U.S. Department of the Interior

National Park Service

Inventory and Monitoring Program

Integrated Upland Monitoring Protocol for the Park Units in the Northern Colorado Plateau Network

Dana Witwicki [1]
Helen Thomas [1]
Rebecca Weissinger [1]
Aneth Wight [1]
Sarah Topp [1]
Steven L. Garman [2]
Mark E. Miller [3]

[1] Northern Colorado Plateau Network Inventory and Monitoring Program
P.O. Box 848, Bldg. 11, Arches National Park
Moab, UT 84532

[2] Previously with the Northern Colorado Plateau Network

[3] Southeast Utah Group of the National Park Service
2282 SW Resource Blvd.
Moab, UT 84532

Version 1.06 (August 2016)

Revision History Log:

Prev. 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	Text in section 4 was	1.04

			fixed typo	out of date	
1.04	7/2013	DLW	Added acknowledgement for protocol review	Omitted when protocol was approved	1.05
1.05	8/2016	DLW HMT	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. Made minor edits to Data Management section	Methods added, updated narrative for publication To reflect current data management practices	1.06

Table of Contents

1. Background and Objectives 6
1.1 Upland ecosystems as a focus for monitoring 6
1.2 Key upland ecosystems in NCPN park units 7
1.2.1 Semiarid grasslands 8
1.2.2 Blackbrush shrublands 8
1.2.3 Sagebrush shrublands and grasslands 8
1.2.4 Pinyon-juniper woodlands 9
1.2.5 Gambel oak/mixed montane shrublands 9
1.2.6 Mixed conifer forests 10
1.2.7 Aspen 10
1.2.8 Subalpine meadows 10
1.3 Historical development of upland monitoring in NCPN park units 13
2. Program Goals and Measureable Objectives 15
3. Sampling Design 15
3.1 Rationale for selected design 16
3.2 Response design 17
3.3 Spatial design 21
3.4 Revisit design 26
4. Field Methods 27
4.1 Field season preparations 27
4.2 Sampling procedures 27
4.2.1 Establishing the plot 27
4.2.2 Vegetation and soil sampling 28
4.3 After monitoring is completed at a park unit 32
4.4 End-of-season procedures 32
5. Data Management 32
5.1 Data organization 32
5.2 Overview of database design 32
5.3 Data entry 33
5.4 Data verification, validation, and certification 33
5.5 Metadata procedures 33

5.6 Data archiving procedures 33
6. Reporting and Analysis 34
6.1 Annual reports and briefs 34
6.2 Status and trend reports 34
7. Personnel Requirements and Training 35
7.1 Roles and responsibilities 35
7.2 Qualifications 35
7.3 Training procedures 35
8. Operational Requirements 36
8.1 Annual workload and field schedule 36
9. Revising the Protocol 37
10. References 37

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 the Field Season
SOP 18: Data Management
SOP 19: Data Analysis and Reporting
SOP 20: Revising the Protocol
SOP 21: Survey Design and Site Selection

List of Tables

Table 1. Park units of the NCPN.. 11
Table 2. Summary of historic and ongoing vegetation monitoring in NCPN park units.. 14
Table 3. Summary of vegetation types monitored and management issues addressed by integrated upland monitoring in NCPN park units..... 22
Table 4. Summary of upland survey designs in NCPN park units 23
Table 5. Schedule of field visits to park units with upland monitoring. 36

List of Figures

Figure 1. Park units and ecoregions of the NCPN. 12
Figure 2. Standard transect layout for grassland/shrubland plots. 19
Figure 3. Locations of tree and fuels measurements at forest and woodland plots, including a 5-m belt transect for measuring saplings, Quad 1 for measuring overstory trees, and four fuels transects 20
Figure 4. Standard transect layout for oak plots. 20
Figure 5. Locations of target vegetation types in the survey design and plots visited in one year of monitoring at Capitol Reef National Park..... 25
Figure 6. Number of plots sampled each year based on a 5-year rotating panel revisit design 27
Figure 7. Outline of field procedures for monitoring upland plots..... 30

Acronyms

(This will be added to final pdf)

Acknowledgements

Many people contributed to the development of this protocol, and several standard operating procedures were derived from established monitoring protocols. Numerous vegetation and soil sampling methods were adapted from the work of Jeff Herrick and colleagues. Tree and fuels sampling were based largely on methods outlined in the NPS Fire Monitoring Handbook. Tom Philippi provided valuable expertise and mentoring for developing surveys designs. Jayne Belnap and colleagues at the US Geological Survey shared their techniques for minimizing impacts to biological soil crusts. Funding for protocol development was provided by the Northern Colorado Plateau Inventory and Monitoring Network (NCPN), the Southern Colorado Plateau Inventory and Monitoring Network (SCPN), and the US Geological Survey-Biological Resources Discipline (USGS-BRD). John Sawyer provided an insightful review of the protocol.

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) Program of the NPS was created to provide managers with credible scientific information about park natural resources. The Northern Colorado Plateau Network (NCPN) serves sixteen 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 since they represent the majority of land on the Colorado Plateau.

Five vital signs were selected for integrated upland 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 integrated upland monitoring: Arches National Park (ARCH), Black Canyon of the Gunnison National Park (BLCA), Bryce Canyon National Park (BRCA), Canyonlands National Park (CANY), Capitol Reef National Park (CARE), Cedar Breaks National Monument (CEBR), Curecanti National Recreation Area (CURE), Dinosaur National Monument (DINO), Timpanogos Cave National Monument (TICA), and Zion National Park (ZION). Related NCPN monitoring efforts are included in the invasive plants protocol (Perkins et al. IN REVIEW), which focuses on early detection of exotic invasive plants along predictable transport pathways.

1.1 Upland ecosystems as a focus for monitoring

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

Upland ecosystems of the Colorado Plateau, where the majority of NCPN park units are located, tend to be dominated by shrubs, perennial grasses, and small trees. Although these life forms play an integral role in defining the structure and function of Colorado Plateau ecosystems (Whitford 2002), it is the highly-pinnacled biological soil crusts that make these dryland systems unique. Biological soil crusts are biotic communities composed of cyanobacteria, algae, microfungi, mosses, and lichens that occur on and within the upper few millimeters of the soil surface (Belnap et al. 2003). Their presence stabilizes the soil surface and reduces susceptibility to wind and water erosion (Williams et al. 1995). They also contribute to nutrient cycling by fixing C (Lange 2003) and N (Evans and Lange 2003, Belnap 2002) and affect the availability of nutrients to plants (Harper and Belnap 2001). Biological soil crusts are particularly sensitive to disturbances that affect the soil surface, such as trampling and off-road vehicle use (Rosentreter and Belnap 2003). In the basins neighboring the Colorado Plateau, where several NCPN park units are located, biological soil crusts also play an important role but are less dramatically pinnacled. In the forests, shrublands, and meadows of the mountain regions surrounding the Colorado Plateau, where numerous NCPN park units are located, biological soil crusts do not play an important role since much of the soil surface is covered by vegetation and litter.

Many upland ecosystems of the region are characterized by low resistance and resilience. Even moderate disturbances can affect vegetative composition and structure, and recovery to pre-disturbance conditions can be relatively slow. Natural disturbance regimes of the region include extreme climatic events, fire, insect and disease out breaks, 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).

1.2 Key upland ecosystems in NCPN park units

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

1.2.1 Semiarid grasslands

Semiarid grasslands occur on deep sand or sandy loam soils at elevations of 4200 to 6500 feet 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*), and are occasionally interspersed with Utah juniper (*Juniperus osteosperma*). Dominant perennial bunchgrass species include C_3 grasses such as Indian ricegrass (*Stipa hymenoides*) and needle and thread (*Stipa comata*) or C_4 grasses like galleta (*Hilaria jamesii*), dropseeds (*Sporobolus* species), and blue grama (*Bouteloua gracilis*). Biological soil crusts play an important role in this ecosystem, and most are generally in good condition in NCPN park units or 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 a historic land use in semiarid grasslands, and still occurs in parts of one park. Semiarid grasslands are not susceptible to fire unless heavily invaded by cheatgrass. This ecosystem is found in ARCH, CANY, CARE, and Pipe Spring National Monument.

1.2.2 Blackbrush shrublands

The most common low elevation (3900-6200 ft) 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 sandy loam soils and well-developed biological soil crusts when 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 since they contain little grass biomass. Blackbrush shrublands occur in ARCH, CANY, CARE, and ZION.

1.2.3 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 (4700-8500 ft) 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, and 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 the lower elevations and precipitation zones. Areas dominated by cheatgrass burn more frequently, making it difficult for native species to survive. Livestock grazing is a historic land use in sagebrush ecosystems that still occurs in parts of 3 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 BLCA, Colorado National Monument (COLM), CURE, DINO, Fossil Butte National Monument (FOBU), Golden Spike National Monument, and Hovenweep National Monument (HOVE).

1.2.4 Pinyon-juniper woodlands

Pinyon-juniper (PJ) woodlands occur at elevations of 5500 to 8200 feet 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. The understory of PJ woodlands varies widely, but often consists of sparse shrubs and perennial bunchgrasses. At lower elevation and precipitation zones, these woodlands may mix with big sagebrush shrublands. At higher elevation 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 an annual grassland after fire. The low biomass of grasses in most PJ woodlands make them less than ideal for livestock grazing, however, this is a historic land use that still occurs in parts of 2 park units. PJ woodlands are found in BLCA, BRCA, COLM, DINO, HOVE, Natural Bridges National Monument, and ZION.

1.2.5 Gambel oak/mixed montane shrublands

Gambel oak/mixed montane shrublands are found on rocky soils at elevations just above PJ woodlands (6200-8700 ft) 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 BLCA, BRCA, CURE, TICA, and ZION.

1.2.6 Mixed conifer forests

Mixed conifer forests are the most common forest type in NCPN park units and are typically found in the mountain ecoregions surrounding the Colorado Plateau. They may occur interspersed with subalpine meadows or aspen forests. At elevations of 7500 to 9000 feet (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 (9000-10500 ft), mixed conifer forests are dominated by subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmanniii*). 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 is not an important land use in this ecosystem. Mixed conifer forests are found in BLCA, BRCA, CEBR, TICA, and ZION.

1.2.7 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 7500 to 10000 feet 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 CEBR, CURE, FOBU, and ZION.

1.2.8 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 (9500-10500 ft) 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, and 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 CEBR and TICA.

Table 1. Park units of the NCPN. Bold type indicates units with NCPN upland monitoring.

Park	Park Code	State	Area (ha)
Arches National Park	**ARCH**	**UT**	**30,966**
Black Canyon of the Gunnison National Park	**BLCA**	**CO**	**12,239**
Bryce Canyon National Park	**BRCA**	**UT**	**14,502**
Canyonlands National Park	**CANY**	**UT**	**136,610**
Capitol Reef National Park	**CARE**	**UT**	**97,895**
Cedar Breaks National Monument	**CEBR**	**UT**	**2,491**
Colorado National Monument	COLM	CO	8,310
Curecanti National Recreation Area	**CURE**	**CO**	**17,433**
Dinosaur National Monument	**DINO**	**CO/UT**	**85,097**
Fossil Butte National Monument	FOBU	WY	3,318
Golden Spike National Historic Site	GOSP	UT	1,107
Hovenweep National Monument	HOVE	UT/CO	318
Natural Bridges National Monument	NABR	UT	3,009
Pipe Spring National Monument	PISP	AZ	16
Timpanogos Cave National Monument	**TICA**	**UT**	**101**
Zion National Park	**ZION**	**UT**	**59,900**

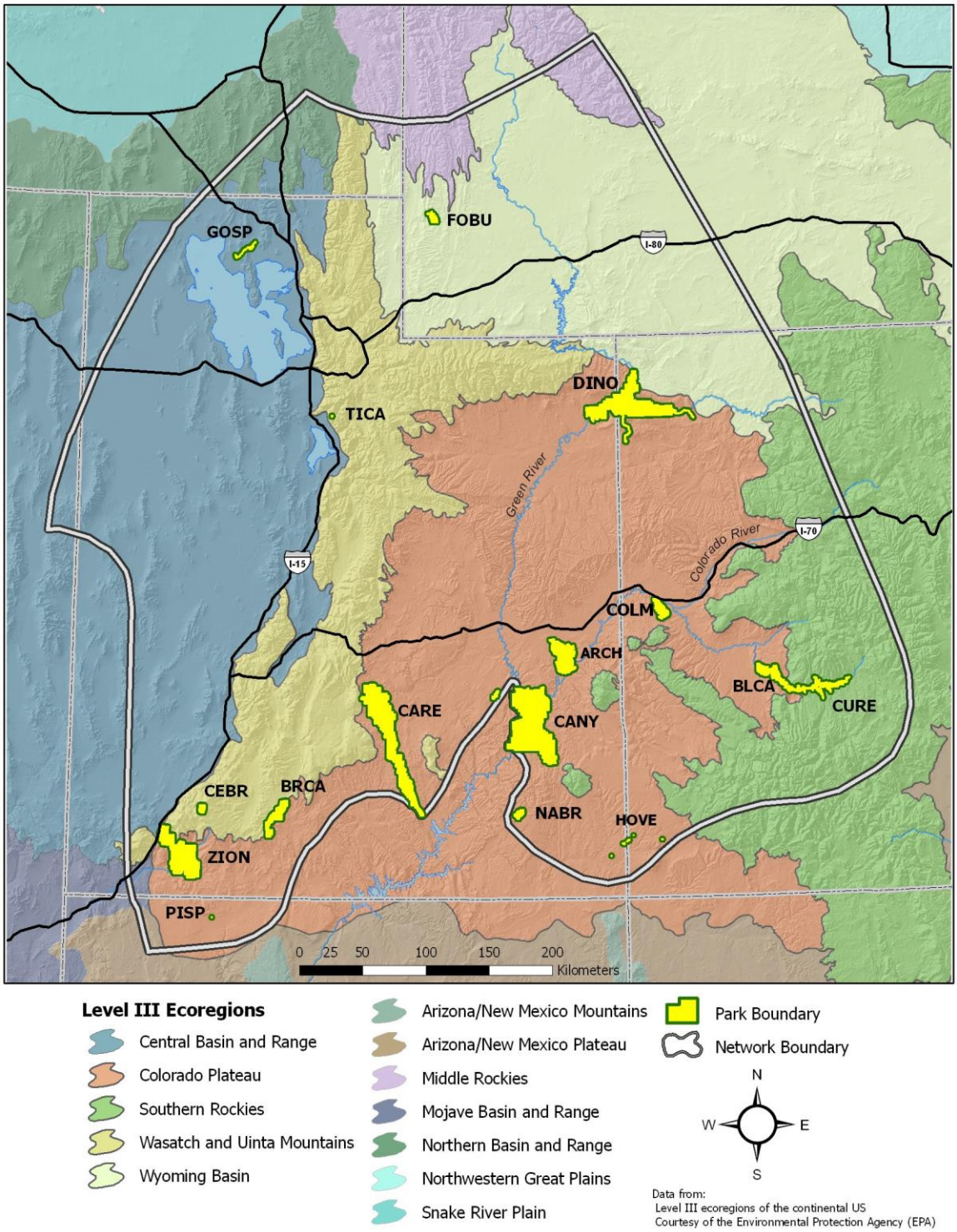


Figure 1. Park units and ecoregions of the NCPN.

1.3 Historical development of upland 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 forty years of annually collected data. These efforts are summarized by type and duration in Table 2. Plant monitoring data in the form of photographs, can be said to occur from as long ago as 1872. The historic photographic record for part of CANY is examined in detail by Webb et al. (2004). Although none of the photo plots are considered ongoing, these efforts are often easy to repeat.

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, but CANY is the only one with an ongoing effort.

Photo points include the re-location of historic photographs (Webb et al. 2004) and the deliberate establishment of photo points for particular purposes. Plant monitoring data in the form of photographs, can be said to occur from as long ago as 1872. The historic photographic record for part of CANY is examined in detail by Webb et al. (2004). Although none of the photo plots are considered ongoing, these efforts are often easy to repeat.

The most extensive ongoing vegetation plot monitoring in the NCPN is in the southeast Utah group of parks (SEUG). 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 ARCH, CANY, and NABR sites have been visited almost every year since 1987, while the first HOVE sites were not established until 1999. Sites were chosen to be representative of particular vegetation types and measurements are recorded in fifty 0.5 m x 0.5 m subplots (quadrats) on two more or less 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 methods changes over the duration of this program, most notably the introduction of permanent markers for each subplot beginning 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 the park. 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 BLCA and CURE has occurred since 1992. This monitoring effort consists of 0.5 x 0.5-m quadrats located every 5 m along five 100-m transects in ten habitat types. Although monitoring has not occurred every year and the monitoring is limited by only having 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 et al. (2002, Volume 2, part III).

Table 2. Summary of historic and ongoing vegetation monitoring in NCPN park units (as of 2011). Ongoing monitored is indicated by bold print.

Park	Long-term vegetation plots	Photo plots (not grazing related)	Fire effects	Grazing trend plots	Other
ARCH	**1 (1987)**	3 (1990)	2 (1999)		
BLCA	**1 (1992)**	3 (1990)			
BRCA	**1 (1957)**	3 (1990)	**1 (1988)**		Relict areas
CANY	**1 (1987)**	2 (1872)			**Grazed/relict comparison;** bunchgrass post-grazing
CARE				**1 (early 1960s)**	
CEBR		3 (1990)			
COLM		3 (1990)			
CURE	**1 (1992)**	3 (1990)			
DINO			**1 (1984)**	1 (1961)	
FOBU	2 (1977)	1 (1985)	**1 (2006)**		
GOSP			**1 (2000)**		
HOVE	**1 (1999)**				
NABR	**1 (1987)**				Grazed/relict comparison
PISP					
TICA					
ZION	3 (1997)		**1 (1995)**		

1 = More than three years of data (beginning year)

2 = Two to three years of data

3 = Plots established but not re-visited

2. Program Goals and Measureable Objectives

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

Determine status and trends in plant communities including:

- overall species richness
- cover of vegetation by dominant species and life form
- density of shrubs by size class
- basal area and density of tree species
- canopy closure
- fuel 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, whereas remote sensing can be used to determine change in vegetation at larger scales caused by land use or climate change. Historical upland monitoring data sets may be integrated with data collected by NCPN to allow earlier detection of trends.

3. Sampling Design

The NCPN sampling design for integrated upland monitoring incorporates efficient approaches to gathering data that are credible and sufficient to achieve monitoring objectives. The sampling design is comprised of 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 re-visit 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, since restoration to the native system becomes extremely difficult and costly after this 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), and NCPN upland sampling objectives will be modified as understanding of these systems increase.

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 consort with Mark Miller 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 development of the integrated upland response design. This effort tested and compared the methods used in *The Monitoring Manual for Grassland, Shrubland and Savannah Ecosystems* (Herrick et al. 2005) with quadrat-based methods similar to those used by the Prairie Cluster Prototype Monitoring Program (DeBacker et al. 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 m^2 vs. 10 m^2), 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 each have separate upland monitoring protocols that differed in some sampling procedures but retained much of the same initial monitoring objectives.

The original NCPN protocol used 10-m^2 quadrats to measure shrub density and ocular cover of vegetation and surface features. After two years of testing, modifications were made to the original field procedures including the addition of point-intercept sampling of vegetation and surface cover (SOP #8) and shrub density in 1-m 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 used for integrated upland monitoring. 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 monitor 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, and then GRTS and RRQRR 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 integrated upland monitoring is a plot. Measurements of vegetation and soils are co-located at each plot and are monitored concurrently. The basic upland

plot consists of three parallel 50-m transects separated by 25 m (Fig. 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, oak, or forest.

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 and basal gaps are recorded.

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 (Fig. 3).

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 (Fig. 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 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 separated by 10 m) due to the difficulty of running long transects in dense vegetation (Fig. 4), and 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 in section 4. 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.

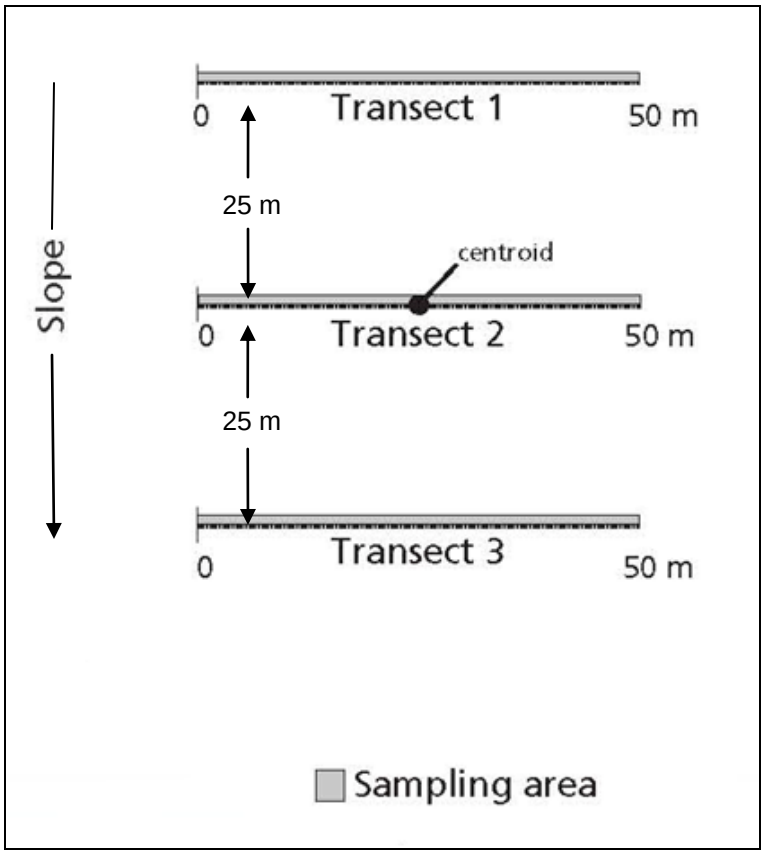


Figure 2. Standard transect layout for grassland/shrubland plots.

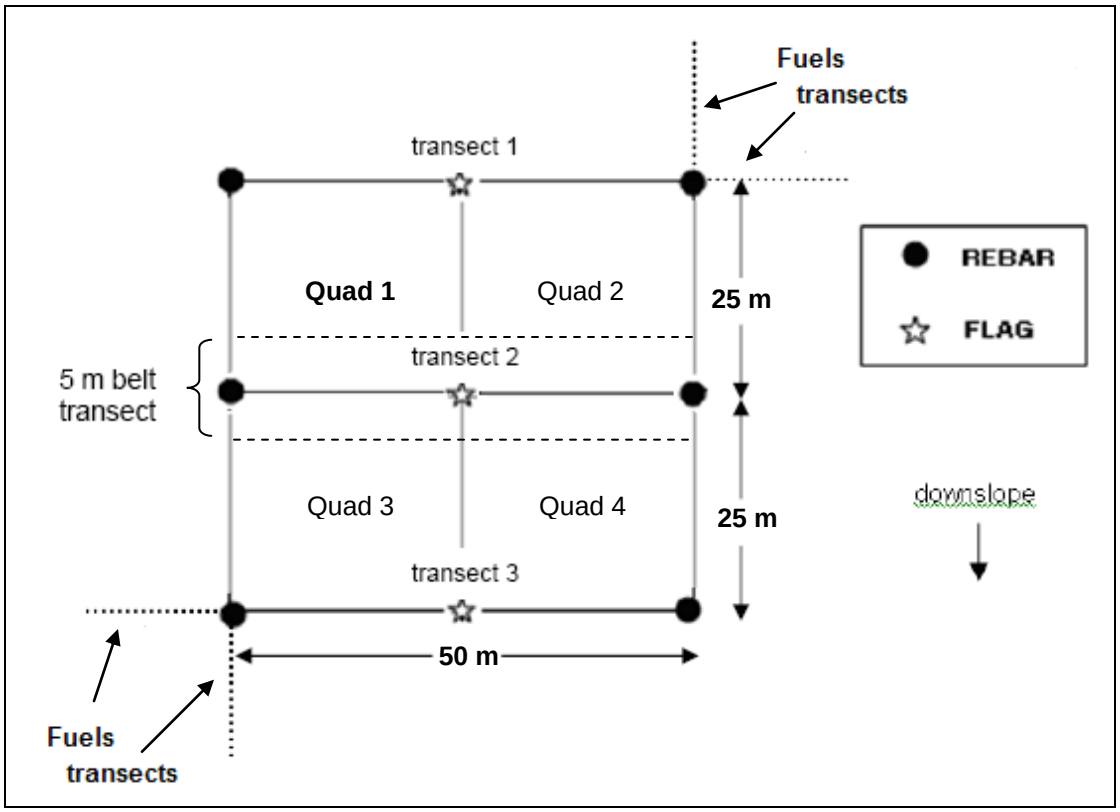


Figure 3. Locations of tree and fuels measurements at forest and woodland plots, including a 5-m belt transect for measuring saplings, Quad 1 for measuring overstory trees, and four fuels transects (not drawn to scale).

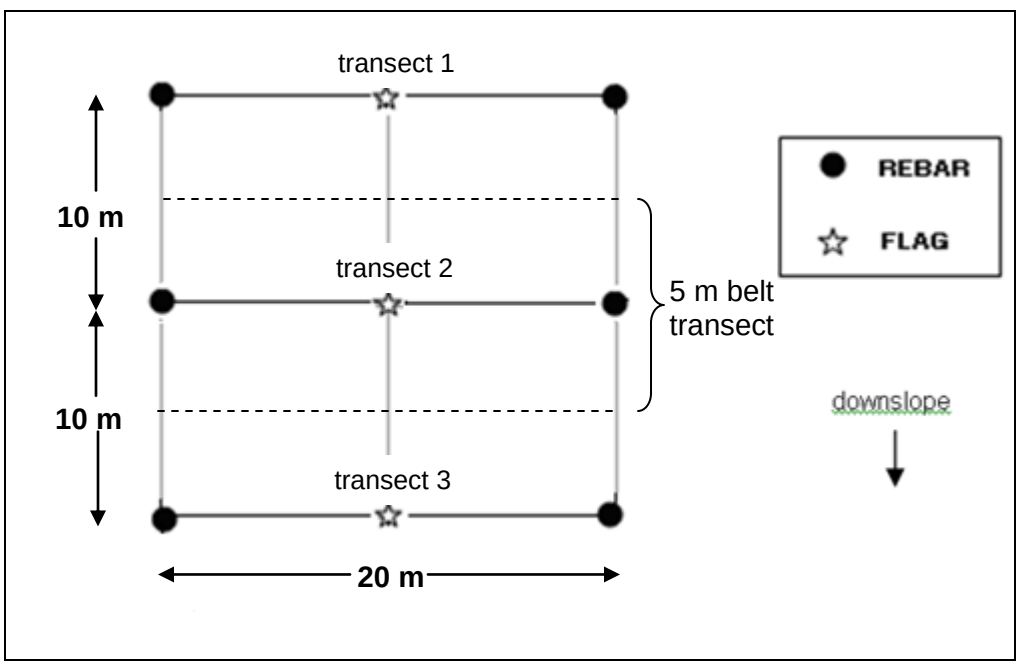


Figure 4. Standard transect layout for oak plots.

3.3 Spatial design

The response design for monitoring integrated upland vital signs is constant among park units, but the vegetation types and management issues addressed are tailored specifically to the needs of each park unit (Table 3). 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 I&M 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 detecting exotic invasive plant species. In addition, land uses such as grazing may be incorporated in the spatial design of monitoring. Once 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 since plots that are located near each other will tend to be more similar and can underestimate the variance of the target population. Only area deemed accessible is considered for monitoring, and this is derived from slope using NCPN-created analytical software (Landscape Access Model [LAM], Garman unpublished). Guidelines for determining the target population and spatial design and for selecting monitoring plots are outlined in SOP #22. Since 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. Survey designs were created for all NCPN park units with upland monitoring except TICA 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 (see Table 4), 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, multiple ecological sites or inclusions such as rock outcrop can be contained within a soil map unit, with only some of the area being target. 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 delineating the spatial extent of each stratum from which monitoring plots are selected (Fig. 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 (Generalized Random Tessellation Stratified) or RRQRR (Reversed Randomized Quadrat-Recursive Raster) 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).

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

Park unit	Year initiated	Total area monitored (ha)	Upland vegetation monitored	Management issues
ARCH	2010	2,509	Grasslands, blackbrush/ juniper shrublands	Social trailing
BLCA	2008	6,795	Sagebrush, pinyon-juniper, mixed montane shrubs	Grazing
BRCA	2010	5,406	Pinyon-juniper, mixed conifers	Fire management
CANY	2006	25,693	Grasslands, blackbrush/ juniper shrublands	Social trailing
CARE	2007	6,423	Grasslands	Grazing
CEBR	2009	548	Mixed conifer forests, subalpine meadows	Spruce budworm outbreaks
CURE	2008	4,938	Sagebrush, aspen	Grazing, sudden aspen decline
DINO	2009	17,306	Sagebrush, pinyon-juniper	Grazing, fire management
TICA	2009	<1	Gambel oak, mixed conifer forest, subalpine meadow	Ecosystem health
ZION	2011	8,892	Gambel oak, pinyon-juniper	Fire management

Table 4. Summary of upland 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*
ARCH	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)
BLCA	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
BLCA/ CURE	4,816	14 or 17	59	Sagebrush	Dry Mountain Loam Mountain Loam
BRCA	4,042	10	25	Pinyon-juniper woodland	None; sampling frame includes all PJ woodlands at elevations <2300 m
	1,404	8	20	Mixed conifer forest	None; sampling frame includes all mixed conifer forest at elevations >2600 m
CANY	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)
CARE	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) 215-Semidesert Sandy Loam (fourwing saltbush)
	2885	16	60	Deep grassland- Hartnet allotment (currently grazed by livestock)	

	1,109	16	60	Rocky grassland (currently grazed by livestock)	242-Semidesert Stony Loam (shadscale) 260-Semidesert Very Steep Stony Loam (Salina wildrye)
CEBR	548	8	28	Spruce-fir forest, subalpine meadow, aspen	None; sampling frame includes all subalpine meadows, aspen, and mixed conifer forest above the rim
CURE	122	1 or 4	4	Aspen	None; sampling frame includes all aspen in CURE
DINO	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
TICA	<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	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 ARCH, CANY, & CARE are from Major Land Resource Area (MLRA) 35. Ecological sites at BLCA & the low elevation sagebrush site with the plant species included in the name at DINO are from MLRA 34. The sites without plant species included in the name at BLCA, CURE, & DINO are range sites from Colorado. The high elevation sagebrush ecological site at DINO is from MLRA 47.

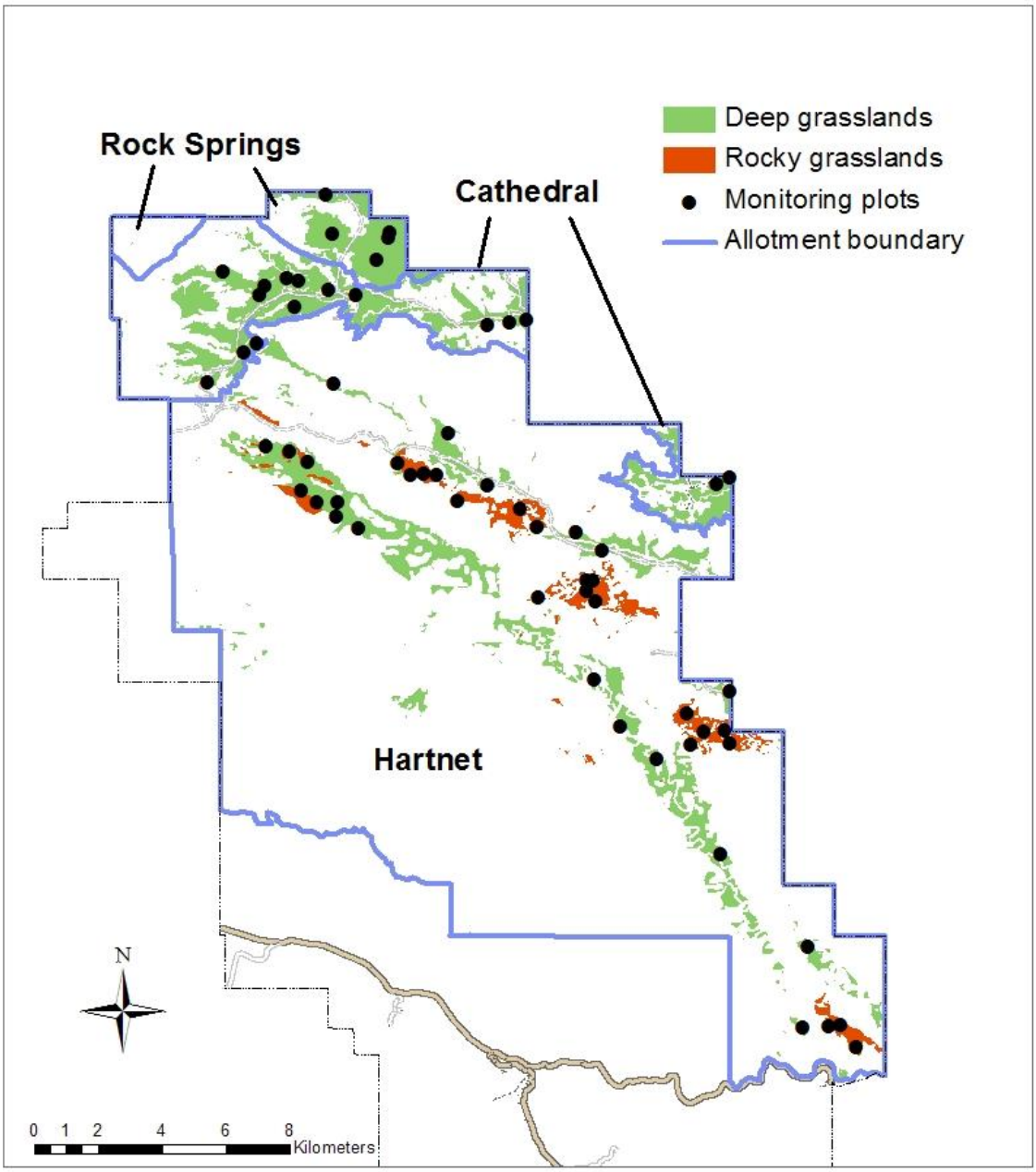


Figure 5. Locations of target vegetation types in the survey design and plots visited in one year of monitoring at Capitol Reef National Park**.** Deep grasslands consist of 3 target ecological sites (Semidesert Sand [fourwing saltbush], Semidesert Sandy Loam [fourwing saltbush], and Semidesert Alkali Sandy Loam [alkali sacaton]. Rocky grasslands consist of 2 target ecological sites (Semidesert Stony Loam [shadscale] and Semidesert Very Steep Stony Loam [Salina wildrye]).

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 TICA). 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 appropriate sample size.

A rotating panel design is used to increase the overall sample size (see Fig. 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 4) and the variability. For at least some of the plots in each stratum, vegetation is sampled for two years in a row to tease out year-to-year differences due to temperature, precipitation, etc. and to better estimate trends.

In most parks, pilot monitoring occurs for 3 years before the operational revisit design is determined. During pilot monitoring, eight to ten plots are established per stratum and revisited each year for three years. Variance estimates from these 3 years of data are used to evaluate the power to detect trends using different revisit designs. The optimal revisit design is selected, and full operational monitoring is implemented according to this design. The initial 3-year pilot monitoring may be skipped for some smaller parks where the number of plots are 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., CANY for ARCH). 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, another stratum may need to be dropped from survey design since the NCPN can only sample a finite number of plots at each park unit.

	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

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

Figure 6. Number of plots sampled each year based on a 5-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 camping or park housing, and acquiring back-country permits (see SOP #1). All of the equipment and supplies are organized, tested, and ordered to assure availability by the beginning of the field season. Directions, revisit data sheets, and species lists are generated for each plot.

Allow ample time 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

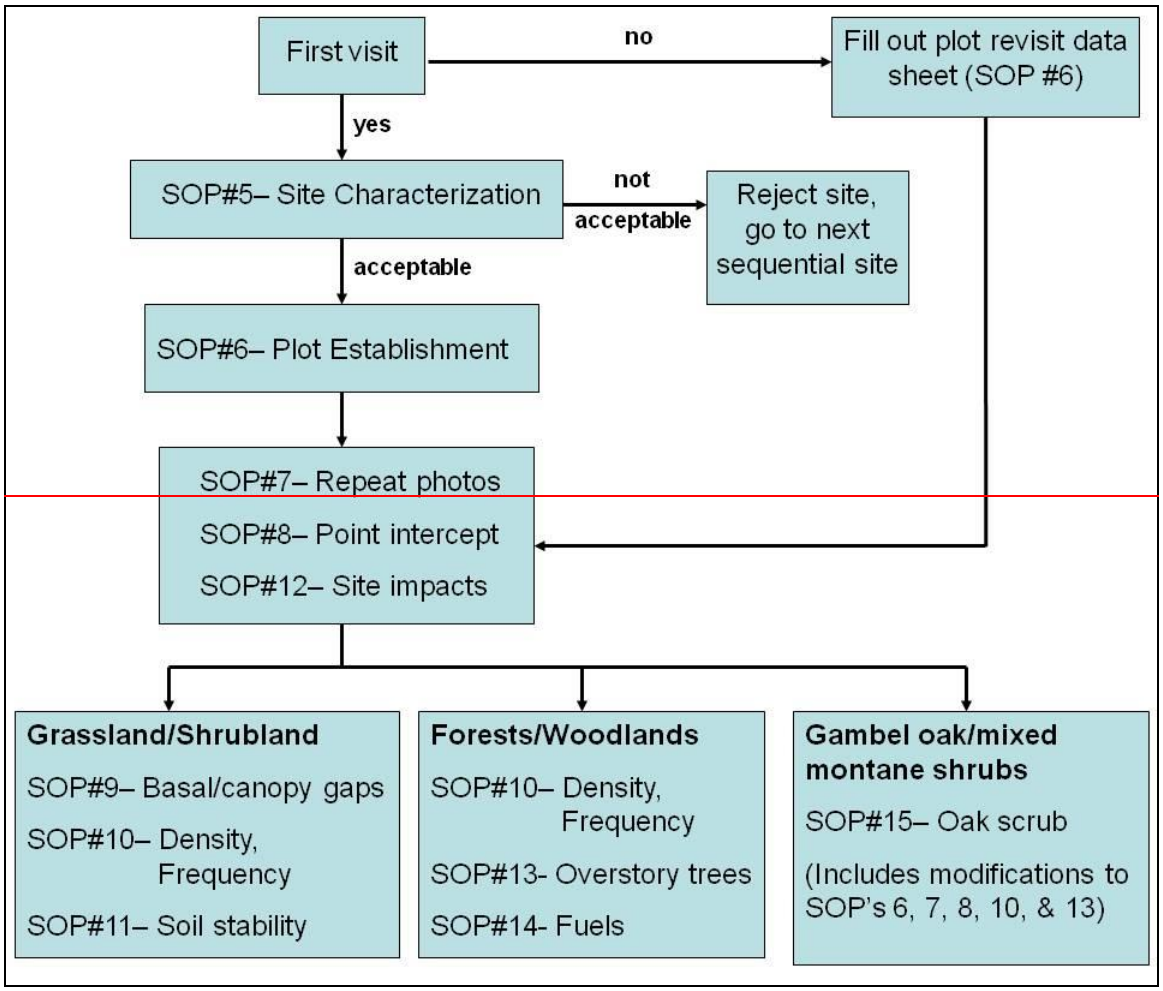
4.2.1 Establishing the plot

After navigating to the plot center, the site is characterized (SOP #5) to determine whether or not 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 help relocate them. Transect tapes marked at 1-cm 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 taken on one transect before visiting the others, and crew members remain downslope of the transect while taking measurements on the upslope side of the transect.

A specific suite of SOPs (see Fig. 7) is used to record measures at each plot depending on the vegetation type (grassland/shrubland, forest, woodland, or oak; see section 3.2 for definitions). It is also clearly outlined in each SOP which vegetation types the SOP is used to monitor. Vegetation types are determined using NRCS ecological site descriptions or National Vegetation Classification associations (FGDC 1997). These are too extensive to list here, but are outlined in detail in the survey design report created for each park unit. In the sections below, the sampling methods are described for each vegetation type.


First visit
no
Fill out plot revisit data sheet (SOP #6)
yes
SOP#5– Site Characterization
not acceptable
Reject site, go to next sequential site
acceptable
SOP#6– Plot Establishment
SOP#7– Repeat photos
SOP#8– Point intercept
SOP#12– Site impacts
Grassland/Shrubland
SOP#9– Basal/canopy gaps
SOP#10– Density, Frequency
SOP#11– Soil stability
Forests/Woodlands
SOP#10– Density, Frequency
SOP#13- Overstory trees
SOP#14- Fuels
Gambel oak/mixed montane shrubs
SOP#15– Oak scrub
(Includes modifications to SOP's 6, 7, 8, 10, & 13)

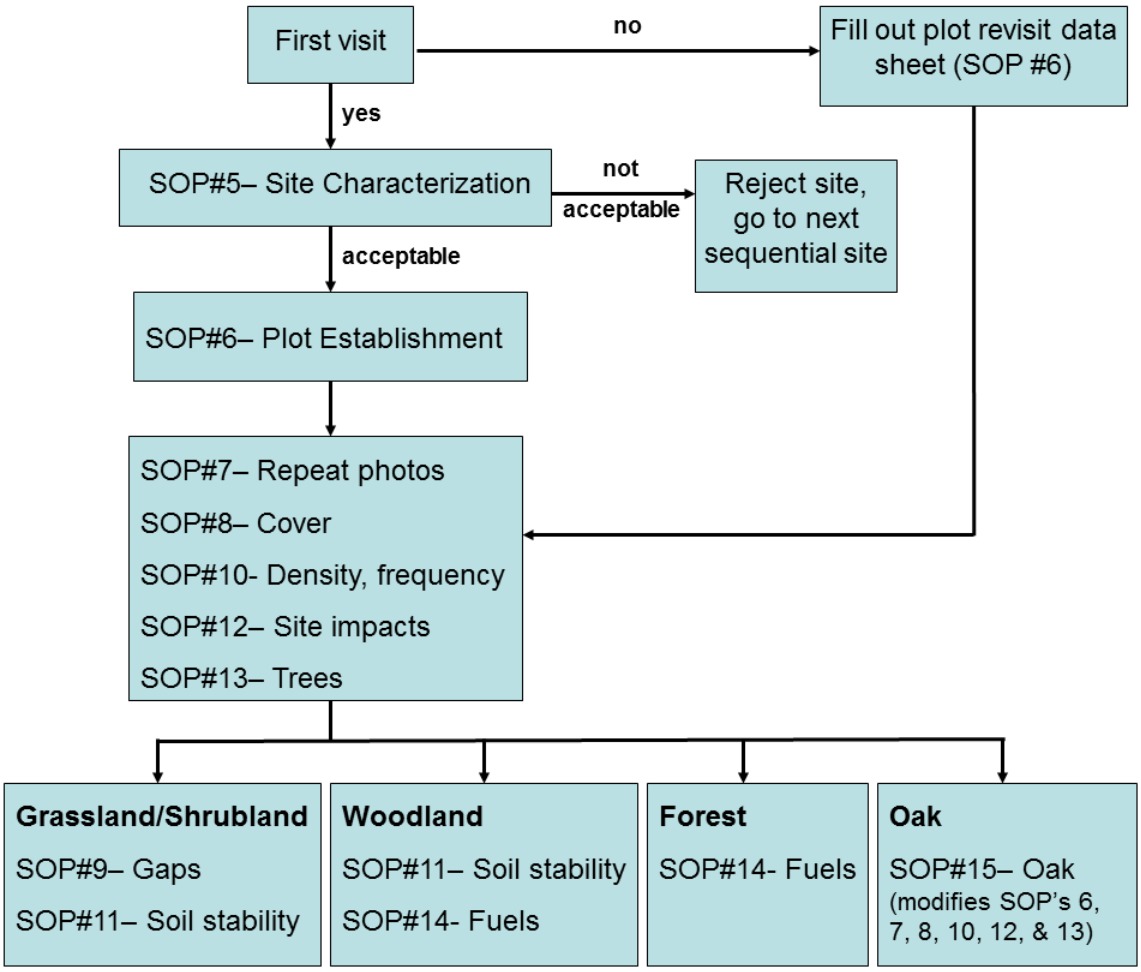


Figure 7. Outline of field procedures for monitoring upland plots.

Grasslands and Shrublands

At the origin of each transect, a photograph is taken down the length of the transect toward the end point (see 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 m intervals along each transect (see SOP #8). Density of shrubs (by species and height class) and tree seedlings (by species) are recorded in a 1-m belt upslope of each transect (see SOP #10). Frequency of exotics species is recorded using 1-m by 1-m quadrats placed every 5 m 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. When saplings or overstory trees occur in grassland or shrubland plots, they are recorded using the same methods as forest and woodland plots (see SOP #13 and section below).

Forests and Woodlands

Photos of each transect are taken from the origin and end (see SOP #7) since vegetation tends to be denser in forests and woodlands. Using the same methods as for grasslands/shrublands, 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) are recorded 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 5-m belt transect centered on transect 2 (see 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 health describes the percent of live foliage for each tree. Crown class describes the relative position of each live tree in the canopy. Overstory canopy closure is measured every 10 m along the transects in forest plots (SOP #10).

Subalpine meadows are sampled following the forest methods outlined above, and in addition, species richness is recorded in a 1-m 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 which extend beyond the plot on two corners (Fig. 3; see 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.

Gambel Oak/Mixed Montane Shrubs

Gambel oak/mixed montane shrub systems are structurally different from other vegetation types on the Colorado Plateau, and the dense, tall vegetation is not easily sampled using standard upland methods. This vegetation type is sampled using three 20-m transects (Fig. 4), and photos are taken at the origin and end of each transect. Point-intercept cover is collected at 0.25 m intervals and exotic frequency is collected at smaller intervals along transects (see SOP #15). Seedlings and saplings are recorded using the same methods as forest and woodland plots. Within the 20 m x 20 m 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 After monitoring is completed at a park unit

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 accomplishments for the season and projected timelines for reports. Any major concerns should be brought to the immediate attention of the 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, which entails asking crew members 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 integrated upland monitoring program. The NCPN has developed a data management plan (Beer et al. 2005) that describes these procedures in general terms. The following outlines the application of those procedures to upland monitoring, and SOP #18 provides explicit instructions.

5.1 Data organization

This long-term monitoring project generates large quantities of data and numerous products, and 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

Upland 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 Program. The database accommodates data collected during plot establishment and each subsequent monitoring visit for all park units where upland 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 is 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 Upland 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 upland 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 that 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 5 years of monitoring, a status and trend assessment will be performed and presented as a comprehensive report. The purposes of this analysis are to:

1) Describe the current conditions (status) of upland indicators (see section 2) using standard univariate and multivariate descriptive statistics and graphical techniques, and interpret these conditions in the context of management objectives,
2) Describe trends (if any) in upland indicators using mixed effects models and multivariate analytical techniques,
3) Use modeling and other data exploration techniques to evaluate potential explanatory variables and covariates over broad thematic and spatial scales,
4) Synthesize this wide-range of information to explore patterns and better understand upland processes and dynamics, and
5) 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 integrated upland monitoring program. The vegetation ecologist acts as the project manager and is responsible for training the permanent biological science technician that acts as the field crew leader. The crew leader oversees approximately 5 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 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 access 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, tailoring the test 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 6 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 monitoring (Table 5). 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, and each team of two will need a dedicated vehicle and sampling equipment. A typical field season consists of thirteen hitches, each with two travel days and six field days. Each 2-person crew will visit approximately 6-8 plots per hitch depending on the location of plots in a park unit relative to roads and trails.

Table 5. Schedule of field visits to park units with upland monitoring.

Time sampled	Park unit
April	ARCH
	CANY
May	
	CARE
June	
	DINO
July	
	BRCA
August	CEBR, TICA
	BLCA, CURE
September	
	ZION
October	

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 summarize 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 NPCN uses a Master Version Table and Version Key Number to track which versions of the narrative and SOPs are used in each version of the monitoring protocol. The Version Key # is essential if project information is to be properly analyzed and interpreted. The protocol narrative, SOPs, and data should never be distributed independently of the Master Version Table.

10. References

Beer, M., E. Nance, A. Wight, M. Powell, and R. DenBleyker. 2005. Northern Colorado Plateau Network, data management plan. National Park Service, Inventory and Monitoring program, Northern Colorado Plateau Network, Moab, UT.

Belnap, J. 2002. Nitrogen fixation in biological soil crusts from southeast Utah, U.S.A.: Biology and Fertility of Soils, v. 35, p. 128-135.

Belnap, J., B. Budel, and O.L. Lange. 2003. Biological soil crusts: Characteristics and distribution, *in* Belnap, J., and Lange, O.L., eds., Biological soil crusts: Structure, function, and management (2nd ed.), Ecological studies series 150: Berlin, Springer-Verlag, p. 3-30.

Bestelmeyer, B. T. 2006. Threshold concepts and their use in rangeland management and restoration: The good, the bad, and the insidious. Restoration Ecology 14: 325-329.

Bock, C. E., J. H. Bock, K. L. Jepsen, and J. C. Ortega. 1986. Ecological effects of planting African lovegrass in Arizona. National Geographic Research, v. 2, no. 4, p. 456-463.

Briske, D. D., S. D. Fuhlendorf, and F. E. Smeins. 2006. A unified framework for assessment and application of ecological thresholds. Rangeland Ecology and Management 59: 225-236.

Brown, J. K. 1974. Handbook for inventorying downed woody material. USDA Forest Service General Tech. Report INT-16, Intermountain Forest and Range Experiment Station, Ogden, UT.

Buchanan, H. 1971. Changing conditions in the forests of Bryce Canyon National Park, Utah. Utah Academy Proceedings. Volume 48, Part 1. p. 31-36.

Buchanan, H., R. A. Graybosch, and K. T. Harper. 1981. Plant community changes at Bryce Canyon national park from 1957-1980. Final report to the National Park Service, Contract No. CX-1200-8-B016. 68 p.

Cochran, W. G. 1977. Sampling techniques. John Wiley & Sons, N.Y. 428pp.

DeBacker, M.D., A.N. Sasseen, C. Becker, G.A. Rowell, L.P. Thomas, J.R. Boetsch and G.D. Wilson. 2004. Vegetation Community Monitoring Protocol for the Heartland I&M Network and Prairie Cluster Prototype Monitoring Program. National Park Service, Heartland Inventory and Monitoring Network and Prairie Cluster Prototype Monitoring Program, Wilson's Creek National Battlefield, Republic, Missouri. 40p. plus appendices.

Edwards, D. 1998. Issues and themes for natural resource trends and change detection. Ecological Applications 8:323-325.

Elzinga, C., D. Salzer and J. Willoughby. 1998. Measuring and monitoring plant populations. BLM Technical Reference 1730-1, 492 pp.

Evans, R. D., and O.L. Lange. 2003. Biological soil crusts and ecosystem nitrogen and carbon dynamics, *in* Belnap, J., and Lange, O.L., eds., Biological soil crusts: Structure, function, and management (2nd ed.), Ecological studies series 150: Berlin, Springer-Verlag, p. 263-279.

Evenden, A., M. Miller, M. Beer, E. Nance, S. Daw, A. Wight, M. Estenson, and L. Cudlip. 2002. Northern Colorado Plateau Vital Signs Network and Prototype Cluster, Plan for Natural Resources Monitoring: Phase I Report, October 1, 2002. [Two volumes]. National Park Service, Northern Colorado Plateau Network, Moab, UT. 138 p. plus appendices.

Federal Geographic Data Committee (FGDC). 1997. Vegetation classification standard [online]. Available from http://www.fgdc.gov/standards/projects/FGDC-standards-projects/vegetation/vegclass.pdf [Cited 1 June 2011].

Garfin, G. M., J. K. Eischeid, M. T. Lenart, K. L. Cole, K. Ironside, and N. Cobb. 2010. Downscaling climate projections in topographically diverse landscapes of the Colorado Plateau in the arid southwestern United States. *In* van Riper III, C., B. F. Wakeling, and T. D. Sisk, eds., The Colorado Plateau IV: Shaping conservation through science and management. Tucson: The University of Arizona Press.

Garman, S. L. 2007. Review of Black Canyon of the Gunnison National Park/Curecanti National Recreation Area Vegetation and Bird Monitoring Programs. Northern Colorado Plateau Inventory and Monitoring Program, Biology Department, Mesa State College, Grand Junction, CO 81501.

Harper, K.T., and J. Belnap. 2001. The influence of biological soil crusts on mineral uptake by associated vascular plants: Journal of Arid Environments, v. 47, no. 3, p. 347–357.

Harris, T.A., G.P. Asner, and M.E. Miller. 2003. Changes in vegetation structure after long-term grazing in pinyon–juniper ecosystems: Integrating imaging spectroscopy and field studies: Ecosystems, v. 6, no. 4, p. 368–383.

Herrick, J.E., J.W. Van Zee, K.M. Havstad, L.M. Burkett, and W.G. Whitford. 2005. Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems. Published as 2 volumes. Jornada Experimental Range, USDA 236 pp.

Lange, O.L. 2003. Photosynthesis of soil-crust biota as dependent on environmental factors, *in* Belnap, J., and Lange, O.L., eds., Biological soil crusts: Structure, function, and management (2nd ed.), Ecological studies series 150: Berlin, Springer-Verlag, p. 217-240.

McKnight, K. B., and H. Buchanan. 2000. The dynamics of forest succession in Bryce Canyon national park. Final report to the National Park Service. 159 p.

Miller, M.E. 2005. The Structure and Functioning of Dryland Ecosystems—Conceptual Models to Inform Long-Term Ecological Monitoring: U.S. Geological Survey Scientific Investigations Report 2005-5197.

Miller, M. E., D. L. Witwicki, R. K. Mann, and N. J. Tancreto. 2007. Field evaluations of sampling methods for long-term monitoring of upland ecosystems on the Colorado Plateau. U.S. Geological Survey Open-File Report 2007-1243. http://pubs.usgs.gov/of/2007/1243/.

Miller, M. E., R. T. Belote, M. A. Bowker, and S. L. Garman. 2011. Alternative states of a semiarid grassland ecosystem: implications for ecosystem services. Ecosphere 2(5):1-18.

Munson, S. M., J. Belnap, C. D. Schelz, M. Moran, and T. W. Carolin. 2011a. On the brink of change: plant responses to climate change on the Colorado Plateau. Ecosphere 2(6):1-15.

Munson, S. M., J. Belnap, and G. S. Okin. 2011b. Responses of wind erosion to climate-induced vegetation changes on the Colorado Plateau. Proceedings of the National Academy of Sciences of the USA 108(10):3854-3859.

Nusser, S. M., F. J. Breidt, and W. A. Fuller. 1998. Design and estimation for investigating the dynamics of natural resources. Ecological Applications 8:234-245.

O'Dell, T.E., S.L. Garman, A. Evenden, M. Beer, E. Nance, A. Wight, M. Powell, D. Perry, R. DenBleyker, *et al*. 2005. Northern Colorado Plateau Inventory and Monitoring Network, Vital Signs Monitoring Plan, National Park Service, Inventory and Monitoring Network, Moab, UT. 174 p. plus appendices.

Peck, D.V., J.M. Lazorchak, and D.J. Klemm (editors). Unpublished draft. Environmental Monitoring and Assessment Program -Surface Waters: Western Pilot Study Field Operations Manual for Streams. EPA/XXX/X-XX/XXXX. U.S. Environmental Protection Agency, Washington, D.C.

Perkins, D., K. Edvarchuk, S. Dewey, H. Thomas, and A. Wight. IN REVIEW. Invasive plant vital signs monitoring protocol for park units in the Northern Colorado Plateau Network. National Park Service, Moab, UT.

Peters, D. P. C., B. T. Bestelmeyer, J. E. Herrick, E. L. Fredrickson, H. C. Monger, and K. M. Havstad. 2006. Disentangling complex landscapes: New insights into arid and semiarid system dynamics. BioScience 56: 491-501.

Rosentreter, R., and J. Belnap. 2003. Biological soil crusts of North America, *in* Belnap, J., and Lange, O.L., eds., Biological soil crusts: Structure, function, and management (2nd ed.), Ecological studies series 150: Berlin, Springer-Verlag, p. 31-51.

Schelz, C. 2002a. Vegetation long-term monitoring – Arches National Park 2002 Annual report. Southeast Utah Group, National Park Service, Moab, UT.

Schelz, C. 2002b. Vegetation long-term monitoring – Canyonlands National Park 2002 Annual report. Southeast Utah Group, National Park Service, Moab, UT.

Schelz, C. 2002c. Vegetation long-term monitoring – Hovenweep National Monument 2002 Annual report. Southeast Utah Group, National Park Service, Moab, UT.

Schelz, C. 2002d. Vegetation long-term monitoring – Natural Bridges National Monument 2002 Annual report. Southeast Utah Group, National Park Service, Moab, UT.

Schreuder, H. T., R. Ernst, and H. Ramirez-Maldonado. 2004. Statistical techniques for sampling and monitoring natural resources. USDA Forest Service, Rocky Mountain Research Stn., RMRS-GTR-126. 111pp.

Scull, P., J. Franklin, and O. A. Chadwick. 2005. The application of classification tree analysis to soil type prediction in a desert landscape. Ecological Modelling 181:1-15.

SRM (Society for Range Management). 1989. Glossary of terms used in range management. 3rd edition. Denver: Society for Range Management.

——. 1995. New concepts for assessment of rangeland condition. Journal of Range Management 48:271–282.

Stevens, D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262-278.

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.

USDI National Park Service. 2003. Fire Monitoring Handbook. Boise (ID): Fire Management Program Center, National Interagency Fire Center, 274p.

VSL (Visual Learning Systems). 2002. User Manual, Feature Analyst Extension for ArcView 3.2, Visual Learning Systems, Inc. Missoula, MT.

Webb, R.H., Belnap, J., and Weisheit, J.S., 2004, Cataract Canyon -- A human and environmental history of the rivers in Canyonlands. Salt Lake City, University of Utah Press, 268 p.

Whelan, R.J. 1995. The ecology of fire: Cambridge, Cambridge University Press, 346 p.

Whitford, W.G. 2002. Ecology of desert systems: San Diego, CA, Academic Press, 343 p.

Williams, J.D., J.P. Dombrowolski, D.A. Gillette, and N.E. West. 1995. Microphytic crust influence on wind erosion: Transactions of the American Society of Agricultural Engineers, v. 38, p. 131-137.

Woodward, A. 2004. Temporal Sampling Frames: Summary of a Workshop. USGS Forest & Rangeland Ecosystem Science Center Olympic Field Station, Park Avenue, Port Angeles, WA.