Shenandoah National Park Forest Vegetation Monitoring Protocol
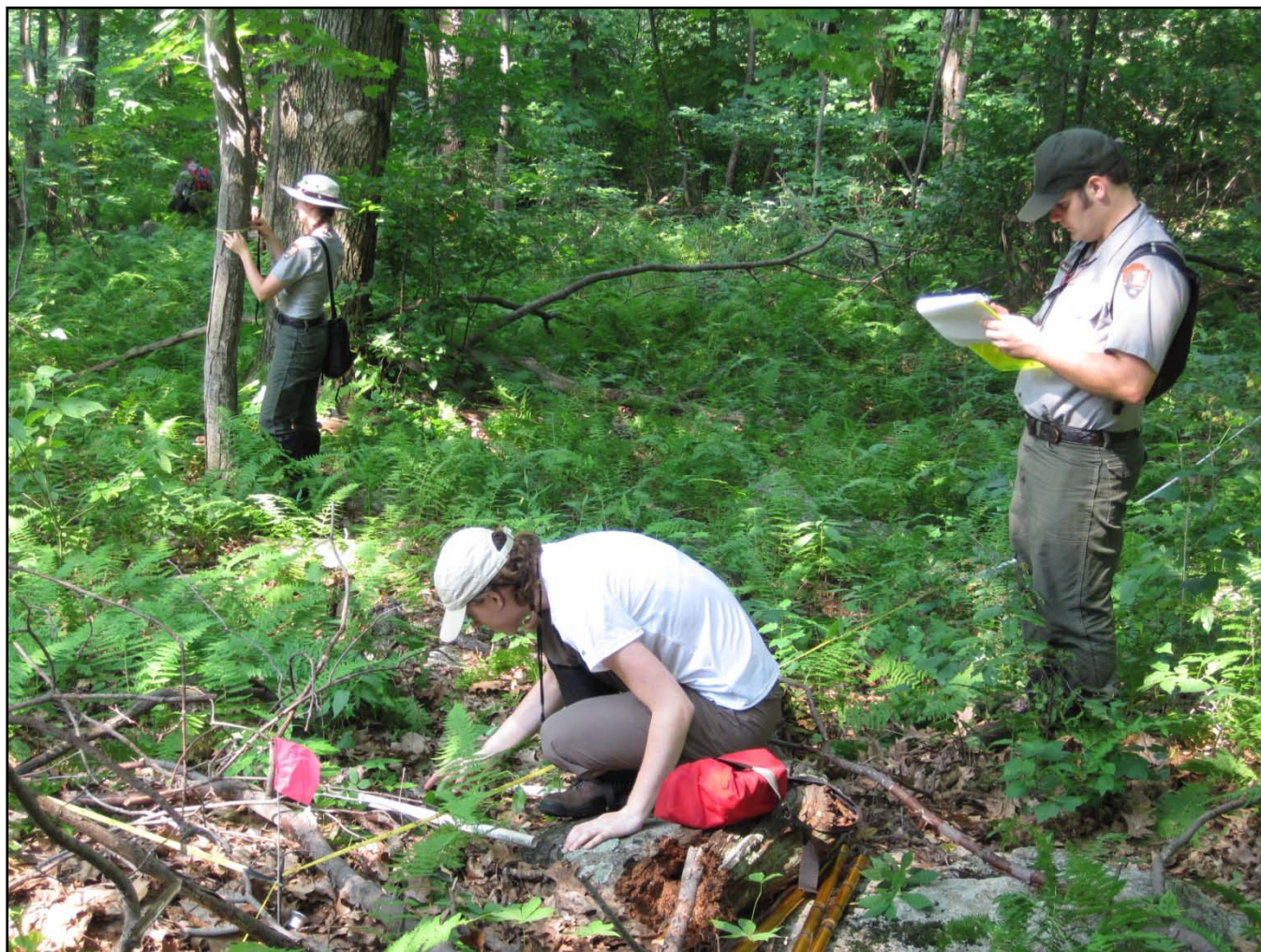
Version 2.3

Shenandoah National Park Forest Vegetation Monitoring Protocol

Version 2.3

Natural Resource Report NPS/MIDN/NRR—2011/475

Wendy B. Cass, Wendy W. Hochstedler, and Nicholas A. Fisichelli

Shenandoah National Park
National Park Service
3655 US Hwy 211 East
Luray, VA 22835

December 2011

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available from Shenandoah National Park (http://www.nps.gov/shen/naturescience/monitoring.htm), the Mid-Atlantic Network (http://science.nature.nps.gov/im/units/midn/ProtocolForestVegetation.cfm, and click on the Blue Ridge tab) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

Please cite this publication as:

Contents

Contents (continued)

Contents (continued)

Figures

Tables

Standard Operating Procedures

This report makes reference to Standard Operating Procedures (SOPs) that outline detailed steps for conducting specific aspects of the monitoring protocol. The latest versions of the SOPs can be accessed at the National Park Service's Mid-Atlantic Inventory & Monitoring Network website (http://science.nature.nps.gov/im/units/midn/) in the Forest Vegetation Monitoring Protocol section. The SOPs are updated on an as-needed basis and all changes are identified in individual Revision History Logs.

Preparations Prior to the Field Season (Standard Operating Procedure 1)

Crew Training and Safety (Standard Operating Procedure 2)

Using the Global Positioning System (Standard Operating Procedure 3)

Establishment and Marking of New Sites (Standard Operating Procedure 4)

Upgrading a Site Established Prior to 2003 (Standard Operating Procedure 5)

Routine Sampling Visit Procedures and Replacing Lost Markings
(Standard Operating Procedure 6)

Photo Documentation (Standard Operating Procedure 7)

Tree Strata Sampling (Standard Operating Procedure 8)

Shrub Strata Sampling (Standard Operating Procedure 9)

Seedling Strata Sampling (Standard Operating Procedure 10)

Determining Vegetation Communities, Species Richness, and Cover of Exotic Plants, Herbs, and Groundcovers (Standard Operating Procedure 11)

Coarse Woody Debris and Fuels Sampling (Standard Operating Procedure 12)

Forest Soils Sampling (Standard Operating Procedure 13)

Collection and Processing of Unknown Plant Species and Voucher Specimens
(Standard Operating Procedure 14)

Data Management and Quality Control (Standard Operating Procedure 15)

Data Analysis (Standard Operating Procedure 16)

Executive Summary

Shenandoah National Park (SHEN), a member of the Mid-Atlantic Network (MIDN) and part of the National Park Service's (NPS) Inventory and Monitoring (I&M) Program, has identified forest vegetation and several associated vital signs as high priority for long-term monitoring. Development of the SHEN forest vegetation monitoring program began in 1987, with staffing increases and field sampling commencing in 1989. Reviews of the forest vegetation monitoring program's objectives, statistical power, and sampling design were completed from 2000 – 2003. In response to these reviews, the forest vegetation monitoring program protocol was revised to address concerns about program sampling objectives, statistical power to detect changes in forest community composition and growth, plot design, and field sampling efficiency. The current forest vegetation monitoring protocol was initiated in 2003 and assesses the status and trends of forest plant communities, including herbaceous and exotic vegetation, downed woody debris and snags, and soils. The current protocol has been designed to sample the 160 forest sites within the program over a four year sampling rotation. Sites are stratified according to elevation, aspect and bedrock geology. Site locations were randomly chosen within forested areas of the park occurring beyond the influence of roads, trails, and developed areas. Each site consists of a 24 x 24 m slope corrected square plot where all woody vegetation with a diameter at breast height (DBH) ≥ 10 cm are identified, measured, tagged, and marked, and their conditions assessed. Woody vegetation with a DBH < 10 cm and a height ≥ 1.5 m are identified and measured in two nested 24 x 2 m subplots. Woody vegetation with a DBH < 10 cm and a height < 1.5 m are identified and measured in two nested 12 x 0.5 m subplots. A complete species list, and percent cover classes of dominant herbs and all exotic plant species are also recorded for the entire plot. Coarse woody debris is measured along two 15 m transects. Certain other metrics, such as soil composition, and tree height and age, have been sampled once over the course of the program, and may be sampled again if data are needed. Additional metrics such as evidence of deer browse and leaf damage may be incorporated in future protocol versions to assess the impacts of stressors such as white-tailed deer, exotic plant diseases and pathogens, and native forest pests, and to allow greater comparability with the MIDN forest vegetation monitoring program (Comiskey, Schmit and Tierney 2009), and other protocols in the region. This report makes reference to Standard Operating Procedures (SOPs) that outline detailed steps for conducting specific aspects of the monitoring protocol. The latest versions of the SOPs can be accessed at the National Park Service's Mid-Atlantic Inventory & Monitoring Network website (http://science.nature.nps.gov/im/units/midn/) in the Forest Vegetation Monitoring Protocol section. The SOPs are updated on an as-needed basis and all changes are identified in individual Revision History Logs.

Acknowledgments

Protocol Revision History

The following revision history log summarizes the long development history of Shenandoah National Park's forest vegetation monitoring protocol. Prior to 2006, all aspects of the protocol were combined into a single document. From 2006 to 2011, individual standard operating procedures (SOPs) were created for each protocol component. This document (version 2.3) presents the protocol narrative. The latest versions of the SOPs can be accessed at the National Park Service's Mid-Atlantic Inventory & Monitoring Network website (http://science.nature.nps.gov/im/units/midn/) in the Forest Vegetation Monitoring Protocol section. SOPs are updated as needed, with changes identified in separate Revision History Logs.

Version #	Completion Date	Revised By	Changes	Justification
precursor	1988	Tom Blount	Expansion of researcher Tom Nichols, 1986 Virginia Tech. research protocols	Adaptation of initial university research protocols to parkwide forest vegetation monitoring
1.0	1990	Smith and Torbert	Creation of original NPS I&M forest vegetation monitoring protocol; peer reviewed and published	Standardization of field sampling and installation of additional sites
1.1	1999	Wendy Cass	Clarification of monitoring protocols and site documentation techniques	Increase field efficiency and improve data quality
1.2	2001	Wendy Cass	Protocol clarification	Improve data quality
2.0	2003	Wendy Cass Mary Willeford Bair	Writing new site installation methods and field sampling data sheets. Exotic species, and fire fuels sampling initiated.	Implementation of peer reviewed program modifications resulting from the recently completed program review
2.1	2005	Wendy Cass Nick Fisichelli	Text clarification, site installation diagrams added, updated data sheets.	Improve protocol clarity and field implementation
2.2	2007	Wendy Cass Nick Fisichelli Jacob Hughes David Demarest	Extensive writing and reformatting in SOP style, Soil and course woody debris sampling initiated	To conform to Oakley et al. (2003) standards
2.3	2011	Wendy Cass Wendy Hochstedler	Formatted to NPS NRR standards; addition of program narrative and SOPs for data management and analysis. Initiation of full plot species lists. Exotic species documentation expanded.	To create a cohesive set of standard operating procedures in preparation for peer review and publishing

1. Background and Objectives

1.1 Protocol History

This protocol is designed to monitor changes to the forest vegetation of Shenandoah National Park (SHEN, Figure 1), a member of the Mid-Atlantic Network (MIDN) (Figure 2) and part of the National Park Service's (NPS) Inventory and Monitoring Program (I&M). Parkwide vegetation monitoring was originally conceived in 1984 when SHEN and regional NPS staff began working together to develop a comprehensive natural resources long-term ecological monitoring system for the park. The long-term ecological monitoring program was designed to monitor a basic set of ecological parameters that characterize the broad types and rates of change likely to take place in the park, and to provide appropriate information to address management needs. Of particular concern were the impacts of the exotic gypsy moth (*Lymantria dispar*) on forest systems. Other likely perturbations such as wildfire (or lack thereof), acid deposition, air pollution impacts, and visitor use impacts were also considered when determining monitoring design and protocols. Forest vegetation communities were chosen as one of the primary monitoring components of this program (Ravlin et al. 1990, Shenandoah National Park 1992).

The initial focus of the terrestrial vegetation monitoring program was to better understand threats to the ecosystem. Forest community monitoring was established to measure changes in forest vegetation communities, especially the response to gypsy moth defoliation. Field sampling began in 1987 with a Natural Resource Preservation Program (NRPP) funded collaborative research project between the NPS and Virginia Polytechnic Institute and State University to document gypsy moth impacts on oak forests of the park. In 1989, the protocol used in the gypsy moth study was expanded to encompass the range of forest cover types (Teetor 1988) found within the park, and implemented by park personnel as the parkwide forest long-term monitoring program. Additional information about the program history may be found in the SHEN Natural Resource Inventory and Long-Term Ecological Monitoring Plan (Shenandoah National Park 1992).

In 1990, SHEN was selected as a prototype park within the NPS Inventory and Monitoring (I&M) Program, and joined ten other prototype parks selected to provide trials of long-term monitoring program designs and sampling methods. At this point, the existing forest vegetation monitoring protocol by Smith and Torbert (1990) developed for the SHEN forest vegetation monitoring program became incorporated into the National I&M program as the official SHEN prototype I&M version 1.0 forest vegetation monitoring protocol. This protocol was used in its entirety through 1998, and with minor modifications through 2001.

Program reviews (USGS 1996, Oderwald 1996, Gibbs 1998) of the vegetation monitoring program provided preliminary data summarization and indicated the need to better define the program's goals and objectives for community and forest dynamics monitoring. However, staff turnover lead to little progress being made on addressing these concerns. In response to continued concerns over the program's sampling objectives, sampling design, and site design, a review of the program's design and data, and an objective setting workshop were completed from 2000 – 2003 (Mahan 2000, Diefenbach 2001, Diefenbach 2002, Diefenbach 2003, Diefenbach and Mahan 2002, Diefenbach and Vreeland 2003, and Mahan et al. 2007). These

reviews helped focus the program's objectives, and revealed ways to increase field efficiency, and the program's statistical power to detect changes of interest. The version 2.0 protocol initiated in 2003 was written in response to these recommendations, and review of other forest vegetation monitoring protocols (Russell 1997; British Columbia Ministry of Environment, Land and Parks 1998; Peet et al. 1998; Roberts-Pichette and Gillespie 1999; USFS 2002; Roland et al. 2004, DeBacker et al. 2005; Jenkins 2006; Schulz et al. 2009a; and Schulz et al. 2009b) and represents a major revision of the original program protocol by Smith and Torbert (1990). The review of other protocols was done primarily to compare aspects of sampling designs such as 1) plot shape and size, 2) how woody vegetation strata were defined and measured, and 3) how coarse woody debris was evaluated. The goal in making the version 2.0 changes to the SHEN forest vegetation monitoring protocol was to maintain continuity with as much historic data as possible, while simultaneously addressing the program's challenges (Diefenbach and Vreeland 2003), and improving the regional compatibility of SHEN forest vegetation monitoring data. The rational for most vegetation measurements is described in Diefenbach and Vreeland (2003). Other decisions, such as the collection of vegetation community classification data were opportunistic and used to provide accuracy assessment for a vegetation mapping project, or were, in the case of groundcover, simply held-over from the version 1.0 protocol. Other decisions, such as the one to collect total plot richness and cover values for all exotic species, but only cover values for the five most abundant herbs, were made based on the need to maintain field efficiency.

The 2000-2003 SHEN forest vegetation monitoring program review and version 2.0 protocol modifications were largely completed before most Eastern NPS I&M Networks were fully operational. Despite this difference in timing, efforts have been made to bring the SHEN sampling design into closer alignment with others used at Eastern NPS units. SHEN staff has actively participated in a monitoring working group formed to ensure the compatibility of protocols among eastern networks engaged in forest vegetation monitoring. The focus of this working group has been to assure that data sharing is possible through standardized metrics and field methods (Tierney et al. 2009). Protocol version 2.3 (this document) has also been written to the current I&M program standards for Standard Operating Procedures recommended by Oakley et al. (2003).
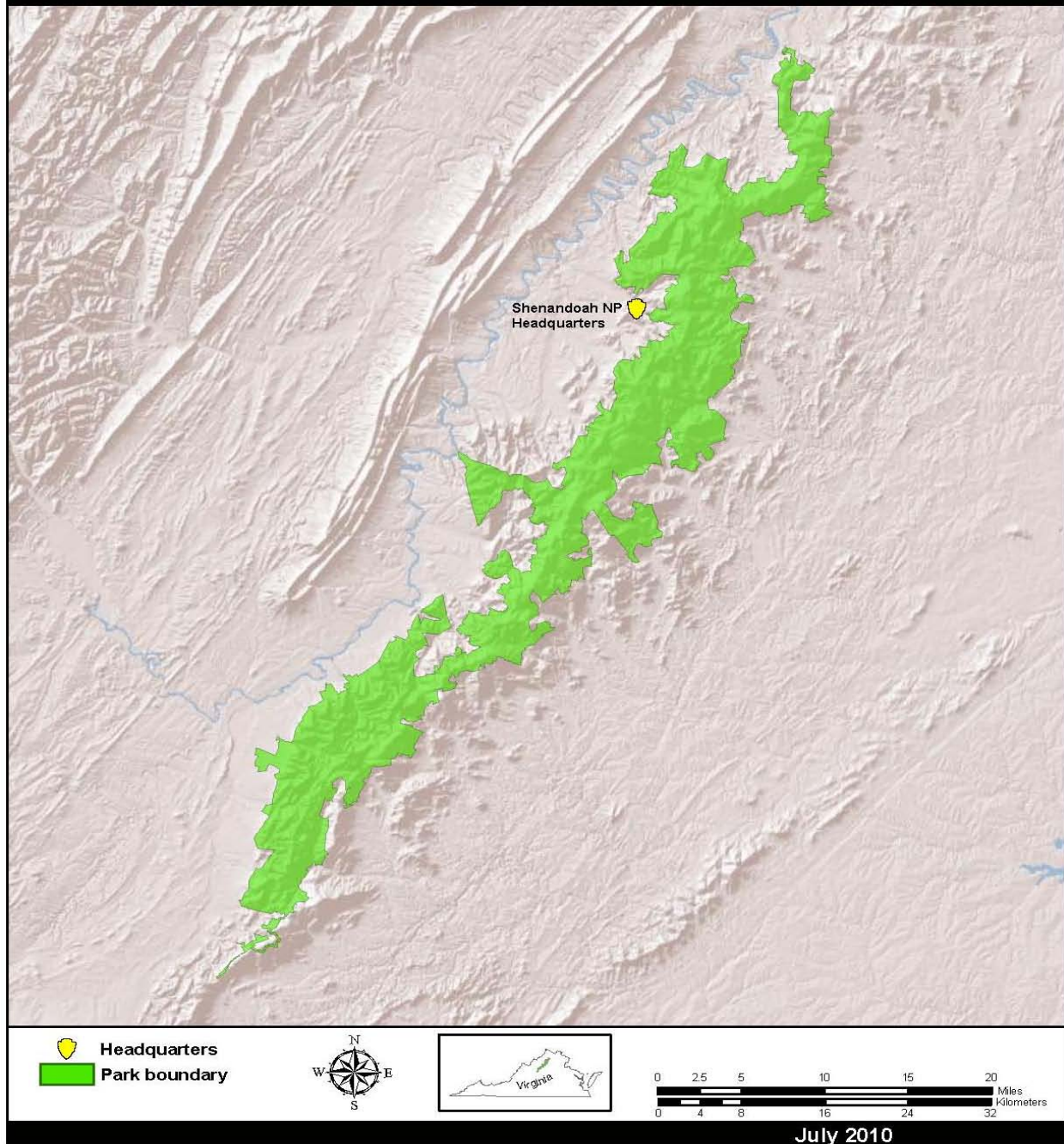
Figure 1. Shenandoah National Park in the Blue Ridge Mountains of northern Virginia.
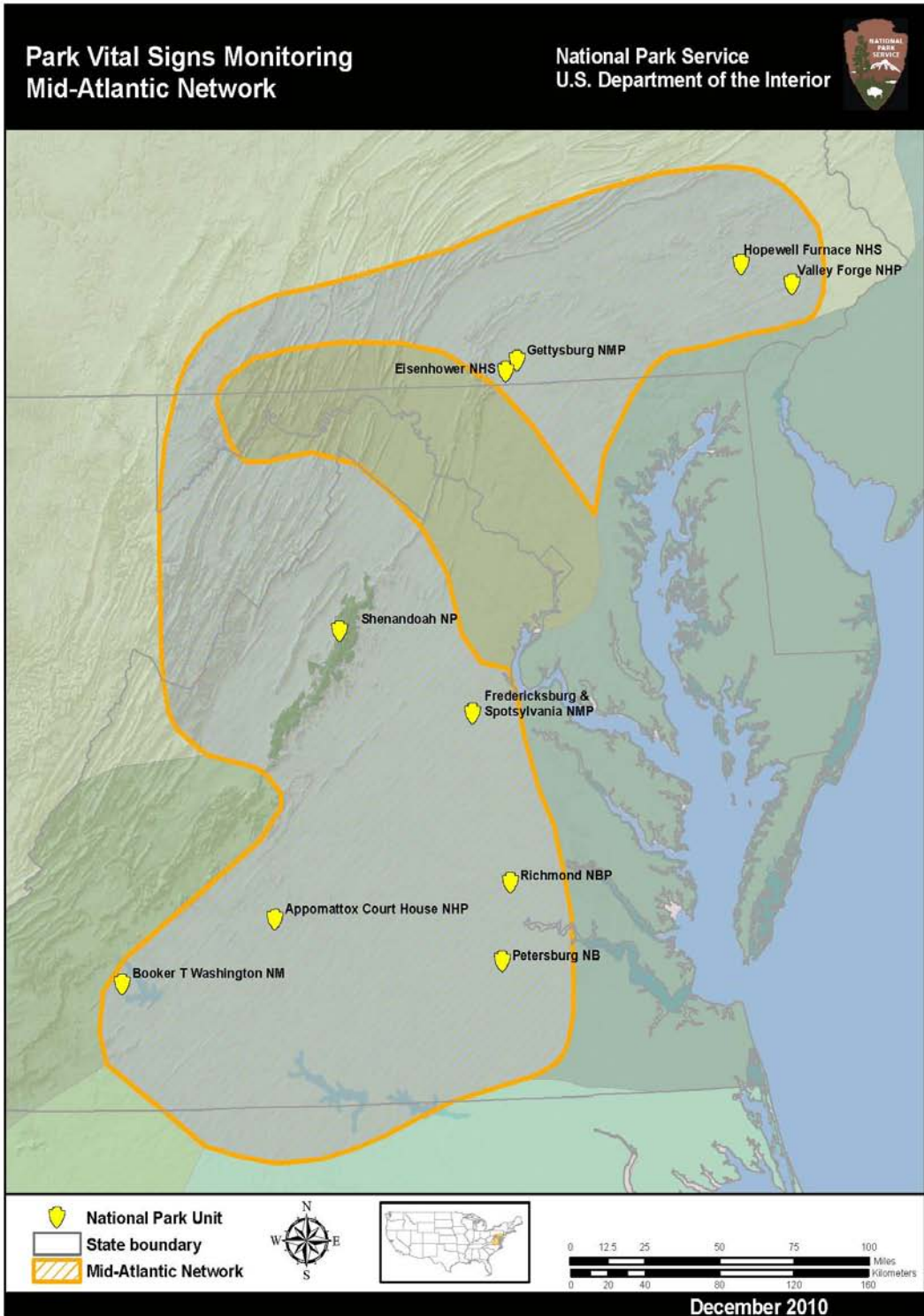
Figure 2. Parks in the National Park Service Inventory & Monitoring Mid-Atlantic Network. All parks other than SHEN share a forest vegetation monitoring protocol (Comiskey et al. 2009).

1.2 Park Overview

Shenandoah National Park was established in 1935 and covers 80,539 hectares (199,015 acres) of forested terrain on the crest of the Blue Ridge Mountains in northern Virginia. The park has a long uneven boundary with a total perimeter of 612 km (380 miles). Elevations within SHEN range from 192 to 1231 meters (530-4,050 feet) above sea level, with about 60 peaks above 914 meters (3,000 feet) (Conners 1988). The park is divided east to west by the ridge top Skyline Drive and Appalachian Trail, and into three districts north to south by U.S. Highways 33 and 211. SHEN contains three major bedrock units of different age and composition: igneous/metamorphic, greenstone, and metasedimentary (Gathright 1976, Southworth et al 2009a). Each of the three main bedrock formations (Basement, Catoctin, Chilhowee) have distinct chemical and physical properties that directly influence the surrounding landscape and vegetation communities (Butler 2006, Southworth et al. 2009b, Young et al. 2009). The park contains 1,413 vascular plant species (NPSpecies 2009), 80 of which are considered rare by the Virginia Natural Heritage Program (Mahan 2006, Townsend, 2009).

Shenandoah National Park's forest plant communities are relatively young (less than 100 years old) and vary based on numerous factors including slope, aspect, elevation, geology, and moisture, as well as land use history, and natural and anthropogenic disturbances. Forest communities dominated by oak (*Quercus* spp.), hickory (*Carya* spp.), and pine (*Pinus* spp.) compose 74% of park vegetation, while rich mixed hardwood forests of maple (*Acer* spp.), birch (*Betula* spp.), tulip tree (*Liriodendron tulipifera*), basswood (*Tilia americana*), and ash (*Fraxinus* spp.) compose 25% of park vegetation. The remaining 1% of park vegetation is composed of wetland and rock outcrop communities (Young et al. 2009).

1.3 Rationale for Monitoring Forest Vegetation

Forests are the dominant ecosystem in the eastern United States, and in SHEN occupy 97% of the land (Young et al. 2009). Forests are a logical choice for monitoring because they are a resource specifically mentioned in the park's enabling legislation (1926 Act of Congress, 44 Stat. 616) and because they represent a large key ecosystem component. Forest vegetation forms the matrix upon which many other organisms depend, and is an essential visual component of the landscape. Understanding forest health is fundamental to knowing the condition of park resources. Park managers need information on the status and trends of prevalent and influential park resources like forest vegetation, in order to make management decisions and work with other agencies, and the public to protect park ecosystems (Fancy et al. 2009).

Shenandoah National Park's forests are influenced by pronounced seasons, and strong annual cycles of temperature and precipitation. Ice storms regularly cause severe crown damage to park trees, high winds and heavy rains associated with tropical storms often result in numerous blow downs, and wildfires periodically impact large sections of the park changing the forest regeneration and understory characteristics (Gawtry and Stenger 2006). Wildlife herbivory also impacts park forests primarily by affecting the composition and abundance of woody species regeneration but also by impacting herbaceous composition and abundance (McShea and Rappole 1992, McShea and Rappole 1997, McShea et al. 1997).

In addition to these natural disturbances, anthropogenic disturbances, non-native forest insects and diseases, and exotic plants are a constant threat to the health of park forests. Dominant among these disturbances are gypsy moth (*Lymantria dispar*), hemlock wooly adelgid (*Adelges*

tsugae), dogwood anthracnose (*Discula destructiva*), and acid deposition. While emerging threats such as emerald ash borer (*Agrilus planipennis*), Asian longhorn beetle (*Anoplophora glabripennis*), sudden oak death (*Phytophthora ramorum*), and climate change loom on the horizon, with the potential to cause wide-spread changes to forest community composition (Mahan 2006). Invasive exotic plants are aggressively spreading in many areas of the park. Species including tree-of-heaven (*Ailanthus altissima*), mile-a-minute weed (*Polygonum perfoliatum*), garlic mustard (*Alliaria petiolata*), Japanese stiltgrass (*Microstegium vimineum*), Oriental lady's thumb (*Polygonum caespitosum*), Oriental bittersweet (*Celastrus orbiculatus*), and Japanese honeysuckle (*Lonicera japonica*) threaten natural forested habitats throughout the park (Mahan 2006). Finally, disruption of the natural fire regime, via suppression, has impacted natural successional cycles. Many oak and pine species are experiencing reduced regeneration while more shade tolerant species are becoming increasingly common (Brose et al. 2006).

Some of the benefits of forest vegetation monitoring, as articulated for the Mid-Atlantic Inventory and Monitoring Network (Comiskey and Callahan 2008, Comiskey et al. 2009) include the following examples. Forest structure, composition, and dynamics are important measures of forest condition and health (Yahner 2000). Changes in these metrics can be indicative of stressors that may result in alterations in the future ecological integrity of the forest communities and the species that depend on them (Keddy and Drummond 1996, Rutters et al. 1992). For example, high mortality rates among canopy trees may signal a change in the dominant forest species (Orwig and Abrams 1994, Abrams and Black 2000); declines in seedling and sapling densities could indicate a reduced capacity of the forest to regenerate (McWilliams et al. 2005); or increases in invasive exotic plant cover could result in the competitive exclusion of other herbaceous plants in the forest understory (Simberloff et al. 2005). Other anthropogenic stressors may have a long-term effect on forest communities, for example, acid deposition can alter soil chemistry, disrupting nutrient cycles (Fowler et al. 1999). Habitat fragmentation in the area surrounding parks can weaken the ecological integrity of the forests inside parks, increasing their susceptibility to exotic plant and pest invasions (Collinge 1996).

The SHEN forest vegetation monitoring protocol assesses the status and trends in forest vegetation, the impacts of stressors such as exotic plants, and the effect of acid deposition on forest soils. Evaluation of snags and downed woody debris provides information on additional important habitat and helps predict wildfire behavior. Future versions of the protocol may also assess the impacts of stressors such as white-tailed deer, exotic plant diseases and pathogens, and native forest pests.

1.4 Measurable Objectives
The objective of the forest component of SHEN Vital Signs Monitoring is to evaluate changes in forest composition, structure, regeneration, and growth as influenced by natural and anthropogenic factors over time (Smith and Torbert 1990). The program's intent is to describe forest status and trends to better inform park managers responsible for making resource management decisions. *Status* refers to data from one sampling period, and *trends* refers to a comparison of data from more than one sampling period. The program also seeks to provide a reference point for comparing the conditions of other eastern forest environments, and to promote a greater understanding of forest status and trends by members of the scientific community and public interested and involved in forest protection. Additional program objectives include maintaining the potential to provide an early warning of gradual shifts toward

abnormal forest conditions needing mitigation, and to provide information to identify where detailed research is needed.

Specific monitoring objectives include:

1. **Determine the status and trends in the composition, abundance, and structure of forest canopy and understory woody species within/between/among sampling rotations.**

   Justification: Information on forest vegetation composition, abundance and structure can be used to describe the current status of park forests, and to anticipate the vulnerability of the forests to known or emerging threats (insects, diseases, pathogens). Trends in forest vegetation composition, abundance and structure can be used to identify emerging threats, and to monitor the response of forest communities to known stressors. Both types of information can be used to improve visitor's understanding of the park's forest resources and to inform management actions.

   Metrics used in assessment: basal area per ha, density per ha, basal area-density distributions, alive to dead density ratio, coarse woody debris volume to live tree volume, growth and mortality rates, frequency, crown health, crown class, importance value, species richness, similarity, native to non-native ratio, and diversity.

2. **Determine the status and trends in the composition and abundance of exotic plants and forest herbs within/between/among sampling rotations.**

   Justification: Information on the parkwide extent of exotic plant infestations helps justify the need and select the location for management efforts. Changes in herb composition helps describe impacts of deer herbivory and exotic plant pressures on forest communities.

   Metrics used in assessment: frequency, percent cover, species richness, similarity, native to non-native ratio, and diversity.

3. **Determine the status and trends in the abundance of forest woody fuels and coarse woody debris, litter, and duff within/between/among sampling rotations.**

   Justification: Abundance of snags and woody debris are indicators of forest health and vulnerability to wildfire. Information on the litter and duff also provides fuel loading estimates to help predict wildfire behavior.

   Metrics used in assessment: alive to dead density ratio, and coarse woody debris volume to live tree volume. Litter and duff measurements are assessed according to Brown (1974).

4. Determine the status and trends in the composition of forest soils within/between/among sampling rotations.

Justification: Soil chemistry data aids in the documentation of acid deposition impacts to forest soils, and the level of nutrients available for forest vegetation.

Metrics used in assessment: Soil texture, acidity, fertility, and morphology; soil acid stress; and soil nitrogen saturation.

2. Sampling Design

2.1 Sampling Design Rationale

Shenandoah National Park's forest vegetation monitoring protocol is designed to document changes in forest composition, structure, regeneration, and growth over time in a standardized and cost efficient manner. The periodic measurement of permanent sample sites will increase power to detect change over time by decreasing spatial variation. Field site locations were selected using a stratified random design where strata are ecological land units (ELU) defined by unique combinations of slope aspect (two classes: SW = 315-124 degrees, NE = 125-314 degrees), elevation (three classes: Low = 0-609 m, Mid = 610-914 m, High = 915-1144 m), and bedrock geology (three classes: Basaltic, Granitic, and Siliciclastic) (Diefenbach and Vreeland 2003). Stratification was done in this way because elevation, aspect, and geology are important environmental variables that directly and indirectly affect forest cover and will change minimally over time.

Elevation and aspect affect temperature and water availability on a site-specific basis. As elevation increases, temperature decreases which will affect site conditions by increasing soil moisture, and decreasing rock weathering, and soil formation. Precipitation and the associated weathering effects increase with higher elevation. Slope aspect affects the soil moisture by determining exposure to solar radiation and weather patterns. As the aspect shifts from cool, moist north and northeast exposures to warm, dry south and southwest exposures, evapotranspiration rates increase because of higher afternoon air and soil temperatures, reduced relative humidity, and direct solar radiation (Smith and Torbert 1990). Bedrock geology directly influences the topography, physical character, and soil chemistry within the park, and thus the vegetation communities (Young et al. 2009). Three fundamentally different rock types occur within discrete areas of the park, producing chemically distinct landforms and habitats—igneous/metamorphic (i.e., ELU category "granitic"), greenstone (i.e., ELU category "basaltic"), and metasedimentary (i.e., ELU category "siliciclastic") (Butler 2006).

Stratification of sites among slope, aspect, elevation, and bedrock geology class ensures distribution of sites within the diverse park landscape, and captures the variation in park plant communities parkwide. This stratification also allows analyses to explore the response of vegetation within different strata, and their response to various stressors.

Square 24 x 24 m slope corrected plots were selected by the designers of the version 1.0 forest vegetation monitoring program (Ravlin et al. 1990, Smith and Torbert 1990). Other plot sizes and shapes were considered as part of the program review process prior to implementing the version 2.0 program changes. However, maintaining the size and shape of sampling plots between the version 1.0 and 2.0 programs was determined to be the most cost effective way to ensure some consistency with historic data, and maintain field efficiency given the vegetation density and need for slope correction (Diefenbach 2003, Diefenbach and Vreeland 2003).

Some of the vegetation sampling methods were changed between protocol versions 1.0 and 2.0 to improve data quality and usefulness. The square shrub and seedling plots of version 1.0 were replaced with narrow rectangular plots in version 2.0, because plots of linear dimension sample across environmental variation better than square plots, reducing variation among samples (Elzinga et al. 1998). For herb, exotic species, and groundcover sampling, the six 1 x 1 m plots used in the version 1.0 protocol were replaced with a single 24 x 24 m plot. This was done because exploratory analysis of the herb data from the version 1.0 program showed extreme variability in the data, and no applicability for detecting change over time. The version 1.0 data also failed to detect low-density species of interest such as exotic species. The version 2.0 protocol assigns cover classes to dominant herbs, all exotic species, and groundcover over the entire plot to give an estimate of their status within each sample plot. The most likely applications are for calculating frequency of occurrence, examining changes in exotic species abundance over time, and for characterizing the groundcover of a particular Ecological Land Unit type.

The version 2.0 forest vegetation monitoring program contains 160 sites, each of which contains one 24 x 24 m sampling plot. This number was selected following a power analysis done using data from version 1.0 of the program applied to the version 2.0 program's ELU categories and sampling objectives. The 160 sites are allocated among ELU categories in proportion to the area occupied by each ELU (Table 1 and Table 2) with a minimum of three sites in any given ELU. Because the high elevation siliciclastic categories contained only 230 ha, this region of the park was incorporated into the mid-elevation siliciclastic strata (Diefenbach and Vreeland 2003). The portion of the park with elevations above 1144 m were not included in the stratification design because of their sensitive plant communities and comprise 0.2% (141.9 ha) of total park area.

2.2 Site Selection

2.2.1 Criteria for site selection
The target monitoring population is the interior forested areas of the park. This is defined as land areas located at least 40 m from a park trail, 50 m from an unpaved road or the park boundary, and 100 m from the edge of Skyline drive or a developed area. The buffer distances specified were included to minimize edge effects on forest vegetation monitoring plots. Plots were placed within the target population where the average slope within the plot was less than 50%. The choice to exclude forests with greater than 50% slope was based on monitoring crew safety, and the potential to cause excessive damage to the forest understory during sampling. After these restriction were imposed, 53,190 ha or 70% of the park was available for site placement.

2.2.2 Procedures for selecting sampling locations, stratification, spatial design

Procedures for selecting site locations began with the consideration of historic sites from the version 1.0 program. Geographic information system (GIS) was used to assign the historic (version 1.0) sites to the appropriate version 2.0 ELU. If the number of historic sites present in an ELU was greater than the number required by the stratification design, then the required number of sites were randomly selected for inclusion, and the remainder were discarded. If the number of historic sites present in an ELU was lower than the number required by the stratification design, additional new sites were randomly placed.

Placement of the additional sites was done using GIS to randomly select 500 points within the park. Each point was then attributed to the appropriate ELU and randomly assigned a number. Park staff used this list, in numeric order, to visit potential site locations. Locations were either accepted or rejected before moving on to the next site on the list. In the field, additional criteria to those stated in Section 2.2.1 above were used to accept or reject sites. These included change in aspect across the sampling area, the presence of recent or historical human disturbance, and proximity to the boundary of the ELU (Table 3). This latter restriction limits the sampling universe to 40% of the park. It ensures the data accurately represent each ELU given the limits of the digital elevation model accuracy, and the algorithm used to create the ELU boundaries. This sampling universe hereafter is referred to as "the park", "parkwide", or "the entire park". Complete procedures for selecting new sampling locations are found in SOP 4. A full description of the ELU establishment and site selection procedure can be found in Diefenbach and Vreeland (2003).

The resulting field sites within the version 2.0 SHEN forest vegetation monitoring program are a composite of 160 sites installed by three separate phases of the program. Sixty-six of the historic sites were grandfathered into the version 2.0 program from the version 1.0 program, and field markings were upgraded according to the version 2.0 protocol. These 66 historic sites are composed of 58 sites that were installed by NPS personnel, and eight sites that were installed by Virginia Tech University personnel in the developmental phase of the program. The remaining 94 sites were newly installed according to the version 2.0 protocol.

All 160 sites included within the program were randomly located within forest stands that met the strata definition for the program phase from which they originated. The 94 sites installed as part of the version 2.0 program are distributed among strata defined by combinations of slope aspect, elevation, and bedrock geology. The 58 sites installed by NPS personnel during version 1.0 of the program were distributed among strata defined by combinations of slope aspect (2 classes), elevation (3 classes)and forest cover type (8 classes) (Ravlin et al. 1990, Smith and Torbert 1990). The eight remaining site locations were chosen by Virginia Tech University personnel according to the version 1.0 strata (elevation, aspect, and forest cover type), however they were restricted to only red oak or chestnut oak forest cover types (Blount 2002). Regardless of their original stratification, all sites within the program were assigned to the version 2.0 stratification scheme (aspect, elevation, and bedrock geology).

Table 1. Forest vegetation monitoring stratification design by ecological land units (ELU). ELUs are based on combinations of three bedrock geology types (Basaltic, Granitic, and Siliciclastic), three elevation ranges (Low: 0-609 m, Mid: 610-914 m, High: 915-1144 m), and two slope aspects (SW: 315-124 degrees, NE: 125-314 degrees).

ELU ID	Geology	Elevation	Aspect	Area of ELU (ha)	Plots in ELU
B-H-NE	Basaltic	High	NE	2453.5	5
B-H-SW	Basaltic	High	SW	2798.6	6
B-L-NE	Basaltic	Low	NE	3733.6	8
B-L-SW	Basaltic	Low	SW	4139.8	9
B-M-NE	Basaltic	Mid	NE	6662.2	14
B-M-SW	Basaltic	Mid	SW	8351.2	17
G-H-NE	Granitic	High	NE	1264.5	3
G-H-SW	Granitic	High	SW	1293.1	3
G-L-NE	Granitic	Low	NE	5669.0	12
G-L-SW	Granitic	Low	SW	4934.1	10
G-M-NE	Granitic	Mid	NE	6470.5	14
G-M-SW	Granitic	Mid	SW	5602.3	12
S-L-NE	Siliciclastic	Low	NE	4867.8	10
S-L-SW	Siliciclastic	Low	SW	6200.6	13
S-M-NE	Siliciclastic	Mid	NE	5179.0	11
S-M-SW	Siliciclastic	Mid	SW	6200.6	13

Table 2. Number and identification code of forest vegetation monitoring sites located within each ELU. The first number of the site identification code designates the park district where the site is located (1=North District, 2=Central District, and 3=South District). "L" designates the long-term forest vegetation monitoring program. The next three numbers are unique identifiers within each district; numbers less than 399 indicate sites that were incorporated from the Version 1.0 protocol and numbers greater than or equal to 400 indicate new sites added to the Version 2.0 protocol. For site numbers less than 399, the final number after the dash indicates the number of the original plot (plot 1, 2 or 3) from the Version 1.0 protocol that was incorporated into the Version 2.0 protocol. For site numbers greater than or equal to 400, the "1" after the dash is a place holder; only one plot exists at these sites. An asterisk (*) denotes sites that were originally established by F. W. Ravlin and colleagues at Virginia Polytechnic Institute and University prior to the Version 1.0 protocol.

ELU ID	Number of Sites	Site Identification Codes
B-H-NE	5	2L110-3, 2L120-1, 2L316-1*, 2L437-1, 2L540-1
B-H-SW	6	1L100-1, 2L103-2, 2L431-1, 3L104-1, 3L117-1, 3L552-1
B-L-NE	8	1L126-1, 1L407-1, 1L409-1, 1L569-1, 1L708-1, 3L111-2, 3L114-3, 3L121-1
B-L-SW	9	1L105-2, 1L112-3, 1L113-1, 1L318-2*, 1L416-1, 1L478-1, 1L498-1, 2L595-1, 3L120-1
B-M-NE	14	1L123-1, 1L302-1*, 1L312-1*, 1L410-1, 1L415-1, 1L505-1, 2L121-1, 2L133-3, 2L443-1, 3L100-1, 3L113-1, 3L473-1, 3L550-1, 3L600-1
B-M-SW	17	1L104-1, 1L110-1, 1L115-1, 1L120-1, 1L301-2*, 1L413-1, 1L506-1, 2L107-1, 2L119-1, 2L130-1, 2L310-1*, 2L459-1, 3L105-2, 3L112-3, 3L115-2, 3L123-1, 3L465-1
G-H-NE	3	1L106-3, 2L115-1, 2L452-1
G-H-SW	3	2L104-1, 2L435-1, 2L518-1
G-L-NE	12	1L108-1, 1L114-1, 1L124-1, 1L417-1, 2L106-1, 2L113-1, 2L117-1, 2L126-1, 2L440-1, 2L523-1, 2L578-1, 2L710-1
G-L-SW	10	1L117-3, 1L402-1, 1L565-1, 2L109-1, 2L511-1, 2L529-1, 2L702-1, 2L713-1, 2L714-1, 3L608-1
G-M-NE	14	1L109-1, 2L108-1, 2L111-1, 2L129-1, 2L430-1, 2L448-1, 2L456-1, 2L525-1, 2L536-1, 2L587-1, 3L122-1, 3L462-1, 3L546-1, 3L547-1
G-M-SW	12	1L128-1, 2L314-2*, 2L449-1, 2L457-1, 2L520-1, 2L521-1, 2L531-1, 2L577-1, 2L592-1, 2L709-1, 2L711-1, 2L712-1
S-L-NE	10	1L103-1, 1L129-1, 1L480-1, 1L484-1, 1L503-1, 1L706-1, 1L707-1, 2L125-1, 3L107-1, 3L125-1
S-L-SW	13	1L122-1, 1L405-1, 1L408-1, 1L411-1, 1L485-1, 1L504-1, 1L561-1, 1L564-1, 1L704-1, 1L705-1, 2L101-1, 3L124-1, 3L703-1
S-M-NE	11	1L303-1*, 2L432-1, 2L717-1, 3L463-1, 3L467-1, 3L472-1, 3L530-1, 3L549-1, 3L559-1, 3L607-1, 3L715-1
S-M-SW	13	2L131-1, 2L533-1, 2L535-1, 3L119-1, 3L464-1, 3L470-1, 3L474-1, 3L551-1, 3L553-1, 3L555-1, 3L558-1, 3L560-1, 3L602-1

Table 3. Criteria for accepting sites during the site establishment phase of the program. Assuming that all criteria are met, the minimum area needed for a plot is 1.5 ha.

Category	Criteria
Safety	$\leq$ 50% (26.5°) slope
Biological	Corner 1 located a minimum of 40 m from an established trail, 50 m from an administrative road, and 100 m from Skyline Drive and developed areas.
	Located in a sufficiently large landscape feature so that it is buffered 40 meters on all sides by the same ELU (aspect, elevation and geology classes) as defined by the model.
	Boundaries of nearby plots must be at least 50 m away.
	Aspect of the plot must vary 10° or less between sides D and B to avoid plot placement within two separate aspect classes.
Cultural	Area should be free of significant signs of recent human disturbance or archeological resources that cause a change in the forest cover or otherwise make the area stand out from the matrix forest of the ELU, e.g. foundations, cemeteries, tree removals, exotic vegetation treatment, dumps, and roads. Acceptable features include small rock walls, rock piles, terraced slopes, wells, and small ditches.
	All plot corners must be able to be installed at a sufficient distance from trails so that markers are not visible from the trail, even in winter.
	Located a minimum of 50 m from the park boundary.

2.3 Sampling Frequency, Replication and Timing

The scheme of sampling frequency and timing was determined after evaluating both statistical and logistical considerations. A compressed sampling period reduces variability introduced by weather and other environmental factors. However, a longer sampling period is more feasible given budget restraints.

Variations in program funding and staffing from 2003-2007 lead to one 3-year sampling rotation (2003-2005) and one 1-year sampling rotation (2007). However, beginning in 2008 the program adopted a 4-year sampling rotation and has maintained consistency. Vegetation monitoring is conducted annually, but each individual site is visited only once every four years. Each of the four blocks within the rotation contains a proportional representation of sites from each ELU, and each park district. Sampling is conducted between May and September, beginning with the south end of the park and progressing toward the north end of the park. This progression allows for sites to be sampled within the same time frame of the growing season to minimize seasonal variation in the herbaceous cover across sampling rotations.

2.4 Level of Change that can be Detected

When the forest vegetation monitoring program at SHEN was revised from 2000-2003, historic data from two sample rotations occurring between 1987 and 2001 were used in a power analysis to determine the sample size needed to achieve different levels of detectable change at a power

of 0.8 and an alpha level of 0.1 for a variety of variables (Diefenbach and Vreeland 2003). This protocol is based on the 160 site design recommended by the revision process.

Data from the 2003-2005 and 2007 sample rotations were then used to calculate the minimum detectable change achieved by the version 2.3 protocol. Estimates of the population variance of the mean were calculated according to Diefenbach and Vreeland (2003) Appendix B. Minimum detectable change was calculated using the following formula (Elzinga et al. 1998):

$$MDC = \sqrt{\frac{(s)^2 (Z_\alpha + Z_\beta)^2}{n}}$$

Where, Minimum Detectable Change (MDC) is the smallest level of change that can be detected for a given variable, s is the variance in the difference between sample rotations calculated for all 160 sites; Z_α is the z-coefficient using α for the false-change (Type I) error rate of 0.1; Z_β is the Z-coefficient for the missed-change (Type II) error rate of 0.2 (power 1-β = 0.8); and, n is the number of sites in the sample (160).

$$\% \ Change = \frac{MDC}{mean} \ x \ 100$$

Where % Change (or % effect size) is the percent change that can be detected; and, mean is the average values in the sample (including sites with no values).

2.4.1 Trees
Tree Density Sampling Objective:
For tree density at the parkwide level, we expect to be able to detect a change of 5% with a power of 0.8 and alpha level of 0.10 between adjacent 4-year sample rotations.

Tree Density Calculated MDC:
For tree density at the parkwide level, data from the first two complete sampling rotations (2003-2005, 2007) indicates that we can detect a change of 0.7% (3 trees/ha) with a power of 0.8 and alpha level of 0.10 between the two sample rotations.

Tree Basal Area Sampling Objective:
For tree basal area at the parkwide level, we expect to be able to detect a change of 5% with a power of 0.8 and an alpha level of 0.10 between adjacent 4-year sample rotations.

Tree Basal Area Calculated MDC:
For tree basal area at the parkwide level, data from the first two complete sampling rotations (2003- 2005, 2007) indicates that we can detect a change of 0.5% (0.14 m^2/ha) with a power of 0.8 and alpha level of 0.10 between the two sample rotations.

The large difference between the amount of change articulated in the sampling objective change percentages and the calculated MDC was unexpected. One possible explanation is that the sampling objective change percentages were derived from a power analysis using data spanning

1987-2001. This 14 year span likely introduced greater variability into the data than did the four year span (2003-2007) of the data used to calculate MDC. Another possible contributing factor is that the change percentages calculated by the sampling objective power analyses were rounded upward in the process of sampling objective development with the hopes of making them attainable.

2.4.2 Shrubs and saplings

Shrub and Sapling Density Sampling Objective:
For shrub and sapling density at the parkwide level, we expect to be able to detect a change of 25% with a power of 0.8 and an alpha level of 0.10 between adjacent 4-year sample rotations.

Shrub and Sapling Density Calculated MDC:
For shrub and sapling density at the parkwide level, data from the first two complete sampling rotations (2003-2005, 2007) indicate that we can detect a change of 11.8% (433 stems/ha) with a power of 0.8 and alpha level of 0.10 between the two sample rotations.

Shrub and Sapling Basal Area Sampling Objective:
For shrub and sapling basal area at the parkwide level, we expect to be able to detect a change of 10% with a power of 0.8 and an alpha level of 0.10 between adjacent 4-year sample rotations.

Shrub and Sapling Basal Area Calculated MDC:
For shrub and sapling basal area at the parkwide level, data from the first two complete sampling rotations (2003-2005, 2007) indicate that we can detect a change of 2.3% (0.18 m^2/ha) with a power of 0.8 and alpha level of 0.10 between the two sample rotations.

The large difference between the amount of change articulated in the sampling objective change percentages and the calculated MDC was unexpected. One possible explanation is that the sampling objective change percentages were derived from a power analysis using data spanning 1987-2001. This 14 year span likely introduced greater variability into the data than did the four year span (2003-2007) of the data used to calculate MDC. Another possible contributing is that the change percentages calculated by the sampling objective power analyses were rounded upward in the process of sampling objective development with the hopes of making them attainable.

2.4.3 Seedlings

Seedling data are highly variable. When all woody seedlings are combined, power analysis has shown that we have no power to detect change in the density of seedlings (Diefenbach and Vreeland 2003). Seedling data are however still useful for helping to describe recruitment of shrub and tree species by comparing the composition and abundance of seedlings to data from the shrub and tree strata.

In version 2.3 of the protocol woody seedlings are sampled within two height classes. Limiting the analysis to just tree seedlings in the higher (≥15 cm) height class may allow for the detection of changes in seedling density over time.

3. Field Methods

This report makes reference to Standard Operating Procedures (SOPs) that outline detailed steps for conducting specific aspects of the forest vegetation monitoring protocol. The latest versions of the SOPs can be accessed at the National Park Service's Mid-Atlantic Inventory & Monitoring Network website (http://science.nature.nps.gov/im/units/midn/) in the Forest Vegetation Monitoring Protocol section. The SOPs are updated on an as-needed basis and all changes are identified in individual Revision History Logs.

3.1 Safety
Shenandoah National Park considers the occupational health and safety of their employees, cooperators, and volunteers to be of utmost importance, and is committed to ensuring that all seasonal field technicians receive adequate training on National Park Service safety procedures, accident reporting, and emergency response prior to field work. Field crew leaders are responsible for giving safety briefings to the crew each week to keep safety topics covered during training at the forefront of daily activities throughout the field season. Emergency procedures and contacts, accident reporting, field preparation, safe field procedures, vehicle safety, and workers compensation procedures are outlined in SOP 2.

3.2 Field Season Preparations and Equipment Setup
Prior to the field season, all equipment is reviewed against the equipment list, and tested to ensure proper functioning, particularly electronics and equipment with moveable parts. Any consumable items (tags, nails, rebar caps, "Rite in the Rain"® paper, etc.) are ordered if sufficient quantities are not in stock. Permission to cross private land to access sites near the boundary is obtained, technicians and volunteers selected, and park housing reserved. Maps of site locations, tree tag numbers, and photos from previous visits are printed from the database. Data sheets are prepared, and sample points uploaded to the GPS. The standing park compliance is updated by the Botanist, if needed. Additional details and a full list of equipment are provided in SOP 1.

3.3 Field Season Schedule
Seasonal technicians and volunteers arrive at the park in early to mid-May. Orientation, trainings, and continued preparations take place during the first one to two weeks. Safety and program related trainings are detailed in SOP 2, geographic information systems equipment and software training in SOP 3, and camera and photo processing software training in SOP 7. Sampling is conducted between May and September, beginning with the south end of the park and progressing toward the north end of the park. This progression allows for sites to be sampled within the same time frame of the growing season to minimize seasonal variation in the herbaceous cover across sampling rotations. Data processing is conducted daily as time allows, and on rainy and 'data entry days' throughout the season.

3.4 Site Location

3.4.1 Initial visit to the site
During the initial site visit the plot and corner locations are established according to predefined criteria (see section 2.2 above and SOP 4). The plot consists of a 24 m x 24 m square with four nested subplots (Figure 3). A tripod mounted staff compass and measuring tapes are used to

establish the plot boundaries. After the plot location and all four corners are established, a GPS measurement is recorded for Corner 1 of the plot (SOP 3). Plot corners are marked with rebar and aluminum caps embossed with plot and corner numbers, and monument trees are established to further document corner locations. Information is recorded that describes the site, including slope, aspect, elevation, bearings between all corners, slope-corrected distances between corners, and comments on biological and cultural history of the area. Detailed map and compass directions are recorded from the office to the plot. Complete directions for establishment, installation and documentation of a new monitoring site are detailed in SOP 4. Complete directions for plot upgrades from protocol version 1.0 are detailed in SOP 5.
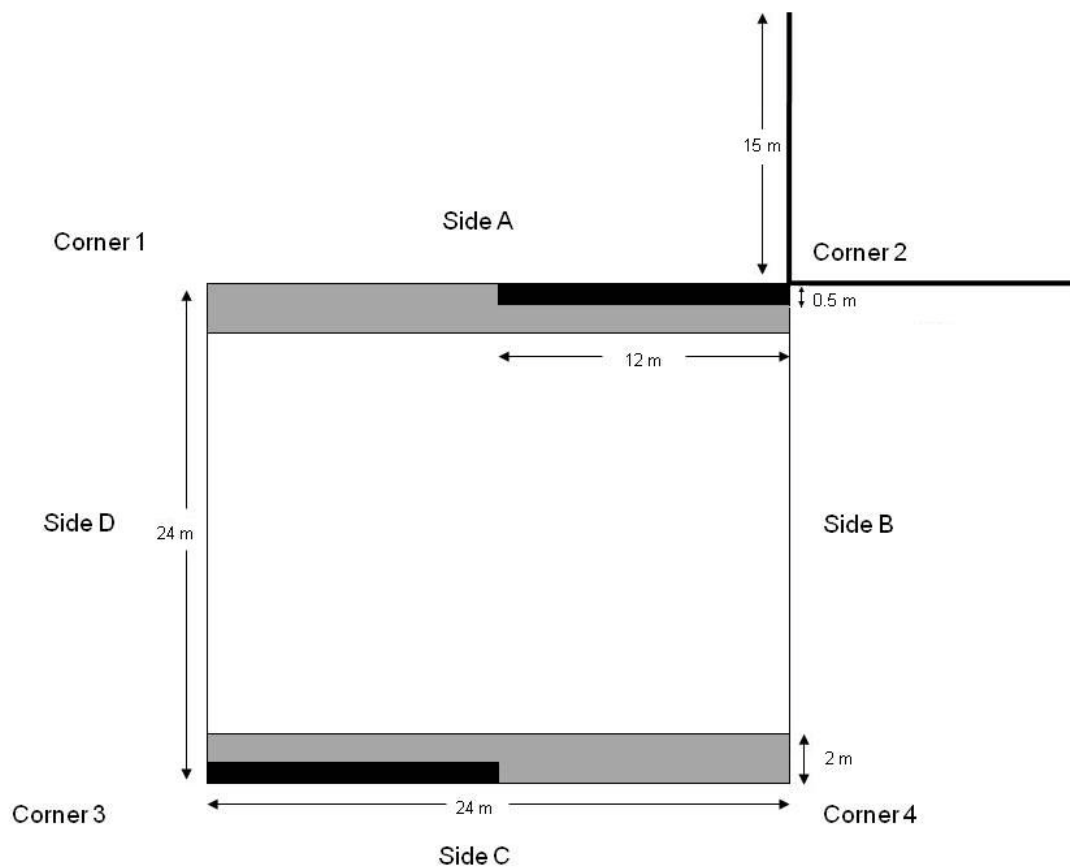
Figure 3. Forest vegetation monitoring site in Shenandoah National Park.

3.4.2 Returning to the site
On return visits, field teams navigate to sites using GPS, and/or map and compass directions and monument trees. At each site, marking posts and rebar caps that are missing or have been disturbed are replaced based on existing markings, and written records. Monument trees that are missing or dead are also replaced. The plot is delineated with measuring tapes in preparation for data collection. Complete directions for a routine site visit set-up are detailed in SOP 6.

3.5 Details of Taking Measurements

3.5.1 Plot photo points
Digital photographs are taken from Corners 1 & 2 diagonally across the plot and aligned with a reference photo from a prior visit (SOP 7). The site name, date, photo direction, and file name are recorded in a photo log.

3.5.2 Vegetation measurements
All woody plant species in the entire 24 x 24 m plot with a diameter at breast height (DBH) $\geq$ 10 cm are identified to species, measured for DBH, tagged with steel nails and brass numbered tags, and their condition and location in the canopy assessed (SOP 8). Woody plant stems with a DBH < 10 cm and a height $\geq$ 1.5 m in each of two 2 x 24 m subplots are identified to species, measured and recorded in stem diameter classes (SOP 9). Woody plant stems with a DBH < 10 cm and a height < 1.5 m in each of two 0.5 x 12 m subplots are identified, measured, and recorded in height classes (SOP 10). Additional data collected within the entire 24 x 24 m plot include cover class values for all exotic plant species, dominant herbs, and ground cover types; a complete plant species list; and identification of the vegetation community association (SOP 11). Any plant species that cannot be identified in the field is documented and collected outside the plot if sufficient individuals are available (SOP 14).

3.5.3 Woody debris and soil measurements
Fine fuels and coarse woody debris are measured along two transects extending outward from plot Corner 2 (SOP 12). An average duff thickness is calculated, and a composite A-horizon soil sample is collected from multiple points using a soil punch-auger. Soil samples are collected from a 2 m wide band extending from 2 m to 4 m outside of the plot along each of the four sides, in order not to disturb the vegetation and soil properties and processes within the plot (SOP 12). Soil is collected from within the rooting zone only, as an indicator of nutrient status and stressors affecting vegetation.

3.6 Future Additions
Additional SOPs are being considered for addition to the program. These include some SOP's already in use by other I&M networks including assessment of impacts from stressors such as white-tailed deer, exotic plant diseases and pathogens, and native forest pests, as well as landscape context, standards for reporting, and end-of-season procedures.

4. Data Handling, Analysis, and Reporting

4.1 Metadata Procedures
Data compiled by SHEN must be accompanied by Federal Geographic Data Committee (FGDC) compliant metadata. (Federal Geographic Data Committee 1998). This includes both spatial and non-spatial datasets. Specific metadata procedures are outlined in SOP 15.

4.2 Overview of Database Design and Management
Database design and management is performed by the Natural Resources Division Data Manager. The SHEN forest vegetation monitoring database (FORVEG) is updated to the current Access database version. This database predates the Natural Resources Database Template (NRDT) but many of the design principles are present. It should be noted that the database's name prior to 2012 was "TLTEM" for the program's historic name, SHEN Terrestrial Long Term Ecological Monitoring. In addition, all data sheets, database printouts, historic program files and geospatial data created prior to this date referenced this former name.

Data files are stored in a directory structure on a file server with appropriate access levels granted to users. Prior to a data entry session an automated backup of the back-end data file is made and stored. A back-up utility is scheduled to make copies of changed files to a server in a different building at the SHEN Headquarters campus nightly, and are annually evaluated, archived and updated. For more information on database design and management, see SOP 15.

4.3 Field Quality Control, Data Entry, Verification, and Archiving
The Botanist and field crew leader are responsible for ensuring that all crew members can correctly identify plant species, understand all field protocols, and understand field data sheets and database fields for data entry. Crew members are responsible for learning species identification, field protocols, and asking questions whenever uncertainties exist. All crew members complete a week long training during which details of the protocol, plant identification, data collection, and data entry are taught in the field and lab. After this training, all field technicians must work closely with the lead field technician or Botanist until they have shown that they possess the skills needed to sample with less supervision.

Attempts have been made to integrate the use of data-loggers and computers into field data collection, but technological hurdles and the decreases in field efficiency have been significant deterrents to long-term integration of these tools. Field crews currently record data on paper field forms, field check the data before leaving the site, and enter the data into the database when back at the office. Field data sheets are scanned and these and the database are backed up daily to an external location at SHEN headquarters. Complete details on data management are available in SOP 15.

Five percent of the sample sites completed in any given year are randomly selected for resampling to determine the reliability of field data collection. Field QA/QC occurs as close as possible to the original sample date of the plot to reduce seasonal variability. Remeasurment is completed by field staff who were not involved in the original plot measurement.

After data entry is complete, 100% of the data are verified and corrected. Ten percent of these verified records are then reviewed a second time by the crew leader, Botanist, or data manager. If

an error rate greater than 2% is observed, an additional 40% of the records must be double verified and corrected. If an error rate greater than 2% is observed in this next data set, then the entire remaining 50% of the records must receive double verification and correction.

4.4 Data Analysis
The SHEN forest vegetation monitoring program will estimate status and trends over time of specific measures in forested systems for the entire park after each sampling rotation is completed. Analyses will be based on a repeated measures linear mixed model which partitions spatial and temporal variability to allow assessment of change over time. Complete details on data analysis are available in SOP 16.

4.5 Reporting Schedule and Format
The SHEN Botanist and forest vegetation monitoring program will produce annual data summary reports on highlights from each year's field work. Upon completion of each 4-year sampling rotation, a more detailed report will provide information on the status and trends in forest metrics for the park as a whole, and by ELU, if statistical power allows. Ad-hoc reports and scientific papers will be published, and presentations given as appropriate. Reporting details will be added to SOP 16 once the details of data analysis are finalized following additional external review.

5. Personnel Requirements and Training

5.1 Roles, Responsibilities, and Qualifications

This monitoring protocol is implemented by a GS-07 crew leader and 3-4 technicians and interns. If two crews are working, the field crew leader leads one crew and the assistant field crew leader leads the second crew.

5.1.1 Park Botanist (Program Coordinator)

The Park Botanist operates as the project manager to oversee the implementation of the monitoring program including:

- Permits, scheduling, hiring, purchasing, contracting, and budget

- Maintain and update forest vegetation monitoring protocol

- Conduct training and participate in field work as needed

- Oversee field crew, providing logistical, administrative, and technical support

- Ensure QA/QC standards are met

- Analyze data and prepare reports

5.1.2 Data Manager

The Data Manager in the Natural and Cultural Resources Division provides oversight for all data related aspects of the project including:

- Provide database training to the crew

- Maintain the forest vegetation monitoring database

- Prepare maps of sample point locations

- Ensure data management practices are met, including data backup, transfer, and archiving

5.1.3 Vegetation Crew Leader and Assistant Crew Leader

The Crew Leader and Assistant Crew Leader (if available) are responsible for managing the vegetation crew and must have a strong knowledge of the flora of the mid-Atlantic region. Tasks include:

- Coordinate daily field activities and ensure equipment is in working order

- Coordinate directly with Botanist and Communication Center when conducting field work

- Conduct weekly safety briefings and offer safety reminders appropriate to current activities

- Ensure that all field crew members are following proper data collection procedures

- Identify plants accurately and/or process unknown plants for later identification

- Coordinate data entry into database, verification, corrections, and archiving of data from paper field sheets

- Assist Botanist with updating the protocol, analyzing data, and preparing reports

5.1.4 Vegetation Crew Technicians and Interns

The Crew Technicians are responsible for data collection and must have a working knowledge of the flora of the mid-Atlantic region. Tasks include:

- Collect field data accurately as described in the SOPs

- Identify plants accurately and/or process unknown plants for later identification

- Enter data accurately into the project database either in the field or from paper data sheets

- Ensure all necessary equipment is assembled, clean and functional prior to each trip

- Maintain time sheet

5.2 Training Procedures

A one to two-week training session is conducted in mid-May to address health and safety concerns and emergency procedures, review and learn plant identification, and review and learn forest vegetation monitoring SOPs and practice sampling of monitoring sites (SOP 2). The park Botanist works with the field crew during the first site visits and as available and needed throughout the summer. The Data Manager works with the field crew at the office to establish careful data management practices, and to address any technical issues that arise with data processing.

6. Operational Requirements

6.1 Annual Workload and Field Schedule
Field work and data entry, verification, and archiving are conducted primarily between mid-May and the end of September. Field planning, data analysis and report writing largely occur between October and April. Hiring of temporary employees commences in the fall and continues throughout the spring. Budget and other administrative support activities occur year round.

6.2 Facility and Equipment Needs
The field crew is based at SHEN Headquarters and operates out of the Natural and Cultural Resource Division's Lower office. All equipment needed to conduct the field work is listed in SOP 1, and is stored in the office or in a nearby storage building. The crew leader is responsible for ensuring that all equipment is in working order and coordinating with the Botanist to replenish supplies as needed.

6.3 Operating Costs and Budget Considerations
Annual operating costs are based on the anticipated costs to run the program as described in the Version 2.0 protocol (Table 4). Additional costs are incurred to replace or repair equipment including computers, GPS units, cameras, and vehicles.

The anticipated budget cost reflects a doubling (500 hour increase) in the total number of hours currently contributed by the park Botanist in direct support of the forest vegetation monitoring program. These hours are currently being devoted to a wide variety of park support tasks unrelated to long-term vegetation monitoring.

Table 4. Anticipated annual cost to implement the SHEN forest vegetation monitoring protocol in thousands of dollars. The permanent staff cost estimate includes 312 hours of a GS-11 Data Manager's time, 1,664 hours of a GS-11 Botanist's time, and 1,440 hours of a GS-07 Crew Leader's time. Temporary staff costs include 2,240 hours of GS-05 technician time.

Category	Anticipated Cost (2010 dollars)
Permanent staff	$131K
Temporary staff	$37K
Equipment	$2K
Supplies	$2K
Total	**$172K**

Literature Cited

Abrams, M. D. and B. A. Black. 2000. Dendroecological analysis of a mature loblolly pine-mixed hardwood forest at the George Washington Birthplace National Monument, eastern Virginia. Journal of the Torrey Botanical Society 127(2):139-148.

Blount, T. 2002. Personal communication. Overview of the Shenandoah National Park Long Term Monitoring program history and status. Electronic mail transmission to Gordon Olson, Natural Resources Branch Chief, Shenandoah National Park. May 9, 2002.

British Columbia Ministry of Environment, Land and Parks. 1998. Field manual for describing terrestrial ecosystems, Section 3: Vegetation. Land Management Handbook Number 25. ISSN 0229-1622. British Columbia Ministry of Environment, Land and Parks/British Columbia Ministry of Forests. Victoria, British Columbia, Canada.

Brose, P. H.; T.M. Schuler, J.S. Ward. 2006. Responses of oak and other hardwood regeneration to prescribed fire: what we know as of 2005. In: Dickinson, Matthew B., ed. 2006. Fire in eastern oak forests: delivering science to land managers, proceedings of a conference; 2005 November 15-17; Columbus, OH. Gen. Tech. Rep. NRS-P-1. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 123-135.

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

Butler, E. 2006. Character and condition of geological resources of interest to the Rock Outcrop Management Project, final report. National Park Service, Shenandoah National Park Unpublished Report, Luray, Virginia.

Collinge, S. 1996. Ecological consequences of habitat fragmentation: Implications for landscape architecture and planning. Landscape and Urban Planning 36(1):59-77.

Comiskey, J. A. and K. K. Callahan. 2008. Mid-Atlantic Network vital signs monitoring plan. Natural Resource Report NPS/MIDN/NRR—2008/071. National Park Service, Fort Collins, Colorado.

Comiskey, J. A., J. P. Schmit, and G. Tierney. 2009. Mid-Atlantic Network forest vegetation monitoring protocol. Natural Resource Report NPS/MIDN/NRR—2009/119. National Park Service, Fort Collins, Colorado.

Conners, J.A. 1988. Shenandoah National Park – An Interpretive Guide. McDonald and Woodward Publishing Company, Blacksburg, Virginia.

DeBacker, M.D., C.C. Young (editor), P. Adams, L. Morrison, D. Peitz, G.A. Rowell, M. Williams, and D. Bowles. 2005. Heartland Inventory and Monitoring Network and Prairie Cluster Prototype Monitoring Program Vital Signs Monitoring Plan. National Park Service, Heartland Inventory and Monitoring Network and Prairie Cluster Prototype Monitoring Program, Wilson's Creek National Battlefield, Republic, Missouri.

Diefenbach, D. R. 2001. Statistical evaluation of the vegetation inventory and monitoring program at Shenandoah National Park. Cooperative Agreement 4000-8-9028. National Park Service Unpublished Report, Fort Collins, Colorado.

Diefenbach, D. R. 2002. A revised sampling design for vegetation inventory and monitoring at Shenandoah National Park: A proposal prepared for peer review. Cooperative Agreement 4000-8-9028. National Park Service Unpublished Report, Fort Collins, Colorado.

Diefenbach, D.R. 2003. Summary of reviewer comments and decisions for Shenandoah's revised sampling design for vegetation monitoring. Cooperative Agreement 4000-8-9028.Unpublished Memorandum, January 31, 2003, Penn State University, State College, Pennsylvania.

Diefenbach, D. R., and C. G. Mahan. 2002. Setting realistic objectives: vegetation inventory and monitoring at Shenandoah National Park. Technical Report NPS/PHSO/NRTR- 02/087. National Park Service. Northeast Region. Philadelphia Support Office. Philadelphia, Pennsylvania.

Diefenbach, D. R., and J. K. Vreeland. 2003. A revised sampling design for vegetation inventory and monitoring at Shenandoah National Park. Cooperative Agreement 4000-08-9028. National Park Service Unpublished Report, Fort Collins, Colorado.

Elzinga, C. L., D. W. Salzer, and J. H. Willoughby, editors. 1998. Measuring and monitoring plant populations. Bureau of Land Management, Denver, Colorado.

Fancy, S. G., J. E. Gross, and S. L. Carter. 2009. Monitoring the condition of natural resources in US National Parks. *Environmental Monitoring and Assessment*, 151:161-174.

Federal Geographic Data Committee. 1998. Content standard for digital geospatial metadata (revised June 1998). FGDC-STD-001-1998. Federal Geographic Data Committee. Washington, D.C.

Fowler, D., J. N. Cape, M. Coyle, C. Flechard, J. Kuylenstierna, K. Hicks, D. Derwent, C. Johnson, and D. Stevenson. 1999. The global exposure of forests to air pollutants. Water Air and Soil Pollution 116(1-2):5-32.

Gathright, T. M. 1976 (reprinted 2003). Geology of the Shenandoah National Park, Virginia. Bulletin 86. Virginia Department of Mineral Resources. Charlottesville, VA.

Gawtry, S. and J. Stenger. 2006. Climate summary, Shenandoah National Park. Natural Resources Report NPS/NER/NRR—2007/017. National Park Service. Philadelphia, PA.

Gibbs, J. P. 1998. Integrating monitoring objectives with sound sampling design: A pilot review of selected monitoring programs at Shenandoah National Park, final report. State University of New York College of Environmental Science and Forestry Unpublished Report, Syracuse, New York.

Jenkins, M. A. 2006. Great Smoky Mountains National Park: vegetation monitoring protocols, 2006 update. Great Smoky Mountains National Park Inventory and Monitoring Program Unpublished Report, Gatlinburg, Tennessee.

Keddy, P. A. and C. G. Drummond. 1996. Ecological properties for the evaluation, management, and restoration of temperate deciduous forest ecosystems. Ecological Applications 6(3):748-762.

Mahan, C. G. 2000. Vegetation inventory and monitoring workshop for Shenandoah National Park: Setting objectives and priorities. Summary report of workshop objectives. Pennsylvania State University Unpublished Report, Altoona, Pennsylvania.

Mahan, C. G. 2006. A Natural resource assessment for Shenandoah National Park. Technical Report NPS/NER/NRTR—2006/071. National Park Service. Philadelphia, Pennsylvania.

Mahan, C. G., D. R. Diefenbach, and W. B. Cass. 2007. Evaluating and revising a long-term monitoring program for vascular plants: Lessons from Shenandoah National Park. *Natural Areas Journal* 27(1):16-24.

McShea, W. J., and J. H. Rappole. 1992. White-tailed deer as keystone species within forest habitats of Virginia. *Virginia Journal of Science* 43:177-186.

McShea, W. J. and J. H. Rappole. 1997. The Science and politics of managing deer within a protected area. *Wildlife Society Bulletin*, 25(2):443-446.

McShea, W. J., H. B. Underwood, and J. H. Rappole, editors. 1997. The science of overabundance: deer ecology and population management. Smithsonian Institution Press, Washington, D. C.

McWilliams, W. H., T. W. Bowersox, P. H. Brose, D. A. Devlin, J. C. Finley, K. W. Gottschalk, S. Horsley, S. L. King, B. M. LaPoint, T. W. Lister, L. H. McCormick, G. W. Miller, C. T. Scott, H. Steele, K. C. Steiner, S. L. Stout, J. A. Westfall, and R. L. White 2005. Measuring tree seedlings and associated understory vegetation in Pennsylvania`s forests. Pages 21-26 *in* Proceedings of the fourth annual forest inventory and analysis symposium. Gen. Tech. Rep. NC-252. U.S. Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN.

NPSpecies - The National Park Service Biodiversity Database. IRMA Portal version. https://irma.nps.gov/App/Species/Welcome (accessed 2009).

Oakley, K. L., L. P. Thomas, and S. G. Fancy. 2003. Guidelines for long-term monitoring protocols. Wildlife Society Bulletin 31(4):1000-1003.

Oderwald, R. G. 1996. Evaluation of long term monitoring forest plant community plots, final report, Resource Study Project N-180. Virginia Polytechnic Institute Unpublished report, Blacksburg, Virginia.

Orwig, D. A. and M. D. Abrams. 1994. Land-use history (1720-1992), composition, and dynamics of oak-pine forests within the Piedmont and Coastal Plain of northern Virginia. Canadian Journal of Forest Research 24:1216-1225.

Peet, R. K., T. R. Wentworth and P. S. White. 1998. A flexible, multipurpose method for recording vegetation composition and structure. *Castanea* 63:262-274.

Ravlin, F. W., J. R. Voshell, Jr., D. W. Smith, S. L. Rutherford, S. W. Hiner, and D. A. Haskell. 1990. Shenandoah National Park long-term ecological monitoring system, Section 1, Overview in NPS/NRSHEN/NRTR-90/02. National Park Service, Denver, Colorado.

Roberts-Pichette, P. and L. Gillespie. 1999. Terrestrial vegetation biodiversity monitoring protocols. Ecological Monitoring and Assessment Network Occasional Paper Series, Report No. 9. Ecological Monitoring Coordinating Office, Burlington, Ontario.

Roland, C., K. Oakley, E. M. Debevec, and P. Loomis. 2004. Monitoring vegetation structure and composition at multiple spatial scales in the Central Alaska Network, Version 1.00. National Park Service Unpublished Report, Fairbanks, Alaska.

Russell, E.W.B. 1997. Terrestrial vegetation monitoring with permanent plots: a procedural manual (draft). National Park Service Chesapeake/Allegheny Clusters Unpublished Report, Philadelphia, Pennsylvania.

Rutters, K. H., B. E. Law, R. C. Kucera, A. L. Gallant, R. L. DeVelice, and C. J. Palmer. 1992. A selection of forest condition indicators for monitoring. Environmental Monitoring and Assessment 20(1):21-33.

Schulz, B. K., W. A. Bechtold, S. J. Zarnoch. 2009. Sampling and estimation procedures for the vegetation diversity and structure indicator. Gen. Tech. Rep. PNW-GTR-781. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 53 p. Available at http://treesearch.fs.fed.us/ (accessed Feb 2011).

Schulz, B. K., S. Oswalt, W. K. Moser. 2009. Vegetation inventory data: How much is enough? In: W. McWilliams, G. Moisen, and R. Czaplewski, comps. Forest Inventory and Analysis (FIA) Symposium 2008; October 21-23, 2008; Park City, UT. Proc. RMRS-P-56CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 11 p. Available at http://treesearch.fs.fed.us/ (accessed Feb 2011).

Shenandoah National Park. 1992. Natural resource inventory and long-term ecological monitoring plan. National Park Service Unpublished Report, Luray, Virginia.

Simberloff, D., I. Parker, and P. Windle. 2005. Introduced species policy, management, and future research needs. Frontiers in Ecology and the Environment 3(1):12-20.

Smith, D. W., and J. L. Torbert. 1990. Shenandoah National Park long-term ecological monitoring system, Section II, forest components user manual. NPS/NRSHEN/NRTR-90/02. National Park Service, Denver, Colorado.

Southworth, S., C. M. Bailey, L. S. Eaton, G. Hancock, M. H. Lamoreaux, R. J. Litwin, W. C. Burton, and J. Whitten. 2009a. Geology of the Shenandoah National Park region; 39th Annual Virginia Geological Field Conference, October 2-3, 2009. Big Meadows, Shenandoah National Park, Virginia.

Southworth, S., Aleinikoff, J. N., Bailey, C. M., Burton, W. C., Crider, E. A., Hackley, P. C., Smoot, J. P., and Tollo, R. P. 2009b. Geologic map of the Shenandoah National Park region, Virginia. U.S. Geological Survey Open-File Report 2009–1153, Reston, Virginia. Available at http://pubs.usgs.gov/of/2009/1153/.

Teetor, A. 1988. Identification and mapping of vegetation communities in Shenandoah National park, Virginia, final report MAR-34. National Park Service Shenandoah National Park, Unpublished Report. Luray, Virginia.

Tierney, G. L., D. Faber-Langendoen, B. R. Mitchell, W. G. Shriver, and J. P. Gibbs. 2009. Monitoring and evaluating the ecological integrity of forest ecosystems. *Frontiers in Ecology and the Environment* 7(6):308-316. Available from http://www.esajournals.org/doi/pdf/10.1890/070176 (accessed 2 November 2010).

Townsend, John F. 2009. Natural heritage resources of Virginia: rare plants. Natural Heritage Technical Report 09-07. Virginia Department of Conservation and Recreation, Division of Natural Heritage, Richmond, Virginia.

U.S. Forest Service. 2002. Forest inventory and analysis field methods for Phase 3 measurements: vegetation diversity and structure, Section 13. Arlington, Virginia. Available from: http://fia.fs.fed.us/library/field-guides-methods-proc/ (accessed 15 November 2010).

U.S. Geological Survey. 1996. Review of long-term monitoring program at Shenandoah National Park. Unpublished Report, Reston, Virginia.

Yahner, R. H. 2000. Eastern deciduous forest: ecology and wildlife conservation. Second edition. University Minnesota Press, Minneapolis, Minnesota.

Young, J., G. P. Fleming, W. B. Cass, and C. Lea. 2009. Vegetation of Shenandoah National Park in relation to environmental gradients, version 2.0. Technical Report NPS/NER/NRTR-2009/142. National Park Service, Philadelphia, Pennsylvania.

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov