other site types, and the cheatgrass that was detected had low cover and frequency. This was probably due both to the sandier soils in this ecological site and the location of this ecological site in a very remote part of the park.

In 2012, we plan to monitor 36 plots according to the full operational monitoring design. One-half of the plots visited in 2011 will be revisited and the remaining plots will be established. 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 at least five full years of monitoring have been completed.

5 Literature Cited

- Belnap, J. 2002. Nitrogen fixation in biological soil crusts from southeast Utah, U.S.A. *Biology and Fertility of Soils* 35:128–135.
- Belnap, J., B. Budel, and O. L. Lange. 2003. Biological soil crusts: Characteristics and distribution. Pages 3–30 *in* J. Belnap and O. L. Lange, eds., *Biological soil crusts: Structure, function, and management* (2nd ed.). Ecological studies series 150. Berlin: Springer-Verlag.
- Bock, C. E., J. H. Bock, K. L. Jepsen, and J. C. Ortega. 1986. Ecological effects of planting African lovegrass in Arizona. *National Geographic Research* 2(4):456–463.
- Brown, J. K. 1974. Handbook for inventorying downed woody material. USDA Forest Service General Tech. Report INT-16, Intermountain Forest and Range Experiment Station, Ogden, Utah.
- Evans, R. D., and O. L. Lange. 2003. Biological soil crusts and ecosystem nitrogen and carbon dynamics. Pages 263–279 *in* J. Belnap and O. L. Lange, eds., *Biological soil crusts: Structure, function, and management* (2nd ed.). Ecological studies series 150. Berlin: Springer-Verlag.
- Fertig, W., and J. Alexander. 2009. Annotated checklist of vascular flora: Zion National Park. Natural Resource Technical Report NPS/NCPN/NRTR—2009/157. National Park Service, Fort Collins, Colorado.
- Garfin, G. M., J. K. Eischeid, M. T. Lenart, K. L. Cole, K. Ironside, and N. Cobb. 2010. Downscaling climate projections in topographically diverse landscapes of the Colorado Plateau in the arid southwestern United States. *In* C. van Riper III, B. F. Wakeling, and T. D. Sisk, eds., *The Colorado Plateau IV: Shaping conservation through science and management*. Tucson: The University of Arizona Press.
- Harper, K. T., and J. Belnap. 2001. The influence of biological soil crusts on mineral uptake by associated vascular plants. *Journal of Arid Environments* 47(3):347–357.
- Harris, T. A., G. P. Asner, and M. E. Miller. 2003. Changes in vegetation structure after long-term grazing in pinyon–juniper ecosystems: Integrating imaging spectroscopy and field studies. *Ecosystems* 6(4):368–383.
- Herrick, J. E., J. W. Van Zee, K. M. Havstad, L. M. Burkett, and W. G. Whitford. 2005. Monitoring manual for grassland, shrubland, and savanna ecosystems. Published as 2 volumes. USDA Jornada Experimental Range, Las Cruces, New Mexico.
- Lange, O. L. 2003. Photosynthesis of soil-crust biota as dependent on environmental factors. Pages 217–240 *in* J. Belnap and O. L. Lange, eds., *Biological soil crusts: Structure, function, and management* (2nd ed.). Ecological studies series 150. Berlin: Springer-Verlag.
- Miller, M. E. 2005. The structure and functioning of dryland ecosystems: Conceptual models to inform long-term ecological monitoring. U.S. Geological Survey Scientific Investigations Report 2005-5197.
- Miller, M. E., R. T. Belote, M. A. Bowker, and S. L. Garman. 2011. Alternative states of a semiarid grassland ecosystem: implications for ecosystem services. *Ecosphere* 2(5):1–18.
- Munson, S. M., J. Belnap, C. D. Schelz, M. Moran, and T. W. Carolin. 2011a. On the brink of change: Plant responses to climate change on the Colorado Plateau. *Ecosphere* 2(6):1–15.
- Munson, S. M., J. Belnap, and G. S. Okin. 2011b. Responses of wind erosion to climate-induced vegetation changes on the Colorado Plateau. *Proceedings of the National Academy of Sciences of the USA* 108(10):3854–3859.
- National Park Service. 2003. Fire monitoring handbook. Fire Management Program Center, National Interagency Fire Center, Boise, Idaho. 274p.

- Rosentreter, R., and J. Belnap. 2003. Biological soil crusts of North America. Pages 31–51 *in* J. Belnap and O. L. Lange, eds., *Biological soil crusts: Structure, function, and management* (2nd ed.). Ecological studies series 150. Berlin: Springer-Verlag.
- Society for Range Management (SRM). 1989. *Glossary of terms used in range management*. 3rd edition. Society for Range Management, Denver, Colorado.
- . 1995. New concepts for assessment of rangeland condition. *Journal of Range Management* 48:271–282.
- Theobald, D. M., D. L. Stevens Jr., D. White, S. Urquhart, A. R. Olsen, and J. B. Norman. 2007. Using GIS to generate spatially balanced random survey designs for natural resource applications. *Environmental Management* 40:134–146.
- U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS). 1977. *Soil Survey of Washington County Area, Utah*, Salt Lake City, Utah.
- Whelan, R. J. 1995. *The ecology of fire*. Cambridge, U.K.: Cambridge University Press.
- Whitford, W. G. 2002. *Ecology of desert systems*. San Diego, Calif.: Academic Press.
- Williams, J. D., J. P. Dombrowski, D. A. Gillette, and N. E. West. 1995. Microphytic crust influence on wind erosion. *Transactions of the American Society of Agricultural Engineers* 38:131–137.

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