Zion National Park
Survey Design and Site Selection Report

Defining the Upland Resources for Monitoring

Initial discussion with ZION resource staff identified numerous potential vegetation types for long-term monitoring including Ponderosa pine forests, Gambel oak/mixed montane shrublands, sagebrush shrublands, pinyon-juniper (PJ) woodlands, and desert grasslands and shrublands. Zion is located at the edge of the Colorado Plateau, the Great Basin, and the Mohave Desert ecoregions, and therefore much of the vegetation is a transition between dominant vegetation types of these regions. The large range of elevation in the park (3425 to 9430 ft) also contributes to the complexity of the vegetation. It was suggested that the entire accessible area of the park could be included in NCPN upland monitoring since so much of the park is not accessible (see next section). However, after an initial visit to the park, it was determined that the predominance of dense Gambel oak sites interspersed with open Ponderosa pine stands at higher elevations made this stratification scheme unreasonable, since different size plots are used to monitor each of these vegetation types.

To resolve this issue, the vegetation at ZION needed to be stratified by ecological site. The park resource staff was asked to prioritize vegetation types and ecological sites for monitoring. PJ and Gambel oak were selected as the highest priorities. PJ woodlands occur at middle elevations on the east side of the park, and vary depending on elevation, aspect, and soil properties. Gambel oak and mixed montane shrubs are the dominant vegetation at the highest elevations of the park. One goal of selecting these vegetation types is to collect data on vegetation types not well-represented in plots sampled by the fire-effects monitoring program at ZION (see Figure 1). Another interest in monitoring 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 elevational shifts in vegetation expected from a warming climate, natural variability of upland resources, and early warning of system degradation.

Accessibility

An accessibility map was created for ZION based on road and trail access. Steep slopes ($\geq$ 40%) and areas isolated due to steep slopes (e.g., mesa tops) were considered inaccessible. Accessibility in ZION was derived using the NCPN Landscape Accessibility Model. Approximately 2/3 of the area of ZION is not accessible for upland monitoring (Figure 2). After additional discussion with park resource staff, the Dakota Hills area was excluded from the accessible area for monitoring since it requires a 3-5 mile hike to reach the park boundary.

Delineating the Target Population

Defining Target Soils and Ecological Sites

The National Resource Conservation Service (NRCS) mapped soils for ZION within the Washington County Soil Survey (1977). The soil survey contains soil map units that are explicitly mapped across the landscape. Soil map units typically have multiple soil components, and it is the soil component that is directly associated with a specific ecological site. Using the Washington County Soil Survey, ecological sites associated with PJ and Gambel oak were summarized in Table 1.

NRCS did not have permission to dig soil pits within the park for this soil survey, and thus, accuracy of soil map units within the park was somewhat questionable. After strata based on elevation were deemed to be unreasonable for sampling the wide range of vegetation types at higher elevations in the park, field visits reassured us that the soil survey was a reasonable predictor of ecological sites in the park.

The ecological sites in Table 1 were evaluated, and two PJ ecological sites were determined not to be suitable for NCPN upland vegetation and soils monitoring. Upland Gravelly Loam (Pinyon-juniper) had an extremely small area within the park (i.e., only 12 ha). Upland Very Steep Stony Loam (Pinyon –Utah juniper) had a relatively small area and was located primarily on slopes steeper than NCPN can monitor with its response design.

After further discussion with park staff, the remaining PJ and Gambel oak ecological sites were selected for upland monitoring. Due to the large differences between soil characteristics of the PJ ecological sites, these 3 ecological sites were kept as separate ecological site types in the sampling frame. The vegetation and soils were much more similar for the Gamble oak ecological sites, and thus, the two Gamble oak ecological sites were combined into a single ecological site type for the sampling frame. The target ecological sites for monitoring were described in Table 2 and illustrated in Figure 3.

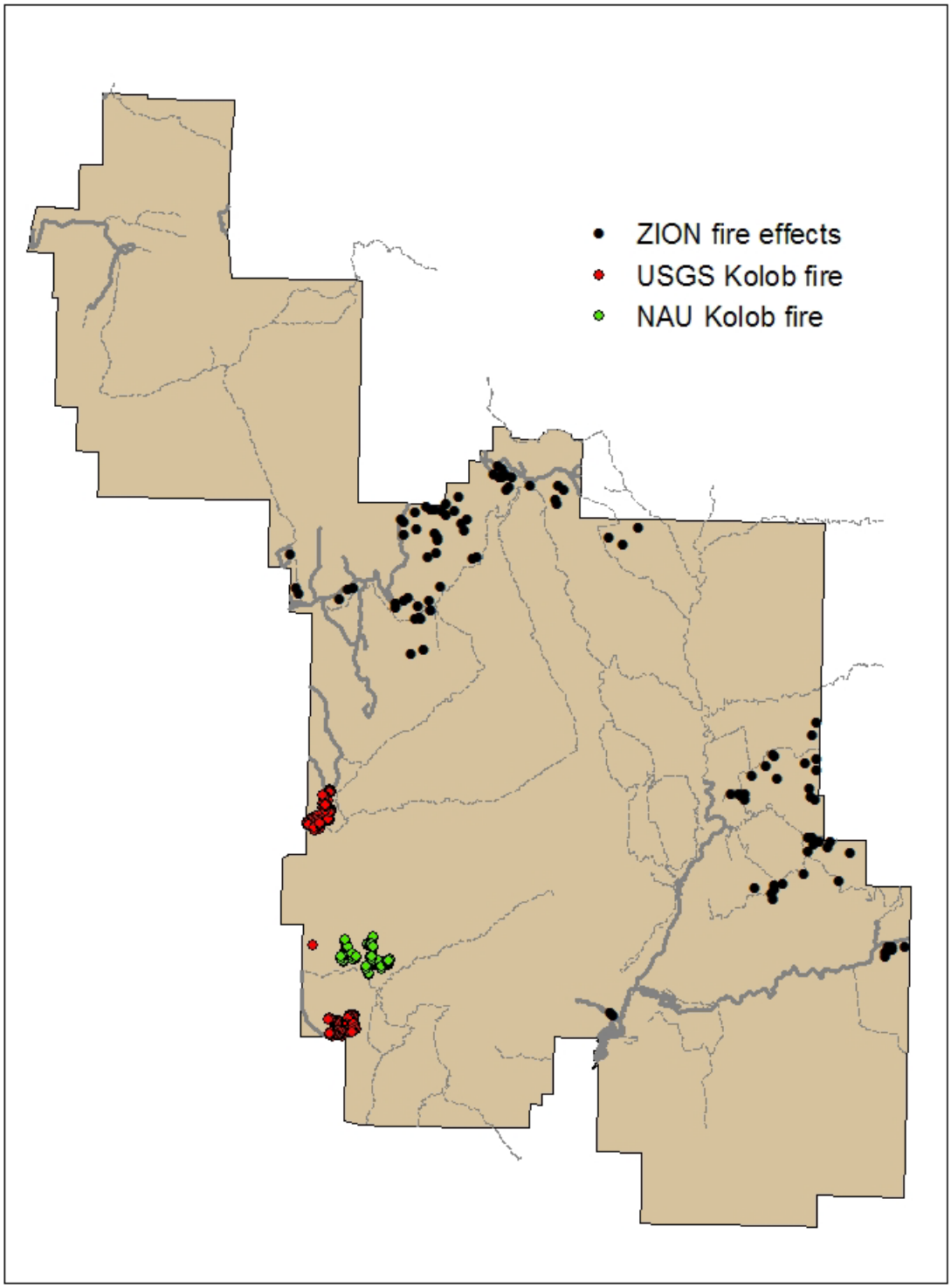

Figure 1. Existing monitoring plots at Zion National Park. ZION fire effects is part of a national NPS monitoring program that monitors recovery after fires. The U.S. Geological Survey (USGS) and Northern Arizona University (NAU) plots were set up to monitor cheatgrass (*Bromus tectorum*) treatments after the Kolob fire in 2006. These plots continue to be monitored by the ZION fire effects crew.

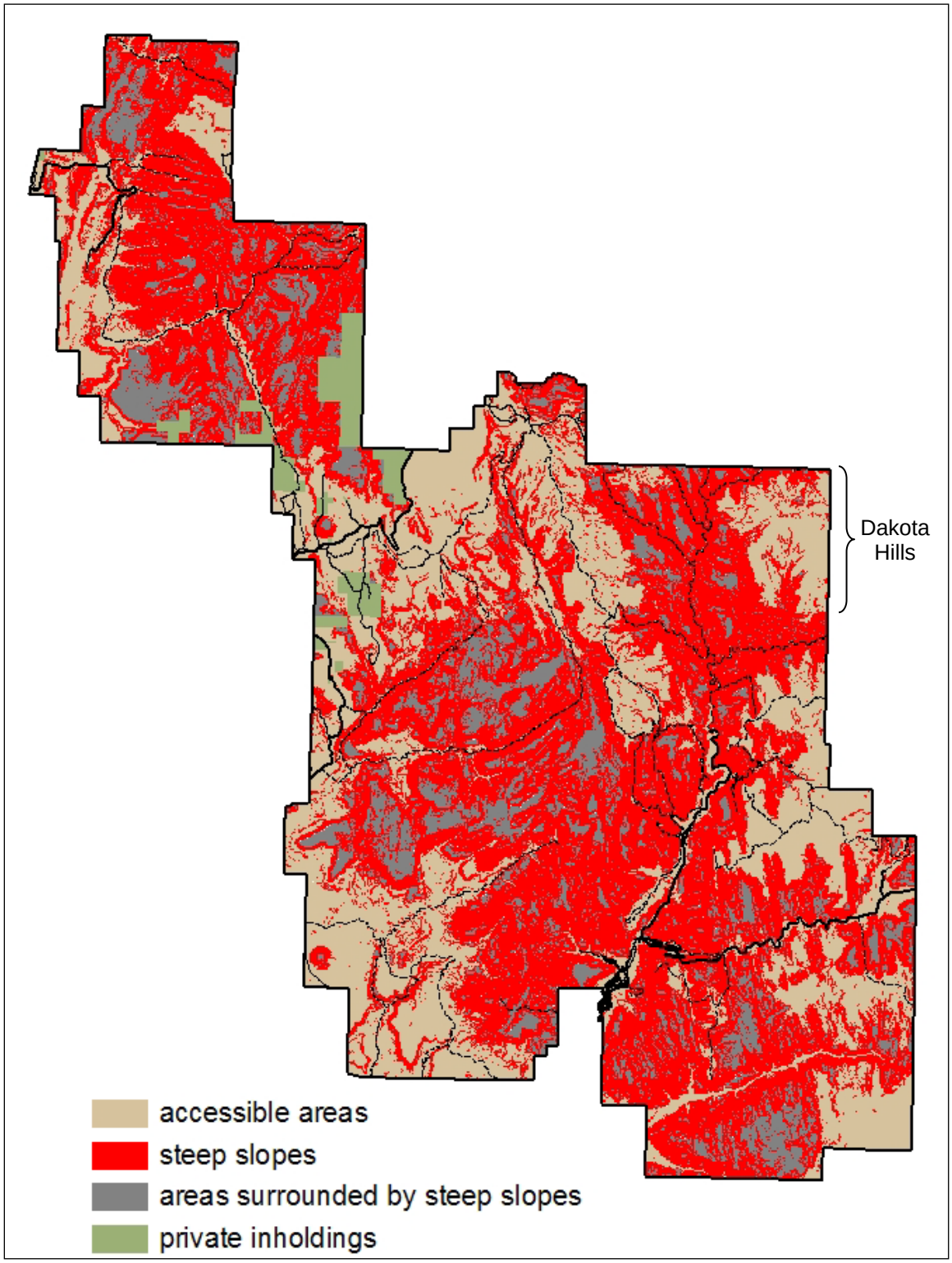

Figure 2. Accessible areas of Zion National Park.

Table 1. Estimated accessible area (ha) and associated soil map units for ecological sites supporting pinyon-juniper woodlands and Gambel oak shrublands in Zion National Park.

Vegetation type	Ecological site #	Ecological site name	Estimated accessible area (ha)	% of total land area	Associated soil map units
Pinyon-juniper	R035XY303UT	Upland Gravelly Loam (Pinyon- juniper)	12	0.02	CHF
	R035XY324UT	Upland Sand (Juniper-pinyon)	424	0.7	MFD
	R035XY315UT	Upland Shallow Loam (Pinyon-Utah juniper)	434	0.7	BOD
	R035XY321UT	Upland Stony Loam (Pinyon-Utah juniper)	1507	2.5	MBG, TAG
	R035XY328UT	Upland Very Steep Stony Loam (Pinyon-Utah juniper)	109	0.2	MEG
Gambel oak	none	Mountain Loam (Oak)	417	0.7	KAE, KBD, KCE
	R047XB463UT	Mountain Stony Loam (Oak)	2644	4.4	DBD, DKG, KCE, KD, KHC, PG
Total ZION area =			59836		

Table 2. Description of ecological sites selected for upland monitoring in Zion National Park.

Ecological site type	Ecological site same **Notation / No.**	Soil properties	Geological properties	Vegetative properties	Disturbance-mediated alternative states
PJ-Upland Sand	Upland Sand (Juniper-pinyon) **US324 / 324**	deep sands on plateau slopes & valleys	eolian deposits derived from sandstone	dominated by Utah juniper & single leaf pinyon pine	Decreased Indian ricegrass & squirreltail and increased pinyon, juniper, sandhill muhly, & snakeweed from overgrazing. Pinyon, juniper, & some shrubs may decrease temporarily after fire. Annual forbs & grasses are most likely to invade.
PJ-Upland Shallow Loam	Upland Shallow Loam (Pinyon-Utah juniper) **UShL315 / 315**	shallow sandy loams on mesas	residuum weathered from conglomerate or sandstone	dominated by Utah juniper & single leaf pinyon pine	Decreased bunchgrass & increased pinyon, juniper, snakeweed, & prickly pear from overgrazing. Pinyon, juniper, & some shrubs may decrease temporarily after fire.
PJ-Upland Stony Loam	Upland Stony Loam (Pinyon-Utah juniper) **UStL321 / 321**	deep very stony loamy sands & sandy loams on mesas & mountain slopes	residuum, alluvium, & colluvium derived from sandstone, siltstone & shale	dominated by Utah juniper & two-needle or single leaf pinyon pine	Decreased grass & bitterbrush & increased pinyon & juniper from overgrazing. Decreased pinyon & juniper & increased grass, forbs, Gambel oak, & manzanita from fire. Cheatgrass is likely to invade.
Gambel oak	Mountain Loam (Oak) **MLO**	deep sandy loams on mesa tops, valleys, & mountain side slopes	material weathered from limestone & some sandstone	dominated by Gambel oak, snowberry, & mountain big sagebrush	Decreased grasses & forbs & increased Gamble oak & less palatable shrubs from overgrazing.
	Mountain Stony Loam (Oak) **MStL463 / 436**	deep stony & cobbly silt & sandy loams on mountain side slopes & mesa tops	residuum & slope alluvium weathered from shale, limestone, & sandstone	dominated by Gambel oak	*Description currently N/A*

Figure 3. Examples of the ecological sites selected for upland monitoring at Zion National Park. See Table 2 for descriptions.

Upland Sand (Juniper-pinyon)

Upland Shallow Loam (Pinyon-Utah juniper)

Upland Stony Loam (Pinyon-Utah juniper)

Mountain Loam (Oak)

Mountain Stony Loam (Oak)

Basis for Sampling Frame

The sampling frame was created using accessible areas in the park (see Figure 2). Areas with bedrock and no vegetation cover were removed using the corresponding map units in the vegetation map (Table 3). Zion Canyon was also excluded from the sampling frame due to the high visitor use and intense management of vegetation in this area of the park.

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 (Figure 4).

Monitoring sites were then selected using the buffered sampling frame and the procedures detailed in the next section. When the strategy changed from sampling all elevation zones to sampling specific ecological sites, some modifications needed to be made to the original sampling frame. Areas of the sampling frame with relevant soil maps units for each target ecological site (see associated soil maps units in Table 1) were clipped from the original sampling frame and used to create a sampling frame for the four target ecological site types (Figure 5). The area of each part of the sampling frame is summarized in Table 4.

Monitoring Site Selection

Monitoring sites were selected using RRQRR (Reversed Randomized Quadrant Recursive Raster - Theobald et al. 2007). The sampling frame was converted to a 10-m grid to ensure complete coverage of the landscape. Sites were selected for the entire buffered sampling frame (see Figure 4) then clipped to the ecological site types that were used in the final monitoring design (see Figure 5). The following shape files were created, and all locations listed in them have a selection probability of 1.
ZION_smp_pts- ordered list of all possible monitoring points selected through RRQRR.
ZION_sample_pts- ordered list of 500 initial monitoring points selected through RRQRR.

Table 3. Vegetation map units used to remove bedrock areas from accessible areas for upland monitoring at Zion National Park.

Map unit #	Vegetation map unit name	area (ha)
1	Carmel Formation (Limestone)	5.3
2	Temple Cap (Sandstone)	0.3
3	Navajo Formation (Sandstone)	492.8
4	Kayenta Formation (Sandstone)	1.8
5	Moenave Formation (Sandstone)	1.1
6	Chinle Formation - Petrified Forest (Shale)	80.0
7	Chinle Formation - Shinarump (Shale)	14.7
8	Moenkopi Formation (Conglomerate)	6.0
9	Kaibab Formation (Limestone)	0.3
10	Basalt Talus	43.0
15	Volcanic and Basalt Cliffs	5.2
	total	650.7

Table 4. Area of the sampling frame and number of plots sampled in each ecological site type for upland monitoring at Zion National Park.

Ecological site type	Area of sampling frame (ha)	Predicted percent target area	Predicted area of target ecosites in sampling frame (ha)	# plots / panel	Total # of plots sampled
PJ-Upland Sand	499	85%	424	4	20
PJ-Upland Shallow Loam	511	85%	434	4	20
PJ-Upland Stony Loam	2514	60%	1507	4	20
Gamble oak	5368	57%	3061	6	30
total	**8892**		**5426**	**18**	**90**

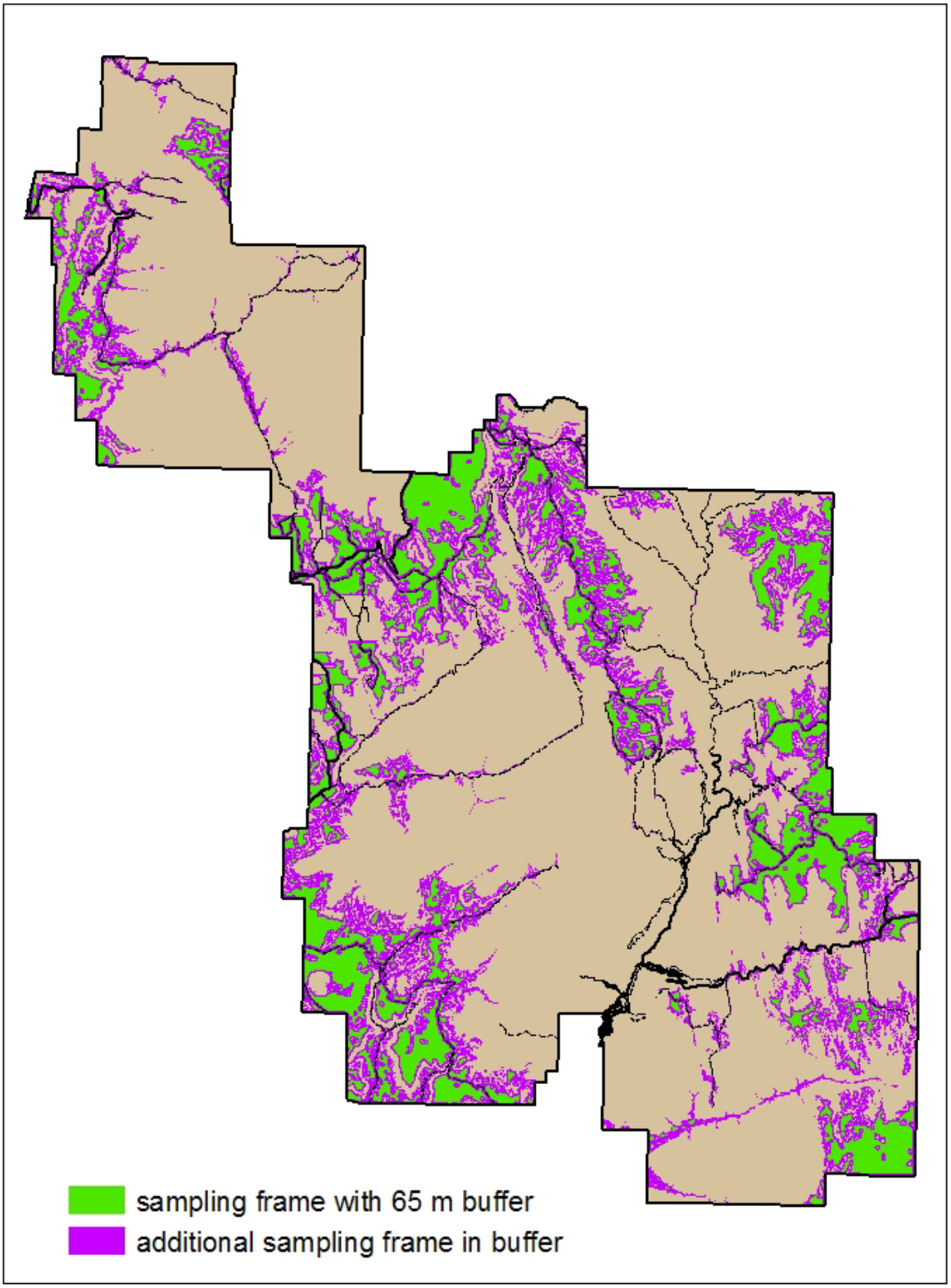

Figure 4. Sampling frame used for site selection of upland monitoring plots at Zion National Park.

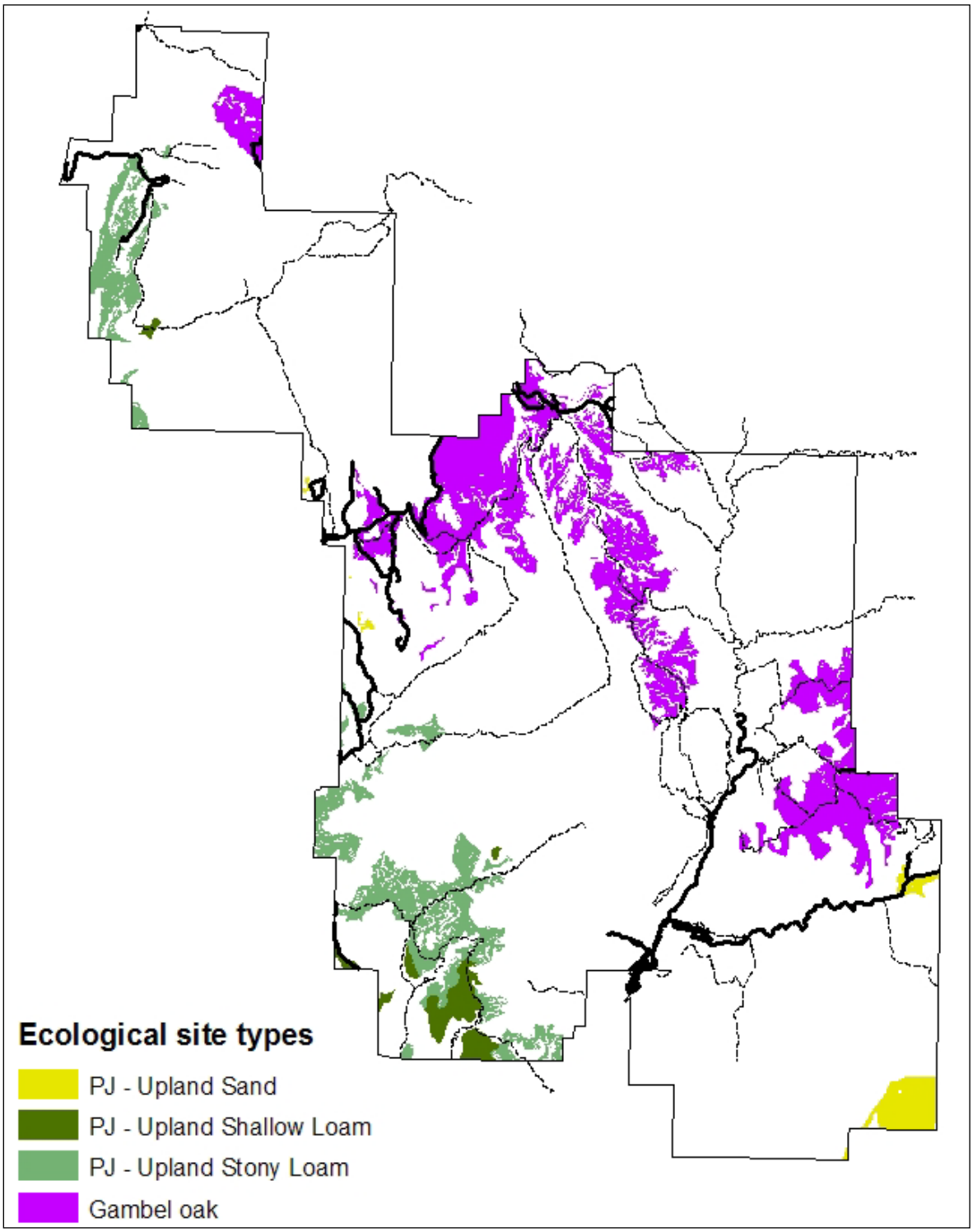

Figure 5. Sampling frame of ecological site types monitored in Zion National Park.

Tracking Monitoring Sites

ZION_upland_master.shp, derived from ZION_sample_pts.shp, contains the first 500 potential monitoring plots and any relevant tracking information (Table 5). The attributes include acceptance or rejections of plots, reasons for rejection, and date of plot establishment. It is used to schedule pre-monitoring evaluation of sites and for the eventual derivation of selection probabilities. In this file, the "order_" attribute was renamed "RQorder" for consistency among parks.

Table 5. Attributes of ZION_upland_master.shp for tracking upland monitoring locations in Zion National Park.

Field	Description
Veg_Type	Vegetation type for upland sampling methods (woodland, oak)
EcoType	Predicted ecological site type based on sampling frame (Mountain & St Loam [oak]; Upland Sand [PJ]; Upland Shallow Loam [PJ]; Upland Stony Loam [PJ])
MasterStra	Indicates groups for analyzing data
PlotID	The plot number, based on ascending order of the RQorder field, renumbered to give unique plot numbers for each point on the list.
Panel	Panel that plot is associated with in the revisit design (1-5, panel=0 for rejected plots)
PanelYear	Year(s) that panel is sampled (1-5)
EvalStatus	Ultimate status of a plot (estab = established; NotEval = not visited; accept = visited and deemed to be acceptable as a monitoring site; reject = rejected; not used = not used for monitoring)
S_Action	Status of plot determined in the field and recorded on GPS (accept or reject)
EvalReason	Describes why a site was accepted or rejected
Estab_Date	Month, day, and year of plot establishment
Soil_MU	Soil map unit from UT641 (Washington County Soil Survey) associated with the monitoring plot
X	UTM E (NAD83, Zone 12)
Y	UTM N (NAD83, Zone 12)
Hike_km	Hiking distance to plot in kilometers
AreaDescr	General area of the park where the plot is located
Comments	Miscellaneous
RQorder	Sequence number produced by RRQRR that doesn't start at 1 or increment by 1 (=order_ in sample_pts shape files and =GRID_CODE in smpts shape files)
inc_prob	inclusion probability; 1 indicates equal probability of selection for all points from the sample_pts shape file

Revisit Design

We decided that there was no need for pilot monitoring in ZION because the number of monitoring plots is more limited by affordable effort than variability of vegetation. The affordable effort for ZION is two pay periods for a 6-person crew or approximately 36 monitoring plots per year.

Plots are sampled following a rotating-panel design for each priority ecological site type (Figure 6). This ensures the same number of plots are sampled in each ecological site type each year. The number of plots sampled in each ecological site type is based roughly on the area of each ecological site type in the park (see Table 4). Among all ecological site types, 36 plots are sampled each year and a total of 90 plots are sampled over 5 years. Plots are sampled 2 years in a row (in order to detect year-to-year differences due to temperature, precipitation, etc.) and rested for 3 years. Every 5 years, the sampling scheme repeats itself.

Response Design

The response design for ZION is based on the NCPN upland monitoring protocol. Core vegetation sampling methods are performed at each plot, and additional measurements are determined by vegetation type (Table 6).

Literature Cited

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.

USDA NRCS. 1977. Soil Survey of Washington County Area, Utah, Salt Lake City, UT.

A. Pinyon-juniper

This design is used for each of the following ecological site types:
PJ - Upland Sand,
PJ - Upland Shallow Loam,
PJ - Upland Stony Loam

	Year									
panel	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

This design includes a combination of Mountain Loam (Oak) & Mountain Stony Loam (Oak) ecological sites

	Year									
panel	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 6. Number of pinyon-juniper (A) and Gamble oak (B) plots sampled each year based on a 5-year rotating panel revisit design for long-term upland monitoring at Zion National Park. Note that the same panel design will be used for each of the pinyon-juniper ecological site types.

Table 6. Response design for NCPN upland monitoring by vegetation type.

Method	Woodland	Oak
Ecological sites	Upland Sand (PJ) Upland Shallow Loam (PJ) Upland Stony Loam (PJ)	Mountain Loam (oak) Mountain Stony Loam (oak)
Transects	3 – 50 m transects	3 – 20 m transects
Photos	Transect origin & end, soil surface	Transect origin & end
Line-point intercept (vegetation and surface cover)	0.5 m intervals	0.25 m intervals
Soil stability	X	
Exotic frequency	X	X
1-m belt (shrub & tree seedling density)	X	Tree seedling density only
5-m belt (sapling density)	X	X
Tree census	Quadrat 1 only	Entire plot & include Gambel oak >10 cm DBH
Fuels	X	
Site Impact	X	X