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Greater Yellowstone Network Upland Vegetation Monitoring Protocol

Narrative, Version 1.0

Natural Resource Report NPS/GRYN/NRR—2013/623

ON THE COVER
Upland vegetation monitoring at Bighorn Canyon National Recreation Area
Photograph by: NPS, Erin Shanahan

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Natural Resource Report NPS/GRYN/NRR—2013/623

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This protocol uses methods based on an established peer-reviewed protocol. Additional formal peer review was received by a subject-matter expert not directly involved in the development of the sample design and sample size analysis, and whose background and expertise put them on par technically and scientifically with the authors.

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Standard Operating Procedures

This report is linked to the following Standard Operating Procedures (SOPs), which can be found in Jean et al. (2013).

SOP 1: Field Safety

SOP 2: Field Preparation and Season Close-out

SOP 3: Training Observers

SOP 4: Locating and Establishing Sampling Quadrats

SOP 5: Measuring Plant Community Attributes

SOP 6: Data Management

SOP 7: Data Analysis and Reporting

SOP 8: Protocol Revision

Abstract

This document describes a protocol for monitoring indicators of ecological condition within upland plant communities of Bighorn Canyon National Recreation Area (Bighorn Canyon). Upland vegetation and soils at Bighorn Canyon were identified as a vital sign in the Greater Yellowstone Network's (GRYN) monitoring plan (Jean et al. 2005) and as an important indicator of ecological response to climate change in the National Park Service's (NPS) climate change response strategy for high elevation parks (Bingham et al. 2010). The upland plant community types of interest for monitoring in this protocol are sagebrush (*Artemisia tridentata*), juniper (*Juniperus* spp.), and juniper-mountain mahogany (*Cercocarpus ledifolius*).

Sagebrush and woodland communities are among the most dominant and common vegetation types in Bighorn Canyon, occurring over 60% of the land area inside the park (Knight et al. 1987). These vegetation communities provide important habitat for wildlife and are used by the Pryor Mountain wild horse herd (Komp et al. 2012). The quality and abundance of key plant species and soil cover in these communities are considered indicators of overall rangeland health and the focus of our monitoring objectives which are to determine the status (current condition) and trends (change in condition over time) in composition and abundance of key plant species and soil cover attributes. The selected monitoring metrics include ocular estimation of canopy and ground cover by Daubenmire (1959) cover class and stem counts of juniper and mountain mahogany trees <10 cm tall.

Since protocols with similar objectives have previously been produced by the NPS Inventory and Monitoring (I&M) network (Manier et al. 2011, Garmen et al. 2008) GRYN adapted the Upper Columbia Basin Network's (UCBN) sagebrush steppe monitoring protocol (Yeo et al. 2009). The GRYN protocol is very similar but the monitoring design has an option for a larger quadrat when sampling woodlands (not included in the UCBN monitoring design) and also includes both litter and cryptogamic crust soil in addition to bare ground as ground cover attributes. The sample and revisit design are specific to Bighorn Canyon and the Standard Operating Procedures (SOPs) described in Jean et al. (2013) reflect current data collection and management practices of the GRYN which differ somewhat from the UCBN.

The sample design for this protocol uses temporary quadrats that are randomly assigned each year prior to a sampling visit. The quadrats are distributed within each sample frame by the Generalized Random-Tessellation Stratified (GRTS) algorithm. A total of 925 sample quadrats within 15 permanent sample frames will be visited in a cycle that repeats every three years with a portion of the sample frames visited annually.

Field methods for this protocol are designed to be readily learned by individuals with some field experience identifying plants but do not depend on advanced expertise in plant taxonomy. A week of field training includes calibration exercises for ocular cover estimation and plant identification for each target species. Observed and measured data values are entered directly into a database on a field computer. At the end of the field season, the database and all physical project materials are quality-control checked and then filed with the project records archived in the GRYN office. Status results are summarized and reported after each year of data collection; analysis will primarily focus on estimating the proportion of sampling plots within each Daubenmire cover class. Differences in plant cover (%) measured during two different years (a

“step-change”) will be assessed with a proportion test (Sheskin 2007, described in the text.) The significance of linear trends in plant cover will be tested using a Proportional Odds Model, following the methods of Irvine and Rodhouse (2010).

Glossary of Important Terms

Canopy cover: The percentage of the ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of plants. Openings within an individual plant's foliar canopy are included in cover estimation. Canopy cover is typically restricted to live plants and live portions of plants with dead limbs, unless otherwise specified.

Forb: Herbaceous plants other than grasses, sedges, and rushes (graminoids).

Frequency of occurrence: A measure of the number of occurrences of an event in space or time. In plant sampling, percent frequency is the proportion of all sample quadrats containing a particular species of interest. To compare occurrence from sites having different sample sizes, percent frequency of occurrence must be used.

Generalized Linear Model: A generalization of the ordinary least squares method of regression. A generalized linear model relates the random response component of the model, which may be non-linear, to the non-random predictor variables (e.g., year) through a link function.

Odds ratio: A statistical measure of effect size between two proportions. It is calculated as the ratio of the odds of an event happening in one group (e.g., of a quadrat occurring in cover classes ≤3 in year 1) to the odds of an event happening in another group (e.g., of a quadrat occurring in cover classes ≤3 in year 2).

Ordinal data: Categorical data having naturally ordered ranks or scale, such as vegetation cover classes and ranked soil/site stability classes.

Perennial versus annual plants: Perennial plants live for two or more years and have structures such as tubers, rhizomes, and woody crowns that allow them to survive winters. Annual plants live through a single season, and reproduce from seed.

Phenology: The timing of plant and animal life-cycle events that are influenced by climate and seasonal changes in the environment; the time frame for any seasonal phenomena. Examples include the date of emergence of particular species of leaves and flowers, the first flight of butterflies, and the first appearance of migratory birds.

Power analysis: A power analysis determines the probability of correctly rejecting a false null hypothesis given fixed values of effect size, variance, and sample size. The **power** of a statistical test is the probability that the test will reject a false null hypothesis (i.e., that it will not make a Type II statistical error). As power increases, the chance of a Type II error decreases, while the probability of a Type I statistical error increases in direct relation. The probability of a Type II error is referred to as β. Therefore power is equal to 1-β. Power is a function of effect size or minimum detectable change, variance of the parameter (e.g., standard error of the mean), and sample size.

Quadrats: A spatial sampling unit usually used for quantifying vegetation or habitat having a standardized fixed area. Quadrats are usually delineated using a sampling device either square or circular in shape. The purpose of using a quadrat is to enable comparable samples to be obtained from areas of consistent size and shape. Quadrats of increasing size can be nested in order to capture scalar processes or to efficiently sample a range of species of different sizes and distributions.

Sample Frame: An area designated by geographical boundaries within which the sampling units are placed and evaluated (Jean et al. 2005).

Sample Unit: The area within the sample frame that is actually sampled. In this protocol the sample unit is a quadrat (see definition).

Spatially-balanced sample: Spatial balance refers to distributing sample locations across a resource in a regular or balanced pattern for the purposes of optimizing sampling efficiency. Such a sample typically has advantages over alternatives such as **simple random** and **stratified** samples in terms of statistical efficiency and logistical flexibility. The generalized random tessellation stratified (GRTS) approach is one important and widely used method of obtaining a spatially-balanced sample.

Status: Status is a measure of a current attribute, condition, or state, and is typically presented as a mean value.

Step change
A change in plant cover measured during two different years. For example, the step change difference between plant cover values from two consecutive years may be tested for statistical significance using a proportion test. A step change stands in contrast to a linear trend over time, which includes data from multiple years in a time series.

Temporal variation: Variation over time. In a population it is reflected as variation around a mean over time. For our purposes this typically refers to variation seasonally or annually.

Threshold: A threshold is a point "…in space and time at which one or more of the primary ecological processes responsible for maintaining the sustained equilibrium transition to an alternate level or state. Of concern are thresholds where the condition degrades beyond the point of repair. Fundamental processes often must be actively restored before the return to the previous state is possible. In the absence of active restoration, a new state is formed (Stringham et al. 2001:5)."

Trend: Trend is a measure of directional change in condition over time. It can occur in some population parameter, such as a mean (net trend), or in an individual member or unit of a population (gross trend).

Type I error: The declaration of a statistically significant difference when in fact, no difference exists. It is referred to as a "false change" error, or an error of commission in statistical hypothesis tests.

Type II error: The declaration that no statistically significant difference exists when in fact a real difference does exist. It is also referred to as a “missed change” error, or an error of omission in statistical hypothesis tests.

Vital signs: A subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values (Fancy et al. 2009) The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve “unimpaired for future generations,” including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population, or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes).

Introduction

This document describes a protocol for monitoring indicators of ecological condition in upland plant communities of Bighorn Canyon National Recreation Area (Bighorn Canyon). Upland vegetation and soils at Bighorn Canyon were identified as a vital sign in the Greater Yellowstone Network's (GRYN) monitoring plan (Jean et al. 2005) and as an important indicator of ecological response to climate change in the National Park Service's (NPS) climate change response strategy for high elevation parks (Bingham et al. 2010). Plant communities described by Knight et al. (1987) that are dominated by sagebrush (*Artemisia tridentata, A. nova*), juniper (*Juniperus* spp.), and juniper-mountain mahogany (*Cercocarpus ledifolius*) are of specific interest to park managers because of their importance to wildlife. Since protocols with similar objectives have already been produced by the NPS Inventory and Monitoring (I&M) Program, GRYN conducted a thorough review of multiple candidate protocols (Garmen et al. 2008, Manier et al. 2011, Yeo et al. 2009), and adapted the Upper Columbia Basin Network's (UCBN) sagebrush steppe monitoring protocol (Yeo et al 2009). The protocol described here contains minor substantive modifications of the UCBN protocol, and some of the sections have been organized differently.

A pilot monitoring effort using the methods described here was conducted during 2011 - 2012 (Tercek 2012). Following this trial, GRYN worked with Bighorn Canyon staff to define sample frame boundaries suitable for long-term monitoring. The greatest change to the original UCBN methods involved the adoption of a second, larger quadrat (3.16 m^2) to accommodate the presence of larger trees in the sample frames at Bighorn Canyon which were not found in the areas monitored by UCBN.

The UCBN protocol is also being implemented in Grand Teton National Park (Grand Teton) by the original authors (Yeo and Rodhouse 2012a) as part of the NPS climate change strategy (Bingham et al. 2010). While the duration of monitoring in Grand Teton may be limited by funding, using similar protocols among parks within GRYN and across networks (i.e., GRYN and UCBN) increases the potential for analyzing patterns and trends at a larger regional scale.

Bighorn Canyon is one of the four national park units for which the GRYN provides long-term monitoring of select vital signs as part of the NPS inventory and monitoring program, which was established as part of the NPS Natural Resource Challenge (National Park Service 1999). The park is located on the Wyoming-Montana border within an arid region east of the Pryor Mountains, and a portion of the Pryor Mountain Wild Horse Range (PMWHR) is included within its boundaries (Komp et al. 2012). Three major floristic ecoregions occur within the park: Great Basin, Rocky Mountain, and Great Plains (Knight et al. 1987). This protocol focuses only on upland steppe and woodland communities.

Rationale for Monitoring Sagebrush Steppe and Woodlands

Sagebrush steppe and woodland communities are among the most dominant and common vegetation types in Bighorn Canyon, occurring over 60% of the land area inside the park (Knight et al. 1987). Woodland communities are composed of Utah juniper (*Juniperus osteosperma*) and curl-leaf mountain mahogany (*Cercocarpus ledifolius* var. *ledifolius)*, whereas sagebrush steppe is a mosaic of Wyoming big sagebrush (*Artemisia tridentata* var. *wyomingensis*) and black sagebrush (*Artemisia nova*) shrublands with patches of grasslands dominated by bluebunch wheatgrass (*Pseudoroegneria spicata*).

These vegetation communities provide important habitat for wildlife in Bighorn Canyon. Mountain mahogany communities provide food and habitat for both bighorn sheep (*Ovis canadensis*) and mule deer (*Odocoileus hemionus*), as well as other ungulates (BLM 2009). Sagebrush steppe provides habitat for ungulates and sagebrush-obligate birds such as the sage sparrow (*Amphispiza belli*) and Brewer's sparrow (*Spizella breweri*), which often require stands having specific plant densities for successful nesting to occur. All three community types included in this protocol are used to some extent by the park's wild horse herd, and the quality and abundance of key plant species in these communities are considered indicators of overall rangeland health by many researchers and agencies that cooperatively manage the area with the National Park Service (Ricketts et al. 2004, BLM et al. 2008).

Across the west, shrublands and grasslands have been extensively modified by human development (Bingham et al. 2010), and in Bighorn Canyon, which has a long history of human inhabitance (Komp et al. 2012), anthropogenic effects on upland vegetation are particularly apparent. Prior to the establishment of the national recreation area in 1967, several large cattle ranches operated in the area, and cattle grazing is still permitted adjacent to the main road and in two small pastures. In addition, wild horses graze within the PMWHR in the south district of Bighorn Canyon, and several areas have been degraded by invasive weeds, particularly cheatgrass (*Bromus tectorum*; Ricketts et al. 2004, BLM et al. 2008).

As a result of these disturbances, a recent rangeland health assessment concluded that the Bighorn Canyon portion of the PMWHR had only 44% similarity to baseline data collected in 1981, and that 67% of the plant communities surveyed were in a "downward trend" (Ricketts et al. 2004). Thirty-one percent of the area was experiencing severe soil erosion; bare soil cover ranged from 22% to 74% of the surface area; and biological soil-crust cover ranged from 0 to 5% (Ricketts et al. 2004). Overall, the PMWHR was described as being in a state of "moderate-to-extreme departure" from historic conditions (Ricketts et al. 2004).

Park managers are particularly concerned with the change in structure and function of the soils in upland habitats, including the loss of cryptobiotic soils (Jean et al. 2005). Indeed, factors that contribute to change in native vegetation also impact native soils and may result in erosion, loss of biological soil crust cover and high incidence of bare soil. Soil crusts and cryptobiotic soils are particularly important to arid regions as they provide soil stability and nutrients that are otherwise lacking and tend to fill in the undisturbed gaps between vegetation (Rosentreter et al. 2007).

Objectives

The objectives for this monitoring protocol focus on measuring a few key attributes that are fundamental indicators of ecosystem health (i.e., representing targeted monitoring). These objectives measure a subset of ecological indicators commonly used to assess rangeland soil/site stability, hydrologic function and biotic integrity (National Research Council 1994, Pellant 2005). A detailed rationale for their selection is given in subsequent sections of this protocol. Routine data on these key features of plant community health will facilitate effective adaptive management strategies.

This protocol addresses the following monitoring objectives:

1. Determine the status (i.e., current condition) and trends (i.e., change in condition over time) in the composition and abundance (cover) of principal native plant species, in targeted communities within Bighorn Canyon that contain Utah juniper-mountain mahogany woodlands, sagebrush shrubland, and/or grasslands. Each principal species will be quantified separately.
2. Determine the status and trends in composition and abundance (cover) of principal invasive plant species, including annual grasses, in targeted communities within Bighorn Canyon that contain Utah juniper-mountain mahogany woodlands, sagebrush shrubland, and/or grasslands. Each invasive species will be quantified separately.
3. Determine the status and trend in the amount of exposed soil (cover), a fundamental indicator of soil stability, in targeted communities within Bighorn Canyon that contain Utah juniper-mountain mahogany woodlands, sagebrush shrubland and/or grasslands.
4. Determine the status and trend in the amount of cryptobiotic crust (cover), in targeted communities within Bighorn Canyon that contain Utah juniper-mountain mahogany woodlands, sagebrush shrubland, and/or grasslands.

Differences between the GRYN and the UCBN Protocol

As mentioned previously, this GRYN protocol was adapted from the peer-reviewed and approved Sagebrush Steppe Protocol developed by the UCBN (Yeo et al. 2009). The GRYN made primarily minor changes to the UCBN protocol. Most of these involved formatting and organization, such as combining and reducing the number of standard operating procedures. The changes worth noting made for this version of the GRYN protocol are:

1. The GRYN protocol extends vegetation monitoring to the Bighorn Canyon National Recreation Area and conditions therein. As such, the GRYN sample design employed is essentially the same; however, the monitoring objectives and target population include woodland communities dominated by Utah juniper or Utah juniper-mountain mahogany in addition to shrub steppe communities, not found in the UCBN monitoring areas of interest.

2. The GRYN protocol response design was expanded by adding a larger quadrat when sampling woodlands to accommodate crown size of shrubs and trees. This is in contrast to the response design for the UCBN protocol which is specific to sagebrush steppe vegetation (e.g., shrubs <1 m tall). The UCBN tested several different sample plots during the preparation of their protocol and concluded that a 1 m^2 quadrat was optimal for sagebrush steppe vegetation because it allowed for efficient assessment since the observer does not need to move to see the entire area. Since the protocol described here is expanded to include woodlands, a 10 square meter (3.16 m x 3.16 m) sampling quadrat is added to the response design to measure tree cover. In addition, juniper and mountain mahogany trees less than 10 cm in height are counted in the 10 square meter sampling quadrat to measure recruitment of these species. All other plant species encountered by this protocol are measured in the 1 m^2 quadrat following the methods of UCBN.

3. The GRYN power analysis includes an examination of how “clumpy,” sparsely distributed species like Utah juniper trees are quantified analytically under scenarios of different sample size. These species are patchy across the landscape with large areas of no occurrence broken by infrequent, high-density aggregations, which is referred to as “clumpy” throughout the protocol. This analysis found that rare cover classes (classes that have low frequency of occurrence, occurring in a small proportion of plots) of these spatially clumpy species may not be detected by our sampling every year because of the random selection of Generalized Random-Tessellation Stratified (GRTS) points, but that these “gains and losses” should not be interpreted as “real.” This effect is due to the detectability of rare phenomena, a consideration that is separate from power. The rest of our power analysis is logically and mathematically consistent with the UCBN analysis.

4. The GRYN protocol has been expanded to add litter and cryptogamic soil crust cover to the ground cover attributes measured. Park managers at Bighorn Canyon are concerned about soil/ site stability and measures of soil cover attributes provide greater resolution for evaluating soil condition. Soil stability was a selected as a vital sign for the GRYN (Jean et. al. 2005).

5. The protocol was modified to reflect more updated data collection and management practices and technologies available to the GRYN which have no bearing on quantification methods. Procedures used by the GRYN differ somewhat from the UCBN in that the protocol was changed to reflect local practices. Changes include: (a) the GRYN uses a tablet computer for collecting and entering data directly into the Microsoft ™ Access database. However, the database structure is exactly the same as the UCBN; (b) the GRYN protocol includes procedures for repeat photography of sample frames to help visually describe changes; and (c) for safety reasons, the GRYN requires field staff to work in teams of two unless there is prior approval by the Network Program Manager.

Sampling Design

Our monitoring design uses temporary 1 m^2 and 3.16 m^2 (10 square meter) quadrats that are randomly assigned each year within permanent sampling frames geographically delineated to meet long-term monitoring objectives (see a "never revisit" design [1-n] *sensu* McDonald 2003). In this design, quadrat locations change from year to year, but the areas of inference (the sample frames) remain constant. Each sample frame is located within one of three target plant communities: sagebrush steppe, Utah juniper woodland, or Utah juniper-mountain mahogany woodland. Within each quadrat, principal indicator plant species and soil cover attributes (Table 1) are assessed using ocular estimation of cover and recorded in cover classes developed by Daubenmire (1959), herein referred to as "cover class or as Daubenmire's cover class." In this approach, 1 m^2 quadrats are used for all species and ground cover estimates at all sample points. However, when any one of Utah juniper, Rocky Mountain juniper *(Juniperus scopulorum),* mountain mahogany, or limber pine (*Pinus flexilis*), occur within a 10 square meter quadrat area, a 3.16 m x 3.16 m quadrat is superimposed over the 1 m^2 quadrat to quantify these species. In addition to cover, trees <10 cm in height are counted in the larger plot and the number recorded for each species.

Sampling Design Rationale

Monitoring large landscapes with limited funding and time poses unique challenges that require compromises among (1) the accuracy and precision of measurements needed to detect meaningful change, (2) the large sample sizes and extensive sampling required to reflect the high natural variability in vegetation across large landscapes, and (3) the logistical constraints posed by rugged and often inaccessible terrain. As a result, our criteria for selecting this design for long-term monitoring are:

- an efficient response design that permits rapid measurements, thus allowing for large sample sizes and good dispersion of sample units;
- rapid quantification of principal indicators of ecological condition with sufficient precision to detect meaningful estimates of status and trend; and
- accessible, easily learned and repeatable field methods that can be consistently applied among observers.

Sampling design development is an exercise in cost-benefit trade-offs, and given the highly disturbed and environmentally heterogeneous (sees Introduction) landscapes in Bighorn Canyon, we have placed a premium on obtaining large and truly representative samples. To this end, we kept the amount of information gathered at each quadrat (Bonham 1989, Elzinga et al. 2001, de Gruijter et al. 2006) to a minimum, in favor of gathering data over a broader area at more frequent intervals. The benefits of measuring less detailed information on key indicators of community condition from many locations across the park far outweigh the added costs of gathering detailed information from only a few locations. The upland vegetation communities that we monitor in Bighorn Canyon are subject to high inter-annual variability, largely driven by seasonal precipitation patterns (Singer and Schoenecker 2000, Tercek 2010), and we have increased our sampling frequency in order to accommodate this natural variability. As described below, many of our sample frames are visited every year.

Attempting to monitor many ecosystem attributes (i.e., many species or metrics about species) that may be useful to know, but that require an expense of time and personnel is not practical for monitoring large landscapes (i.e., surveillance monitoring *sensu* Nichols and Williams 2006). This protocol, therefore, will focus on measuring a few key attributes that are fundamental indicators ecosystem health (i.e., representing targeted monitoring). The National Research Council (1994) recommended key indicators of rangelands that should be the basis for monitoring all rangeland conditions and trends. Subsequent to these recommendations, Pellant (1999), Pellant et al. (2005), Pyke et al. (2002), O'Brien et al. (2003), and Herrick et al. (2005) developed assessments using specific indicators of key attributes of rangeland condition. We have adopted a subset of those indicators for monitoring (Table 1). We also consulted Knight et al. (1987), Ricketts et al. (2004), and the Bureau of Land Management (BLM 2008) to identify the principal plant species that were both common to the specific sites being visited and considered important indicators of rangeland condition and develop a target list for monitoring.

Table 1. Indicators for rangeland health and their quantitative attributes for Bighorn Canyon. Refer to Appendix A for a complete list of principal plant species targeted for monitoring in this protocol.

Indicator	Quantitative attributes	Interpretation
Biotic integrity	Percent plant (foliar) cover of principal trees and shrubs, including, but not limited to Utah juniper, sagebrush, and mountain mahogany. Stem counts of juniper, limber pine and mountain mahogany shrubs/trees less than 10 cm in height Percent plant (foliar) cover of principal native grasses, including but not limited to, bluebunch wheatgrass, needle and thread, and Sandburg's bluegrass Percent (foliar) cover of principal non-native and invasive species	Changes in species composition can signal a direction of change in ecological status The number of non-native species and their cover signify a deteriorating condition
Soil/site stability	Percent litter cover defined as detached dead stems, leaves, and other woody debris in contact with the ground Percent cryptogamic crust ground cover (e.g., non-vascular plants)	Litter and cryptogamic crust cover protect soil from erosion
Hydrologic function	Percent exposed bare ground cover defined as bare soil (mineral soil) not covered by plant canopies. Gravel greater than ¼", rock, cryptogamic crust, and litter are excluded from bare ground cover estimates	Bare ground is positively correlated with run-off and erosion Non-native plants colonize and increase on bare ground

The chosen indicators are readily and efficiently measured, and address rangeland manager concerns regarding maintenance of biotic integrity, soil stability, and hydrologic function. The extent of bare ground is directly tied to hydrologic and soil stability (National Research Council 1994, Van Haveren 2001, Pellant et al. 2005). Abundances of shrubs and native grasses are crucial to the function of upland vegetation communities. Moreover, they are also monitored as part of the rangeland condition assessments conducted by cooperating agencies (e.g., Natural Resource Conservation Service, Bureau of Land Management) on lands in and surrounding Bighorn Canyon (BLM et al. 2008, Ricketts et al. 2004). Finally, because of the region's long history of human disturbance, including cattle ranching, dam construction, mining on nearby lands, and continued grazing activity within Bighorn Canyon, invasive weeds are a pervasive concern to park management and clearly observed in our sample frames during our pilot work (BLM et al. 2008, Ricketts et al. 2004, Tercek 2012).

Response Design

To monitor landscapes efficiently, a technique is needed that allows rapid and reliable estimation of the monitoring parameters and a sample unit that is practical, large enough to encompass the average community patch size (species assemblage) to reduce sample variance, but small enough to be quickly measured. This is particularly important in rough terrain and dense vegetation.

Sample Metrics

The principal monitoring metric used in this protocol is the visually estimated canopy cover class (Daubenmire 1959; Table 2) of live or current-year foliage of principal sagebrush steppe and Utah juniper woodland plant species (refer to Appendix A for target list), exposed bare soil, litter, and cryptogams, estimated in either 1 m^2 or 10 square meter quadrats. The smaller 1 m^2 quadrats are used for all but four tree species on the target list (Utah juniper, Rocky Mountain juniper, mountain mahogany, and limber pine), which are measured only in the 10 square meter quadrat. Sampling using both size quadrats is hierarchical; all sample locations will be sampled using the 1 m^2 quadrat. If any of the aforementioned four tree species occur within the immediate area, the larger 3.16 m x 3.16 m quadrat will be placed with its lower right corner in the same location as the corner of the 1 m^2 quadrat and shrubs and trees quantified in the larger quadrat (see Standard Operating Procedure (SOP) 4: Locating and Establishing Sampling Quadrats).

Table 2. Daubenmire cover classes and the median values used for calculating overall percent cover a species (Daubenmire 1959, BLM 1992).

Cover Class	Range	Median
0	0%	0%
1	>0-5%	2.50%
2	>5-25%	15%
3	>25-50%	37.50%
4	>50-75%	62.50%
5	>75-95%	85%
6	>95%	97.50%

Canopy cover is defined herein as the percentage of the ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of plants (Society of Range Management 1999). Openings within an individual plant’s foliar canopy are included in cover estimation (Pellant et al. 2005). Although canopy cover estimation is sensitive to seasonal variation in precipitation and plant phenology, and visual estimates can differ among observers, cover estimates can be readily visualized by managers and are more sensitive to species occurring in low abundance, such as invasive forbs and incipient infestations of annual grasses (Elzinga et al. 2001).

Visual estimation of plant cover has been widely used and recommended (Daubenmire 1959, Grieg-Smith 1983, Mitchell et al. 1988, Bonham 1989, Peet et al. 1998, Elzinga et al. 2001, McCune and Grace 2002, Beck et al. 2009). Visual estimates of plant cover can be assessed rapidly, and can be equal to or more accurate and precise than estimates obtained through more intensive (and seemingly more "objective") means such as line or point intercept methods. This is especially true when a cover class scheme is used that has narrow cover width categories at the tails and broader cover width categories in the center, and when consistent training and calibration exercises are conducted (Hatton et al. 1986, Meese and Tomich 1992, Dethier et al. 1993, Brakenhielm and Qinghong 1995, Murphy and Lodge 2002, McCune and Grace 2002). Daubenmire's (1959) ranked cover categories satisfy the need for narrow cover classes at the extremes with broad cover ranges in the middle (Table 2), and the distinction between cover classes can be readily learned by a wide range of field people. The large sample sizes, acceptable precision, and the small quadrat sizes utilized by this protocol are also likely to mitigate problems inherent in the visual estimation of cover classes (Mitchell et al. 1988).

Frequency of invasive species occurrence, measured as the proportion of quadrats containing an invasive, can be obtained by querying the project database for all quadrats with cover >0% for each invasive species. Frequency provides additional information on spatial distribution and is particularly useful in monitoring rangeland invasions by annual grasses and forbs where annual fluctuations in cover can be extreme due to precipitation patterns (Elzinga et al. 2001, McCune and Grace 2002). In 2011, GRYN pilot sampling, for example, Tercek (2012) noted that in some park areas, key bunch grasses such as bluebunch wheatgrass (*Pseudoroegneria spicata)* had high frequency but low cover in each plot, suggesting that these species were widespread but in low abundance.

Sample Unit

The sampling units for this monitoring protocol are quadrats of two sizes: 1 m^2 employed for grasses, forbs, and shrubs and a 3.16 m^2 quadrant for trees (or tree like). Kenkel and Podani (1991) recommended that for visual estimation of cover, quadrats should be as large as possible within the constraints of efficient sampling, because larger quadrats generally are more efficient relative to estimates of variance. They also recommended that quadrats be large enough to encompass average patch size within the sampled community. The recommendations for quadrat sizes to sample grassland and shrub steppe vegetation range from 0.5 m^2 to 4 m^2 (e.g., Curtis and McIntosh 1950, Daubenmire 1959, Meurk 1989, Brummer et al. 1994).

The UCBN tested several different sample quadrats during the preparation of the protocol on which our current effort is based (Yeo et al. 2009) and concluded that a 1 m^2 quadrat was optimal for sagebrush steppe vegetation because it allowed for efficient assessment from one observer location. We have adopted Yeo et al.'s (2009) 1 m^2 quadrat for all species and community indicators except for four large tree species found in Bighorn Canyon, namely Utah juniper, Rocky Mountain juniper, mountain mahogany, and limber pine, simply because these larger species are widely spaced and not adequately detected in the 1 m^2 quadrat. The larger sampling quadrats are implemented after first setting up the smaller 1 m^2 quadrat and then determining whether any of the four larger species occur within range of the larger quadrat. The 3.16 m^2 quadrat has its lower right corner in the same location as the corner of the 1 m^2 quadrat (Figure 1; also see SOP 4: Locating and Establishing Sampling Quadrats, Jean et al. 2013). Despite their larger size, the 3.16 m^2 plots can be rapidly assessed if the observer uses the 1 m^2 plot, located in the corner of the larger plot, as a guide indicating 10% cover. In sagebrush steppe communities, Yeo et al. (2009) found that the larger 3.16 m^2 frame required a 25% increase in sampling time and actually resulted in lower sample variances (improved accuracy). The extra time required to sample the larger quadrats is justified in Bighorn Canyon, which contains larger trees and shrubs and spatially heterogeneous vegetation.

Figure 1. A typical layout for a 1 m^2 quadrat.

Sampling Frames and Allocation of Samples

The target plant communities for monitoring in Bighorn Canyon are the Utah juniper and mountain mahogany woodlands, sagebrush shrublands, and grasslands in the south district of Bighorn Canyon. These communities occur on upland habitats that are characterized by deep, steep-walled canyons, isolated grassy plateaus, extremely rocky, shrub-dominated foothill slopes and benches above the main canyon formed by the Bighorn River. Utah juniper and mountain mahogany woodlands occur on shallow soils or fractured bedrock, which funnel rainfall and snowmelt to provide the primary water source for vegetation (Knight et al. 1987). In these habitats, vegetation cover is generally low and shrub/tree distributions are discontinuous (Knight et al. 1987).

For monitoring purposes, we narrowed our focus from the entire population of target communities to a subset of locations called sample frames. These frames are irregularly shaped polygons that contain the communities of interest, in areas with known land-use history, such as former cattle grazing allotments, historic ranch sites, and areas that are being actively managed as habitat for mammals such as bighorn sheep. Most of the sample frames are not representative of a historic climax plant community and the ecological processes within them may be outside the range of natural variation. Indeed, there are no known areas within Bighorn Canyon that do not have a long history of human disturbance. Additionally, potential management treatments within these frames could include periodic prescribed fire, herbicide application, and removal of vegetation with heavy machinery, including tractors. We expect changes in vegetation and soil cover to be influenced by both past and future land-use activities. Consequently, our monitoring will measure recovery from human disturbance and long-term response to management treatments. A detailed rationale for selecting each sample frame for monitoring is given in Table 3.

Sample frames are permanent, geographic areas of inference (map polygons). Every sample frame is independent from the others, so each is its own area of inference for the means and other statistics that are calculated from the data collected within it. Quadrats, in contrast, are the actual sites of data collection (1 m^2 and 3.16 m^2 plots) within the sample frames and their locations are assigned anew each year by the GRTS algorithm (Stevens and Olsen 2004). Using independent frames, rather than ecologically stratified groups of frames, will enable status and trend estimates to be explicit to areas of management importance and will facilitate greater spatial resolution in monitoring data. Temporary quadrats will be used because they greatly reduce the risk of site disturbance from repeated visits (i.e., “conditioning” or “response burden” *sensu* McDonald 2003, Miller et al. 2006). Bighorn Canyon is particularly prone to conditioning with its xeric, unstable soils. Therefore, sampling will proceed with impermanent quadrats and any loss in statistical power will be mitigated by increasing the number of quadrats sampled each year, a feasible option in this case given the efficient response design. Furthermore, since little time is needed to establish a new sample frame with impermanent quadrats, our sampling design has the flexibility to adapt to changing conditions. For example, Bighorn Canyon expects to receive a new vegetation map within the next few years, which may affect sampling priorities. Alternatively, short-term frames might be established and monitored for a period of just a few years if, for example, park staff needs to measure the results of a management action in a particular area.

Rationale for the Sample Frames

A total of 15 permanent sample frames will be established over time; seven will be sampled every year) and eight will be sampled every three years on rotation (Figure 2). The total surface area of the frames in this monitoring plan is 704.7 hectares, which is about 7% of the available Utah juniper, Utah juniper-mountain mahogany, and sagebrush steppe communities in Bighorn Canyon. To select these frames, Bighorn Canyon staff ground-truthed an initial candidate list of sample frames provided by GRYN, which contained all sagebrush, juniper, and juniper-mountain mahogany communities mapped by Myers et al. (1986). After discarding frames that did not contain these target vegetation communities during ground-truthing, the Bighorn Canyon staff further narrowed the list by selecting areas of long-standing management interest, including areas that are undergoing range restoration. They also eliminated all the potential sample frames on Sykes Ridge because these higher-elevation areas are noticeably different from the foothill slopes and upland habitats targeted for this protocol. Within all frames, 10 m buffers were established that removed areas adjacent to park roads and near other modern developed areas, such as parking lots or buildings. Sampling frame delineation errors arising from map inaccuracies will be corrected iteratively over the first few years of implementation and documented in an updated version of this protocol. A detailed rationale for each sample frame is given in Table 3.

Table 3. Sample frames for Bighorn Canyon National Recreation Area, the sample size (number of quadrats) within each frame to be sampled in a single year, the reasons they are of interest to park management, and the frame surface area. Panel one is the minimum number of quadrats to be sampled; the over sample is the number of extra quadrats available as replacements for quadrats that are rejected as unsuitable by the field crew. Asterisks indicate "BASE" sample frames (see text).

Sample Frame Name	Surface Area (Ha)	Sample Size *(panel one/over-sample)*	Rationale for Monitoring: Target vegetation	Rationale for Monitoring: Management Interest
BICA_LTM_Veg10	94.9	100/50	Sagebrush steppe	Representative Bighorn Canyon sagebrush habitat adjacent to a fence that marks the beginning of private land.
*BICA_LTM_Veg20**	27.5	50/25	Juniper-mountain mahogany woodland	Juniper-mountain mahogany community that is outside the horse range, also in the northern part of the south district, where precipitation is higher than in the south. All the other juniper-mountain mahogany frames are inside the horse range.
BICA_LTM_Veg30	78.2	75/35	Sagebrush steppe	Representative sagebrush habitat near northern boundary of south district.
BICA_LTM_Veg40	40.4	75/35	Juniper woodland	According to the Knight et al. (1987) map, this area contains several different vegetation community types, but it is the target of long-term park restoration and management efforts. In particular, it contains juniper stands near the north end of the south district.
BICA_LTM_Veg50	60.6	75/35	Juniper woodland.	Juniper habitat that includes foothill canyons adjacent to the Pryor Mountains. Although still classified as juniper by Knight et al. (1987), this community differs in species composition and density from juniper habitats that are not on hillsides.
BICA_LTM_Veg60	35.6	50/25	Juniper woodland	This area was used as a "historical reference" plant community in Ricketts et al. (2004). (i.e., the historical reference for juniper against which all others are compared in range assessments in this area.) Since other agencies collect data here and consider it representative of Juniper habitat, the park would like to have continuing data at this location.
*BICA_LTM_Veg70**	37	50/25	Sagebrush steppe and grassland communities	These areas were all chosen because they have been documented as good sage grouse habitat by research done previously in the park. *BICA_LTM_Veg80* is within the area often referred to as "Common Corral" because it was a cattle corral for many years and is actively being restored. *BICA_LTM_Veg80* will be tracked long-term to determine the effectiveness of re-seeding efforts. Treatments in all three of these sample frames might include cattle grazing on a periodic basis.
*BICA_LTM_Veg80**	10.9	50/25		
*BICA_LTM_Veg90**	18.1	50/25		
*BICA_LTM_Veg100**	33	50/25	Juniper woodland	These frames contain juniper habitat that straddles the wild horse range boundary. These frames are adjacent to one another, with *BICA_LTM_Veg100* outside the wild horse range and *BICA_LTM_Veg110* inside.
*BICA_LTM_Veg110**	84.8	75/35		
*BICA_LTM_Veg120**	22.1	50/25	Juniper – mountain mahogany woodland	Representative juniper-mountain mahogany habitat inside the wild horse range.
BICA_LTM_Veg130	60.4	75/35	Juniper-mountain mahogany woodland	Lowland (flat) juniper-mountain mahogany habitat. Contrast with BICA_LTM_Veg140.
BICA_LTM_Veg140	49.6	50/25	Juniper-mountain mahogany woodland	Juniper-mountain mahogany habitat that includes foothill canyons adjacent to the Pryor Mountains. The landscape here differs from the flatter juniper-mountain mahogany habitats exemplified by BICA_LTM_Veg120 and BICA_LTMVeg130. The park believes these "finger ridges" that extend from the Pryor Mountains are different than the lowland juniper–mountain mahogany habitats.
BICA_LTM_Veg150	51.6	50/25	Juniper-mountain mahogany woodland	Also known as "Yellow Hill" or "State Line." This is a juniper-mountain mahogany community that is actively managed as habitat for Bighorn Sheep. Prescribed fire treatments will be routine here, and the park wants to track the effects. This is considered "a long-term improvement area."

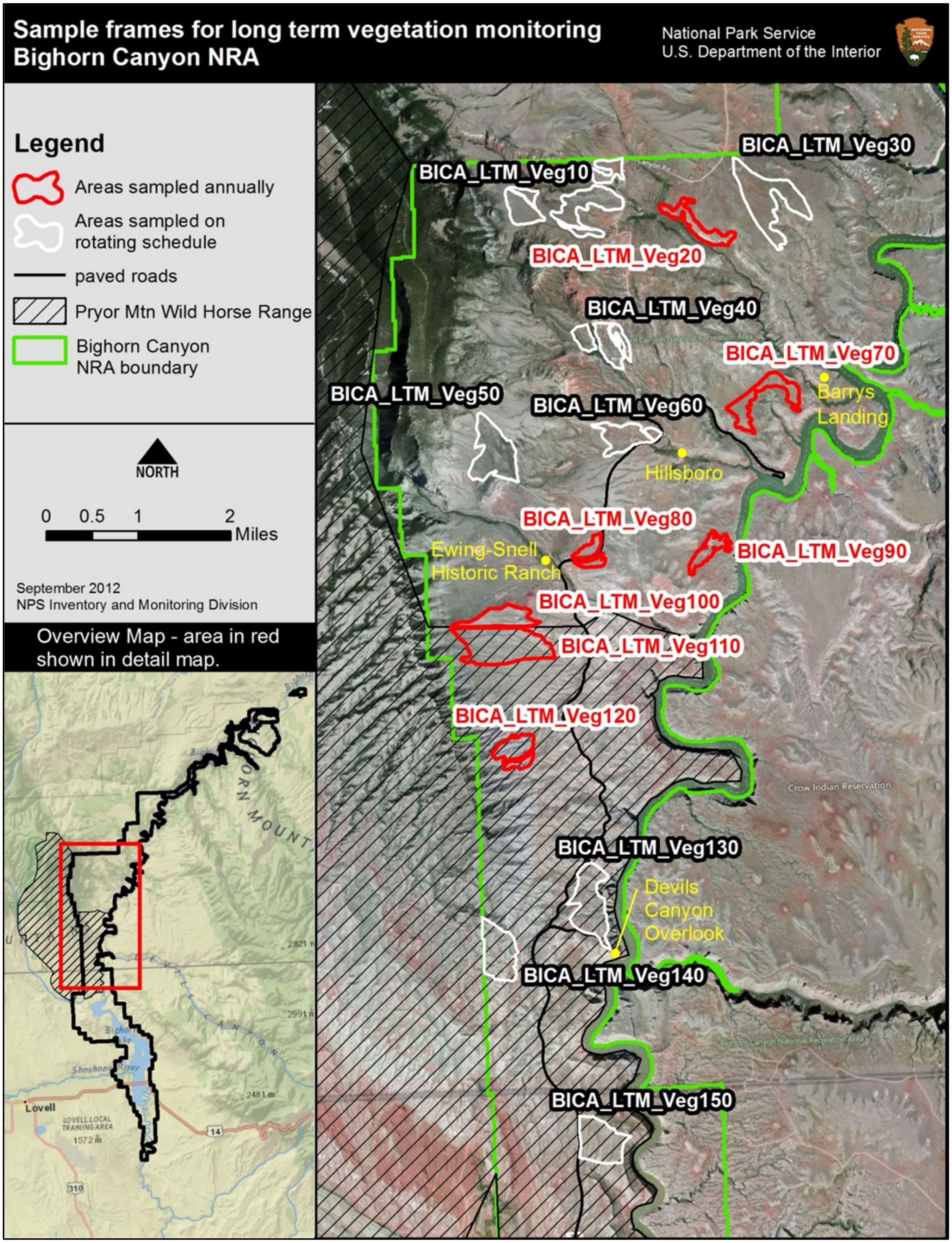

Figure 2. Southern portion of Bighorn Canyon National Recreation Area showing locations of the 15 selected sample frames (numbered 10-150). In red are the seven priority “BASE” frames to be sampled annually; other sample frames (white) will be sampled on a 3-year rotation.

Sampling Frequency and Timing

A total of 925 sample quadrats in 15 sample frames will be visited in a cycle that repeats every three years. Three hundred and seventy-five of these quadrats are in “BASE” sample frames that will be visited every year, allowing for measurement of inter-annual variability, while the remaining 550 quadrats are in secondary frames that will be distributed over three years. This revisit design is based on the field crew visiting 500-600 quadrats each year, in accord with the 550-600 visited during the pilot years of 2011 and 2012. Table 4 contains details of the revisit design for Bighorn Canyon. Higher priority areas, referred to as “BASE” sample frames, are monitored every year. BASE sample frames include three sagebrush-dominated areas (BICA_LTM_Veg70, BICA_LTM_Veg80, and BICA_LTM_Veg90), which have historically been of interest to park managers and been the focus of past research. In addition, there are several BASE sample frames that comprise natural contrasts with each other, namely (1) BICA_LTM_Veg100 versus BICA_LTM_Veg110, which contrast adjacent juniper patches that are inside versus outside the Pryor Mountain Wild Horse Range (PMWHR); and (2) BICA_LTM_Veg120 versus BICA_LTM_Veg20, which contrast Utah juniper-mountain mahogany inside versus outside the PMWHR.

Table 4. Revisit design for sample frames in Bighorn Canyon National Recreation Area. A sampling cycle will be completed in three years. Starting in 2013, the cycle will begin again in 2016.

Sample Frame	Sampling Occasion					
	2013	2014	2015	2016	2017	2018
BICA_LTM_Veg20*	50	50	50	50	50	50
BICA_LTM_Veg70*	50	50	50	50	50	50
BICA_LTM_Veg80*	50	50	50	50	50	50
BICA_LTM_Veg90*	50	50	50	50	50	50
BICA_LTM_Veg100*	50	50	50	50	50	50
BICA_LTM_Veg110*	75	75	75	75	75	75
BICA_LTM_Veg120*	50	50	50	50	50	50
BICA_LTM_Veg30	75			75		
BICA_LTM_Veg130	75			75		
BICA_LTM_Veg140	50			75		
BICA_LTM_Veg10		100			100	
BICA_LTM_Veg40		75			75	
BICA_LTM_Veg150		50			50	
BICA_LTM_Veg50			75			75
BICA_LTM_Veg60			50			50

*Asterisks indicate BASE Sample Frames

It is important to note that the effect of wild horses on vegetation is only one of many factors to be considered in comparing frames inside versus outside the horse range. For example, there is a north-south precipitation gradient (Tercek 2010) that coincides with the north-south arrangement of the areas inside vs. outside the PMWHR. Nevertheless, the condition of vegetation across this boundary is of long-standing, recurring interest to regional resource managers (e.g., Ricketts et al. 2004, BLM et al. 2008). It is therefore considered important to measure both frames in any of these pairs during the same year, so that comparisons can be made without considering inter-annual variation. Another natural contrast can be made between BICA_LTM_Veg130 vs.

BICA_LTM_Veg140, which are Utah juniper-mountain mahogany communities located on the benches above the main canyon versus the foothills of the Pryor Mountains, respectively. If changes are made to the sampling design in the future, these two frames should be measured in the same year.

Sample Size Requirements and Power Analysis

We developed the following sampling objectives to guide sample size decisions:

- Estimate the proportion of quadrats covered by principal plant species and exposed soil, for each Daubenmire category (Daubenmire 1959), within (±) at least 0.1 of the true proportion with 90% confidence. For example, if the true proportion of a Daubenmire cover class within a given frame is 0.5, our 90% confidence interval will be 0.5±0.1 or better.
- Detect differences of 0.25 or more in the proportion of quadrats (i.e. 25%) assigned to a given cover class or classes between any two sampling periods for a frame with ≥80% power and ≤10% false-change error (Type I or α).
- Detect linear trends of 7.5% annual increase/decrease or more in the proportion of quadrats containing each Daubenmire cover class during the first 10 years with 80% power and ≤10% false-change error.

Power analysis indicates that all of the monitoring objectives can be met with a minimum sample size of 50 quadrats per frame. Since larger sample frames (i.e., frames of larger aerial extent) often contain more heterogeneous vegetation, sample size will be increased as needed so that there is at least one quadrat for every hectare in each sample frame. The maximum sample size in any sample frame will be 150 (Table 3). Our power analysis presented here is consistent with the one in Yeo et al. (2009) for the NPS UCBN's upland vegetation monitoring protocol.

Cover class data, our principal monitoring metric, will be analyzed as ordinal categories. Specifically, we will estimate the proportion of quadrats within each Daubenmire cover class and assess trends in those proportions over time. These objectives serve as guidelines for ensuring that this monitoring effort has the capability to detect ecologically meaningful trends in core vegetation cover metrics for the selected discrete areas of management interest across a range of habitats within park.

Sampling objectives include both short-term and long-term status and trend monitoring goals, and address the statistical reality that many years of sampling are required before trends, if present, can be detected. It is important to underscore that considerable information regarding the status of the resource will be available to park managers immediately after the first year of sampling, as has already been demonstrated with the vegetation monitoring annual report following the 2011 pilot sampling (Tercek 2012). Monitoring data will become more valuable in time as standardized sampling continues.

Power Analysis

Power for Annual Status Estimates

The quadrats in this protocol are distributed within each sample frame by the GRTS algorithm (Stevens and Olsen 2004). Because GRTS sampling allows for a more efficient variance estimator (Stevens and Olsen 2004), a simple random sampling formula to determine adequate sample size to achieve a desired confidence interval is conservative. For status monitoring, we used the simple random sampling formula to determine the sample size required for a specific margin of error (confidence interval half-width) (Sheskin 2007):

$$n_0=((1.64^2\, p(1-p))/(e^2) \qquad \text{(Equation 1)}$$

where:

1.64 is the 90% confidence interval multiplier from a standard normal distribution,
e is the margin of error, and
p is the proportion the of plots containing the cover class

Using this equation, Figure 4 indicates that the required sample size is greatest when the estimated proportion is 0.5. For example, using a sample size of 50, if the estimated proportion of plots in a sample frame containing the 5-25% % cover class is 0.5, the 90% confidence interval for the frequency of this cover class will be 0.5±0.11. Similarly, if the frequency of this cover class is 0.2, a sample size of 50 will yield a 90% confidence interval of 0.2±0.093 (Figure 3).

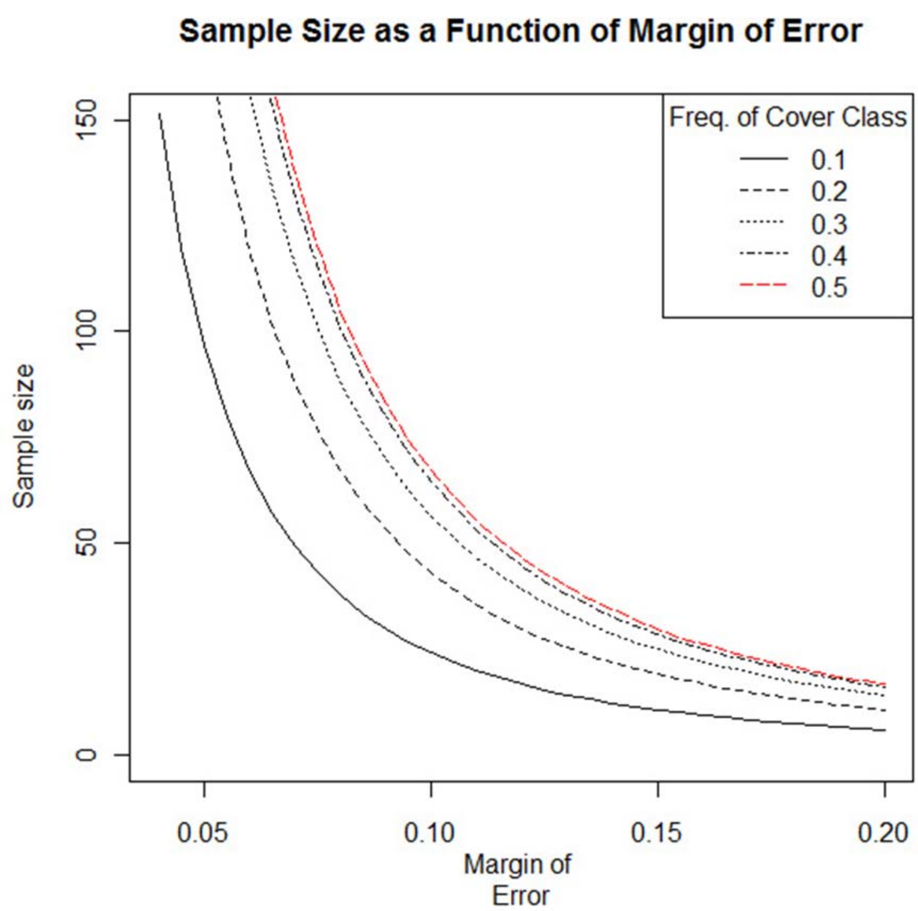

Figure 3. Power analysis for status estimates of cover class frequency based on a 90% confidence interval. Margin of error is the confidence interval half-width, expressed as proportional units. For example, with a sample size of 50 and frequency of 0.5, the confidence interval for the proportion of plots containing a particular Daubenmire cover class would be 0.5±0.11. Calculations are based on Equation 1.

The foregoing calculations are based on the assumption that the vegetation within our sampling frame is relatively homogeneous, (i.e., that one part of the sample frame is vegetatively much like the rest). In other words, we assumed that the GRTS sample was both spatially balanced and that the variance of its estimates were representative of the spatial variability in vegetative structure that occurs in the field. There are, however, situations in which a particular species is not spread evenly across a sample frame. Instead, the species occurs in discrete clumps of high density that are separated by large areas that do not contain the species. Imagine for example, a rectangular sampling frame that contains stands of juniper in only two of its corners and no juniper anywhere else. In this case, most plots will register cover class 0, and it would be only by chance that a small number of plots occur in high density juniper areas, registering perhaps 75-95% cover or greater.

The statistical effect of this "clumpy" juniper distribution is illustrated by the analysis of 2011 pilot data shown in Figures 4 and 5. Since GRTS samples can be broken into numerically contiguous subsets, all of which are spatially balanced with respect to the sampling frame (Stevens and Olsen 2004), it is possible to empirically determine the effect of increasing sample size by re-calculating the status estimate for a particular plant species for all subsets of the data contained within the pilot sample. To make these calculations, we took data from the first two quadrats in a frame (quadrats number 1 and 2 from the frame of interest) and calculated percent cover for each species and the 90% confidence interval for the estimate. Then the calculations were repeated for three samples (GRTS samples 1-3), and then again for four samples (GRTS samples 1-4), and so on, until the entire pilot sample (150 quadrats in the example shown below) had been included. In this way, the magnitude of the "drift" in calculated statistics due to spatial variability in vegetation can be estimated. Figure 4 shows the result of this procedure when overall percent cover of juniper and big sagebrush were calculated by replacing each Daubenmire cover class with its median value (see Table 2). Figure 5 shows the result of this procedure when the calculated statistics are instead the frequency of each Daubenmire cover class.

In Figure 4, notice that percent cover for juniper increased in steps as sample size increased, and that it continued to drift (did not entirely stabilize) by the time the maximum sample size of 150 was reached. Percent cover for juniper calculated from the first 75 plots was 4.7%, but percent cover for juniper calculated from the last 75 plots was 2.4%. There is nearly a 100% difference between these two estimates even though these two subsets of 75 samples are spatially balanced by the GRTS algorithm and may therefore be considered equivalent (Stevens and Olsen 2004). In contrast to juniper, big sagebrush, which was more evenly (homogeneously) distributed across the sample frame, achieved a relatively stable value after 50 plots were included. The results of this analysis indicate that species like juniper, which exhibit a "clumpy" distribution within a sample frame will have greater error associated with their annual status estimates than species like big sagebrush, which are more evenly spread.

The effect of juniper's "clumpiness" manifests itself differently when the data are presented in terms of frequency for each cover class (Figure 5).

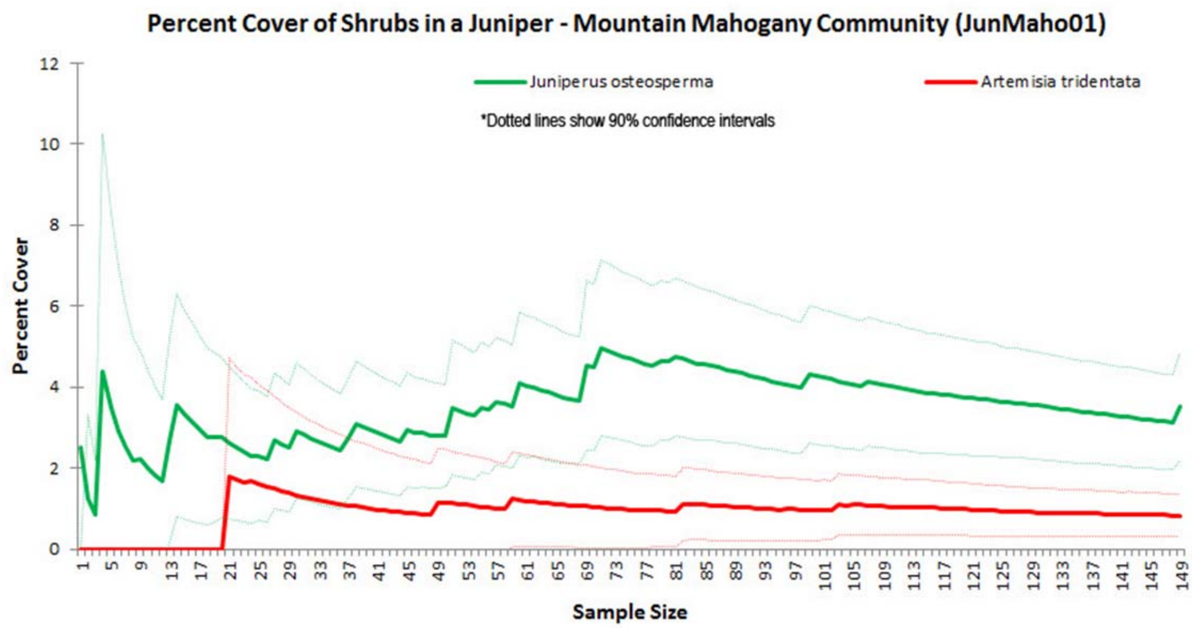

Figure 4. Overall percent cover of Utah juniper (*Juniperus osteosperma*) and big sagebrush (*Artemisia tridentata*) calculated for subsets of increasing sample size. Results shown here are based on 2011 pilot data taken from Bighorn Canyon National Recreation Area sample frame JunMaho01. Percent cover was calculated by replacing each Daubenmire cover class with its median value (see Table 2).

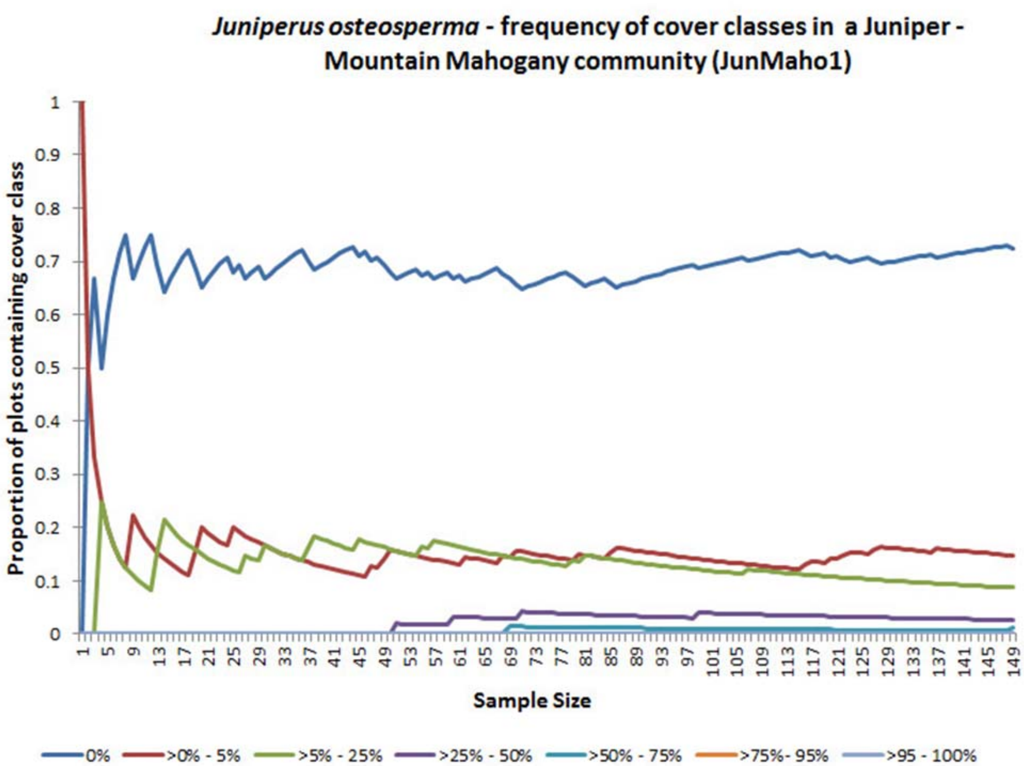

Figure 5. Frequency of each Daubenmire cover class calculated for subsets of increasing sample size, based on 2011 pilot data collected in Bighorn Canyon National Recreation Area. Colors for each line indicate Daubenmire cover classes (compare Table 2 and the key at the bottom of the figure).

In Figure 5, the measured values for many of the cover classes stabilized quickly as sample size increased. Unlike the median-derived values in Figure 4, which showed as much as 100% variation between two equivalent 75 sample subsets of the data, the proportions calculated for lower cover values (e.g. 0%, >0-5%) in Figure 5 generally varied by less than 50% after 50 samples had been included. For example, the calculated frequency of cover class 0 ("frequency of plots that do not contain the species") varies by less than 0.1 (out of a calculated value of 0.7) after 50 plots had been included. In contrast, higher cover classes showed more variability. Cover class 3 (25-50% cover) was not detected until 52 plots had been included, and cover class 4 (50-75% cover) was not detected until 68 plots had been included. Even though these higher cover classes are rare (detected infrequently), they are important to characterizing the sample frame because they represent the sparse, clumpy juniper stands that occur in only some parts of the plot. There are two conclusions to be drawn from this analysis. First, *every effort should be made to select sample frames with relatively homogeneous vegetation*, and areas with vegetation of differing density should be split into separate sample frames whenever possible (Daubenmire 1959). Second, when it is impossible to create sample frames that contain only homogeneous (evenly spread) vegetation, expressing the data in terms of cover class frequencies (as in Figure 4) will be superior to expressing the data as median-derived overall percent cover (as in Figure 4) because it provides more stable values, which are less sensitive to the "drift" caused by clumpy species distribution. Calculations such as those shown in Figure 5, which substitute median values (Table 2) for each Daubenmire class have a long history (most notably appearing in Daubenmire 1959) and they are still recommended by some standard statistical texts that focus on rangeland management (e.g., BLM 1992), but we emphasize that they have less accuracy than a focus on the frequency of each cover class, as presented in Figure 5.

Even when the data are expressed as the frequency of Daubenmire cover classes (as in Figure 5), it is important to bear in mind that status estimates for rare cover classes of clumpy species (e.g., classes 25-50% or higher) may be less accurate than status estimates for the more common (often lower) cover classes (e.g., classes indicated 0 or >0 to 5% cover). In the example case described above, where a sample frame contains dense juniper stands in only two corners and no juniper anywhere else, the higher cover classes might not be detected during every year of sampling, due to the random nature of where GRTS plots fall within the sample frame, and whether or not the plots selected for that year fall within the juniper stands.

In general, the probability of detecting a cover class at least once (Sheskin 2007) is

$$1-(1-p)^n \qquad \text{(Equation 2)}$$

where:

p=the frequency of the cover class and n is the number of plots measured

For example, if on average a cover class occurs in only 1/100 of the plots, then a sample size of 161 would be needed to have an 80% chance of detecting the class during a given year (Figure 6). In other words, with a sample size of 161, there is a 20% chance that a given year's sampling effort will fail to detect the cover class by chance alone.

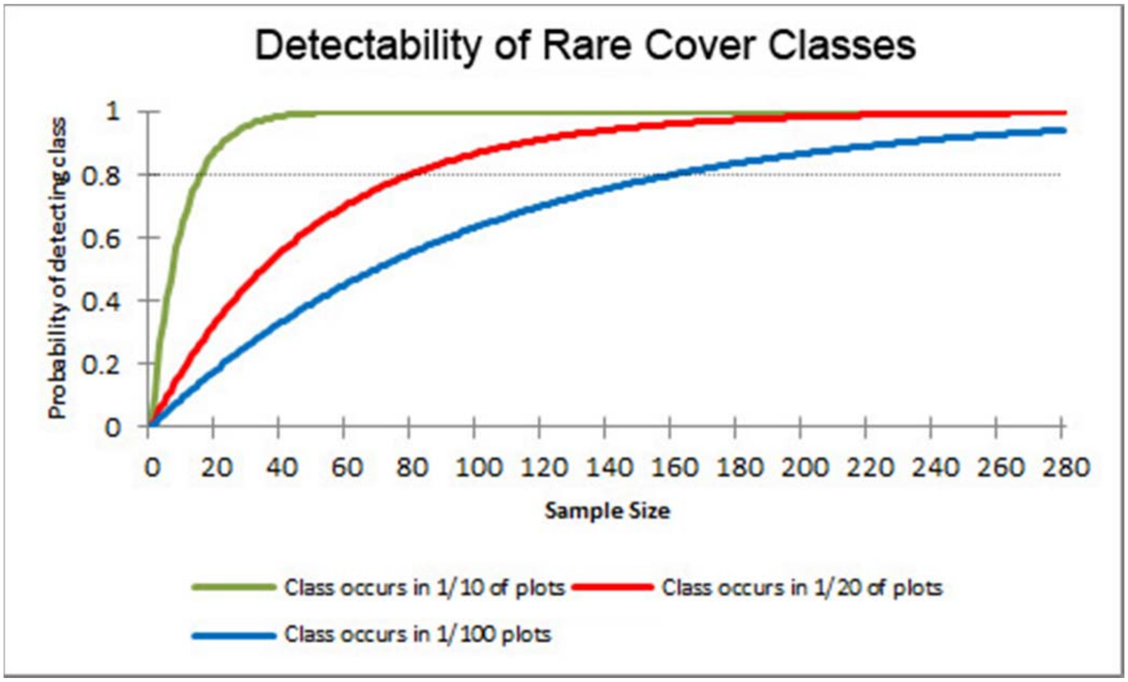

Figure 6. Probability of detecting a Daubenmire cover class during one year as a function of sample size and the frequency of the class' occurrence within the frame. The horizontal, dotted line indicates 80% probability of detecting the cover class. Calculations are based on Equation 2.

Chance of detection due to the random location of GRTS plots is separate from power, and Figure 6 may seem counter-intuitive when compared to Figure 3. When considering power, Figure 3 shows that cover classes with frequencies approaching 0.5 have the largest confidence intervals (more error), but Figure 6 instead indicates that cover classes with very low frequencies (such as 0.01) are difficult to detect in a given year. The conclusion to be drawn from Figure 6 is simply that one should not interpret the year-to-year fluctuations in the detection of rare cover classes as genuine "gains" or "losses." If high cover classes (e.g., 75-95% cover) of clumpy species like juniper occur in some years but not others, this may be due merely to the random GRTS assignment of sample plots within a heterogeneous environment.

Power for a "Step-change" Comparison between Two Years

Although more advanced statistical methods may be used, a simple test for comparing the frequencies of a cover class measured during two different years is the proportion test (Sheskin 2007). This approach is also suggested by Yeo et al. (2009) for application in the NPS units monitored by the UCBN Inventory and Monitoring Program. Power for this test is affected both by the initial frequency of the cover class and by the amount of change in cover class frequencies as shown in Figure 7. The analytical code used to generate this power analysis, written in the R programming language (R Development Core Team 2012), is available in the protocol 'tool box' on the GRYN server.

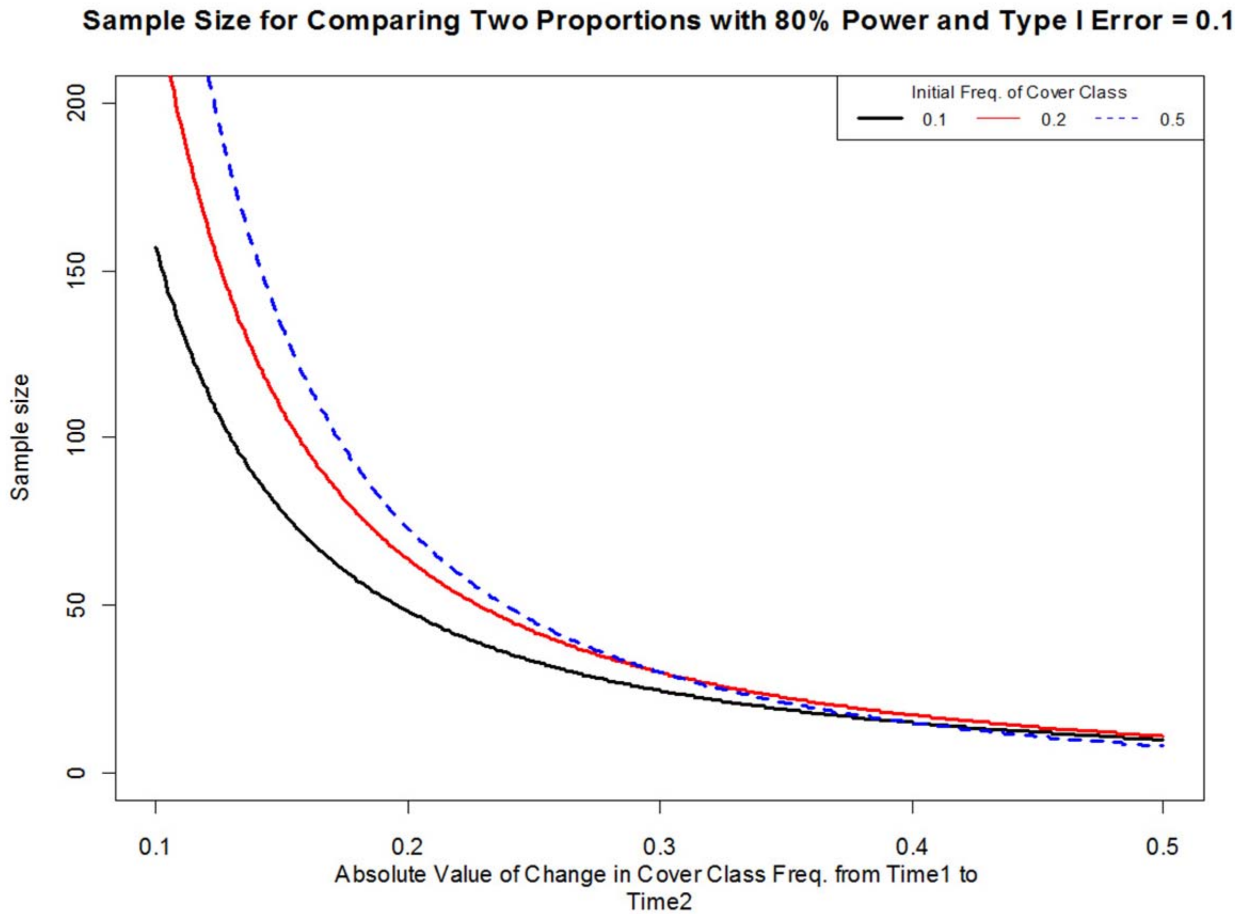

Figure 7. Power analysis for a step-change for cover class frequency measured at two different sampling times (years). The samples sizes indicated are for BOTH samples separately, taken during each measurement period. For example, a sample size of 50 in year 1 followed by a re-measurement of n=50 during year two will detect a change in frequency of approximately 0.24 or greater if the starting frequency of the cover class was 0.5.

This analysis shows, for example, that when a cover class has an initial frequency of 0.5 (a cover class occurring in 50% of the plots within a frame), a sample size of 50 will detect a change in frequency of roughly 0.24 or greater, which could be measured as either an increase to 0.74 frequency (occurring in 74% of plots within a frame) during the second year or a decrease to 0.26 (occurring in 26% of the plots within a frame). The sample size needed for a given effect size will be maximized when initial probability is 0.5. Power curves for initial probabilities larger than 0.5 are similar to the ones shown in Figure 7 for initial probabilities below 0.5.

Power for Detecting Trend

Irvine and Rodhouse (2010) have conducted a detailed examination of power for trend detection in data derived from ordinal cover classes, including the 7-point Daubenmire cover class used by this monitoring protocol. Those authors show that the sample size needed to detect a given trend depends on both the shape of the unobserved (latent) distribution of plant cover and on the type of regression model used. For the purposes of this protocol, we have based our sample size estimates on the Proportional Odds Model (POM) described by Irvine and Rodhouse (2010), which they demonstrated to have generally the highest power among all the models that they examined. With regard to the latent plant cover distribution, a lower sample size is needed when an equal number of plots register within each cover class (represented in their analysis by a beta (1,1) distribution). In contrast, when plant cover is skewed to the left (represented by a beta (0.5,6) distribution), so that a higher proportion of plots within a frame register in the lower cover classes (e.g., 0% and >0-5%) and a continuously decreasing proportion of plots are found in the higher cover classes, then higher sample sizes are needed to detect trend. The rate of change for these trend models can be interpreted as the *annual* multiplicative increase (or decrease) in the odds ratio of a cover class, which is equal to (p/(1-p)), where p is the proportion of plots containing a cover class.

Using the supplementary R code (R Development Core Team 2012) that accompanies Irvine and Rodhouse (2010), we determined the sample size needed to detect a linear increase in a *Bromus tectorum* (a typical invasive weed). According to our 2011 pilot data, when this species occurs in a frame, it typically has a frequency (p) greater than 0.9 in cover class 0, and decreasing frequency in the higher cover classes, usually registering p=0.05-0.1 in cover class 1 and p=0 in the higher classes. Therefore, selecting a latent cover distribution of beta (0.5,6), we estimated that the sample size needed to detect an annual increase or decrease of 5% over 10 years at 80% power with Type I error rate=0.1 as approximately 110. A sample size of approximately 50 will detect an annual increase or decrease of 7.5% over 10 years with 80% power and Type I error rate=0.1. For an annual increase or decrease of 10% per year over 10 years, the sample size needed to detect the change with 80% power is 35.

Summary and Conclusions from the Power Analysis

- Our monitoring objectives can be met with a minimum sample size of 50. In order to address the heterogeneous distribution of vegetation observed in some frames (see Figure 5 and the discussion of juniper "clumpiness" above), sample size will be increased in larger sample frames (frames of larger aerial extent) so that there is a minimum of one sample plot for every hectare in a sample frame.
- To address the heterogeneous or "clumpy" spatial distribution of shrubs in our sample frames, we have modified our sample frame boundaries to include areas of more homogenous vegetation following the 2011 and 2012 pilot years.
- Rare cover classes may not be detected every year, and the year-to-year fluctuations in their detection should not be over interpreted as genuine gains or losses to the vegetation community. This phenomenon is particularly likely for species like juniper that have a clumpy spatial distribution.
- When possible, the boundaries of any sample frames that are introduced in the future should be adjusted to include homogeneous vegetation of relatively uniform density. This may not always be possible in areas that have experienced human disturbance. Even though some of the frames in this protocol were chosen to represent "typical" regional vegetation, many were designed to monitor recovery from human disturbances in areas with a known history.
- Data collected under this protocol should be presented as frequencies of Daubenmire cover classes (Figures 7 and 8) for each frame rather than as overall mean cover for a species derived from the median values of each cover class.

Summary of Benefits of the Selected Design

- The sampling design using frames and quadrats within frames allows estimation of key indicators of rangeland health across large landscapes with just a few personnel
- The sampling design facilitates rapid collection of cover class data with sufficient spatial extent and intensity (i.e., sample size) to obtain adequate precision in estimates of important community indicators for managers to detect meaningful changes in rangeland health.
- The inclusion of "BASE" sampling frames that are sampled every year gives us the ability to calibrate data with inter-annual variation in weather and other factors. Secondary sample frames will be visited on a staggered rotation that completes every three years.
- The use of temporary sample locations to place quadrats within frames avoids the potential bias from trampling effects and promotes quick field sampling.
- The field techniques are easy to learn allowing for the use of observers from diverse academic backgrounds to be employed, and the use of Global Position System (GPS) technology provides an objective approach to locating sample locations.
- The GRTS spatially balanced sample design has less spatial autocorrelation than more traditional random sampling techniques.

Field Methods

Field Season Preparation and Field Schedule

Each year, preparation for the next field season actually begins with closure of the current field season with reviewing and revising field notes and summarizing results from the previous year. The next steps, beginning in January for the upcoming year, involve determining sample locations (GRTS points), gathering and preparing equipment, and fulfilling permitting and compliance requirements using the NPS research permit and reporting system. Hiring and scheduling field personnel will be subject to overall programmatic requirements and schedules. Some preparation can be completed during the previous season's close-out period to reduce the work load in the subsequent year. Field training should be conducted in early May during the week preceding field sampling. The field team will practice identification and sampling techniques outdoors with vegetation that is phenologically similar to what will be encountered during sampling. Complete instructions for pre-season preparation and training are in SOP 2: Field Season Preparation and SOP 3: Training Observers (Jean et al. 2013).

Training, Calibration, and Consistency

The sampling protocol is designed to be easily learned by individuals with some field experience identifying plants; it does not depend on individuals with advanced expertise in plant taxonomy. All field teams receive a week of training in sampling techniques, identification of the target plant species, and use of GPS for locating sample locations at the start of each season. Each field team member will be provided with a Field Reference Manual that gives clear descriptions of field methods and principal species lists for each park. Graphical cover estimation guides are included in SOP 3: Training Observers (Jean et al. 2013). The rulers and measuring devices used to delineate the 1 m^2 and 3.16 m^2 quadrats will be marked into quarters along the edges to provide a visual reference on the quadrat for 5% and 25% cover areas. During the week-long training, team members will practice visual estimation of plant cover using known cover values within quadrats and under field conditions. Team members' cover estimates will be compared to achieve consistency among team members. Cardboard cutouts in different shapes, sizes, and colors will be employed during training to facilitate visualization of various permutations of plant cover patterns (SOP 3: Training Observers, Jean et al. 2013). These cutouts will have known areas and will facilitate consistency among observers across years. Team members will calibrate with each other and record results of comparisons at periods throughout the sampling season.

Preparing for Field Surveys

- Crew members must follow all safety procedures outlined in SOP 1: Field Safety (Jean et al. 2013), including maintaining close communication with the park resource manager and other park contacts as identified regarding field schedules and daily check-in procedures. Park hazards, including emerging threats such as extreme weather or fire hazards, should be discussed with park staff prior to initiating field work and as needed throughout the duration of field activities. First aid supplies and safety equipment must be in immediate reach of each crew member at all times.

- Boots will be cleaned to prevent transfer of exotic vegetation into or between sample frames.

- Access to sampling areas requires hiking across rugged terrain. Field teams must be prepared for challenging weather conditions, including extreme heat, cold, rain, and snow. Each team member should maintain a supply of warm clothes and rain gear, sun protection, and plenty of water.

- Before each field day the survey team consults the prepared sample frame map showing labeled quadrat locations and a coordinate grid on a true-color background image from recent aerial imagery. Using the map as a reference and based on the time of day, terrain factors, and other conditions and circumstances, the crew prepares an ordered list of 20-30 target quadrats that constitute a safe and efficient route of travel. This list is updated and adjusted throughout the day as progress is made and/or conditions change.

Locating and Establishing Quadrats

Procedures for locating and establishing quadrats are found in SOP 4: Locating and Establishing Sampling Quadrats (Jean et al. 2013). Field personnel navigate to quadrat locations using recreational-grade GPS units pre-loaded with waypoints of randomly determined sample locations within each sample frame. Technicians focus only on their proximity to the target coordinates and ignore nearby vegetation or the ease/difficulty of the route to the target point unless there are obvious hazards that need to be avoided. It is necessary to follow the most direct, rather than the easiest, route to each quadrat from the last, and when necessary to walk into or through thick pockets of vegetation to reach each target point. Since recreation-grade GPS units normally provide position accuracy between 2-5 meters, the distance to the target point tends to "drift" as the user gets close to the waypoint. Consequently, the technician should immediately stop walking the first time the GPS unit indicates that the distance to the target is two meters or less. The lower right-hand corner of the quadrat is marked on the ground at the tip of the locator's right boot. From this location edge markers for the 1 m^2 quadrat are placed in front of survey personnel in line with the direction of travel to avoid trampling vegetation in that area prior to the survey. Edge markers for a 10 square meter quadrat start at the same lower right corner and extend 3.16 meters in length (explained below).

Measuring Community Attributes

Field training will be conducted at the start of each season. Training procedures outlined in SOP 3: Training Observers (Jean et al. 2013), includes calibration exercises for ocular cover estimation, as well as review of plant identification for each target species (see Appendix A) and similar species subject to misidentification. The size of sampling quadrats is scaled depending on the plant species encountered. If Utah juniper, Rocky Mountain juniper, mountain mahogany or limber pine occur at the sample location then a 3.16 m^2 quadrat (10 square meters) is established for measuring just these four species. All other plant species and attributes are measured within a 1 m^2 quadrat. In practice this is accomplished by first setting up the 1 m^2 quadrat described in the previous section and then determining whether any of the four larger species occur within range of the larger quadrat starting at the same point. The percent cover of target species within or overhanging into the quadrat will be estimated visually using Daubenmire cover class categories (see Table 2). Unknown plants can be photographed or, if common, collected for later identification. Photographs are taken for visual reference and to obtain stock imagery suitable for reports, management briefs, and other publications.

The order of field operations and data entry steps are as follows:

1. Locate the quadrat corner point using GPS.
2. Lay out the 1 m^2 quadrat.
3. Check to see if any targeted tree species are in range of the 10 square meter quadrat. Lay out the markers for this plot if needed.
4. Enter cover data for each target species and ground cover attribute found in the quadrat.
5. Add objective and relevant comments if necessary in the notes field.
6. Take specimen photographs or collect physical specimens for later identification if necessary.
7. Review data entry and be sure that all fields are filled correctly and clearly before moving to the next sample location.
8. Save/backup data.
9. Select and navigate directly to the next sampling point using the GPS device.

Repeat Photography

One permanent photo point depicting the vegetation composition and structure at the landscape scale will be established for each long-term vegetation monitoring sample frame. The time of year that the photograph is taken should coincide, as closely as possible, with anthesis of the principal grass species. The location for the photo point will be decided by the Protocol Leader who will consider the objective of capturing the overall vegetation composition and structure and also the ease of relocating for future repeat photography. Once the initial photo point and photograph is established, repeat photographs of each monitored sample frame are taken annually by the technicians completing the vegetation monitoring field work.

Data Entry and Management

Observed and measured data values are entered directly into a database on a field computer. Paper data sheets are carried as backup. A document with explicit data entry instructions is updated annually and carried by field personnel. The electronic data are backed up several times each day to a memory card, and the card is swapped daily with another card stored in the crew vehicle or field operations base in order to provide physical separation and security of the electronic data. Data entry is streamlined and data quality is controlled by limiting entered values to pre-defined choices on pick lists and requiring entries before advancing to the next record. The biggest risk to data integrity during data entry is accidentally picking an adjacent listed value instead of the intended value. To minimize or eliminate this risk, crew members must not hurry when selecting values from drop-down lists and must be able to clearly see the computer screen. Those entering data should also visually double-check entered values before leaving each record. Field data are copied to the GRYN server between field trips, and these files serve as an archive of accumulated data that are added to the master project database at the end of each field season.

Promptly Share Watch-list Information with Park Staff

Information about the location(s) of watch-list invasive species is shared with park managers as soon as possible during the field season.

After the Field Season

Following field work, all equipment will be checked in and stored at the GRYN headquarters in labeled bins. All electronic equipment is turned in to the data manager for maintenance and storage. Data from the current season are merged with the master project database following review, validation, and certification by program personnel.

Data Handling, Analysis and Reporting

This chapter describes the overall plan for data handling, analysis, and report development for this monitoring protocol. Detailed instructions are found in SOP 6: Data Management and SOP 7: Data Analysis and Reporting (Jean et al. 2013). The GRYN Data Management Plan (Daley 2005) and the national Inventory and Monitoring Data Management Plan (NPS 2008) are also useful resources for more comprehensive philosophy and general guidance on data management.

Database Design

GRYN adopted an existing Microsoft Access database application developed by UCBN for their sagebrush steppe monitoring protocol. GRYN plans to coordinate regularly with UCBN to maintain a common database schema in order to facilitate potential data summarization, analysis, and reporting efforts among parks. The fundamental data tables and relationships (Figure 8) include referential integrity settings that establish and maintain valid relationships between survey locations, survey events, and measured and observed data values from each survey. The master database application includes objects and code to support data summarization, formatting, and output requirements for analysis.

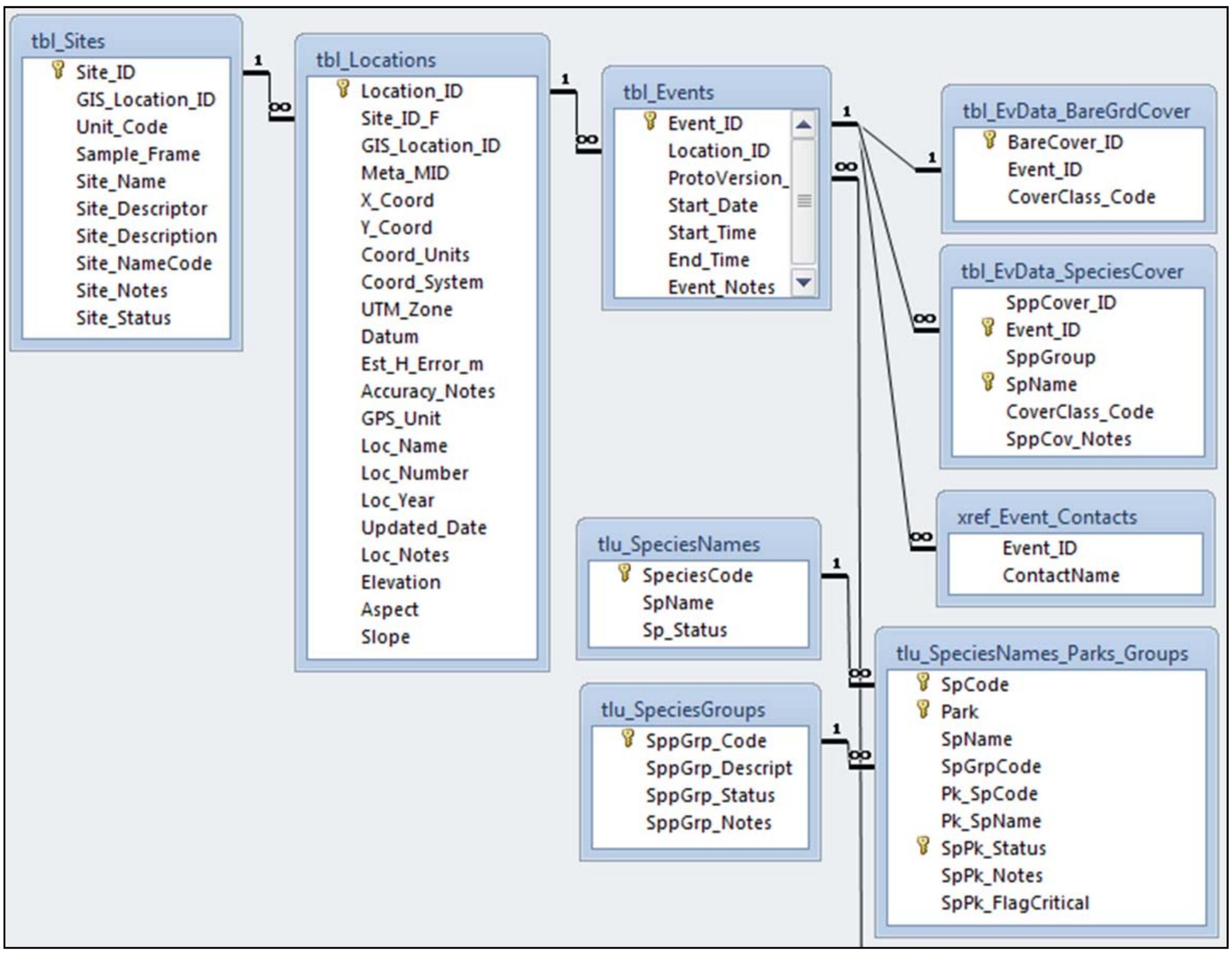

Figure 8. Database entity relationship diagram showing key tables that hold data for locations, survey events, and bare ground and species cover values using a pre-defined species list for GRYN.

GRYN adapted UCBN's existing database user interface (Figure 9) for entering Bighorn Canyon data into the master data file. Each entered survey value is immediately screened for validity using pre-defined values from reference tables and database functions.

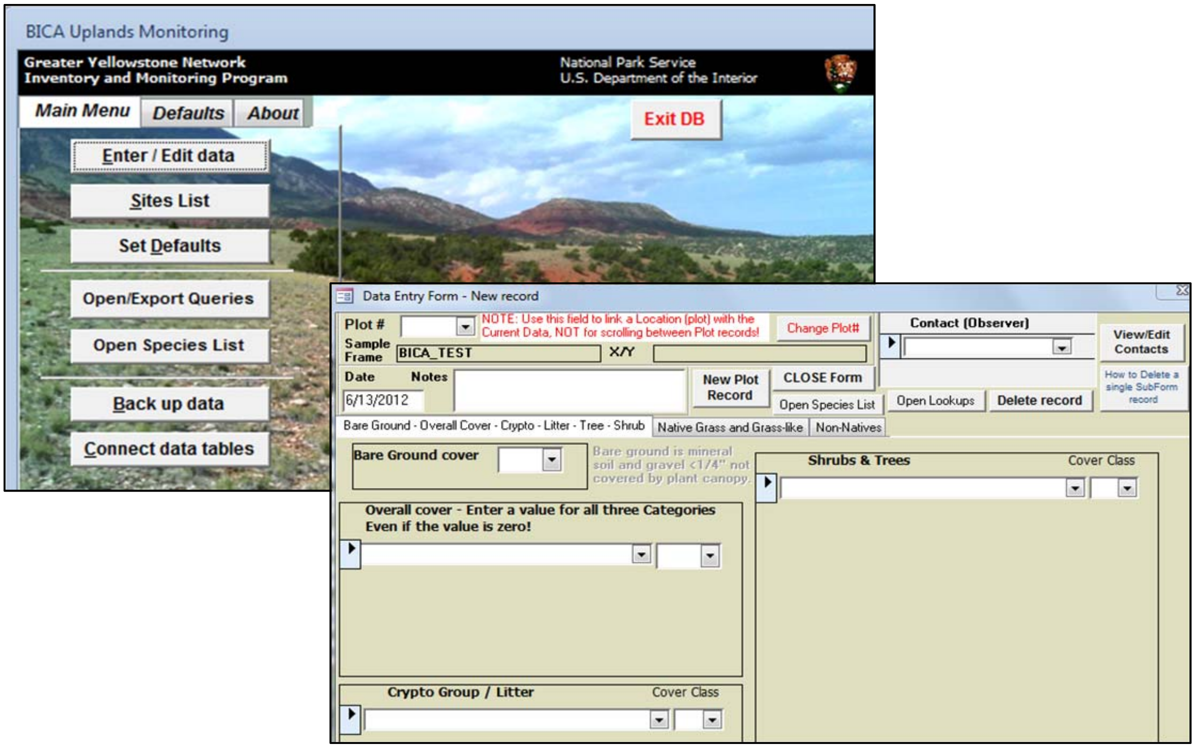

Figure 9. The main menu (background) and the primary data entry form (foreground) showing tabs for each species group in the Bighorn Canyon Upland Vegetation Monitoring database.

Data Entry and Quality Assurance

Careful professional data entry is a critical step in the overall quality of project data and results derived thereof. Each field season, one or more survey crews operate a tablet computer to directly record data electronically as surveys are carried out in the field. In case technology fails, crew members carry hard copy, paper field data collection forms to use. If hard copy forms are used, written values are entered into the field database at the next possible opportunity, and the original forms are kept as part of the permanent project record. Normally survey crew members carefully select and double check entries using pick lists of available values on the electronic data entry form. Choosing an existing value or option from a pick list provides a high level of quality control, but surveyors must avoid hurrying during data entry and be able to clearly see the computer screen in order to prevent the inadvertent selection of an adjacent (incorrect) value from the list of options. The field database holds only those records collected during the current year. Several times each day crew members back up the field data to one or more memory cards on the tablet computer, and a full copy of the field data from each tablet is archived at the main GRYN office between field trips. At the end of each field season the data are combined with all other project data, summarized, and submitted for review by one or more subject matter experts. Once validated by the expert(s) the data are certified for use by the protocol leader, the data manager, and the program manager. Only after the certification documentation is filed at the GRYN office are the data used for analysis, reporting, and distribution.

Data Documentation

Complete and current descriptions of all project data are required to ensure their long term utility and applicability to meet stated project objectives, and possibly to support related purposes for which the data are suited. Documentation for this project's data includes descriptions of site, survey, and cover type parameters/variables in this monitoring protocol document, database object descriptions in the project database, and data field/variable descriptions in standard operating procedures, field manuals, and training materials. Annual geospatial data for the project, including sample frame boundaries and sampled quadrats (represented as point features), are described in geospatial metadata within the project's master Geodatabase that meet Federal Geographic Data Committee (FGDC) and NPS standards. The protocol leader works with the GRYN data manager to develop and maintain current and comprehensive data documentation and geospatial metadata following established procedures from the GRYN Data Management Plan (Daley 2005) and SOP 6: Data Management (Jean et al. 2013).

Sensitive Information

The protocol leader, working with a park resource manager, determines whether existing or potential sensitive information from this protocol needs to be identified and addressed for rare, threatened, or endangered species. While the presence of sensitive information is not anticipated for this monitoring protocol, identified cases that may occur are documented in writing and communicated to the data manager, who will help identify sensitive records in the database and prevent their release. Only the park Resource Manager, Superintendent, or other appropriate authority may authorize the release of sensitive data after following appropriate review procedures and distribution restrictions for sensitive information (SOP 6: Data Management, Jean et al. 2013).

Data Certification, Distribution, and Archives

Data quality, according to NPS Director's Order #11B (Mainella 2002), "Ensuring Quality of Information Disseminated by the National Park Service," incorporates three key components: objectivity, utility, and integrity. Objectivity consists of presentation—disseminated information is being presented in an accurate, clear, complete, and unbiased manner within a proper context; and substance—ensuring accurate, usable, and reliable information. Utility refers to the usefulness of the information to its intended users. Integrity refers to the security of information; for example, protection from unauthorized access or revision to ensure that information is not compromised through corruption or falsification.

Data certification is a data quality assurance process resulting in a signed, written statement from the project leader, data manager, and program manager confirming that a set of data comply with NPS Director's Order #11B (Mainella 2002). Certification is not an absolute guarantee that data are completely free of errors or inconsistencies. The protocol leader is responsible for completing written certification of data collected each year as a prerequisite to using or sharing project data from that year. SOP 6: Data Management (Jean et al. 2013) provides complete instructions for certifying and distributing data. Electronic archives for project data are maintained on the GRYN server. All data on the server are restricted for read/write access to specific project and program staff and receive daily differential and monthly full backups stored on-site and quarterly backups stored off-site. At the end of each field season all physical project materials, including field data collection forms, site sketches, and log books, and other materials are submitted by the protocol leader for filing with the project record in the GRYN office. Paper data sheets, when used, are managed as permanent records and kept on file with other project materials. Certified data and related reports are stored on the GRYN server, posted to the GRYN website, and uploaded to the NPS online national database for resource information. The NPS master database for biodiversity is updated annually as new or additional information about Bighorn Canyon species is discovered from this monitoring effort.

Data Analysis

Annual Status Analysis

Vegetation status results will be summarized after each year of data collection. Graphical representation of data as well as standard summary statistics will be presented. Ordinal vegetation cover data can be analyzed as continuous data by taking the midpoints of cover classes, or with categorical analytical methods by estimating the proportions of sample quadrats in each cover class (Agresti 2010). For example, Figure 10 shows the mean % cover (derived from midpoints) and the percent of plots occupied within each sample frame (cover class 1 or greater) for cheatgrass in Bighorn Canyon during 2011. Plots of this type can be used to quickly target areas that are in greater need of management attention. In the case of weed control efforts, management can be even more targeted through the use of maps like those shown in Figure 11, which identify the exact locations in which weeds were encountered. Margins of errors, computed with a GRTS variance estimator can be calculated with the spsurvey package (Kincaid 2008) available in R (instructions for these calculations are available in SOP 7: Data Analysis and Reporting, Jean et al. 2013). The sampling design, with its emphasis on large and well-distributed samples will make a large number of status estimates like these immediately available each year, as has been demonstrated through the 2011 annual monitoring report (Tercek 2012).

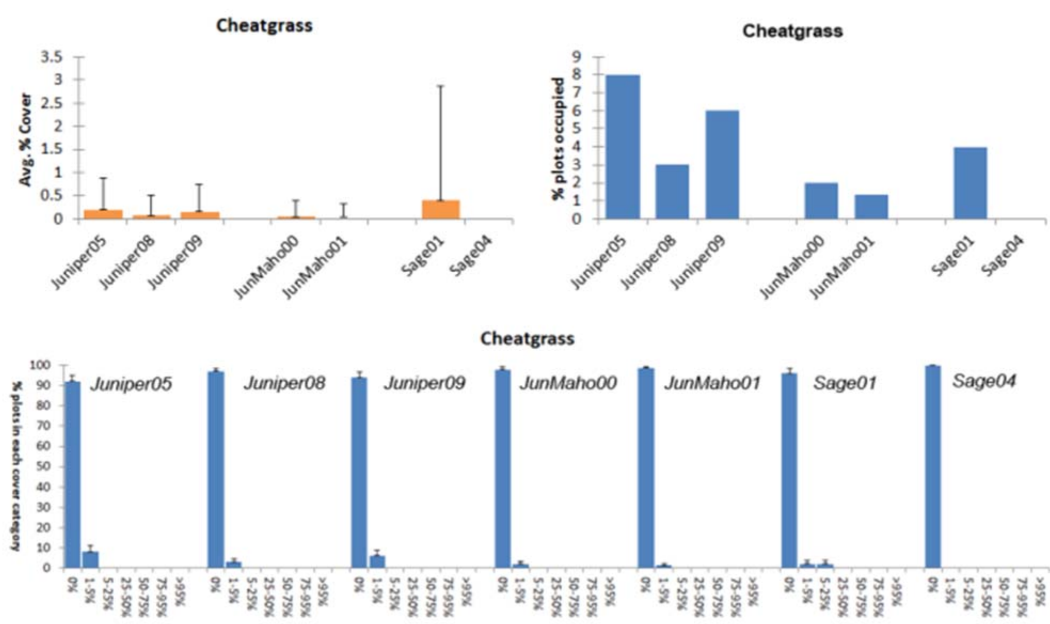

Figure 10. Cover data for cheatgrass collected during 2011 in Bighorn Canyon National Recreation Area using three methods. On the upper left, mean percent cover and on the upper right, percent frequency (occurrence) of cheatgrass among sites by sample frame. On the bottom, the percent of plots in each sample frame having a particular level of percent cover.

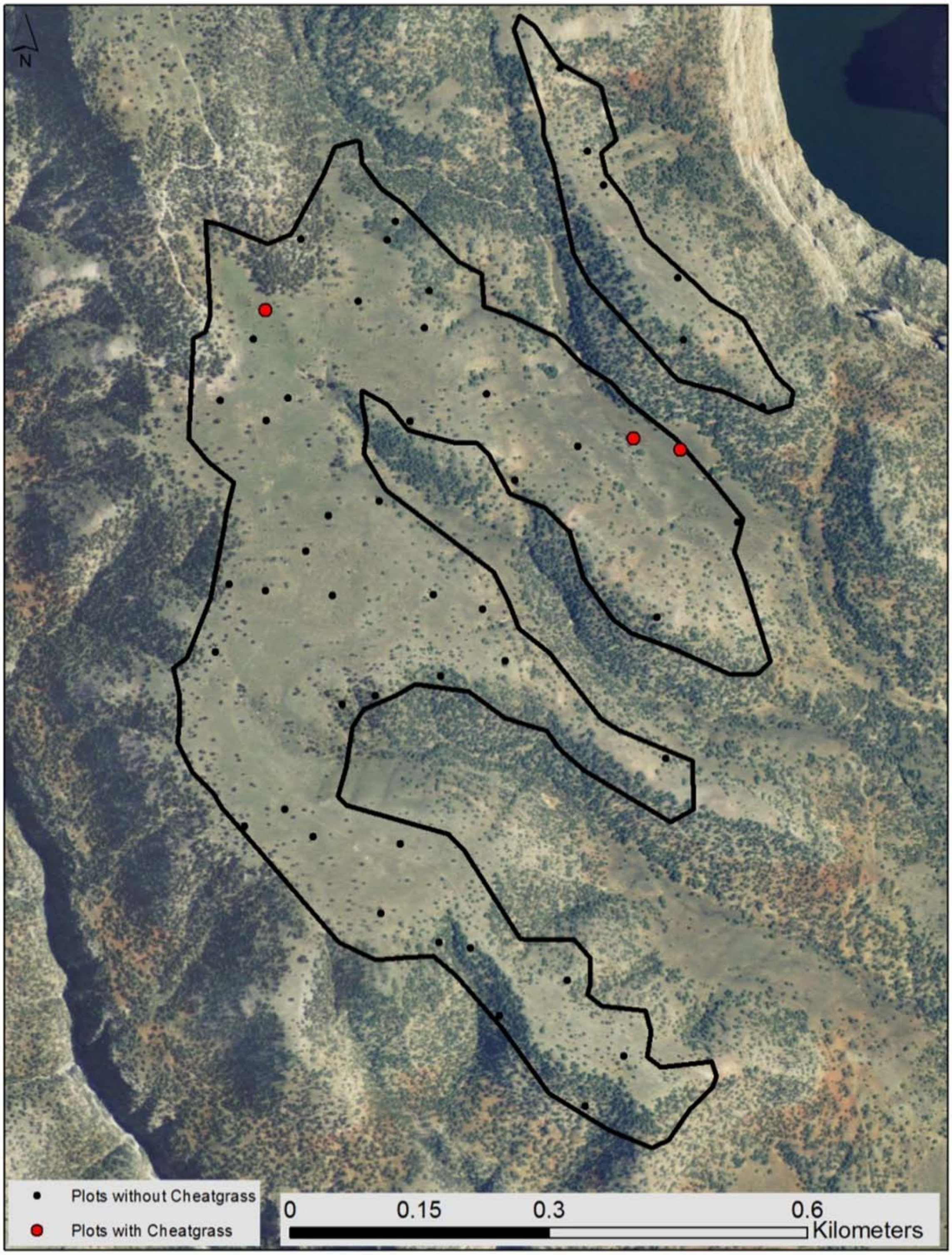

Figure 11. Map showing the locations of cheatgrass in a sample frame Sage01 during 2011 at Bighorn Canyon National Recreation Area.

As described in SOP 7: Data Analysis and Reporting (Jean et al. 2013), to analyze for differences in the percent plant cover occurring between two different years, a proportion test s can be performed (Sheskin 2007). If non-parametric alternatives to this test are used in the future, the power analysis presented previously in this document will still be a good guide. For example, Kruskal-Wallis, Mann-Whitney, or Wilcoxson signed ranks tests all have an Asymptotic Relative Efficiency of about 0.95 compared to the proportion test, which means they will require about (1/0.95)=1.05, or only 5% more samples to achieve the same power when samples are normally distributed. When the data are not normally distributed, non-parametric tests are more efficient than parametric tests, requiring fewer samples (Sheskin 2007).

In addition to step-change comparisons between two years of data collected by this protocol, there will be opportunities to make comparisons to data collected by researchers in the more distant past or in the future that used similar methods. For example, Table 5 shows a comparison between our 2011 pilot data (Tercek 2012) and survey done by Knight et al. (1987) using similar methods. Careful comparisons between data from the present protocol and older work like this can extend the inferential reach of our protocol.

Table 5. Comparison of in Bighorn Canyon by GRYN 2011 versus data collected in the same area by a botanical team in the 1980s.

	Sagebrush Average % cover		**Utah juniper Average % cover**		**Mountain mahogany Average % cover**	
Sample Frame Type	Knight et al. (1987)	Tercek (2012)	Knight et al. (1987)	Tercek (2012)	Knight et al. (1987)	Tercek (2012)
Sagebrush	4-15	1.7-2.7	<1	10-11	<1	0.05-0.4
Juniper	<1	0.5-2.25	16	11.6-19.5	<1	0
Juniper-Mountain Mahogany	<1	<1	11	3.7-7.7	16	1.2-5.8

Change Detection and Trend Analysis

The detection of trends over multiple years of data will follow the methods of Irvine and Rodhouse (2010), who are co-authors on the UCBN protocol that serves as the basis for the protocol presented here. Their methods, which were specifically designed for the field protocol currently under discussion, are considered in more detail in SOP 7: Data Analysis and Reporting (Jean et al. 2013).

Data Reporting

Each year, a summary report will be produced with data collected and will:

- Provide a summary history of quadrat samples taken during each year of the study, tabulating numbers of quadrats for each sampling frame and showing these locations on maps.
- Provide summary status statistics and interpretation of the biological meaningful results.
- Evaluate data quality and identify any data quality concerns and/or deviations from protocols that affect data quality and interpretation.
- Evaluate and identify suggested or required changes to the protocol.

Every six years, a more in-depth trend report will be produced; the first trend report expected following the 2018 sampling season. The purpose of this report will be to assess long-term trends in changes in vegetation from sample frames. In addition, this report will provide greater analytical and interpretive detail, and will evaluate the relevance of findings to long-term management and restoration goals. The report will also evaluate operational aspects of the monitoring program, such as whether sample frame boundaries need to be changed or whether the sampling period remains appropriate (the optimal sampling season could conceivably change over time in response to climate change). The report will also evaluate if there are new management concerns that might dictate some reallocation of effort or additions to the indicator metrics that are routinely examined annually.

Annual reports and six-year analyses of status and trend will follow guidelines for the NPS Natural Resource Publications Series and use a pre-formatted Microsoft Word template document based on current NPS formatting standards. Template guidelines and documentation of the NPS publication standards are available at the following address: http://www.nature.nps.gov/publications/nrpm/index.cfm.

Current versions of the protocol, resource briefs, and annual and six-year reports will be made available on the GRYN website (http://science.nature.nps.gov/im/units/gryn/index.cfm). The protocol and technical reports will also be available from the national NRPM website (http://www.nature.nps.gov/publications/nrpm/nrr.cfm). All NPS protocols are available from (http://science.nature.nps.gov/im/monitor/protocoldb.cfm).

Personnel Requirements and Training

Personnel Requirements

Minimum requirements for this protocol include a team comprised of a protocol lead, field coordinator, and two biological technicians with college-level training in biology or related subjects. One of the two technicians will serve as the field leader responsible for daily oversight. The technicians will be carefully trained in the sampling techniques and in the identification of selected upland plant species and community condition indicators. The protocol leader will have an in depth understanding of the protocol and be responsible for implementing the protocol. This individual will provide oversight for training the technicians, oversee field data collection, and verify, summarize, analyze, and interpret data each year. The field coordinator is responsible for supervising the biological technicians and coordinating their activities across network programs. The protocol leader or field coordinator may also double as one of the two technicians. (Refer to the following section on Roles and Responsibilities.)

Sampling will follow the advance of plant phenology, starting in the spring when cool season grasses have emerged and continuing into early summer when these same grasses have flowered. A two person team can sample around 40 sample plots per day, or about one sampling frame every 1-2 days. Approximately six weeks of sampling time with training will be planned to complete each season's field work. The goal to complete between 550-600 sample quadrats per season will enable the GRYN to meet objectives outlined in the protocol. This goal provides ample time to accommodate travel, foul weather, and unanticipated contingencies.

Depending on staff availability, funding, and other monitoring program needs, the sampling window could be modified to optimize collection and intensify sampling during the best time for identifying plants (i.e. more teams could sample in a shortened time period). This timing will most likely shift annually due to changes in weather (i.e., some year's snow pack and cool springs delay green-up, while in others it occurs earlier). In general though, based on Bighorn Canyon staff knowledge and Moderate Resolution Imaging Spectroradiometer (MODIS) data that measures green up using the Normalized Difference Vegetation Index (NDVI) (Thoma et al. 2013), optimal sampling occurs between the end of May and beginning of July.

Qualifications, Training, and Calibration

Individuals completing the field work must become adept at all aspects of the sampling procedures, must be able and willing to travel and work independently, and must know or be able to learn quickly the principal plant species that will be encountered. They also must be careful and organized, giving attention to accurate sampling site location, sampling documentation, accurate plant identification, and oversight of data recording for accuracy, thoroughness, and clarity. Individuals must be comfortable using electronic field equipment (GPS units and computers).

Roles and Responsibilities

The protocol leader must have a basic understanding of sampling design and data management and analysis, knowledge of and ability to identify plants of the woodland, shrubland, and grassland flora of the Bighorn Basin. This individual in coordination with the Field Coordinator will oversee the training of the technicians and be available for consultation and oversight of their work during the sampling season. The Protocol Leader will work closely with the Field

Coordinator to schedule the field work for this monitoring protocol in coordination with other Network activities. Table 6 provides a general outline for the roles and responsibilities of personnel involved in this monitoring protocol.

The most important training elements are sampling procedures and plant identification. The list of plants targeted for this monitoring protocol include a mix of grasses, shrubs, and trees and many non-native invasive or noxious weeds, several of which are on the park non-native watch list. See Appendix A for a complete list of target plant species. Many aids are available to assist in plant identification including standard taxonomic references, vegetative keys to grasses, invasive plant field guides and species specific monographs and journal articles (see SOP 2: Training Observers, Jean et al. 2013). The herbarium at Bighorn Canyon is another useful resource. The target plant lists will be reviewed annually to consider updates as the database of plant species grows as the vegetation inventory is completed for the Bighorn Canyon, and as knowledge is accumulated of the characteristics that best distinguish easily-confused species in the field. A field reference manual that includes relevant field SOPs, taxonomic reference material, and instructions on using the tablet computer for data entry will be an essential tool for each technician

Table 6. Roles and responsibilities for implementing the upland vegetation monitoring program in the GRYN.

Role	Responsibilities
Protocol Leader	• Implement protocol annually • Track progress towards meeting protocol objectives • Identify budget needs • Identify when specialists are needed to complete different phases of the protocol • Facilitate communications between NPS and cooperator(s) • Coordinate and update changes to protocol • Coordinate training of field teams • Certify each season's data for quality and completeness • Determine whether monitoring data includes sensitive information • Perform data summaries and analyses • Complete reports, metadata, and other products according to schedule • Maintain and archive protocol records
Field Coordinator	• Provide supervision of technicians • Main contact for crew daily check in • Implement safety training of technicians • Work in coordination with the protocol leader to implement the following: o Plan and execute field visits o Oversee data collection and entry, verify accurate data transcription into database • Acquire and maintain field equipment • Facilitate crew logistics (camping, vehicle use, etc.) • Obtain research permit
Technicians (s)	• Collect, record, enter, and verify data • Lead maintains field notes highlighting points of interest for trip report • Lead prepares a short end of season trip summary report • Take photographs and manages photo library
Data Manager	• Prepare database, field forms, GPS for upcoming field season • Consultant on data management activities • Facilitate check-in, review and posting of data, metadata, reports, and other products to national databases and clearinghouses according to schedule • Maintain and update database application • Provide database training as needed • Consultant on GPS use • Work with Protocol Lead to analyze spatial data and develop metadata for spatial data products • Primary steward of Access database and Geographic Information System data and products • Help determine whether monitoring data includes sensitive information and prevent their release • identify sensitive records in the database and prevent their release • Coordinate with UCBN on database updates
Network Program Manager	• Protocol oversight • Administration and budget • Consultant on all phases of protocol review and implementation • Review of annual and 6-year reports • Provide technician supervision if Field Coordinator is unavailable
Park Resource Manager	• Consultant on all phases of protocol implementation • Facilitate logistics planning and coordination • Communicate management and restoration plans and associated information to Protocol Lead • Review reports, data, and other protocol deliverables • Help determine whether monitoring data includes sensitive information • Provide examples of how data have been used in management decision
Cooperator	• Assist with tasks as identified through agreements: data collection, report preparation, trend analysis

Operational Requirements

Annual Workload and Field Schedule

Vegetation surveys will begin no earlier than mid-May and be completed by no later than mid-July, to reduce as much as possible differences in detection, identification, or cover estimates that are caused by changes in plant phenology over the growing season. At the beginning of the growing season, many plants are too immature for ready identification, and late in the season, many of the spring-growing plants that comprise a significant part of the biodiversity are senesced and dried, often no longer identifiable. Thus, roughly two months define the sampling timeframe. The annual workload for field personnel is six weeks, which includes one week of training, and five weeks of sampling and field work close-out. Several additional weeks of preparation and analysis and reporting will be required from the GRYN Protocol Lead. Figure 12 illustrates the annual project lifecycle and schedule.

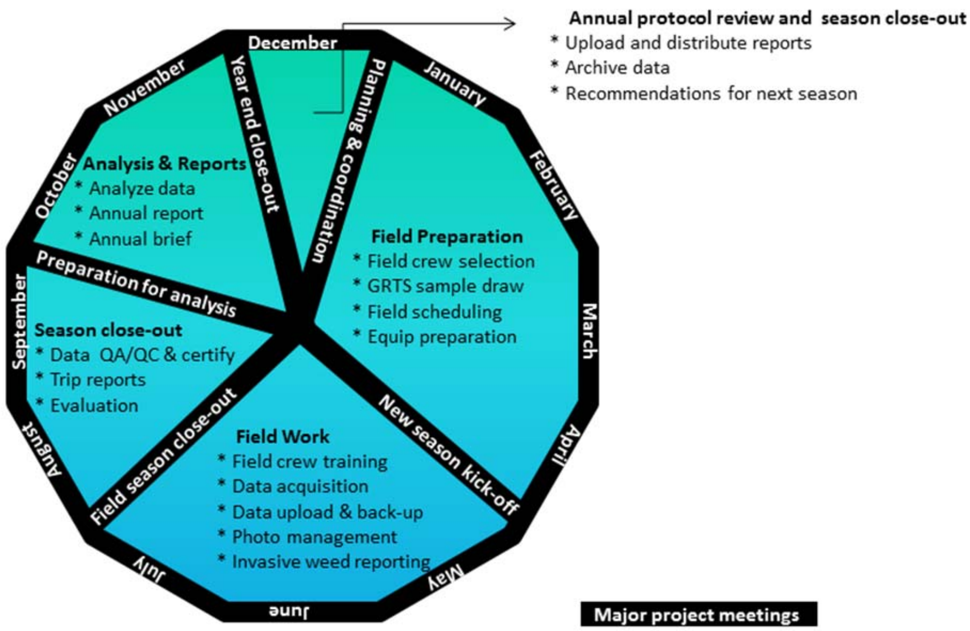

Figure 12. Annual project life cycle and schedule for upland vegetation monitoring.

Facilities and Equipment Needs

The field and safety equipment for this protocol fall into three categories: measuring, navigating and recording, and communication. Measuring devices include inexpensive folding rulers and rods to layout the quadrat and a hand lens for each crew member to use for plant identification. Equipment used for navigating and recording includes a compass for each crew member and a GPS unit and a tablet computer for each two-person crew. Communication equipment include, for each two-person crew, a two-way handheld park radio, a Personal Locator Beacon and a satellite or cell phone. A complete list of field sampling equipment is given in SOP 2: Field Preparation and Season Close-out (Jean et al. 2013). Almost all this equipment is used for other network projects during summer.

Housing, trailer location, or camping must be arranged at or near Bighorn Canyon well in advance of the field season. It is desirable to have use of a trailer on site, although camping should be expected. If digital equipment is to be used, access to power is essential for recharging batteries.

A minimum of one field vehicle dedicated to this effort will be required to support each field season. The GRYN has one government vehicle available and can also rent vehicles from private rental car companies such as Hertz or Enterprise. Vehicle arrangements need to be made well in advance of field work. Seasonal technicians must be 25 years or older in order to rent and drive rental vehicles. Student interns through Montana State University may be able to use a university vehicle.

Protocol Testing and Revision

This protocol was first developed by the UCBN (Yeo et al. 2009) and has been implemented in the UCBN national parks since 2009 (Rodhouse 2009 and 2011, Yeo and Rodhouse 2012b and 2012c). At Bighorn Canyon, the protocol was first piloted by the GRYN in 2011 and was fully implemented in 2012. The Bighorn Canyon sample frames, data entry forms and target species lists were evaluated and updated both years with input from Bighorn Canyon staff (Tercek 2012). This resulted in a solid set of sampling frames and a reliable species list for this protocol, but some revisions are possible in future years. Changes to the protocol and related SOPs will be fully described as specified in SOP 8: Protocol Revision (Jean et al. 2013). The database for each monitoring component will contain a field that identifies which version of the protocol was used when the data were collected. The protocol narrative will be revised if and when changes to monitoring objectives, sampling design, or other methodological components are required.

The standard operating procedures list specific instructions for performing the work required by this monitoring protocol. They are expected to be revised more frequently. All versions of the protocol and SOPs are archived in a descriptively-named, well-organized folder structure on the GRYN server. All applicable versions are archived in the NPS Integrated Resource Management Applications (IRMA) and available there as well as from the GRYN website.

In addition to the SOPs, two digital files are updated annually: the target plant species list and the list of target quadrats (e.g., GRTS sample). Updates to these files do not require a revision to the protocol unless procedures change.

The steps for changing the protocol (either the narrative or an SOP) are given in SOP 8: Protocol Revision (Jean et al. 2013). Each SOP contains a change log that should be filled out each time an SOP is revised to explain why the change was made and to assign a new version number to the revised SOP. The new version of the SOP or Protocol Narrative should be archived in the project library under the appropriate folder.

Budget

Table 7 details the annual operating budget for this protocol, reflecting current costs.

Table 7. Annual budget for upland vegetation monitoring in the GRYN. More than 50% of the upland vegetation budget is spent on data management activities including analysis and reporting.

Greater Yellowstone Network Upland Vegetation Monitoring Budget				
Expenditures	**Time Allotted**	**% Time for Data Management**	**Cost in Dollars for Data Management**	**Total Costs in Dollars (2012)**
Network Program Manager (GS-13)	1 week to review report; manage budget	50%	$1,150	$2,300
Network Data Manager (GS-12)	1 week field season preparation & crew training; 2 weeks QA/QC, data archiving, and close out; 1 week on data requests	100%	$7,600	$7,600
Protocol Leader (GS-12)	2 weeks prep for field work. Logistics, & coordinating cooperators; 2 weeks field training & sampling assistance; 3 weeks data analysis & reporting; close out	60%	$7,980	$13,300
Field Coordinator (GS-9)	3 weeks to hire, supervise & coordinate crews, train, & provide safety check ins	10%	$400	$4,000
Seasonal Personnel 2 Biological Technicians (GS-6)	1 week training; 5 weeks sampling, data validation in the field, & close out	50%	$4,500	$9,000
Park Personnel	1 week field work prep & assistance; verify data questions; housing logistics; report reviews		$ -	IN-KIND
Contracts/Cooperators	Periodic assistance with data analysis; field work; trend reporting (varies by year)		$ -	$
Operations/Equipment	Supplies such as tents; snake gators;		$ -	$1,000
Housing/lodging	camping or trailer pad provided by park		$ -	IN-KIND
Vehicle	Fuel/rental vehicle			$600
Travel	Per Diem		$ -	$1,500
Other (Contingency)			$ -	$500
TOTAL			$21,630	$39,800

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Appendix A. Plant Species and Ground Cover Attributes

Table A-1. Vascular plants and ground cover attributes targeted for monitoring in the Upland Vegetation Monitoring Protocol as of 2013.

Scientific Name	Common Name
Ground Cover	
Bare ground	Bare ground
Cryptobiotic soil crust	Cryptobiotic soil crust
Litter	Litter
Grass or grass-like	
Achnatherum hymenoides	Indian ricegrass
Aristida purpurea var*. fendleriana*	Three awn
Bouteloua gracilis	Blue grama
Bromus inermis	Smooth brome
Carex spp*.*	Sedges
Festuca idahoensis	Idaho fescue
Hesperostipa comata var*. comata*	Needle and thread
Koeleria macrantha	Junegrass
Pascopyrum smithii	Western wheatgrass
Poa secunda	Sandberg's bluegrass
Pseudoroegneria spicata	Bluebunch wheatgrass
Sporobolus spp.	Drop seed
Shrubs and sub-shrubs	
Artemisia nova	Black sagebrush
Artemisia tridentata	Wyoming Sagebrush
Atriplex spp*.*	Saltbush
Gutierrezia sarothrae	Broom snakeweed
Krascheninnikovia lanata	Winter fat
Opuntia polyacantha	Prickly pear
Rhus aromatica var*. trilobata*	Skunkbush
Trees	
Cercocarpus ledifolius	Curlleaf mountain mahogany
Juniperus osteosperma	Utah juniper
Juniperus scopulorum	Rocky Mountain juniper
Pinus flexilis	Limber pine
Non-native (present in park)	
Agropyron cristatum	Crested wheatgrass
Arctium minus	Common burdock
Bassia sieversiana	Kochia
Bromus japonicus	Japanese brome
Bromus tectorum	Cheatgrass
Cardaria chalapensis	White top
Cardaria pubescens	Hoary cress
Centaurea diffusa	Diffuse knapweed
Centaurea maculosa	Spotted knapweed
Centaurea repens	Russian knapweed

Table A-1. Vascular plants and ground cover attributes targeted for monitoring in the Upland Vegetation Monitoring Protocol as of 2013 (continued).

Scientific Name	Common Name
Non-native (present in park) *(cont.)*	
Cirsium arvense	Canada thistle
Cirsium vulgare	Bull thistle
Conium maculatum	Poison hemlock
Convolvulus arvensis	Field bindweed
Cynoglossum officinale	Houndstounge
Dactylis glomerata	Orchard grass
Elaeagnus angustifolia	Russian olive
Elymus repens	Quackgrass
Halogeton glomeratus	Salt lover
Melilotus spp.	Sweet-clover
Salsola tragus	Russian thistle
Tamarix chinensis	Salt cedar
Tanacetum vulgare	Common tansy
Tribulus terrestris	Puncture vine
Non-native (watch list)	
Carduus acanthoides	Plumeless thistle
Cardaria draba	Hoary cress
Carduus nutans	Musk thistle
Chondrilla juncea	Rush skeletonweed
Chrysanthemum leucanthemum	Ox-eye daisy
Euphorbia esula	Leafy spurge
Hypericum perforatum	St. John's wort
Isatis tinctoria	Dyer's woad
Lepidium latifolium	Perennial pepperweed
Linaria dalmatica	Dalmatian toadflax
Linaria vulgaris	Yellow toadflax
Lythrum salicaria	Purple loosestrife
Onopordum acanthium	Scotch thistle
Sonchus arvensis	Perennial sowthistle

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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