



Upland Vegetation and Soils Monitoring Protocol for Park Units in the Northern Colorado Plateau Network

Version 1.07

Natural Resource Report NPS/NCPN/NRR—2017/1570



ON THE COVER

Monitoring vegetation on an uplands transect, Canyonlands National Park. NPS photo.

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Acronyms

C	carbon
I&M	Inventory & Monitoring
N	nitrogen
NCPN	Northern Colorado Plateau Network
NM	national monument
NP	national park
NPS	National Park Service
NRA	national recreation area
PJ	pinyon-juniper
SCPN	Southern Colorado Plateau Network
USGS	U.S. Geological Survey
USGS-BRD	U.S. Geological Survey Biological Resources Discipline
GRTS	Generalized Random Tessellation Stratified
RRQRR	Reversed Randomized Quadrat-Recursive Raster

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Protocol Narrative

Revision History Log

Previous version #	Revision date	Author	Changes made	Reason for change	New version #
1.00	9/2009	DLW	Add point-intercept, forest & oak methods, procedures for after field sampling at a park, update ecoregion figure	Update for change to point-intercept, forest, woodland, and oak methods	1.01
1.01	9/2011	DLW	Expanded background and objectives, revised most other sections, added S. Topp as author	Revised based on review comments	1.02
1.02	4/2012	DLW	Updated Table 4	Long-term sampling design for DINO completed	1.03
1.03	12/2012	DLW	Updated methods and fixed typo	Text in section 4 was out of date	1.04
1.04	7/2013	DLW	Added acknowledgement for protocol review	Omitted when protocol was approved	1.05
1.05	8/2016	DLW	Added seedling and sapling density for oak and tree methods for grasslands/shrublands, changed annual reports to summary reports, updated missing reference, updated timing of reporting and workload	Methods added, updated narrative for publication	1.06
		HMT	Made minor edits to Data Management section	To reflect current data management practices	
1.06	11/2016	AWB	Editorial	Preparation for publication	1.07

1 Introduction

This sampling protocol consists of this protocol narrative and the following standard operating procedures (SOPs), available at <https://irma.nps.gov/DataStore/Reference/Profile/2247807>:

SOP 1: Preparations for the Field Season and Equipment Needed

SOP 2: Hiring and Training Field Technicians

SOP 3: Using Global Positioning System (GPS) Units

SOP 4: Crust-Friendly Field Procedures

SOP 5: Site Characterization

SOP 6: Establishing Plots and Setting Up Transects

SOP 7: Repeat Photos

SOP 8: Measuring Vegetation and Surface Cover

SOP 9: Measuring Canopy and Basal Gaps

SOP 10: Measuring Shrub and Tree Seedling Density, Exotic Frequency, Species Richness, and Canopy Closure

SOP 11: Soil Aggregate Stability

SOP 12: Site Impact Assessment

SOP 13: Measuring Overstory Trees

SOP 14: Measuring Fuels

SOP 15: Sampling Gambel Oak/Mixed Montane Shrub Plots

SOP 16: Unknown Plant Species

SOP 17: After Each Field Visit and after the Field Season

SOP 18: Data Management

SOP 19: Data Analysis and Reporting

SOP 20: Revising the Protocol Narrative and SOPs

SOP 21: Survey Design and Plot Selection

1.1 Background and objectives

The core mission of the National Park Service (NPS) is to preserve and protect natural and cultural resources for the enjoyment of future generations. The Inventory and Monitoring (I&M) Division of the NPS was created, by Congressional mandate, to provide managers with credible, long-term scientific information about park natural resources. The Northern Colorado Plateau Network (NCPN) serves 16 national park units throughout Utah, western Colorado, southwestern Wyoming, and northern Arizona.

In 2003, NCPN staff solicited input on natural resources of concern and ecosystem indicators known as “vital signs” from several hundred NPS staff and regional and national experts (O’Dell et al. 2005). Potential vital signs were evaluated for management significance and utility, ecological significance, scientific validity, feasibility and cost of implementation, and signal-to-noise ratio. Upland ecosystems were quickly identified as a high priority for monitoring because they represent the majority of land on the Colorado Plateau.

Five vital signs were selected for upland vegetation and soils monitoring:

1. plant communities,
2. exotic invasive plants,
3. biological soil crusts,
4. soil stability, and
5. hydrologic function.

Following the determination of network-wide vital signs, parks were asked to select their top priorities for monitoring. Ten parks selected upland vegetation and soils monitoring: Arches National Park (NP), Black Canyon of the Gunnison NP, Bryce Canyon NP, Canyonlands NP, Capitol Reef NP, Cedar Breaks National Monument (NM), Curecanti National Recreation Area (NRA), Dinosaur NM, Timpanogos Cave NM, and Zion NP.

Related NCPN monitoring efforts are included in the network’s invasive plants protocol (Perkins et al. 2016), which focuses on early detection of exotic invasive plants along predictable transport pathways. The work

described in this protocol also supports NPS Director’s Order 100, by facilitating “scientific . . . inquiry that is directly applicable to current or expected resource management challenges,” conducting research related to resilience, and “communicating scientific . . . ideas and findings to internal and external audiences in order to continuously improve professional judgment.”

1.2 Upland ecosystems as a focus for monitoring

Uplands (i.e., terrestrial vegetation and soils) represent the vast majority of land area in national park units of the NCPN. These 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. These, in turn, determine 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 carbon (Lange 2003) and nitrogen (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 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 are less important ecologically 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 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).

1.3 Key upland ecosystems in NCPN park units

Park units in the NCPN occur in four states

(Figure 1-1), and range in size from 16 to over 136,000 hectares (Table 1-1). While the Colorado Plateau forms the core of the NCPN, portions of several other ecoregions are also included (Figure 1-1). The following sections describe the predominant ecosystems in NCPN park units.

1.3.1 Semiarid grasslands

Semiarid grasslands occur on deep sand or sandy loam soils at elevations of 1,250–2,000 meters on the Colorado Plateau. They are characterized by perennial bunchgrasses and salt desert shrubs, such as fourwing saltbush (*Atriplex canescens*), shadscale (*Atriplex confertifolia*), winterfat (*Krascheninnikovia lanata*), and greasewood (*Sarcobatus vermiculatus*). They are occasionally interspersed with Utah juniper (*Juniperus osteosperma*). Dominant perennial bunchgrass species include cool-season (C_3) grasses, such as Indian ricegrass (*Stipa hymenoides*) and needle and thread (*Stipa comata*), or warm-season (C_4) grasses, such as galleta (*Hilaria jamesii*), dropseeds (*Sporobolus* species), and blue grama (*Bouteloua gracilis*). Biological soil crusts play an important role in this ecosystem. Most are generally in good condition in NCPN park units, or are in the process of recovering from earlier land uses. Semiarid grasslands in NCPN park units generally contain a high percentage of native species but are susceptible to invasion by Russian thistle (*Salsola tragus*) and cheatgrass (*Bromus tectorum*) when the soil surface is disturbed. Livestock grazing is an historic land use in semiarid grasslands, and still occurs in parts of one park unit. Semiarid grasslands are not susceptible to fire unless heavily invaded by cheatgrass. This ecosystem is found in Arches, Canyonlands, and Capitol Reef national parks and Pipe Spring NM (Table 1-2).

1.3.2 Blackbrush shrublands

The most common low-elevation (1,150–1,900 m) shrubland in NCPN park units is dominated by blackbrush (*Coleogyne ramosissima*) and may have low cover of Utah juniper and two-needle pinyon (*Pinus edulis*). These ecosystems are found on the Colorado Plateau and have deep or shallow sand or

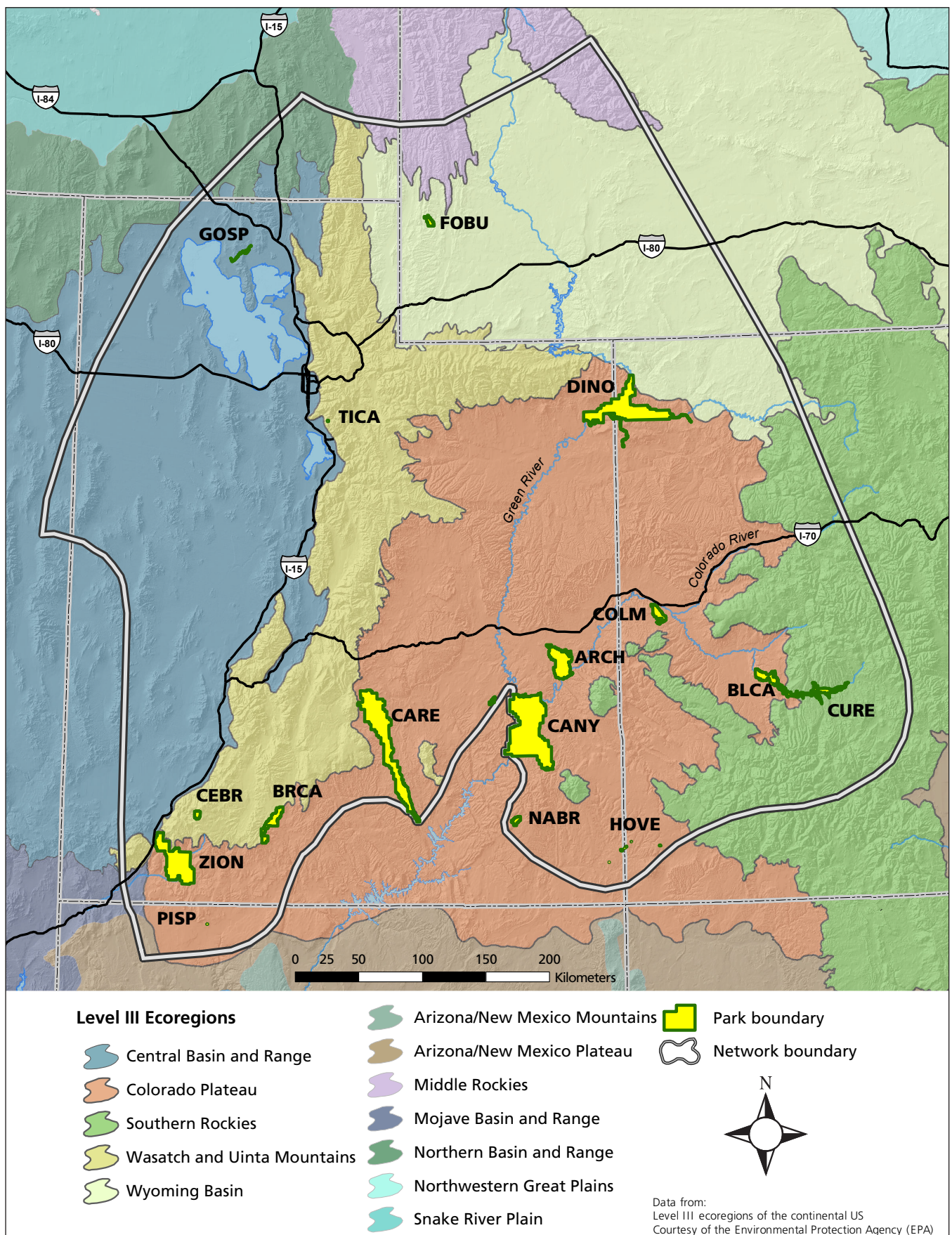


Figure 1-1. Park units and ecoregions of the Northern Colorado Plateau Network. See Table 1-1 for park codes.

Table 1-1. Park units of the Northern Colorado Plateau Network.

Park	Park code	State(s)	Area (ha)	Elevation range (m)	Uplands monitored?
					Yes
Arches National Park	ARCH	UT	30,966	1,219–1,585	Yes
Black Canyon of the Gunnison National Park	BLCA	CO	12,239	1,645–2,675	Yes
Bryce Canyon National Park	BRCA	UT	14,502	1,859–2,774	Yes
Canyonlands National Park	CANY	UT	136,610	1,189–2,188	Yes
Capitol Reef National Park	CARE	UT	97,895	1,183–2,731	Yes
Cedar Breaks National Monument	CEBR	UT	2,491	2,469–3,250	Yes
Colorado National Monument	COLM	CO	8,310	1,408–2,166	No
Curecanti National Recreation Area	CURE	CO	17,433	1,981–2,896	Yes
Dinosaur National Monument	DINO	CO/UT	85,097	1,448–2,743	Yes
Fossil Butte National Monument	FOBU	WY	3,318	2,018–2,464	No
Golden Spike National Historic Site	GOSP	UT	1,107	1,329–1,609	No
Hovenweep National Monument	HOVE	UT/CO	318	1,585–2,060	No
Natural Bridges National Monument	NABR	UT	3,009	1,738–1,951	No
Pipe Spring National Monument	PISP	AZ	16	1,500–1,555	No
Timpanogos Cave National Monument	TICA	UT	101	1,670–2,454	Yes
Zion National Park	ZION	UT	59,900	1,128–2,660	Yes

Table 1-2. Ecosystem types in NCPN parks where upland vegetation and soils are monitored, ordered roughly by park elevation range (from lowest to highest).

Park	Semiarid grasslands	Blackbrush shrublands	Sagebrush shrublands and grasslands	Pinyon-juniper woodlands	Gambel oak/mixed montane shrublands	Mixed conifer forests	Aspen	Subalpine meadows
ARCH	X	X	–	–	–	–	–	–
CANY	X	X	–	–	–	–	–	–
CARE	X	X	–	–	–	–	–	–
ZION	–	X	–	X	X	X	X	–
DINO	–	–	X	X	–	–	–	–
BLCA	–	–	X	X	X	X	–	–
CURE	–	–	X	–	X	–	X	–
BRCA	–	–	–	X	X	X	–	–
TICA	–	–	–	–	X	X	–	X
CEBR	–	–	–	–	–	X	X	X

See Table 1-1 for park codes and elevation ranges.

sandy loam soils and well-developed biological soil crusts where soils are not too rocky. Most blackbrush shrublands in NCPN park units are in good condition, but they are highly susceptible to erosion when biological soil crusts are disturbed. These shrublands are relatively resistant to fire due to low cover of vegetation. They are not commonly used for livestock grazing because they contain little grass biomass. Blackbrush shrublands occur in Arches, Canyonlands, Capitol Reef, and Zion national parks (see Table 1-2).

1.3.3 Sagebrush shrublands and grasslands

Sagebrush shrublands are common on deep, loamy soils on the Colorado Plateau and in the surrounding mountain ecoregions at somewhat higher elevations (1,450–2,600 m) than semiarid grasslands and blackbrush shrublands. Sagebrush shrublands are dominated by big sagebrush (*Artemisia tridentata*) and perennial bunchgrasses, such as bluebunch wheatgrass (*Elymus spicatus*), needle and thread, Sandberg bluegrass (*Poa secunda*), muttongrass (*Poa fendleriana*), junegrass (*Koeleria macrantha*), and Letterman's needlegrass (*Stipa lettermanii*). Two important subspecies of big sagebrush are found in these systems, Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) at lower elevations and mountain big sagebrush (*Artemisia tridentata* sp. *vaseyana*) at higher elevations. Biological soil crusts are an important part of this ecosystem, especially at lower elevations, although they tend to be less pinnacled than those of blackbrush shrublands or semiarid grasslands. Fire plays an important role in sagebrush shrublands. After fire, this ecosystem may be dominated by perennial bunchgrasses before sagebrush becomes established as a dominant part of the ecosystem again.

Sagebrush ecosystems are particularly susceptible to transitioning to an ecological state dominated by cheatgrass and other annual exotics at lower elevations and precipitation zones. Areas dominated by cheatgrass burn more frequently, making it difficult for native species to survive. Livestock grazing is an historic land use in sagebrush ecosystems that still occurs in parts of three park units.

At higher elevations, sagebrush shrublands tend to be more resistant to both grazing and invasion by exotic annuals. Sagebrush shrublands and grasslands are found in Black Canyon of the Gunnison NP, Colorado NM, Curecanti NRA, Dinosaur NM, Fossil Butte NM, Golden Spike National Historic Site, and Hovenweep NM (see Table 1-2).

1.3.4 Pinyon-juniper woodlands

Pinyon-juniper (PJ) woodlands occur at elevations of 1,650–2,500 meters on a wide variety of soils and landforms throughout the Colorado Plateau. In NCPN park units, these woodlands are dominated by Utah juniper and two-needle pinyon. Singleleaf pinyon (*Pinus monophylla*) replaces two-needle pinyon at lower elevations of Zion NP. The understory of PJ woodlands varies widely, but often consists of sparse shrubs and perennial bunchgrasses. At lower elevations and precipitation zones, these woodlands may mix with big sagebrush shrublands. At higher elevations and precipitation zones, pinyon pine and juniper blend with mixed montane shrubs and ponderosa pines (*Pinus ponderosa*). PJ woodlands may be invaded by cheatgrass or other exotic annuals and converted to annual grasslands after fire. The low biomass of grasses in most PJ woodlands make them less than ideal for livestock grazing. However, this is an historic land use that still occurs in parts of two park units. PJ woodlands are found in Black Canyon of the Gunnison and Bryce Canyon national parks, Colorado, Dinosaur, Hovenweep, and Natural Bridges national monuments, and Zion NP (see Table 1-2).

1.3.5 Gambel oak/mixed montane shrublands

Gambel oak/mixed montane shrublands are found on rocky and deep, loamy soils at elevations just above PJ woodlands (1,850–2,700 m) on the Colorado Plateau. They are also found at lower elevations of the surrounding mountain ecoregions. Mixed montane shrublands are dominated by Gambel oak (*Quercus gambelii*), serviceberry (*Amelanchier utahensis*), snowberry (*Symphoricarpos oreophilus*), and mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*).

They form dense stands of tall shrubs that are highly susceptible to fire. Gambel oak/mixed montane shrublands in NPCN park units tend to have high species richness and high cover of native perennial grasses and forbs. The most common exotic species is Kentucky bluegrass (*Poa pratensis*). Although livestock grazing still occurs in two park units, resource managers are less concerned about its impacts on mixed montane shrublands than on some of the other lower-elevation ecosystems. Gambel oak/mixed montane shrublands occur in Black Canyon of the Gunnison and Bryce Canyon national parks, Curecanti NRA, Timpanogos Cave NM, and Zion NP (see Table 1-2).

1.3.6 Mixed conifer forests

Mixed conifer forests are the most common forest type in NCPN park units. They are typically found in the mountain ecoregions surrounding the Colorado Plateau. They may occur interspersed with subalpine meadows or aspen forests. At elevations of 2,250–2,750 meters (or lower on north-facing slopes or canyon bottoms), mixed conifer forests are dominated by white fir (*Abies concolor*), ponderosa pine, and/or Douglas fir (*Pseudotsuga menziesii*), depending on precipitation, steepness, and soil characteristics.

At the highest elevations (2,700–3,200 m), mixed conifer forests are dominated by subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*). These forests tend to have a high cover of native plant species and are relatively resistant to invasion by exotic plant species. Mixed conifer forests are susceptible to fire, with fire return intervals and other burn characteristics varying by forest type. Outbreaks of insects, such as mountain pine beetles and spruce budworms, occur periodically and can cause high tree mortality. Managing the risk of fire from insect outbreaks, fire suppression, and other natural and anthropogenic causes is a top priority of resource management in these systems. Livestock grazing is not an important land use in this ecosystem. Mixed conifer forests are found in Black Canyon of the Gunnison and Bryce Canyon national parks, Cedar Breaks and Timpanogos Cave national monuments, and Zion NP (see Table 1-2).

1.3.7 Aspen

Aspen forests have an overstory dominated by aspen (*Populus tremuloides*) and a rich understory of forbs, perennial grasses, and shrubs that support a high diversity of wildlife. They are typically located in patches within mixed conifer forests at elevations of 2,250–3,050 meters in the mountain ecoregions. This ecosystem may be invaded by conifers if fire is suppressed. The most common exotic species are Kentucky bluegrass and common dandelion (*Taraxacum officinale*). Stands are also threatened by sudden aspen decline (SAD), which is contributing to aspen forest declines throughout the Rocky Mountain region, with some stands exhibiting extremely high mortality. The cause of SAD is not well understood. Potential causes include drought, climate change, and fire management, while the actual mortality agents have included cytospora canker, bark beetles, and poplar borers. Low-elevation and south-facing sites appear to be more susceptible to SAD than others. Aspen forests have historically been grazed by livestock, but are not currently grazed in any NCPN park units. Aspen forests are found in Cedar Breaks NM, Curecanti NRA, Fossil Butte NM, and Zion NP (see Table 1-2).

1.3.8 Subalpine meadows

Subalpine meadows are dominated by perennial grasses and a high diversity of forbs that produce spectacular wildflower displays during the short growing season. Subalpine meadows are found at the highest elevations (2,850–3,200 m) of the mountain ecoregions and may be interspersed with subalpine fir and Engelmann spruce forests. Subalpine meadows contain many rare and sensitive plant species that are believed to be most at risk of extinction in a warming climate. Resource managers are also concerned about trampling of sensitive plant species. Subalpine meadows are prone to invasion by smooth brome (*Bromus inermis*), an exotic perennial grass, and may be threatened by expansion of surrounding spruce-fir forests. This ecosystem is not susceptible to fire. Although subalpine meadows were historically grazed by livestock, this land use has been retired from subalpine meadows in all NCPN

park units. Subalpine meadows occur at Cedar Breaks and Timpanogos Cave national monuments (see Table 1-2).

1.4 Historical development of upland vegetation and soils monitoring in NCPN park units

Most NCPN park units have had some vegetation monitoring in their history, ranging from initial establishment of plots or photo points that have never been revisited to sites with over 40 years of annually collected data. These efforts are summarized by type and duration in Table 1-3.

Four types of monitoring continue to occur: long-term vegetation plots, fire-effects monitoring, grazing trend studies, and grazing/relict comparisons. Plots are typically established to examine long-term trends in plant species cover and other attributes; some are specifically designed to monitor recovery from fire or effects of grazing. Fire-effects

monitoring is conducted by regional NPS Fire Effects Monitoring crews, and typically consists of cover, density, and fuels measurements collected in a standard suite of years after a fire. Monitoring may occur before a fire for some prescribed burns. Grazing trend studies are conducted by land-management agencies to monitor grazing on public grazing allotments, including those on NPS lands. These typically consist of point-intercept (“step-point”) transects and photo plots. Ungrazed relict areas have been studied in a few park units. Canyonlands NP is the only one with an ongoing effort.

Photo plots include the re-location of historic photographs (Webb et al. 2004) and the deliberate establishment of photo points for particular purposes. In the form of photographs, plant monitoring data can be said to have occurred from as long ago as 1872. The historic photographic record for part of Canyonlands NP is examined in detail by Webb and others (2004). Although none of these

Table 1-3. Number of years in which data were collected in historic and ongoing vegetation monitoring in NCPN park units (year initiated).

Park	Long-term vegetation plots	Photo plots (not grazing related)	Fire effects	Grazing trend plots	Other
ARCH	>3 (1987)*	PE (1990)	2–3 (1999)	–	–
BLCA	>3 (1992)*	PE (1990)	–	–	–
BRCA	>3 (1957)*	PE (1990)	>3 (1988)*	–	Relict areas
CANY	>3 (1987) *	2–3 (1872)	–	–	Grazed/relict comparison*; bunchgrass post-grazing
CARE	–	–	–	>3 (early 1960s)*	–
CEBR	–	PE (1990)	–	–	–
COLM	–	PE (1990)	–	–	–
CURE	>3 (1992)*	PE (1990)	–	–	–
DINO	–	–	>3 (1984)*	>3 (1961)	–
FOBU	2–3 (1977)	>3 (1985)	>3 (2006)*	–	–
GOSP	–	–	>3 (2000)*	–	–
HOVE	>3 (1999)*	–	–	–	–
NABR	>3 (1987)*	–	–	–	Grazed/relict comparison
PISP	–	–	–	–	–
TICA	–	–	–	–	–
ZION	PE (1997)	–	>3 (1995)*	–	–

*ongoing monitoring
See Table 1-1 for park codes.
This table is current to year 2011.

photo plots are considered ongoing, these types of efforts are often easy to repeat.

The most extensive ongoing vegetation plot monitoring in the NCPN is in the four parks of the Southeast Utah Group (SEUG): Arches NP, Canyonlands NP, Hovenweep NM, and Natural Bridges NM. Plot-based vegetation monitoring began in SEUG parks as long ago as 1974, but the oldest studies lack permanently marked plots and available data. All four SEUG park units have ongoing vegetation monitoring sites established to “monitor condition and trend of the various vegetation types.” The number of sites and length of data collection varies by park unit. Some sites at Arches, Canyonlands, and Natural Bridges have been visited almost every year since 1987, while the first sites at Hovenweep were not established until 1999. Sites were chosen to be representative of particular vegetation types. Measurements are recorded in fifty 0.5 m × 0.5 m subplots (quadrats) on two approximately parallel transects per site. Measurements include nested frequency, ground cover (bare ground, litter, rock, lichen, moss, cyanobacteria, and *Collema* species), cover of each vascular plant species, and cover and development class of biological soil crust. There have been some changes to methods over the duration of this program—most notably, the introduction of permanent markers for each subplot starting in 1997. This work

is well documented in reports produced by Schelz (2002a–d).

The oldest long-term vegetation monitoring effort in the NCPN is the work of Hayle Buchanan, who initiated sampling in 1957 and has collected over 40 years of data from permanent plots. These plots focus on forest community dynamics and are located on the west side of Bryce Canyon NP. Data from this monitoring effort have been analyzed approximately every 10 years and are documented in numerous reports (Buchanan 1971; Buchanan et al. 1981; McKnight and Buchanan 2000).

Long-term vegetation monitoring in Black Canyon of the Gunnison NP and Curecanti NRA has occurred since 1992. This monitoring effort consists of 0.5 × 0.5-m quadrats located every five meters along five 100-m transects in 10 habitat types. Although monitoring has not occurred every year and is limited by having only one replicate per habitat, this data set begins to allow evaluation of trends in percent cover by species or lifeform. A review of this monitoring effort is provided in Garman (2007).

For a more detailed description of all NCPN vegetation monitoring efforts, see Evenden and others (2002, Volume 2, part III).

2 Program Goals and Measurable Objectives

The overall goal of the NCPN upland vegetation and soils 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 upland vegetation and soils 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 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 (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 facilitate identification of drivers and distinguishing “natural” from anthropogenic change. Local weather-station data can be used to interpret responses. Remote sensing can be used to determine change in vegetation at larger scales caused by land use or climate change. Historical upland monitoring datasets may be integrated with data collected by NCPN to allow earlier detection of trends.

3 Sampling Design

The NCPN sampling design for upland vegetation and soils monitoring incorporates efficient approaches to gathering data that are credible and sufficient to achieve monitoring objectives. The sampling design comprises the following components:

- Response design—data collection methods
- Spatial design—the population of interest and sampling locations within this population
- Revisit design—timing and frequency of visits to sampling locations.

The inherent variability of vital signs in concert with the sampling objectives determines the required number of sampling locations and the revisit design. The sampling objectives of upland monitoring are determined by the specific issues addressed at each park unit and the level of understanding of ecological thresholds and desired management triggers.

A sampling objective indicates the minimum detectable change over a defined period of time, the acceptable level of error (type I), and the probability to detect a change (power). When the purpose of monitoring is to inform management of resource degradation, the minimum detectable change level must be sufficient to detect declines or increases before an ecological threshold is crossed, because restoration to the native system becomes extremely difficult and costly after that point.

Determining the appropriate minimum detectable change level hinges on factors, such as thresholds, that are difficult to determine, and in practice tends to be based on a combination of hypothesized threshold levels and professional judgment. Identifying thresholds and factors that lead to crossing an ecological threshold are critical research needs, especially in arid and semiarid ecosystems of the U.S. (e.g., Bestelmeyer 2006; Briske et al. 2006; Peters et al. 2006). NCPN sampling objectives will be modified as understanding of these systems improves.

3.1 Rationale for selected design

A common approach to upland vegetation monitoring is to use a plot as the sampling unit and subsample the plot by taking measurements along transects (Elzinga et al. 1998; Herrick et al. 2005). A wide range of vegetation sampling methods exist (Elzinga et al. 1998), so the NCPN and the Southern Colorado Plateau Network (SCPN) decided to work in concert with Mark Miller (SEUG) and Jayne Belnap (USGS-BRD, Moab, UT) to test and develop protocols that best characterize vegetation and soils of the Colorado Plateau. The intent of this collaboration was to develop standard methods for use across the range of upland ecosystems in the 16 NCPN and 19 SCPN park units and to provide comparable data over a large region of the Colorado Plateau and adjacent ecoregions.

The 2005 field season was devoted to developing the upland vegetation and soils response design. This effort tested and compared the methods used in Herrick and others (2005), with quadrat-based methods similar to those used by DeBacker and others (2004). Protocol development involved testing the repeatability of observers measuring ocular cover in quadrats versus cover from line-point intercept, the shape and size of quadrats (rectangular vs. square, 1 m² vs. 10 m²), the length of transects and number of quadrats for an appropriate subsample size at each plot, and the efficiency of each method (Miller et al. 2007). Based on the results of this study, standard protocols were developed for monitoring dryland ecosystems on the Colorado Plateau. After the networks received these protocols, each network continued separately testing sampling methods and made further modifications to the protocols. The NCPN and SCPN decided to have separate monitoring protocols that differed in some sampling procedures but retained many of the same initial monitoring objectives.

The original NCPN protocol used 10-m² quadrats to measure shrub density and ocu-

lar cover of vegetation and surface features. After two years of testing, the original field procedures were modified to add point-intercept sampling of vegetation and surface cover (SOP #8) and shrub density in one-meter belts (SOP #10). This focuses sampling of vegetation cover on dominant species (approximately >5% cover). Rare species or species with low cover are not detected with point-intercept sampling, but it is extremely difficult to detect long-term trends in these species anyway.

These changes were made to increase sampling efficiency and improve repeatability of cover measurements. Plots that were monitored using quadrat-based methods in 2006 and 2007 were monitored using both old and new methods in 2008 in order develop a conversion factor between the methods.

The 2005 protocol-development effort also found that the methods tested did not thoroughly characterize woodlands, Gambel oak/mixed montane shrublands, and forests, and that additional sampling methods would need to be developed to suit the monitoring needs of NCPN park units. Additional methods for characterizing forests and fuels were developed based on the procedures in the National Park Service's *Fire Monitoring Handbook* (USDI 2003; Brown 1974). Alterations were made to diameter measurements of multi-stem woodland species, such as pinyon pine and Utah juniper, based on methods used by the U.S. Forest Service Forest Inventory and Analysis program. We could not find any existing methods for long-term monitoring in Gambel oak/mixed montane shrublands, so we developed a reduced-size plot and modified sampling methods to deal with the difficulties of running long transects in this dense vegetation.

The NCPN and SCPN adopted a similar approach for spatial and revisit designs for monitoring upland vegetation and soils. Survey designs are used for upland monitoring because they have fewer assumptions and provide more reliable and legally defensible parameter estimates than other approaches, such as those designed to sample from infinite populations (Schreuder et al. 2004; Edwards 1998; Nusser et al. 1998; Cochran 1977). Both networks attempt to efficiently moni-

tor change in selected areas of specific park units and directly link management needs by focusing on key resources. Sampling frames are developed to make these areas of interest spatially explicit. Then, GRTS (Generalized Random Tessellation Stratified) and RRQRR (Reversed Randomized Quadrat-Recursive Raster) methods of plot selection are used to create spatially balanced random samples within the sampling frame. These methods produce a sample that represents the area of interest, incorporates probabilistic sampling to meet statistical assumptions, and allows flexibility to modify the sample size in the future. These designs were modeled after survey designs developed by the Environmental Protection Agency's Environmental Mapping and Assessment Program for streams (Peck et al. unpublished).

3.2 Response design

The sampling unit for upland vegetation and soils monitoring is a plot. Measurements of vegetation and soils are co-located at each plot and monitored concurrently. The basic upland monitoring plot consists of three parallel, 50-meter transects, spaced 25 meters apart (Figures 3-1, 3-2), with most vegetation and soil measurements occurring along these transects. A suite of sampling methods is used at plots of all vegetation types. However, due to the wide range of ecosystems across the Colorado Plateau, sampling is adapted by vegetation type to capture important characteristics of each one. For the purpose of sampling, all upland vegetation is placed in one of these four categories: grassland/shrubland, woodland, forest, or oak.

At plots of all vegetation types, crew members take repeat photos, measure frequency of exotic plant species, cover of vegetation and soils surface features, and density and diameter of trees, and record a qualitative assessment of site impacts. Shrub density is also recorded at grassland/shrubland, woodland, and forest plots.

All blackbrush and sagebrush shrublands and semiarid grasslands are sampled using grassland/shrubland methods specifically developed for these vegetation types (Herrick et al. 2005). In addition to the measurements listed above, soil stability and canopy

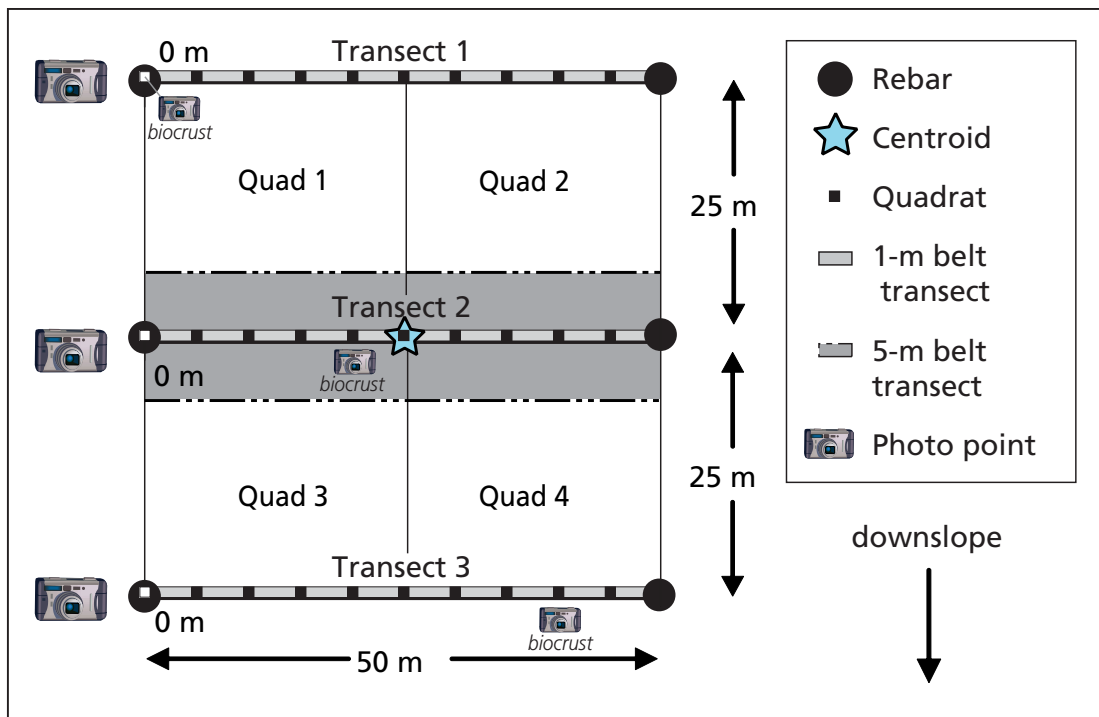


Figure 3-1. Locations of transects and monitoring measurements at grassland/shrubland plots, including repeat photos, 1-m² quadrats for sampling frequency of exotics, one-meter belt transects for measuring shrubs and seedlings, a five-meter belt transect for measuring saplings, and Quad 1 for measuring overstory trees. Soil stability is also collected at six randomized locations along each transect.

gaps are recorded, along with basal gaps (Figure 3-1).

All PJ woodland ecosystems are sampled using woodland methods. In addition to the measurements listed above, soil stability is recorded, and fuels measures are taken (Figure 3-2).

Forest methods are used for aspen and mixed conifer forests and subalpine meadows. At these plots, canopy closure, crown health, and crown class are recorded in addition to the measurements taken at all plots and the fuels methods used for woodlands (Figure 3-3). Species richness is sampled in subalpine meadows but not in any of the other ecosystems. Species richness is one of the more difficult measures in which to detect trends over time, so the NCPN decided not to focus too much of its sampling effort on this metric. In all other ecosystems and vegetation types, species richness of dominant plants will be derived from other sampling methods.

Gambel oak/mixed montane shrub ecosystems are monitored using the oak methods. These require a reduced plot size (three 20-m transects, spaced 10 m apart) due to

the difficulty of running long transects in dense vegetation (Figure 3-4). All sampling methods are modified to accommodate the smaller plot size.

The response design, which is essentially the same as the field methods, is described in detail below. All measures recorded along transects are sub-samples scaled to the plot level. Plot-level measures are the primary values used in summaries and statistical analyses.

3.3 Spatial design

The response design for monitoring upland vegetation and soils vital signs is constant across park units, but the vegetation types and management issues addressed are tailored specifically to the needs of each park unit (Table 3-1). Given that the NCPN has limited resources to monitor upland areas, it is paramount to determine the key issues for upland monitoring at each park unit. Long-term issues of management concern are identified through focused discussion between NCPN staff and park staff. Most park units are interested in the general health and condition of dominant ecosystems, identifying shifts related to climate change, and

Figure 3-2. Locations of transects and monitoring measurements at woodland plots, including repeat photos, 1-m² quadrats for sampling frequency of exotics, one-meter belt transects for measuring shrubs and seedlings, a five-meter belt transect for measuring saplings, Quad 1 for measuring overstory trees, and four fuels transects (not drawn to scale). Soil stability is also collected at six randomized locations along each transect.

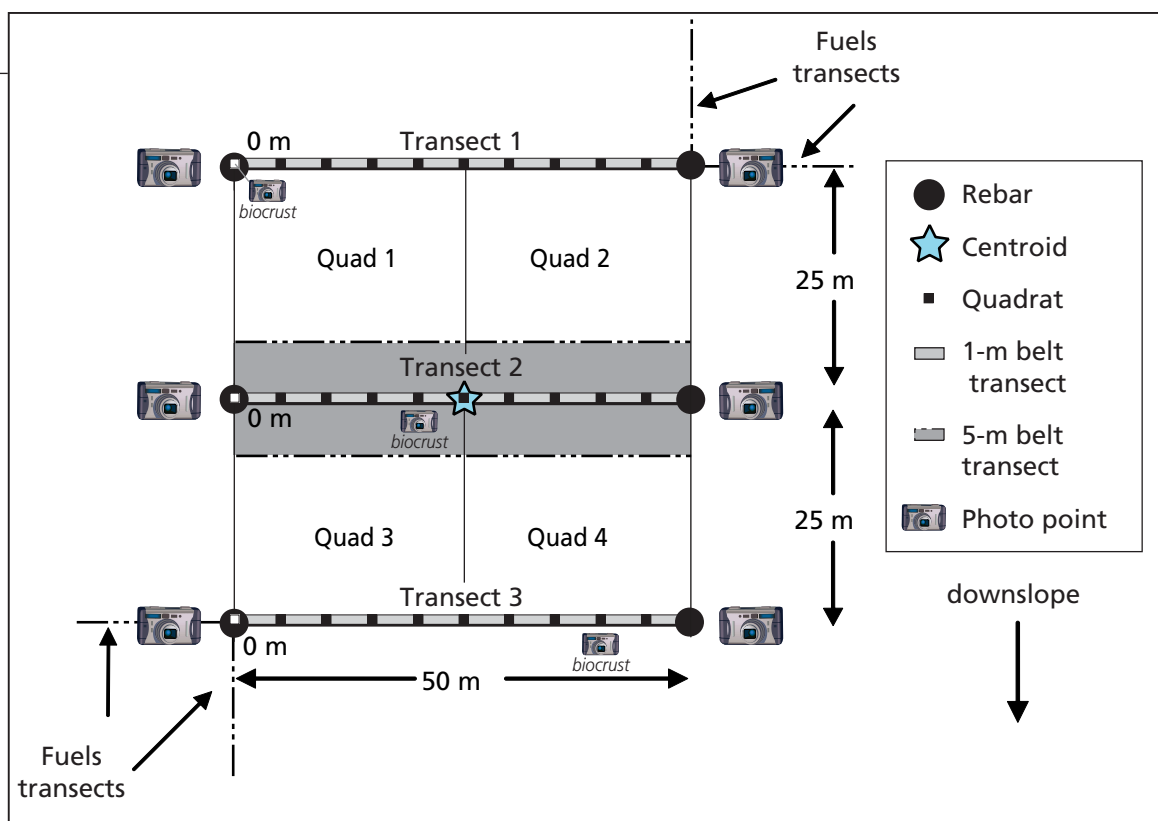
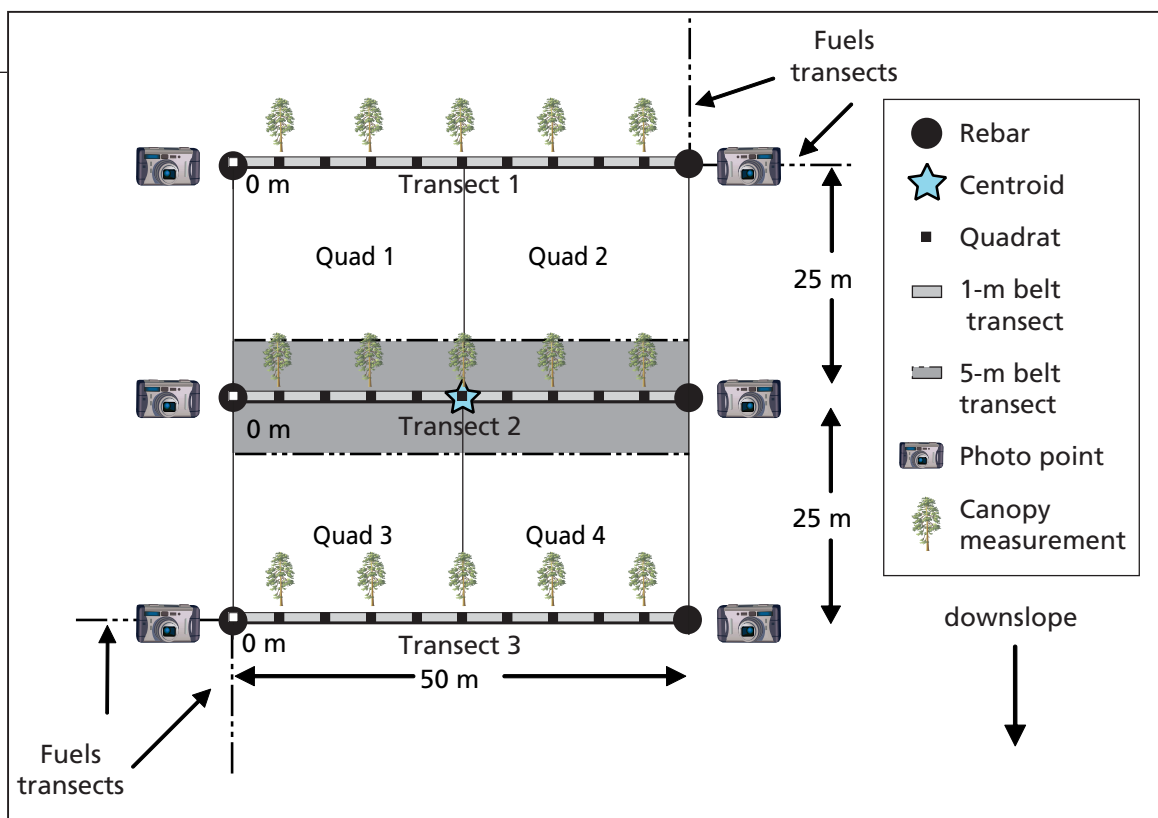


Figure 3-3. Locations of transects and monitoring measurements at forest plots, including canopy measurements, 1-m² quadrats for sampling frequency of exotics, one-meter belt transects for measuring shrubs and seedlings, a five-meter belt transect for measuring saplings, Quad 1 for measuring overstory trees, and four fuels transects (not drawn to scale).



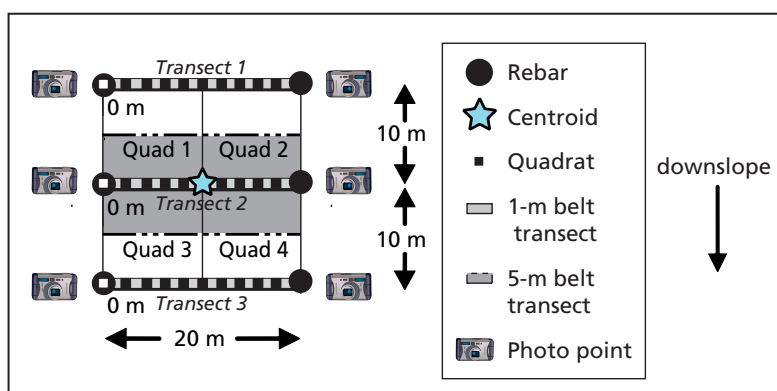


Figure 3-4. Locations of transects and monitoring measurements at oak plots, including repeat photos, 1-m² quadrats for sampling frequency of exotics, one-meter belt transects for measuring seedlings, a five-meter belt transect for measuring saplings, and overstory trees censused in Quads 1–4.

Table 3-1. Summary of vegetation types monitored and management issues addressed by upland vegetation and soils monitoring in NCPN park units.

Park unit	Year initiated	Total area monitored (ha)	Upland vegetation monitored	Management issues
Arches NP	2010	2,509	Grasslands, blackbrush/ juniper shrublands	Social trailing
Black Canyon of the Gunnison NP	2008	6,795	Sagebrush, pinyon-juniper, mixed montane shrubs	Grazing
Bryce Canyon NP	2010	5,406	Pinyon-juniper, mixed conifers	Fire management
Canyonlands NP	2006	25,693	Grasslands, blackbrush/ juniper shrublands	Social trailing
Capitol Reef NP	2007	6,423	Grasslands	Grazing
Cedar Breaks NM	2009	548	Mixed conifer forests, subalpine meadows	Spruce budworm outbreaks
Curecanti NRA	2008	4,938	Sagebrush, aspen	Grazing, sudden aspen decline
Dinosaur NM	2009	17,306	Sagebrush, pinyon-juniper	Grazing, fire management
Timpanogos Cave NM	2009	<1	Gambel oak, mixed conifer forest, subalpine meadow	Ecosystem health
Zion NP	2011	8,892	Gambel oak, pinyon-juniper	Fire management

detecting exotic invasive plant species. In addition, land uses, such as grazing, may be incorporated into the spatial design of monitoring. After key upland issues are identified at a park unit, the target area for monitoring must be delineated.

A central tenet of survey designs is the delineation of a finite target population, which defines the limit of statistical inference and serves as the basis for selecting samples. Within the defined sampling frame, it is important that plots are distributed over space. Plots located near each other will tend to be more similar and can underestimate the variance of the target population. Only areas deemed accessible are considered for monitoring. This is determined by slope, using analytical software created by network staff (Landscape Access Model [LAM], Garman unpublished).

Guidelines for determining the target population and spatial design, and for selecting monitoring plots, are outlined in SOP #21. Because survey designs vary among NCPN park units according to park-specific needs and issues, the specifics are documented in a separate report for each park unit after each design is created. This information is also summarized in Appendix A (<https://irma.nps.gov/DataStore/Reference/Profile/2247834>). Survey designs were created for all NCPN park units with upland monitoring except Timpanogos Cave NM, due to its extremely small accessible area (approximately 14 ha). In this case, upland monitoring plots were located in the only three areas large enough to fit a plot.

3.3.1 Delineating the target population

Target vegetation types for monitoring are translated into strata in the survey design (Table 3-2), and are mapped as explicitly as possible. For most vegetation types, National Resources Conservation Service (NRCS) ecological sites are the preferred strata used by the NCPN because ecological site descriptions (SRM 1989, 1995) incorporate soils, geomorphology, and climate in addition to vegetation characteristics. Ecological sites are not explicitly mapped by NRCS, but instead are associated with the soil components that make up soil map units. Thus, mul-

tiple ecological sites or inclusions, such as rock outcrop, can be contained within a soil map unit, with only some of the area being targeted. Ecological sites may be explicitly mapped by the NCPN using methods ranging from spatial-pattern analyses through Feature Analyst (VSL 2002) to Classification and Regression Trees (Scull et al. 2005). Simple mapping techniques may also be employed using NRCS soil map units dominated by target ecological sites. The mapping method of choice is highly dependent on the type and quality of relevant spatial data layers. When recent soil surveys and ecological sites are not available for a park unit, the target sampling area should be delineated using other features that are not expected to change over the period of long-term monitoring, such as geology, elevation, or aspect. The end product of this step is a map of the sampling frame that delineates the spatial extent of each stratum from which monitoring plots are selected (Figure 3-5).

3.3.2 Monitoring plot selection

After the sampling frame has been finalized, a spatially balanced random sample of monitoring plots is selected. NCPN uses the GRTS or RRQRR method for plot selection. These methods provide an ordered list of potential monitoring plots that allows for plot rejection and plot additions over time (Stevens and Olsen 2004; Theobald et al. 2007).

3.4 Revisit design

Survey designs differ depending on variance estimates and sampling objectives for each park unit. However, complex survey designs with multiple panels and varying frequency of visitation are used for all larger park units with upland monitoring (i.e., all park units with upland monitoring except Timpanogos Cave NM). Revisit designs are park-specific and attempt to balance the need to observe inter-annual variability with the need to maximize replication (Woodward 2004). At each park unit, the number of plots is limited by affordable effort and, in some cases, available area of vegetation. Thus, the NCPN must ensure that each stratum of the sampling frame has an adequate sample size based on the variability of the vegetation where there is a large enough area to accommodate the

Table 3-2. Summary of upland vegetation and soils survey designs in NCPN park units.

Park unit	Total area in sampling frame (ha)	# of plots/ year	Total # of plots	Target vegetation/strata	Ecological sites*
Arches NP	2,509	8	28	Deep grassland	212-Semidesert Sand (fourwing saltbush) 215-Semidesert Sandy Loam (fourwing saltbush)
	4,375	8	28	Deep blackbrush shrubland	210-Semidesert Sand (blackbrush) 218-Semidesert Sandy Loam (blackbrush)
	3,871	8	28	Utah juniper / blackbrush shrubland	236-Semidesert Shallow Sandy Loam (Utah-juniper/blackbrush)
Black Canyon of the Gunnison NP	2,260	12	45	Pinyon-juniper woodland	322-Upland Shallow Loam (pinyon-Utah juniper) 330-Upland Stony Loam (pinyon-Utah juniper)
	4,425	12	45	Gambel oak / mixed montane shrubland	Brushy Loam
Black Canyon of the Gunnison NP/ Curecanti NRA	4,816	14 or 17	59	Sagebrush	Dry Mountain Loam Mountain Loam
Bryce Canyon NP	4,042	10	25	Pinyon-juniper woodland	None; sampling frame includes all PJ woodlands at elevations <2,300 m
	1,404	8	20	Mixed conifer forest	None; sampling frame includes all mixed conifer forest at elevations >2,600 m
Canyonlands NP	9,842	24	126	Grassland	115-Desert Sand (sand sagebrush) 118-Desert Sandy Loam (fourwing saltbush) 212-Semidesert Sand (fourwing saltbush) 215-Semidesert Sandy Loam (fourwing saltbush)
	10,987	12	63	Blackbrush shrubland	133-Desert Shallow Sandy Loam (blackbrush)
	4,864	12	63	Pinyon-juniper / blackbrush shrubland	236-Semidesert Shallow Sandy Loam (Utah-juniper/blackbrush)
Capitol Reef NP	2330	16	60	Deep grassland – Cathedral & Rock Springs allotments (no livestock grazing since 1999)	201-Semidesert Alkali Sandy Loam (alkali sacaton) 212-Semidesert Sand (fourwing saltbush)
	2885	16	60	Deep grassland – Hartnet allotment (currently grazed by livestock)	215-Semidesert Sandy Loam (fourwing saltbush)
	1,109	16	60	Rocky grassland (currently grazed by livestock)	242-Semidesert Stony Loam (shadscale) 260-Semidesert Very Steep Stony Loam (Salina wildrye)
Cedar Breaks NM	548	8	28	Spruce-fir forest, subalpine meadow, aspen	None; sampling frame includes all subalpine meadows, aspen, and mixed conifer forest above the rim
Curecanti NRA	122	1 or 4	4	Aspen	None; sampling frame includes all aspen in the park

Table 3-2. Summary of upland vegetation and soils survey designs in NCPN park units, cont.

Park unit	Total area in sampling frame (ha)	# of plots/ year	Total # of plots	Target vegetation/strata	Ecological sites*
Dinosaur NM	7122	12	45	Sagebrush – low elevation	212-Semidesert Loam (Wyoming big sagebrush) 298-Rolling Loam 327-Semidesert Loam
	5008	12	45	Sagebrush – high elevation	430-Mountain Loam (mountain big sagebrush)
	5076	12	45	Pinyon-juniper woodland	None; stratified by soil map units reported to have PJ
Timpanogos Cave NM	<1	0-1	1	Gambel oak	No survey design; only 3 plots with no additional inference
	<1	0-1	1	Mixed conifer forest	
	<1	0-1	1	Subalpine meadow	
Zion NP	499	8	20	Pinyon-juniper / Upland Sand	324-Upland Sand (Juniper-pinyon)
	511	8	20	Pinyon-juniper / Upland Shallow Loam	315-Upland Shallow Loam (Pinyon-Utah juniper)
	2514	8	20	Pinyon-juniper / Upland Stony Loam	321-Upland Stony Loam (Pinyon-Utah juniper)
	5368	12	30	Gambel oak	Mountain Loam (Oak) 463-Mountain Stony Loam (Oak)

*Ecological sites at Arches, Canyonlands, and Capitol Reef national parks are from Major Land Resource Area (MLRA) 35. Ecological sites at Black Canyon of the Gunnison NP and the low-elevation sagebrush site with the plant species included in the name at Dinosaur NM are from MLRA 34. The sites without plant species included in the name at Black Canyon of the Gunnison NP, Curecanti NRA, and Dinosaur NM are range sites from Colorado. The high-elevation sagebrush ecological site at Dinosaur NM is from MLRA 47.

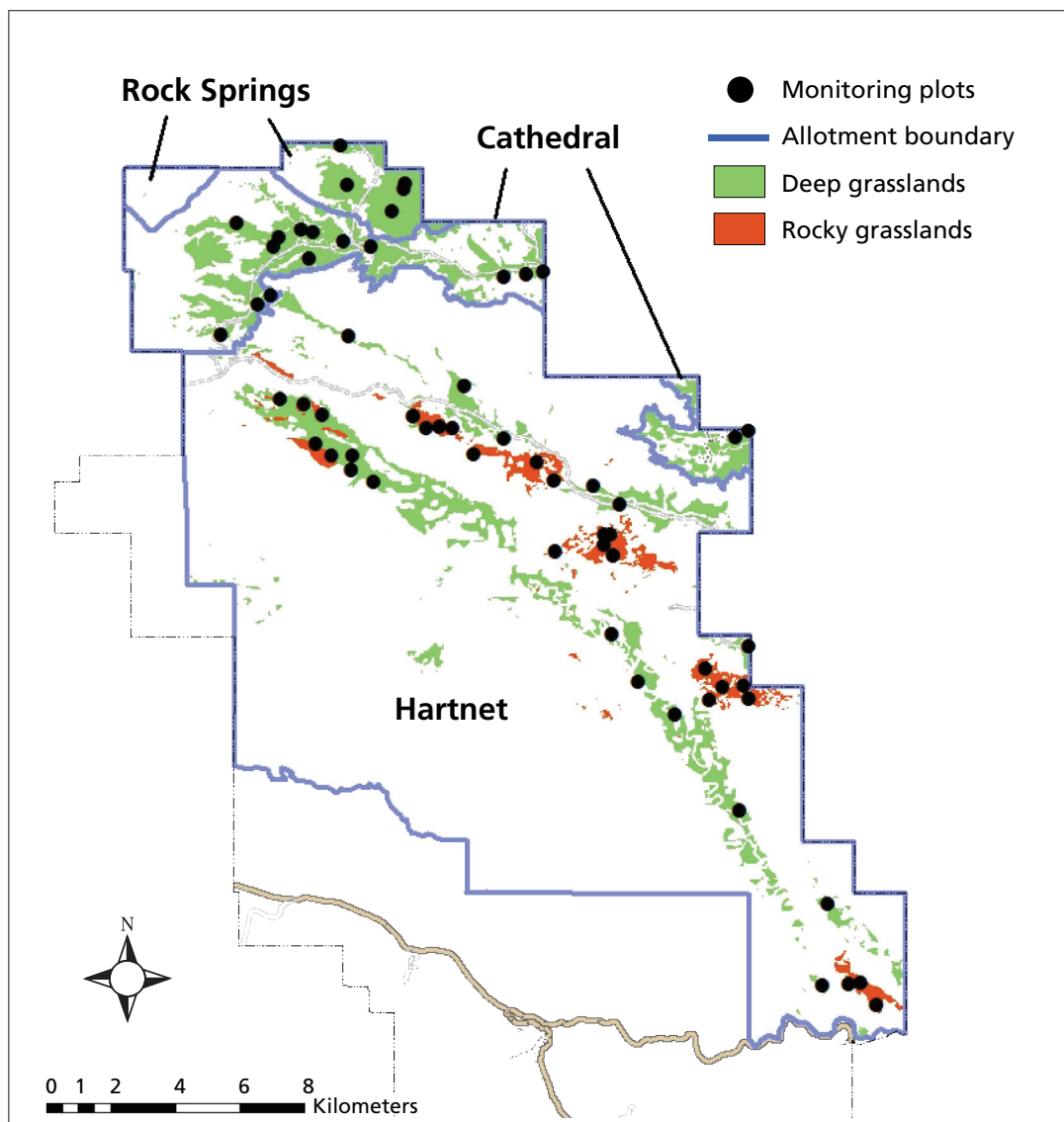


Figure 3-5. Locations of target vegetation types in the survey design and plots visited in one year of monitoring at Capitol Reef National Park. Deep grasslands consist of three target ecological sites: Semidesert Sand (fourwing saltbush), Semidesert Sandy Loam (fourwing saltbush), and Semidesert Alkali Sandy Loam (alkali sacaton). Rocky grasslands consist of two target ecological sites: Semidesert Stony Loam (shadscale) and Semidesert Very Steep Stony Loam (Salina wildrye).

appropriate sample size.

A rotating panel design is used to increase the overall sample size (see Figure 3-6 for an example) and provide a better estimate of the status of the population. Plots are sampled 1–2 years in a row and then rested for 3–6 years. The total number of plots monitored depends largely on the area of the target vegetation (see Table 3-2) and the variability. For at least some plots in each stratum, vegetation is sampled for two years in a row to tease out year-to-year differences due to factors such as temperature and precipitation, and to better estimate trends.

In most parks, pilot monitoring occurs for three years before the operational revisit design is determined. During pilot monitoring, 8–10 plots are established per stratum and revisited each year for three years. Variance estimates from these three years of data are

used to evaluate the power to detect trends using different revisit designs (Appendix B; <https://irma.nps.gov/DataStore/Reference/Profile/2247836>). The optimal revisit design is selected, and full operational monitoring is implemented according to this design. The initial three-year pilot monitoring may be skipped for some smaller parks where the number of plots is limited by the size of the park unit or ecosystem of interest within the park unit, or if an estimate of variance can be obtained from another park with a very similar ecosystem (e.g., Canyonlands for Arches). Sampling designs should then be evaluated every 5–7 years to make sure they are meeting the original monitoring and sampling objectives. If the sample size of one stratum must be increased, then another stratum may need to be dropped from survey design because the NCPN can only sample a finite number of plots at each park unit.

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
6	8					8				
7		8					8			
8			8					8		
9				8					8	
10					8					8

Figure 3-6. Number of plots sampled each year based on a five-year rotating panel revisit design. This revisit design is used to sample deep grassland ecological sites in the Hartnet allotment of Capitol Reef National Park.

4 Field Methods

4.1 Field season preparations

Sampling dates are scheduled and logistics organized prior to the start of the field season. This includes applying for and renewing research permits, hiring the field crew, arranging campsites or park housing, and acquiring backcountry permits (see SOP #1). All of the equipment and supplies are ordered, organized, and tested to ensure availability by the beginning of the field season. Directions, revisit data sheets, and species lists are generated for each plot.

Ample time must be allowed to process background checks and other paperwork for newly hired crew members. Before collecting data, field crew members must be trained in monitoring procedures and plant identification (SOP #2), and must review the entire protocol, especially the field SOPs. The field crew leader must ensure that crew members understand all procedures and evaluate their understanding during training.

4.2 Sampling procedures

4.2.1 Establishing the plot

After navigating to the plot center, the site is characterized (SOP #5) to determine whether it meets criteria for establishing a permanent plot. Site characterization involves describing soil and ecological site attributes, including soil texture and depth, landscape position, elevation, and dominant vegetation. Three permanent transects are established parallel to the slope contour by driving rebar stakes into the ground at the end points of each transect (SOP #6). Each rebar is tagged with the plot and transect number and transect origin or end notation. Waypoints, reference photos, and written instructions are recorded to facilitate relocation. Transect tapes marked at one-centimeter intervals are strung between the rebar. Plots must be established in the order provided to maintain spatial balance of the sampling design.

4.2.2 Vegetation and soil sampling

To minimize impacts to vegetation and biological soil crusts, all measurements are tak-

en on one transect before visiting the others. Crew members remain downslope of the transect while taking measurements on the upslope side of the transect.

A specific suite of SOPs is used to record measures at each plot (Figure 4-1), depending on vegetation type (grassland/shrubland, forest, woodland, or oak). Each SOP clearly outlines the vegetation types it is used to monitor. Vegetation types are determined using NRCS ecological site descriptions or National Vegetation Classification associations (FGDC 1997). Too extensive to list here, these are outlined in detail in Appendix A. The sections below describe the sampling methods for each vegetation type.

4.2.2.1 Grasslands and shrublands

At the origin of each transect, a photograph is taken down the length of the transect toward the end point (see Figure 3-1, SOP #7). 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-meter intervals along each transect (see SOP #8). Density of shrubs (by species and height class) and tree seedlings (by species) are recorded in a one-meter belt

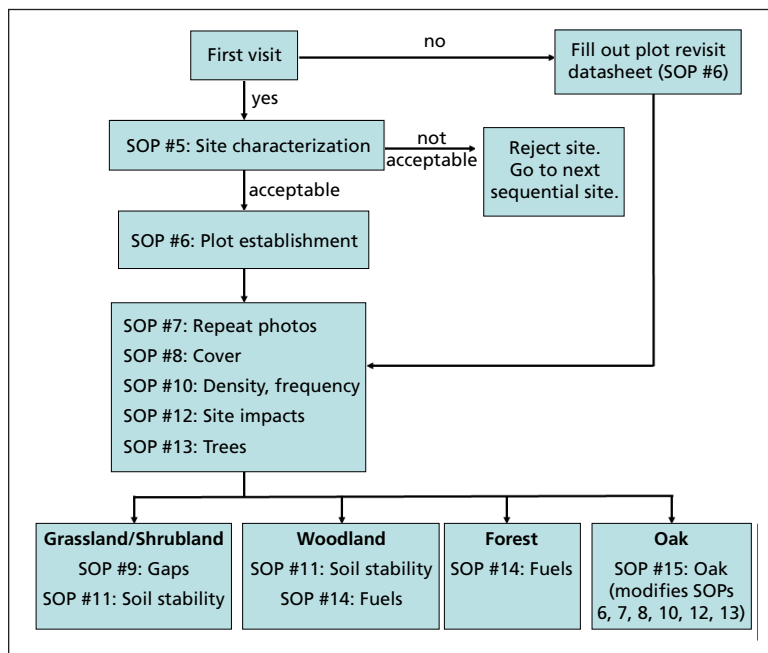


Figure 4-1. Flow chart of field procedures for monitoring upland plots.

upslope of each transect (see SOP #10). Frequency of exotic species is recorded using 1 × 1-meter quadrats placed every five meters along each transect (see SOP #10). Canopy and basal-gap measures are acquired along each of the transects using a line-intercept method (see SOP #9). Six soil surface samples are taken along each of the transects to assess soil-aggregate stability (see SOP #11). Disturbances and exotic plants observed on and around the site are also recorded (see SOP #12). When saplings or overstory trees occur in grassland or shrubland plots, they are recorded using the same methods used for forest and woodland plots (see SOP #13 and section below).

4.2.2.2 Woodlands and forests

Photos of each transect are taken from the origin and end (see SOP #7) because vegetation tends to be denser in forests and woodlands. Using the same methods as for grasslands/shrublands, the field crew records point-intercept cover of vegetation and surface features (SOP #8), density of shrubs and tree seedlings (SOP #10), and frequency of exotic species (SOP #10) for each transect. Vegetation cover is recorded in the understory (<2 m) in forests and at all heights for woodlands. Gaps are not recorded in forest or woodland systems, but soil stability measurements may be recorded for woodland ecological sites with potential erosion issues. Using the same methods as for grasslands/shrublands, disturbances and exotic plants on and around the monitoring plot are recorded (SOP #12).

Additional measurements are taken in forest and woodland systems in order to capture the dynamics of stand replacement or gap dynamics. Saplings (2.5–15 cm diameter) are identified to species, and density by size class is tallied in a five-meter belt transect centered on transect 2 (see Figure 3-2, SOP #13). All overstory trees (>15 cm diameter) in Quadrant 1 are identified to species, tagged with unique numbers, and measured for diameter (see SOP #13). Diameter of trees is typically measured at breast height, except for woodland species that typically have multi-stem growth forms (e.g., pinyon pines [*Pinus edulis* and *P. monophylla*] and Utah juniper [*Juniperus osteosperma*]), which are measured at the root crown (see SOP #13). Crown class

and health of trees are also recorded in forest plots. Crown class describes the relative position of each live tree in the canopy. Crown health describes the percent of live foliage for each tree. Overstory canopy closure is measured every 10 meters along the transects in forest plots (SOP #10).

Subalpine meadows are sampled following the forest methods outlined above. In addition, species richness is recorded in a one-meter belt upslope of each transect. Species richness is not recorded in any of the other ecosystems or vegetation types.

Fuels are measured using Brown's planar method (Brown 1974) along four 50-ft transects that extend beyond the plot on two corners (see Figure 3-2, SOP #14). 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.

4.2.2.3 Gambel Oak/Mixed Montane Shrubs

Gambel oak/mixed montane shrub systems are structurally different from other vegetation types on the Colorado Plateau. The dense, tall vegetation is not easily sampled using standard methods. This vegetation type is sampled using three 20-meter transects (see Figure 3-3, SOP #15). Photos are taken at the origin and end of each transect. Point-intercept cover is collected at 0.25-meter intervals. Exotic frequency is collected at smaller intervals along transects. Seedlings and saplings are recorded using the same methods used for forest and woodland plots. Within the 20 × 20-meter plot, species and diameter are recorded for all mature trees and exceptionally large individuals of Gambel oak. Shrub density, species richness, gaps, soil stability, and fuels 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.

4.3 Updating park staff

Once field sampling has been completed at each park unit, the project manager updates park staff on the progress of monitoring for the year. This update is either an informal meeting or an email detailing accomplish-

ments for the season and projected timelines for reports. Any major concerns should be brought to the immediate attention of the park's chief of resources at this time.

4.4 End-of-season procedures

While all crew members are still available, the project manager should complete a protocol review. This entails asking crew mem-

bers specific questions about the clarity and efficiency of all procedures and acquiring general feedback. The equipment list should be updated with the number of equipment items that are functional and available for the next field season. This updated list should be compared to perceived needs of the next season, and supplies should be replenished as necessary.

5 Data Management

Effective data management to ensure data quality, interpretability, security, longevity, and availability is critical to the success of the upland vegetation and soils monitoring program. The NCPN data management plan (Beer et al. 2005) describes these procedures in general terms. This section outlines the application of those procedures to uplands monitoring. SOP #18 provides specific instructions.

5.1 Data organization

This long-term monitoring project generates large quantities of data and numerous products. A well-organized digital file structure is essential to avoid confusion and potential data corruption. Each NCPN project uses a similar folder structure replicated on both the active (X:\) and archive (R:\) network drives. Data for the current field season are stored on the X:\ drive. At the end of each field season, final data and data products, along with other seasonal files, are transferred to the permanent project folder on the R:\ drive, where they are stored in read-only format.

5.2 Overview of database design

Uplands monitoring data are entered into a Microsoft Access database designed to accommodate all data on the various field forms. The database conforms to Natural Resource Database Template standards established by the Inventory and Monitoring Division. The database accommodates data collected during plot establishment and each subsequent monitoring visit for all park units where upland vegetation and soils monitoring is implemented. The database provides numerous data entry forms for plot measurements, organized largely by SOP. Species, contacts, and attribute look-up tables provide standardized values for many data fields, and metadata tables track database revisions.

5.3 Data entry

Data are recorded by field crews either directly into the database using field laptops or on paper (paper is generally used as a backup data recording method). Spatial data for each

plot is recorded on GPS units. For field measurements, one crew member takes the measurement while the other verifies it by repeating it back and then recording the value.

Data recorded digitally are uploaded to the database. Data recorded on paper data sheets are entered into the database as soon as possible after a field visit. Keeping current with data entry facilitates finding and correcting errors while information is still fresh in the minds of the field crew. Where appropriate, pick lists and domain limits restrict values entered into a field to ensure that only valid names or measures are entered. Field crew members should follow guidelines in the Uplands Database User's Guide when entering data.

5.4 Data verification and validation

Data verification occurs after data entry, when all records in the database are compared to the original paper data sheets and errors are corrected. Data validation is the process of reviewing data for range and logic errors. Although some validation features, such as range limits, are built into the database via data entry forms and queries, the project leader is also responsible for reviewing the data for content or context errors. After all data verification and validation has been completed, the data set is added to the master project database and can be used for data analysis and reporting.

5.5 Metadata procedures

Each table and field in the database is defined and documented in a data dictionary and/or in Section 5 of a Federal Geographic Data Committee (FGDC)-compliant metadata file. FGDC-compliant metadata are created for all spatial data. In addition, information on data manipulations and the status of data verification and validation is recorded by project staff in a data management log.

5.6 Data archiving procedures

Digital data are archived in their native database format at the end of each field season after all data have been entered, verified, and

validated. A complete copy of the database in its native database format is also archived whenever the database version changes. These version archives are supplemented by a platform-independent copy of the database tables in ASCII format. All archived files are designated as read-only. All files, both active and archival, are stored on a secure server with regular backup routines that include an off-site storage rotation.

Field forms and photographic prints or slides are irreplaceable resources that must be

managed so that their quality and integrity are maintained long-term. Copies of these materials are used for project binders that are regularly used or referenced, while originals are accessioned into the NCPN archives for permanent storage and care.

The NCPN archives are located at the Western Archeological and Conservation Center (WACC) in Tucson, Arizona. All uplands monitoring final data and data products, both digital and hard copy formats, are archived at WACC after each field season.

6 Reporting and Analysis

6.1 Data summary reports and briefs

Data summary reports are produced to describe the field effort and briefly summarize data collected in a park for the period reported. These reports also highlight observed resources of management concern and general ecological observations of interest that were noted by the crew. The report includes an overview of any necessary changes to protocol procedures and proposed future monitoring efforts. Each year, information from data summary reports and other analyses is further summarized in 1–2 page briefs that provide resource managers with a concise summary of issues of concern.

6.2 Status and trend reports

After a minimum of five years of monitoring, a status and trend assessment will be performed and presented as a comprehensive report. The purposes of this analysis are to:

- Describe the current conditions (status) of upland vegetation and soils indicators (see Section 2) using standard univariate and multivariate descriptive statistics and graphical techniques, and interpret these conditions in the context of management objectives,
- Describe trends (if any) in upland vegetation and soils indicators using mixed effects models and multivariate analytical techniques,
- Use modeling and other data exploration techniques to evaluate potential explanatory variables and covariates over broad thematic and spatial scales,
- Synthesize this wide-range of information to explore patterns and better understand upland vegetation and soils processes and dynamics, and
- Evaluate the effectiveness of the sampling design by assessing variance and statistical power.

Status and trend reports are completed periodically (approximately every 5–7 years) for each park unit with upland monitoring.

7 Personnel Requirements and Training

7.1 Roles and responsibilities

The NCPN vegetation ecologist organizes and oversees the upland vegetation and soils monitoring program. The vegetation ecologist acts as the project manager and is responsible for training the permanent biological science technician, who acts as the field crew leader. The crew leader oversees approximately five seasonal staff, leads the field data collection, and directs data entry and verification. The project manager is responsible for data validation, as well as data summary, analysis, and reporting. The crew leader may assist with data summaries and reports. The NCPN data manager coordinates data archiving, security, dissemination, and database design. The data manager, in collaboration with the project manager, also develops data entry forms and other database features for quality assurance and data summary. The data manager is ultimately responsible for ensuring that adequate QA/QC (quality assurance/quality control) procedures are built into the database and that appropriate data handling procedures are followed.

7.2 Qualifications

Seasonal biological science technicians (or interns or volunteers): Field technicians must have good botanical skills and preferably have experience identifying upland plant species of the Colorado Plateau. Additional qualifications include attention to detail, experience taking vegetation monitoring measurements, basic knowledge of soil science, good physical fitness, and basic computer skills. Crew members should also have good organizational skills and memory retention, and the ability to work methodically and consistently under difficult conditions.

Lead biological science technician: In addition to the qualifications listed above, the field crew leader should have excellent botanical skills and previous experience identifying upland plant species of the Colorado Plateau. The field crew leader should also have experience leading crews in a backcountry setting.

7.3 Training procedures

Prior to data collection, crews should become intimately familiar with all field-related SOPs and park-specific materials, such as plant species lists and park-information documents. Each person should be trained in all protocol-specific data collection methods, such that s/he can independently perform any necessary task. It is important that all crew members calibrate their measurement techniques with each other before collecting data at plots to ensure that measurements are as consistent as possible among crew members.

The vegetation ecologist and/or field crew leader will provide training on appropriate plant species. Herbarium specimens and comparative notes on difficult or uncommon species will be provided for field observers. Observers should be tested frequently on their ability to identify plant species. The test should be tailored to more problematic species.

The field crew leader is responsible for ensuring that all crew members read and understand the NCPN Field Safety SOP prior to the field season. At a minimum, the crew leader will have a Wilderness First Aid or Wilderness First Responder certification. CPR and first aid training will be provided for all crew members at the beginning of the season. Each crew member must be proficient in the use of safety equipment, such as satellite phones, and is responsible for safeguarding him/herself at all times.

8 Operational Requirements

8.1 Annual workload and field schedule

The annual workload for this protocol consists of six months of field data collection, followed by data verification and validation in fall and winter, and data summary, analysis, and reporting throughout the year. Field data are collected during the growing season, between mid-April and mid-October. Sampling visits are scheduled to optimize phenology for the group of NCPN park units included in upland vegetation and soils monitoring (Figure 8-1). Park units should be visited at approximately the same time each year to minimize seasonal variability.

Approximately six biological science technicians will collect field data. Each team of two will need a dedicated vehicle and sampling equipment. A typical field season consists of 13 hitches, each with two travel days and six field days. Each two-person crew will visit approximately 6–8 plots per hitch, depending on the location of plots relative to roads and trails.

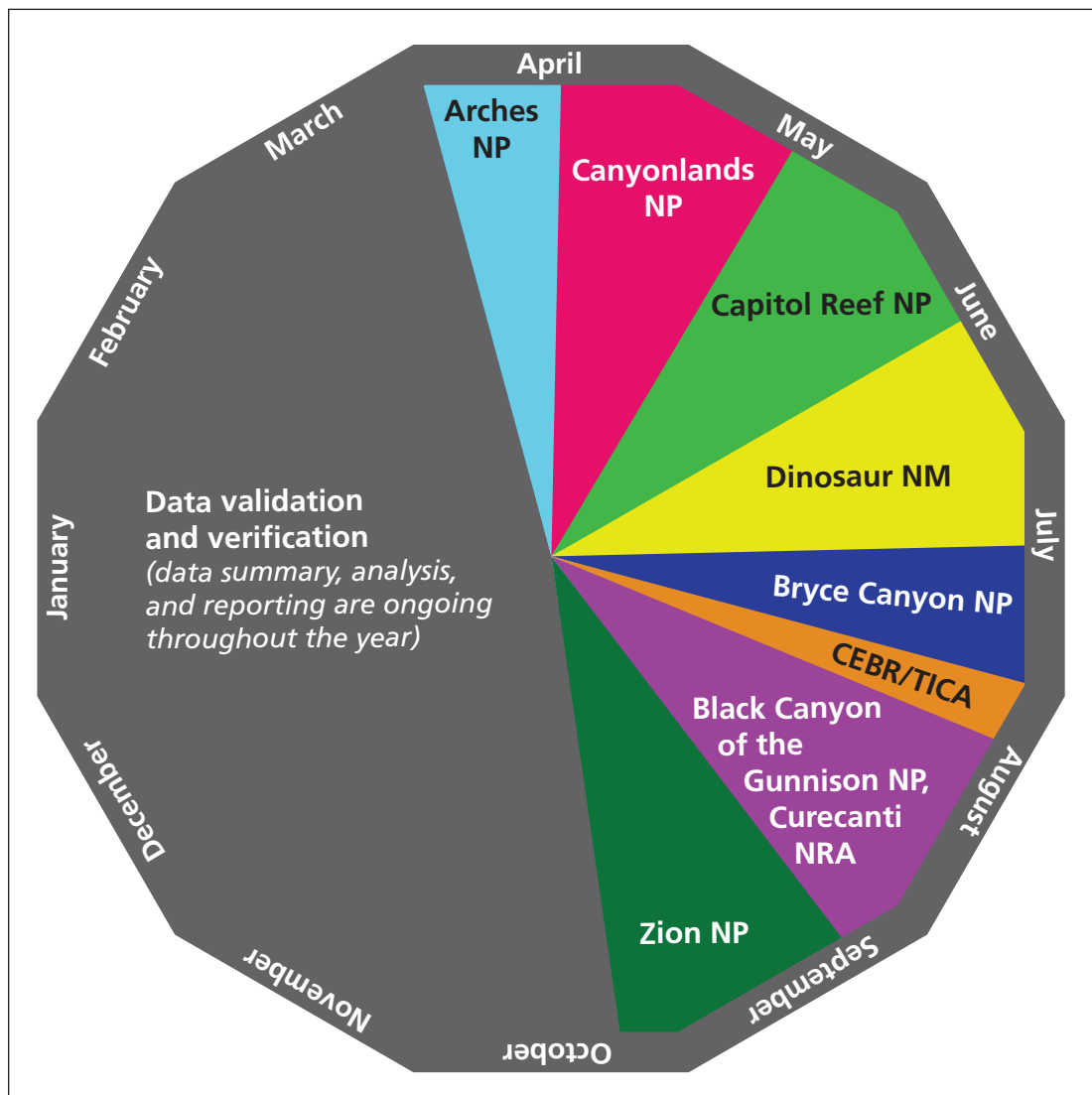


Figure 8-1. Annual work schedule for field-data collection and selected other tasks related to upland vegetation and soils monitoring in Northern Colorado Plateau Network parks.

9 Revising the Protocol

This sampling protocol consists of a protocol narrative and 21 separate SOPs. The protocol narrative provides the history and justification for the program and an overview of sampling methods. The protocol narrative will be revised only if major changes are made to the protocol. The SOPs, in contrast, are step-by-step instructions for performing each task. They are expected to be revised more frequently than the protocol narrative. Steps for changing the protocol narrative and SOPs are outlined in SOP #20.

Careful documentation of such revisions, including an archive of previous versions, is essential for maintaining consistency in data collection, analyses, and reporting. To sum-

marize changes, the monitoring database for each component contains a field to identify the protocol version used to gather and analyze data. The narrative and each SOP contain a Revision History Log that should be completed each time the narrative or an SOP is revised. The purpose of this log is to explain why changes were made and to track document version numbers.

The NCPN uses a Master Version Table, maintained in SOP #20, to track which versions of the narrative and SOPs are used in each version of the monitoring protocol. The information contained in the Master Version Table is essential if project information is to be properly analyzed and interpreted.

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