

**A REVISED SAMPLING DESIGN
for
VEGETATION INVENTORY AND MONITORING
at
SHENANDOAH NATIONAL PARK**

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Table of Contents

List of Figures	iii
List of Tables	v
List of Appendices	vii
Acknowledgments.....	viii
Summary	ix
Introduction.....	1
Review of Existing Sampling Design	2
Issues Associated with Proposed Changes	7
New Sampling Design	9
Strata	9
Power Analysis	25
Results of Simulations	29
Conclusions and Recommendations	32
Literature Cited	34

List of Figures

Figure 1. Shenandoah National Park and its location within Virginia. Three primary districts comprise the park: northern (ND), central (CD), and southern (SD).....	10
Figure 2. Elevation (meters) classes in the northern district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program.	12
Figure 3. Elevation (meters) classes in the central district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program.....	13
Figure 4. Elevation (meters) classes in the southern district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program.	14
Figure 5. Geologic strata in the northern district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program	15
Figure 6. Geologic strata in the central district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program	16
Figure 7. Geologic strata in the southern district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program	17
Figure 8. Aspect (NE = 315 - 124 degrees, SW = 125 - 314) in the northern district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program.....	18
Figure 9. Aspect (NE = 315 - 124 degrees, SW = 125 - 314) in the central district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program.....	19
Figure 10. Aspect (NE = 315 - 124 degrees, SW = 125 - 314) in the southern district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program.....	20

Figure 11. Cross-classification of geology, aspect, and elevation strata in the northern district of Shenandoah National Park (SNP), 2003.....	22
Figure 12. Cross-classification of geology, aspect, and elevation strata in the central district of Shenandoah National Park (SNP), 2003.....	23
Figure 13. Cross-classification of geology, aspect, and elevation strata in the southern district of Shenandoah National Park (SNP), 2003.....	24

List of Tables

Table 1. Area (ha) encompassed by geologic, aspect, and elevation strata for long-term vegetation monitoring at Shenandoah National Park, 2003.....	11
Table 2. Area (ha) of geologic, aspect, and elevation strata cross-classified to stratify plot selection for long-term vegetation monitoring at Shenandoah National Park, 2003.	21
Table 3. Mean and SD of basal area (m ² /ha) for selected tree species in Shenandoah National Park, 1987-2000, based on 103 plots originally stratified by forest vegetation type and re-organized into strata based on geology, elevation, and aspect.....	26
Table 4. Mean and SD of stem density (stems/ha; 1–5 m tall) for tree-of-heaven (<i>Ailanthus altissima</i>), mountain laurel (<i>Kalmia latifolia</i>), spicebush (<i>Lindera benzoin</i>), and sassafras (<i>Sassafras albidum</i>) in Shenandoah National Park, 1987-2000, based on 103 plots originally stratified by forest vegetation type and re-organized into strata based on geology, elevation, and aspect	27
Table 5. Mean and SD of stem density (stems/ha; 1–5 m tall) for flowering dogwood (<i>Cornus florida</i>), ash (<i>Fraxinus</i> spp.), and <i>Rubus</i> species in Shenandoah National Park, 1987-2000, based on 103 plots originally stratified by forest vegetation type and re-organized into strata based on geology, elevation, and aspect.....	28
Table 6. Simulated mean basal area (m ² /ha), Satterthwaite degrees of freedom (df), and CV for black birch (<i>Betula lenta</i>), Virginia (<i>Pinus virginiana</i>) and pitch pine (<i>P. rigida</i>), and red maple (<i>Acer rubrum</i>) under different sample sizes in a stratified random sampling design. Parameters were simulated using 999 replications based on empirical data collected in Shenandoah National Park, 1987-2000.	30
Table 7. Simulated mean basal area (m ² /ha), Satterthwaite degrees of freedom (df), and CV for northern red oak (<i>Quercus rubra</i>) and various groups of oak tree species under different sample sizes in a stratified random sampling design. Parameters were simulated using 999 replications based on empirical data collected in Shenandoah National Park, 1987-2000.	30
Table 8. Simulated mean stem density (stems/ha; 1–5 m tall), Satterthwaite degrees of freedom (df), and CV for tree-of-heaven (<i>Ailanthus altissima</i>), mountain laurel (<i>Kalmia latifolia</i>), spicebush (<i>Lindera benzoin</i>), and sassafras (<i>Sassafras albidum</i>) under different sample sizes in a stratified random sampling design. Parameters were simulated using 999 replications based on empirical data collected in Shenandoah National Park, 1987-2000.	31

Table 9. Simulated mean stem density (stems/ha; 1–5 m tall), Satterthwaite degrees of freedom (df), and CV for flowering dogwood (<i>Cornus florida</i>), ash species (<i>Fraxinus</i> spp.), and <i>Rubus</i> species under different sample sizes in a stratified random sampling design. Parameters were simulated using 999 replications based on empirical data collected in Shenandoah National Park, 1987-2000.	31
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List of Appendices

Appendix A. Memo Summarizing Reviewer Comments for Revised Sampling Design for Vegetation Monitoring in Shenandoah National Park	35
Appendix B: Formulas to Estimate Means and Variances	42
Appendix C: Description of Sampling Points	44
Appendix D: Metadata	54

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Summary

The goal of this project was to develop a sampling design that addressed many of the recommendations provided in a prior evaluation of the vegetation monitoring program at Shenandoah National Park (SNP; Diefenbach and Mahan 2002). Three objectives for this project were to: (1) modify Long Term Ecological Monitoring System (LTEMs) objectives, if necessary, to incorporate information obtained from the work conducted by Diefenbach and Mahan (2002), (2) develop a sampling design to meet LTEMs objectives, and (3) provide a detailed documentation of this sampling design to ensure consistency in the vegetation sampling over the long term.

In consultation with SNP staff, and incorporating suggestions from outside reviewers (Appendix A), we created a sampling design based on a stratified random sample design with interpenetrating sampling over two years. Strata were based on elevation, geology, and aspect. At the finest level of classification, middle elevations consistently occupied the greatest area among all bedrock geology types, followed in area by low elevation and high elevation areas. More than 6,200 unique polygons from <0.001 ha to >1,175 ha comprise these cross-classified strata. However, the high-elevation, siliciclastic strata contained only about 230 ha, so this area was incorporated into the mid-elevation, siliciclastic strata. The resulting stratified design had 16 strata (3 elevations $\times$ 2 aspects $\times$ 3 bedrock geology types – 2 high-elevation siliciclastic strata incorporated into mid-elevation strata = 16 strata).

Plots were allocated among strata proportional to area. When possible, we retained plots used in the previous sampling design (Diefenbach and Mahan 2002); however, selection criteria were established before an existing plot was eligible to be retained. Plot centers had to be ≥ 40 m from an established trail, ≥ 50 m from any administrative road or park boundary, ≥ 100 m from Skyline Drive or any developed area, and have a slope <26.5 degrees. These same criteria were applied to all new plots selected.

To evaluate the statistical power of this new sampling design, we investigated the precision of basal area and stem densities for selected tree and shrub species under the new sampling design in which sample sizes were 100, 140, 180, 220, and 260 plots. Plots were allocated among strata in proportion to strata areas. For each species, we simulated 999 datasets and calculated park-wide means, standard errors (SE), and coefficients of variation (CV) for each sample size (100 – 260 plots).

Simulated estimates of tree (>5 m tall) basal area for black birch (*Betula lenta*), Virginia and pitch pine (*Pinus virginiana* and *P. rigida*, respectively), red maple (*Acer rubrum*), northern red oak (*Quercus rubra*), and groups of oak species (white oaks, red oaks, and all oak species) all had CVs <20% for sample sizes ≥ 100 plots. Sample sizes of 140 – 180 plots produced CVs of 10 – 15%. As expected, CVs of stem density of saplings and shrubs (1 – 5 m tall) were greater than those for basal area, but were <40% for all species examined for sample sizes ≥ 100 plots. Sample sizes of 140 – 180 plots produced CVs of 11 – 35%.

Under the existing sampling design, the mean Satterthwaite degrees of freedom (df) was approximately 4.0 for all species for both basal area and stem density estimates (Diefenbach and Mahan 2002:24). Based on this sample size, Diefenbach and Mahan (2002) estimated statistical power was approximately 80% to detect a mean change in basal area of 5 m²/ha ($\alpha = 0.20$). The mean Satterthwaite df for the proposed sampling design was >16 for all species and sample sizes, which should result in >80% power to detect even small changes in basal area (<2 m²/ha).

For stem density of saplings and shrubs (1 – 5 m tall), only changes of 1,000 – 2,000 stems/ha were expected to have >80% chance of being detected ($\alpha = 0.20$, Satterthwaite df = 4) under the existing sampling design. From the simulation results, Satterthwaite df was >8 for all species and sample sizes ≥ 100 plots, which should result in >80% power to detect changes in stem density of 300 – 400 stems/ha.

Based upon the recommendations of Diefenbach and Mahan (2002) and the findings of this report, the following changes to the vegetation monitoring program at SNP have been adopted:

1. Each sample site will consist of a single plot, 24 m $\times$ 24 m, demarcated by four corner stakes, to record tree species and diameter at breast height (dbh; 1.37 meters above ground level), and coverage of ground cover, target exotic species, and herbs. The plot size will be corrected for slope. Along two sides will be a 2 m $\times$ 24 m strip transect for sampling shrub stem density, and a 1 m $\times$ 12 m strip transect for sampling seedling density.
2. Trees will be permanently marked to reduce data collection errors and provide more consistent dbh measurements.
3. Strata will be defined by elevation, geology, and aspect (Table 2) in 16 categories.
4. All statistical objectives for basal area and stem density will be retained (Diefenbach and Mahan 2002), but the objectives for stem densities of seedling species will be eliminated because of the inability to detect biologically important changes. Instead seedling data will continue to be collected in a quantitative manner (1 m $\times$ 12 m strip transect; see #1 above), because data collection will be more consistent than qualitative assessments of abundance, but will not be expected to provide statistically precise results.
5. A stratified random sampling design will be used to estimate basal area of tree species and stem density of sapling and shrub species. Samples will be allocated among strata proportional to the area of each stratum. Appendix B provides the formulae necessary to calculate means, totals, and corresponding variances (and other measures of precision, e.g., confidence intervals).
6. Plot centers selected will be ≥ 40 m from an established trail, ≥ 50 m from any administrative road or park boundary, ≥ 100 m from Skyline Drive or any developed area, and have a slope <26.5 degrees. If upon actual visitation to a selected plot location these criteria are not met, the site will not be incorporated into the sampling design and another randomly-selected site will be used.
7. The sampling effort will require two years to visit all plots (i.e., interpenetrating sampling). A total of 160 plots (80/yr) was decided upon as being logistically

feasible and providing sufficient precision (Tables 6 – 9). Appendix C provides plots included in the new sampling design. In addition, this appendix includes extra plots in case some selected plots are not acceptable (e.g., too steep).

During summer 2003, fieldwork was initiated to collect data under this new sampling design. Because of unusually wet weather and the additional time and effort involved in establishing new sampling plots (i.e., locating the plot and plot boundary, and installing corner markers), it will likely take >2 years to visit all 160 plots for the first time. However, logistically it should be possible to visit all 160 plots within a two-year time interval once all plots have been established (W. Cass, personal communication).

We strongly recommend that, upon initial completion of all 160 plots, data be analyzed to estimate basal area and stem density for at least the species analyzed in Diefenbach and Mahan (2002). This would indicate if the simulations presented in this report are reasonable and if the selected sample size and sampling design likely will provide the desired precision of estimates of basal area and stem density.

Introduction

Effective programs designed to monitor changes in natural resources set objectives that can be assessed quantitatively, implement a sound sampling design, and evaluate the sampling design, methods, and data with respect to specified objectives. In turn, the evaluation of the program should be used to modify objectives or methods, if necessary, to ensure that results are valid and are useful to scientists, managers, and administrators.

The Long Term Ecological Monitoring System (LTEMs) at Shenandoah National Park (SNP) began vegetation monitoring in 1987. More than 100 sample plots in the LTEMs included randomly-selected plots as well as additional plots established from other research projects. The purpose of LTEMs is to (1) obtain empirical data on the type, abundance, and distribution of natural resources in the park, (2) monitor changes in the resources of interest over time, and (3) monitor natural processes and anthropogenic influences in the park. However, no specific objectives for the vegetation monitoring at SNP were established, and data collected during 1987-2000 had not been evaluated to assess the statistical precision of resulting estimates of vegetation characteristics (e.g., tree basal area, stem densities, etc.).

In 2000, staff of SNP, in conjunction with outside experts, initiated a review of the vegetation component of the LTEMs. This review (Diefenbach and Mahan 2002) provided quantitative objectives for LTEMs and recommendations for improving the vegetation monitoring at SNP. This review identified specific, measurable, and statistically testable objectives and evaluated whether the current LTEMs effort was sufficient to meet these objectives.

Diefenbach and Mahan (2002) reported that the precision of tree basal area estimates was sufficient to detect biologically important changes with >90% statistical power. However, the ability to detect important changes in stem density of saplings, shrubs, and seedlings was insufficient for most species. Also, the temporal sequence of sampling plots restricted estimation of vegetation parameters to specific strata, rather than allowing calculation of parkwide estimates for a given point in time. Most importantly, the strata defined in the sampling design were based on forest vegetation types, whose location and size had changed over time and with natural disturbances.

The goal of this project was to develop a sampling design that addressed many of the recommendations provided in Diefenbach and Mahan (2002). There were three objectives for this project: (1) modify LTEMs objectives, if necessary, to incorporate information obtained from the work conducted by Diefenbach and Mahan (2002), (2) develop a sampling design to meet LTEMs objectives, and (3) provide a detailed documentation of this sampling design to ensure consistency in the vegetation sampling over the long term. This report documents the results of work conducted to meet these three objectives.

Review of Existing Sampling Design

The following objectives, which were established during a workshop held at SNP in 2000, were evaluated by Diefenbach and Mahan (2002):

1. Data collected for the LTEMs program should ensure a 90% probability of detecting a $\geq 50\%$ change in the basal area or stem density of any woody plant species (in a given size class) within any one forest cover type over a 5-year period ($\alpha = 0.20$). Diefenbach and Mahan (2002) assessed the ability of current sampling efforts to meet this objective by calculating power curves for tree (>5 m tall) basal area, shrub and sapling (1-5 m tall) stem density, and seedling (<1 m tall) stem density.
2. Data collected for the LTEMs program should ensure an 80% probability of detecting a $\geq 20\%$ change in the areal coverage of a particular exotic species parkwide over a 5-year period ($\alpha = 0.20$). Diefenbach and Mahan (2002) assessed the ability of the current LTEMs program at SNP to meet this objective for changes in seedling and sapling stem density of tree-of-heaven (*Ailanthus altissima*). Stem density was used as an indicator of areal coverage for this species.
3. Data collected for the LTEMs program should ensure an 80% probability of detecting a $\geq 20\%$ change parkwide in species affected by disease or insects over a 5-year period ($\alpha = 0.20$). Diefenbach and Mahan (2002) assessed the ability of the current LTEMs program at SNP to meet this objective for changes in stem density of flowering dogwood (*Cornus florida*) and basal area of all oak species combined.

Diefenbach and Mahan (2002) used coefficients of variation ($CV = SE/\text{mean} \times 100\%$) to assess precision of basal area and stem density estimates ($CV = 20 - 30\%$ indicates acceptable precision for monitoring programs) and a statistical power analysis to estimate ability to detect important changes in basal area or stem density. Most CVs were $<40\%$ for tree species in forest cover types where a species was dominant (e.g., northern red oak [*Quercus rubra*] in northern red oak cover types). Declines in oaks, Virginia pine (*Pinus virginiana*), and pitch pine (*Pinus rigida*) were evident from the changes in estimated basal area between sampling periods. The results of the power analysis suggested that changes of $5 - 6 \text{ m}^2/\text{ha}$ could be detected with $\geq 90\%$ power. Thus, if basal area of a dominant species of tree in a given forest cover type was $>10 - 12 \text{ m}^2/\text{ha}$ then a $\geq 50\%$ decline could be detected with sufficient power.

For stem density of shrubs and saplings, most CVs were $>50\%$ (Range 31 – 1,169%). The power analysis suggested that stem density changes of $\geq 2,000$ stems/ha had $>90\%$ probability of being detected. Because most stem densities during both sampling periods were $<1,000$ stems/ha, current sample sizes were inadequate to detect important changes in stem density of shrubs and saplings.

Stem density of seedlings was highly variable, and the power analysis suggested that only extremely large changes in stem density ($>50,000$ stems/ha) could be detected under the current sampling effort. Moreover, large enough sample sizes likely could not be obtained to meet stated objectives because of the inherent variability of these data.

Diefenbach and Mahan (2002) listed the following recommended changes to the LTEMs vegetation program at SNP as highest priority.

1. Implement a sampling design that will permit parkwide estimates of vegetation parameters for a given point in time. Currently, changes in basal area or stem density can be estimated within each forest cover type, but cannot be estimated across all cover types for the same time period because each forest cover type is visited in a different year.
2. Investigate the requirements to monitor the spatial distribution of forest cover types before implementing changes to the sampling design. Traditional stratified sampling designs cannot incorporate changes in the distribution of cover types over time.
3. Increase sample sizes such that all strata contain >1 plot. Sample sizes overall may need to be increased, depending on the selected sampling design, to meet objectives for detecting changes in stem density of shrubs and saplings.
4. Continue to permanently mark trees within plots with unique identifiers to reduce misidentification and data collection errors.
5. Implement electronic field-based data entry system to speed data collection, reduce data entry errors, and eliminate transcription errors that may occur with a paper system.
6. Review the purpose and need to collect seedling stem densities. Obtaining adequate sample sizes to detect biologically important changes in seedling density or abundance is unlikely.

We met with NPS staff (J. Karish, W. Cass) in June 2002 to review the recommendations of Diefenbach and Mahan (2002). The following recommendations had already been initiated or implemented: permanently marking trees for basal area measurements (recommendation #4) and using an electronic field-based data entry system (recommendation #5). Although not yet fully implemented, these changes will reduce transcription and data collection errors. Additionally, it was agreed that regeneration data (seedling stem densities; recommendation #6) were not possible to collect in a statistically rigorous manner. However, information on regeneration of various tree species is important and data collection was retained for qualitative purposes, but was not intended to provide statistically precise estimates of stem density.

Recommendation #2 urged SNP staff to consider methods to monitor the spatial distribution of forest cover types before proceeding with a revised sampling design. However, this consideration was dropped for two reasons. First, a separate effort with U.S. Geological Survey, Leetown Science Center staff is using a GIS to map ecological characteristics of SNP. Second, it is evident that insufficient resources (funding, staff, and time) are available to sample enough plots to create a map of vegetative cover using spatio-statistical methods.

Based upon this review of Diefenbach and Mahan (2002), efforts in this project were to be focused on addressing recommendations #1 and #3; that is, develop a sampling design

with sufficient sample size, given the constraints of funding, personnel, and time, to meet the objectives established in Diefenbach and Mahan (2002). The following changes were considered:

Plot layouts and data collection.— At each sampling location, the current design has three $24\text{ m} \times 24\text{ m}$ plots (adjusted for slope) at each sampling site, at which diameter at breast height (dbh), crown class, and crown health of all trees $>5\text{ m}$ tall (by species) were measured. Within each of these three plots are three $6\text{ m} \times 6\text{ m}$ plots in which woody stems (1-5 m tall) were counted, and within each of these 36 m^2 plots are two $1\text{ m} \times 1\text{ m}$ plots for counting woody regeneration $<1\text{ m}$ tall, and estimating ground cover percentages. The problem with this layout is that individual plots are not true replicates because they were not independent samples, and 84 stakes (28 stakes per $24\text{ m} \times 24\text{ m}$ plot) are required to demarcate the corners of all plots (tree, shrub/sapling, and regeneration plots).

The proposed change to plot layout is to retain only one $24\text{ m} \times 24\text{ m}$ plot at each site, and to use four stakes to define the plot corners. Variables measured within the $24\text{ m} \times 24\text{ m}$ area would include tree species dbh, crown health, and crown class, and cover class estimates for ground cover components, the five most common herbaceous species, and 12 targeted invasive exotic plant species identified by NPS staff. An additional stake would be placed at the midpoint of two plot sides. Along each of these two sides a strip transect ($1\text{ m} \times 12\text{ m}$) would define the area sampled for woody seedling stem density. Sampling for sapling and shrub density within four stem diameter classes would take place in two $2\text{ m} \times 24\text{ m}$ strip transects placed along these same sides. The boundary of these transects would be defined by laying a measuring tape along the edge of the $24\text{ m} \times 24\text{ m}$ plot and using a 2-m pole to define the width of the strip transect. These changes would reduce the number of stakes from 28 to six and, thus, reduce maintenance of plots as well as the time required to locate plot boundaries. Also, a timed search will be conducted in the complete $24\text{ m} \times 24\text{ m}$ plot for any exotic plant species.

A circular plot was considered because only 1 stake could define the plot location, but with a circle it is more difficult to decide whether a tree is in the plot, and correction for slope is very difficult. Alternatively, variable radius plots were considered, but fixed area plots are more efficient for detecting changes in basal area, etc. over time (Scott 1990, Scott and Alegria 1990).

In addition to changes in the method of collecting data, definitions of trees, shrubs, saplings, and seedlings have been changed. Previously, these life forms were defined based on height. Under the new protocols these life forms will be defined primarily by dbh. Trees will be defined as woody vegetation with $\text{dbh} \geq 10\text{ cm}$. Shrubs and saplings will be defined as woody vegetation $\geq 1.5\text{ m}$ tall with $\text{dbh} < 10\text{ cm}$. Seedlings and sprouts will be defined as woody vegetation (woody at any stage in their life cycle) $< 1.5\text{ m}$ tall, with $\text{dbh} < 10\text{ cm}$. These changes are intended to increase the efficiency of data collection. It is noteworthy to point out that the simulations in this report were conducted based on life forms defined by height; however, the changes in estimates of basal area and stem density should be relatively minor because of the changes in definitions.

Strata definitions.—The existing design stratified the park according to elevation (high, medium, low), aspect (northeast and southwest), and eight forest vegetation types. This stratification resulted in 48 different strata ($= 3 \text{ elevations} \times 2 \text{ aspects} \times 8 \text{ forest types}$) and too few plots were available in most strata (Diefenbach and Mahan 2002). Moreover, the areal coverage of forest vegetation types changes over time, which results in biased estimates when using estimators for a stratified random design. For example, during 1987-2000, the pitch pine and Virginia pine forest vegetation types virtually disappeared in the park because of mortality from disease.

The proposed change was to define strata according to geology (basaltic, granitic, and siliciclastic), elevation (high, medium, and low), and aspect (northeast [moist] and southwest [dry]). For long-term studies, strata should be stable if they are to be used in a stratified random sampling design.

Sample allocation.—The advantage of stratified sampling designs is of benefit only if the defined strata result in sample plots with similar estimates of the parameter of interest (i.e., minimize variance within strata; Cochran 1977). In addition, greater sampling effort should be allocated to strata with greater variances. A preliminary review of estimates of changes over time of basal area and stem density suggests that the new strata have different variances among strata. However, these results should be interpreted with much caution because the plots were originally allocated according to a different stratification, and the parameter estimates and associated estimates of variance may be biased.

Although evidence exists that parameter estimates under the new strata would have different variances and thus sampling effort should be allocated differently among strata, we are proposing that sampling effort be allocated in proportion to strata area. In essence, this is equivalent to a parkwide simple random sample, but the stratification ensures that the spatial distribution of plots is even across the park (i.e., among elevation, geology, and aspect strata). When possible, established plots will be retained and assigned to the new strata.

Although allocation according to area is not necessarily the most efficient allocation of sampling effort, given the caution that must be applied to existing variance estimates and the number of different tree and shrub species to monitor, it may be the wisest approach. This proposed sampling allocation also would permit estimates for each of the proposed strata, as well as some other post-stratification, such as stratification by different elevation definitions than used in this design (Cochran 1977).

Temporal sampling effort.—We propose interpenetrating sampling (Messer et al. 1991) to permit increased sampling intensity over time, where, for example, $\frac{1}{2}$ of the plots are visited each year. That is, each year $\frac{1}{2}$ of the sample plots are randomly selected to be sampled such that they are distributed across the park, and by the second year all plots have been visited. Thus, inferences of forest conditions may be possible for not only a single year, but for a two-year interval. The advantage of this sampling effort is that

limitations of staff, funding, and time are relaxed because the sampling effort can be expanded spatially and temporally.

Potential new sampling design.—Diefenbach and Mahan (2002) suggested that consideration be given to sampling with partial replacement (SPR; Scott 1984, Scott and Kohl 1994, Urquhart et al. 1998). An SPR design has a set of plots that would be visited each sampling period, but an additional set of plots might only be visited every other (or third, or fourth, etc.) sampling period. For example, there may be 175 total plots in the sampling design but only 75 plots are visited during each sampling period, of which 25 are visited each period and 50 of the 150 other plots are only visited every third sampling period. The advantages of such a design are that (1) this method is an efficient compromise between obtaining accurate parameter estimates at any given point in time and estimating changes over time, and (2) new plots added to the sample help ensure that the sample plots remain representative of the population of interest (especially if population characteristics shift spatially over time). The disadvantages are that (1) variance estimation can be complex, (2) estimates for subpopulations may have reduced precision relative to other sampling designs, and (3) efficiency will be reduced if resource characteristics are poorly correlated over time.

Issues Associated with Proposed Changes

Schreuder and Czaplewski (1993) identified desirable characteristics of a sampling strategy for large-scale monitoring of forest health (e.g., in the Southeastern U.S.). The following have direct relevance to the vegetation inventory and monitoring program at SNP:

1. Use variables with negligible measurement errors. Subjective variables, such as ocular estimates of canopy condition, should not be emphasized in the survey design.
2. Simplicity in design.
3. Consistency of design over time.
4. Flexibility to address new environmental or management issues while maintaining design consistency.
5. Use interpenetrating sampling so sampling intensity can be increased over time and space as needed.
6. Implement a strong quality assurance program so that true changes in sample plots over time will not be confounded with measurement error or changes in protocols.

We believe Items 1, 5, and 6 have been adequately addressed either through implemented changes in the program (e.g., quality assurance of data) or in the proposed changes (e.g., interpenetrating samples). However, Items 2, 3, and 4 are the primary reason why we sought input from other professionals on the re-design of SNP's vegetation monitoring program.

Several issues related to the proposed changes in the monitoring program are listed below. In our effort to determine the best type of sampling design to implement, we received comments from reviewers regarding the best type of sampling design to be implemented. Reviewers also provided comments on additional proposed changes before proceeding with developing a revised monitoring program (Appendix A).

1. Sample sizes need to be increased if the program is going to detect changes in sapling and shrub stem densities. We believe that interpenetrating sampling is the only means of increasing sample size because support (personnel and funds) is not expected to increase such that more plots could be visited in a single summer. The drawback of interpenetrating samples is that inferences regarding changes may have to be made over 2-4 year intervals rather than specific years, although the data collection will permit estimates for a single year.
2. Defined strata must be ones that do not change over time (e.g., vegetation type cannot be used). The proposed strata (geology, elevation, and aspect) are relatively permanent strata; however, a review of means and variances (see appendices) indicate that the response of various species differ in their relationships among strata. Therefore, we propose to use the strata to apportion the plots among the strata in direct proportion to their area within SNP. In

essence, this will provide a simple random sample of plots but ensure that they are spatially distributed across the park. Post-stratification (Cochran 1977) could then be used to obtain estimates (e.g., basal area for red maple) within specific strata, if required.

3. The most critical decision to consider is the actual sampling design. The simplest design would be to randomly select plots (as in #2 above), apply interpenetrating sampling, and then use these same plots over time to monitor vegetation changes. The risk with this approach is that it may fail to adequately capture spatial shifts in vegetation over time (Schreuder et al. 1993:182). The alternative is to implement sampling with partial replacement (SPR; Scott 1984, Scott and Kohl 1994, Urquhart et al. 1998). The advantage of SPR is that it is most efficient for estimating parameters both at a given point in time as well as for changes over time (Schreuder et al. 1993:182). There are disadvantages, however: (1) the estimators are complex (especially variance estimates), (2) implementing the design becomes more involved, and (3) post-stratified estimates may be restricted by limited sample sizes. If an SPR design were to be implemented, one would have to specifically identify which plots would be sampled in what year, as well as create databases for storing data and develop programs (e.g., SAS code or Excel spreadsheets) for data analysis.

New Sampling Design

In consultation with SNP staff, and based on comments from outside reviewers (Appendix A), we created a sampling design based on a stratified random sample design with interpenetrating sampling over 2 years. Strata were based on elevation, geology, and aspect.

Plots were allocated among strata proportional to area. When possible, we retained plots used in the previous sampling design (Diefenbach and Mahan 2002); however, selection criteria were established before an existing plot was eligible to be retained. Plot centers had to be ≥ 40 m from an established trail, ≥ 50 m from any administrative road or park boundary, ≥ 100 m from Skyline Drive or any developed area, and have a slope < 26.5 degrees. These same criteria were applied to all new plots selected.

Strata

Shenandoah National Park is located in northern Virginia and covers approximately 792 km² (Figure 1, Table 1). Elevations range from 213 m to 1,236 m above mean sea level (Figures 2-4). Most (384 km²) SNP area is located in the middle elevation range (610 - 914 m), but 309 km² are in the low elevation range (0 - 609 m) and 80 km² are in the high elevation range (915 - 1,144 m). Fragile plant communities exist at elevations $> 1,144$ m and 142 ha at these elevations were excluded from LTEM sampling design and plot selection. The plant communities at these elevations are unique and are monitored under a different monitoring program.

Geology in SNP is of three primary types: basaltic, granitic, and siliciclastic (Figures 5 - 7). Basaltic bedrock is found throughout all three districts and accounts for 291 km² throughout SNP. Granitic bedrock primarily is found in the northern and central districts and totals 253 km² throughout SNP. Siliciclastic bedrock dominates in the southern district, is found primarily on western slopes, and occupies 223 km² throughout SNP.

Aspects were divided into moist northeastern (315–124 degrees) and dry southwestern (125–314 degrees) throughout SNP (Figures 8–10). Southwest aspects occupied nearly 405 km² while northeast aspects occupied 370 km² (Table 1, Figures 8-10).

When elevation, geology, and aspect were cross-classified, middle elevations consistently occupied the greatest area among all geologic types, followed in area by low elevation and high elevations (Table 2). A total of 6,206 unique polygons from 0.001 ha to 1,174.8 ha comprise these cross-classified strata (Figures 11–13). However, the high-elevation, siliciclastic strata only contained about 230 ha; thus, this area was incorporated into the mid-elevation, siliciclastic strata. The resulting stratified design had 16 strata (3 elevations $\times$ 2 aspects $\times$ 3 bedrock geology types – 2 high-elevation siliciclastic strata incorporated into mid-elevation strata = 16 strata).

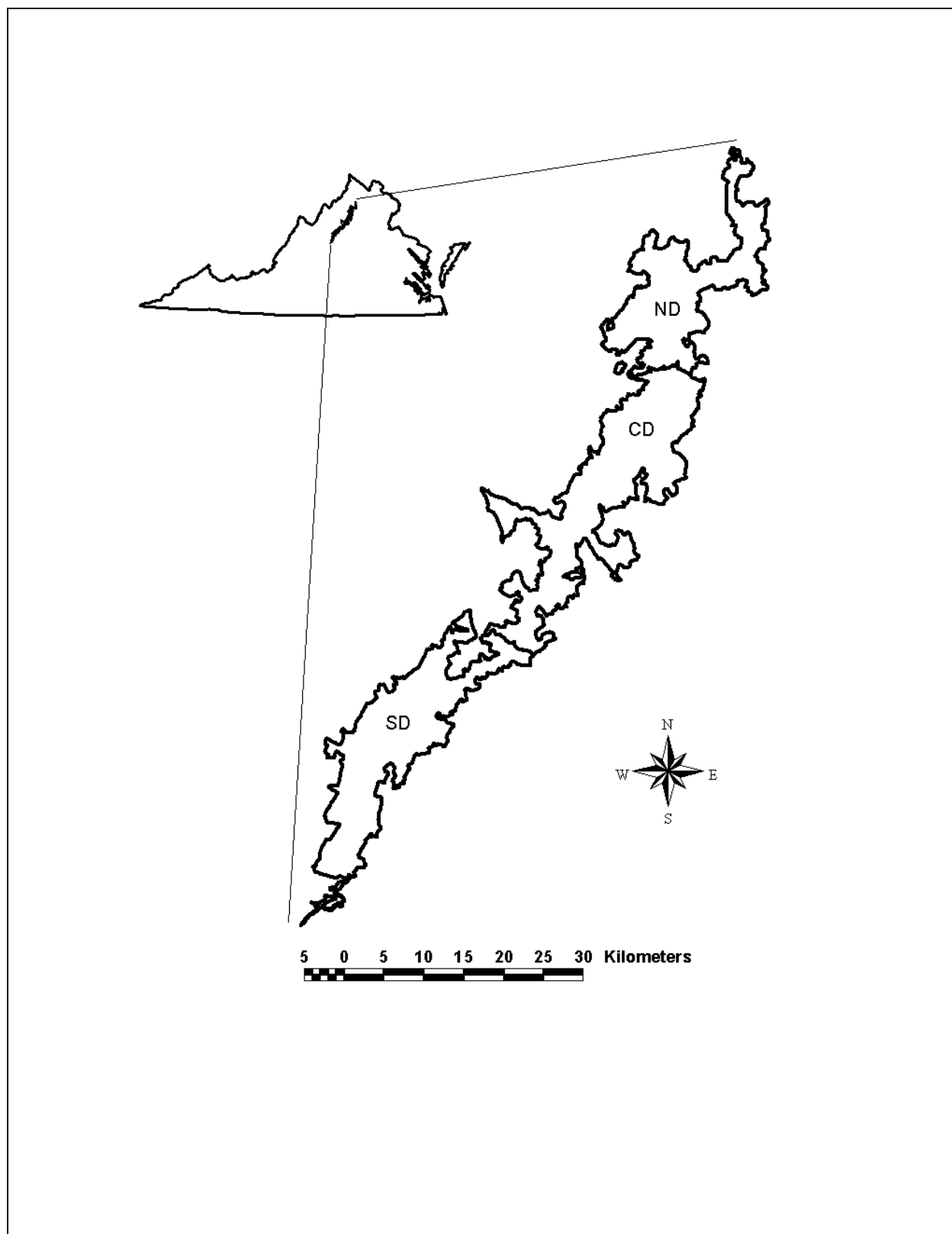


Figure 1. Shenandoah National Park and its location within Virginia. Three primary districts comprise the park: northern (ND), central (CD), and southern (SD).

Table 1. Area (ha) encompassed by geologic, aspect, and elevation strata for long-term vegetation monitoring at Shenandoah National Park, 2003.

Stratum type	Strata	Area (ha) ^a
Elevation	Low (0–609 m)	30,853
	Medium (610–914 m)	38,404
	High (915–1,144 m)	8,047
	>1,144 m ^b	142
	Total ^a	77,446
Geologic	Basaltic	29,060
	Granitic	25,301
	Siliciclastic	22,340
	Total ^a	76,701
Aspect	NE (315–124 degrees)	36,982
	SW (125–314 degrees)	40,456
	Total ^a	77,438

^a Discrepancies exist in total area among strata because extent of spatial data varied. Total area for each stratum is less than total park area (approx. 792.45 km²) because spatial coverage of strata did not extend to park boundaries in some areas.

^b Elevations >1,144 meters were excluded from plot selection criteria.

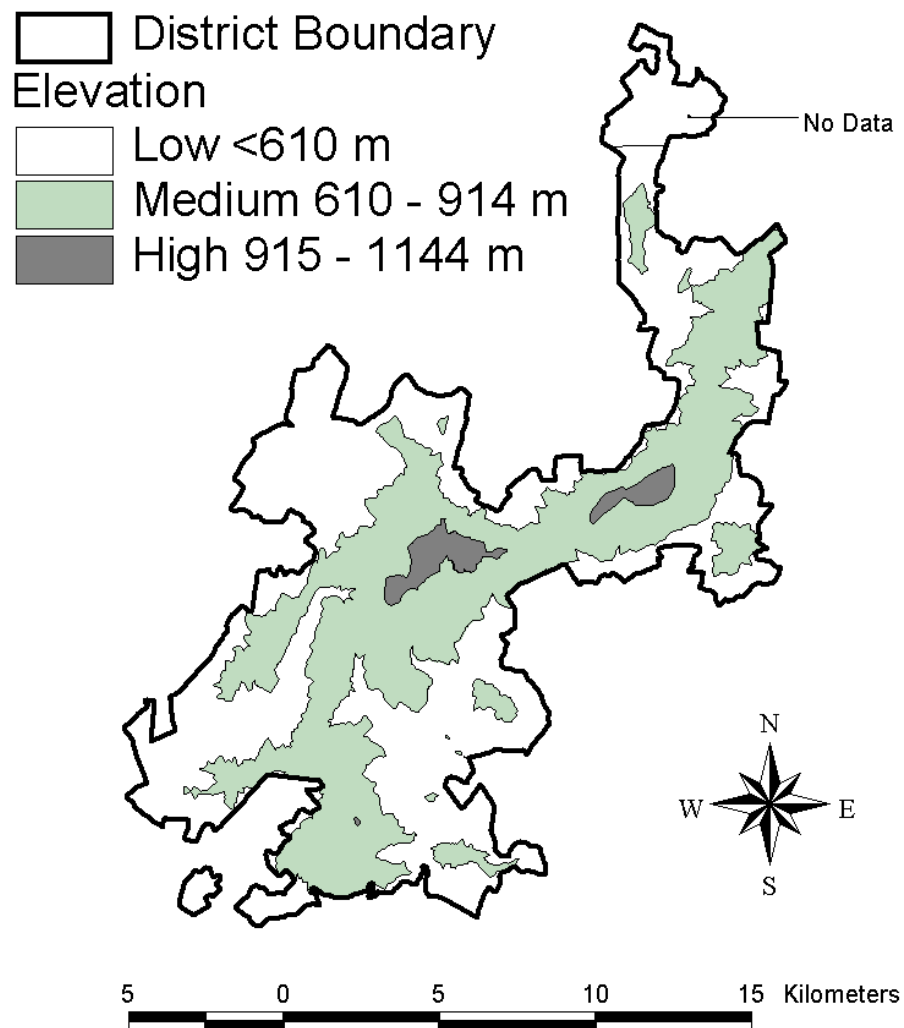


Figure 2. Elevation (meters) classes in the northern district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program.

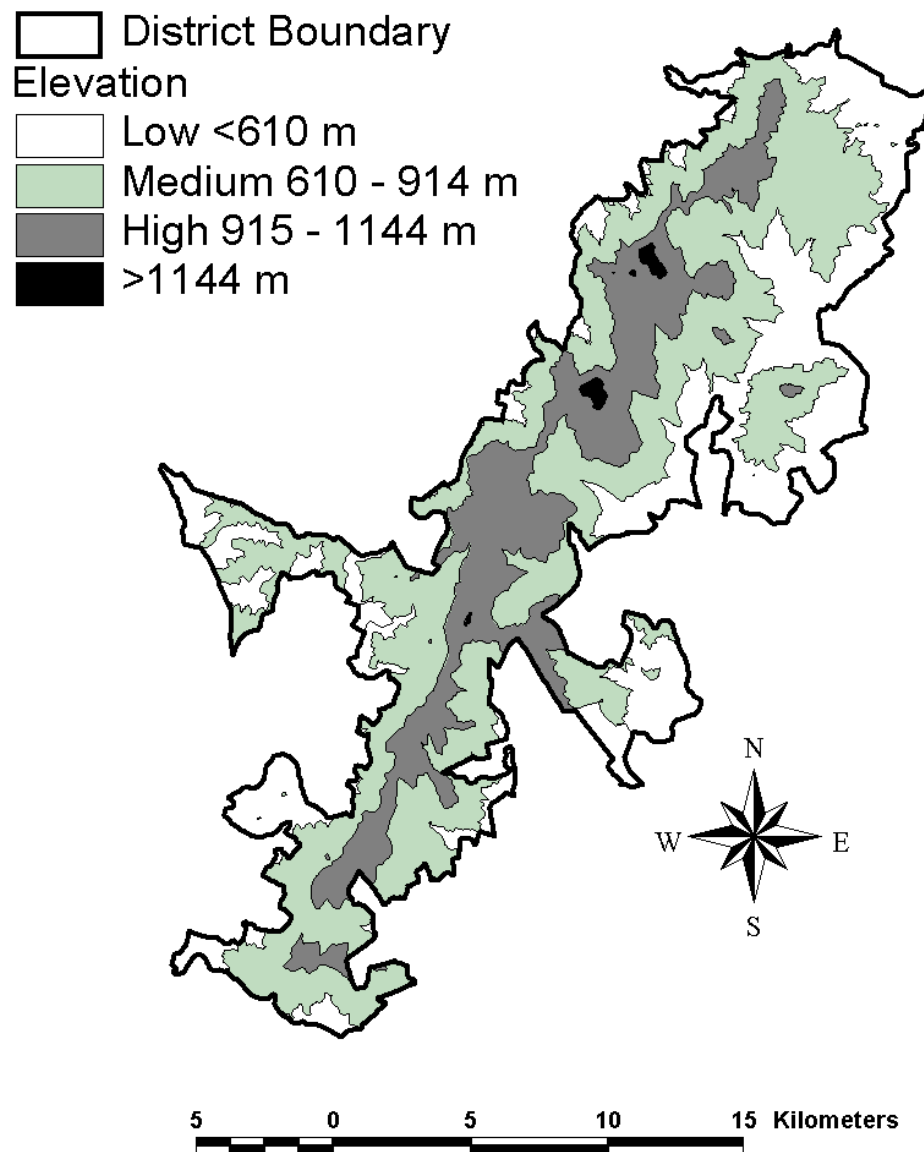


Figure 3. Elevation (meters) classes in the central district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program.

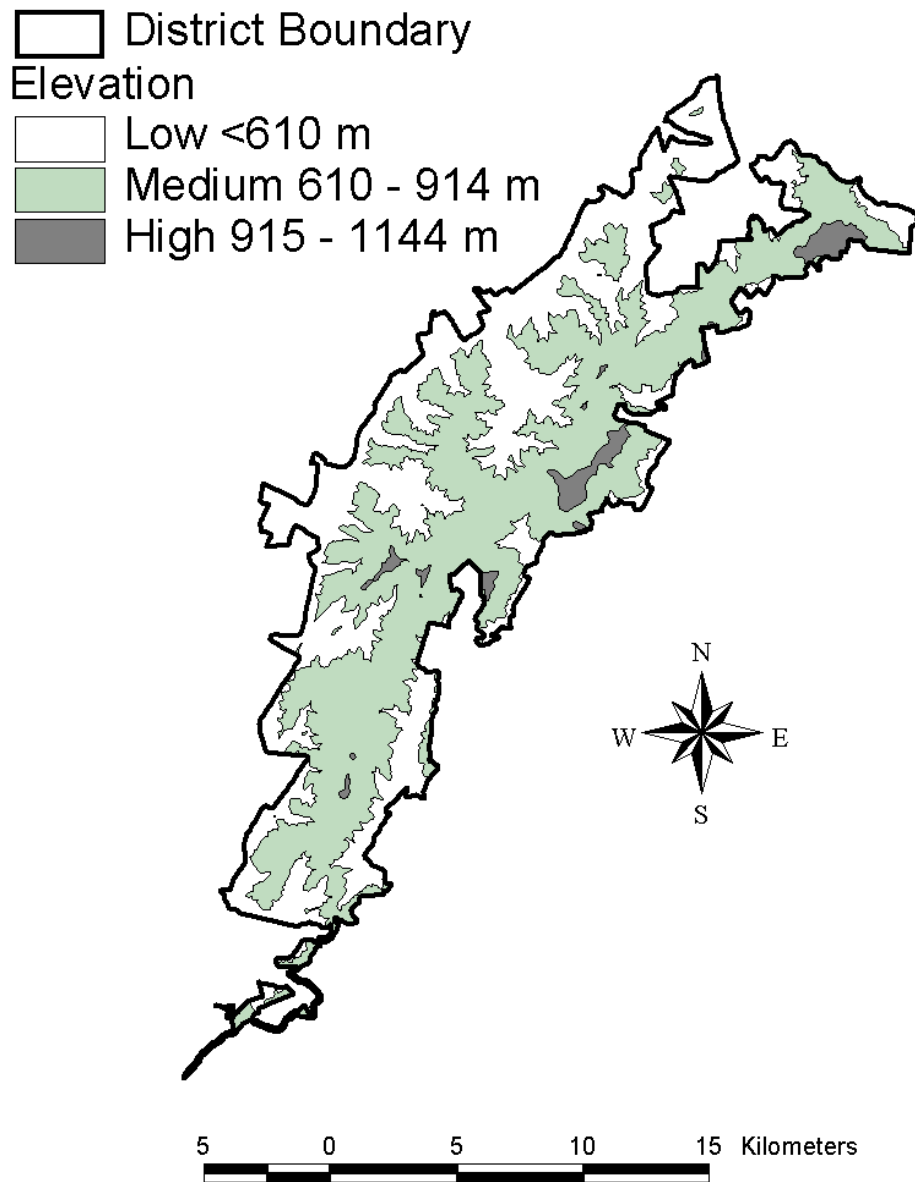


Figure 4. Elevation (meters) classes in the southern district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program.

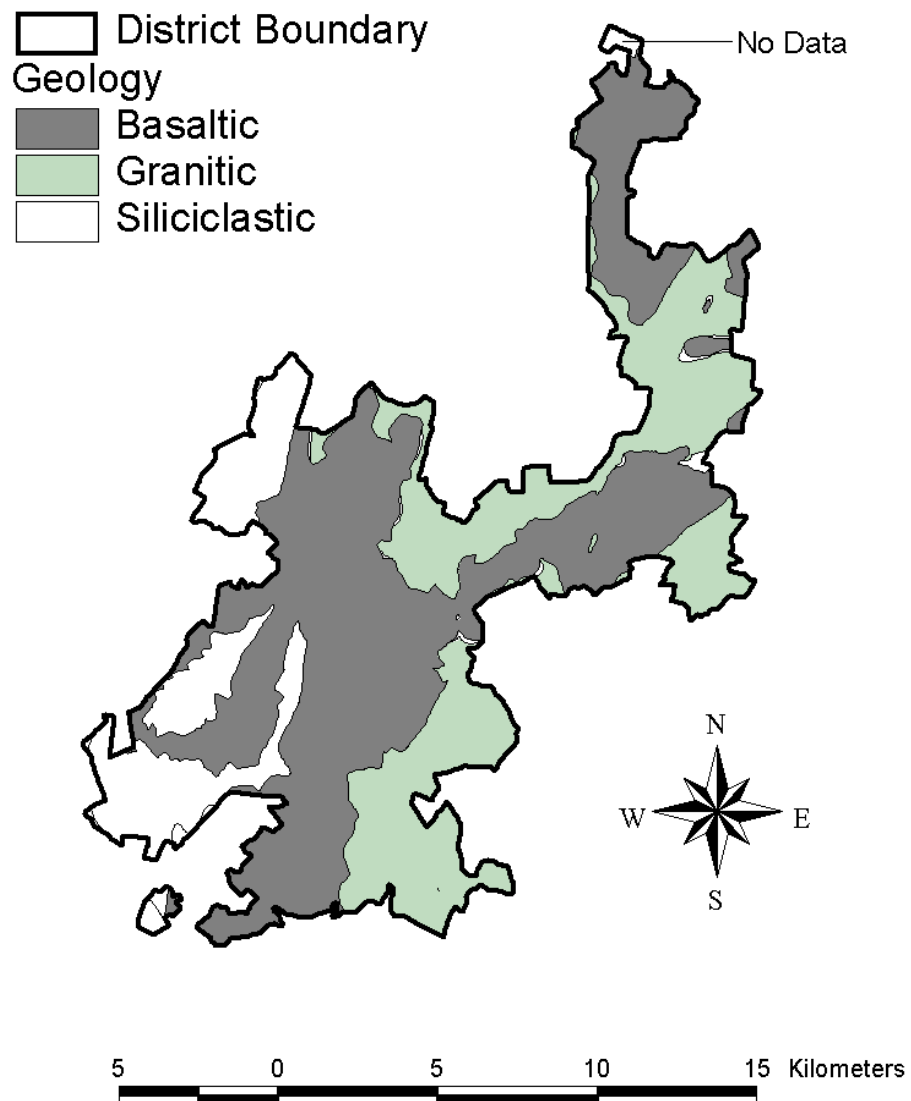


Figure 5. Geologic strata in the northern district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program.

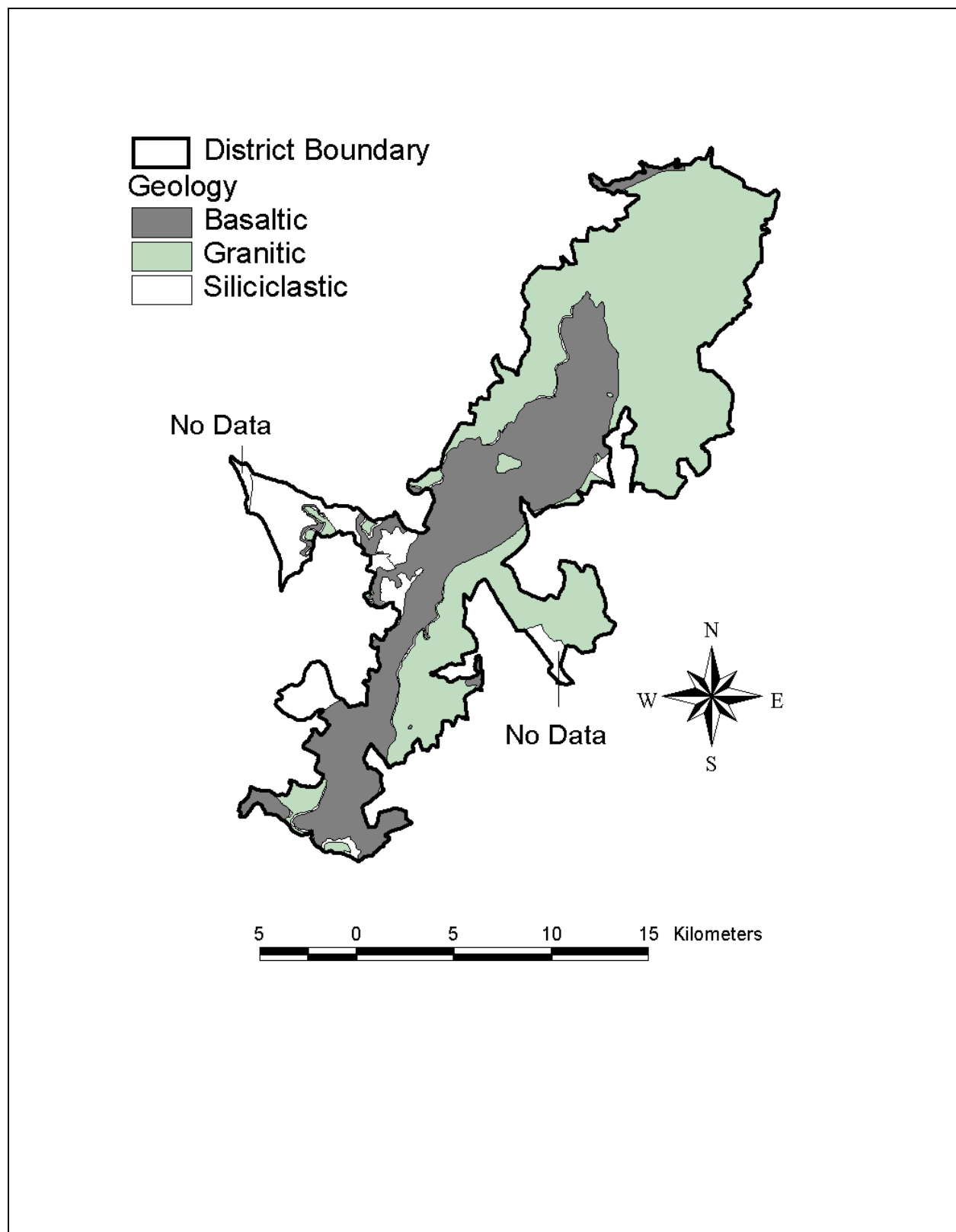


Figure 6. Geologic strata in the central district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program.

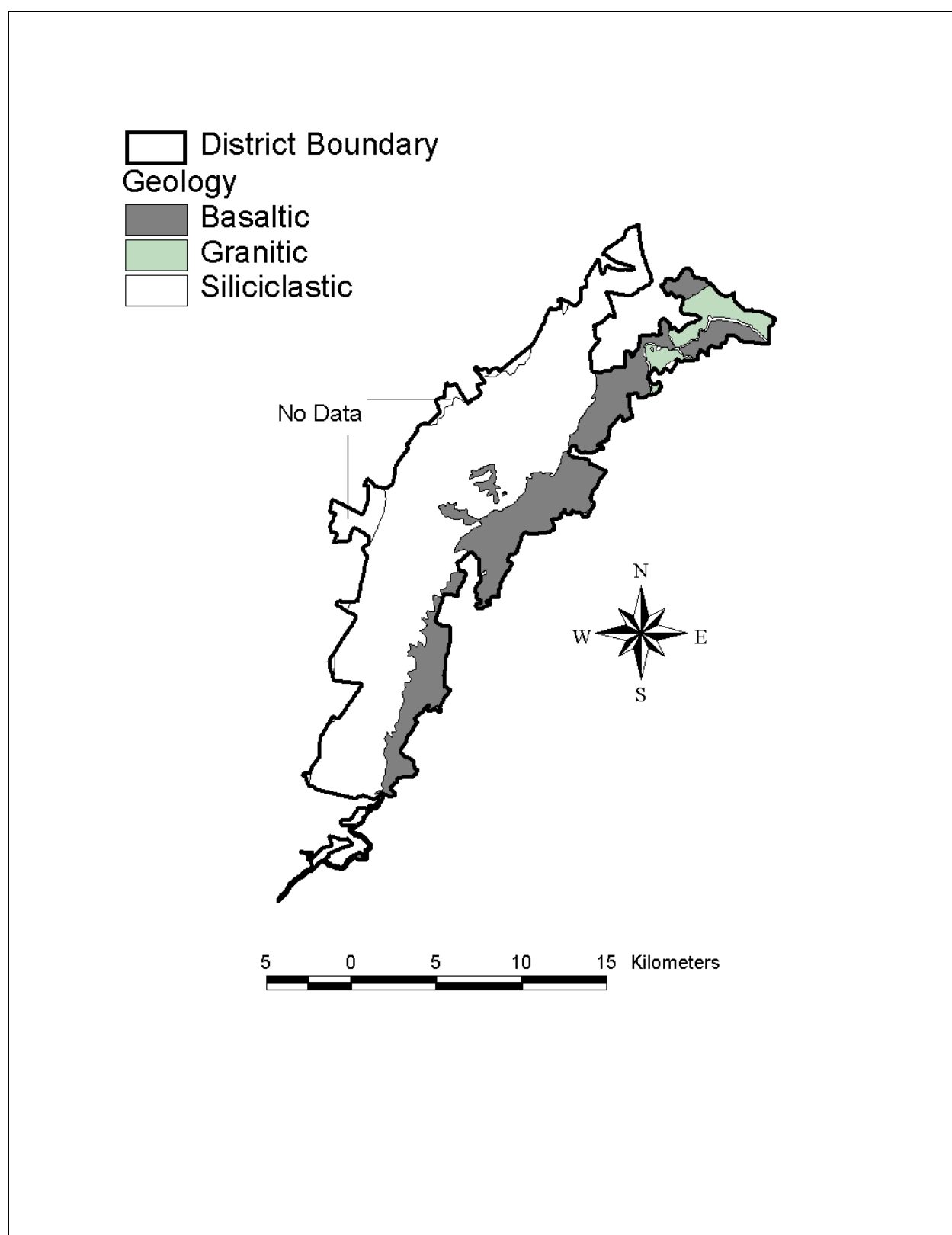


Figure 7. Geologic strata in the southern district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program.

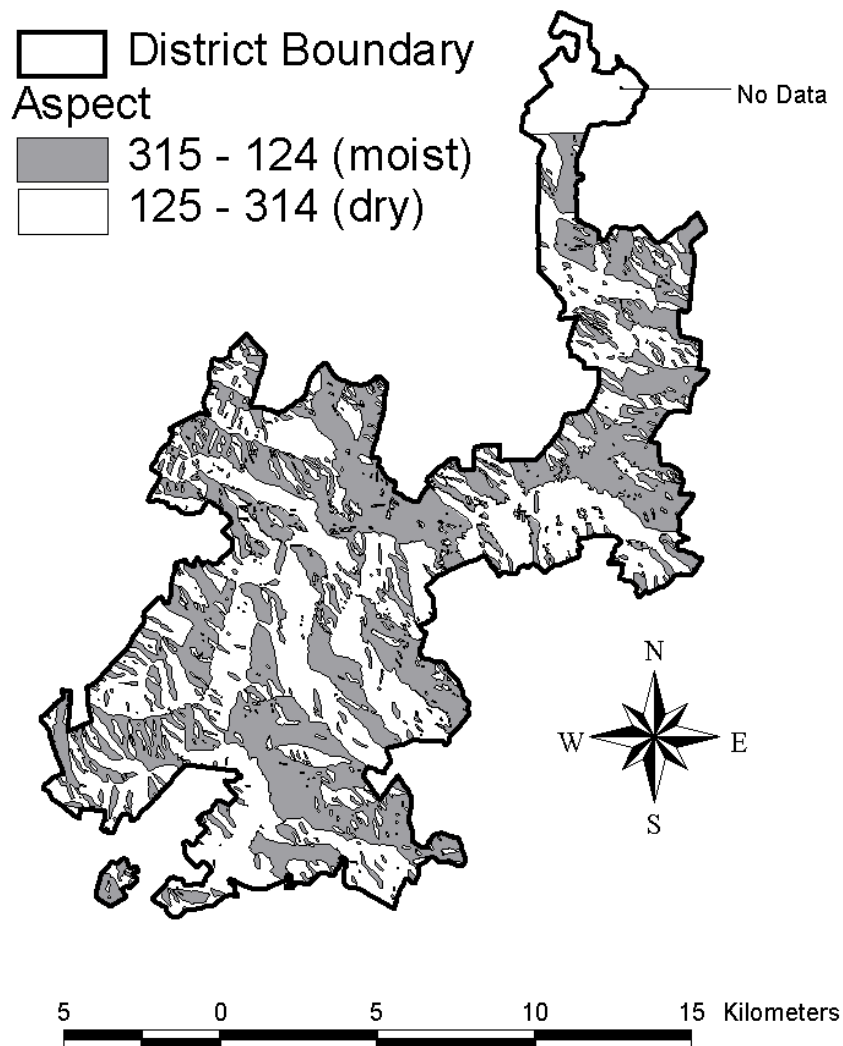


Figure 8. Aspect (NE = 315 - 124 degrees, SW = 125 - 314) in the northern district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program.

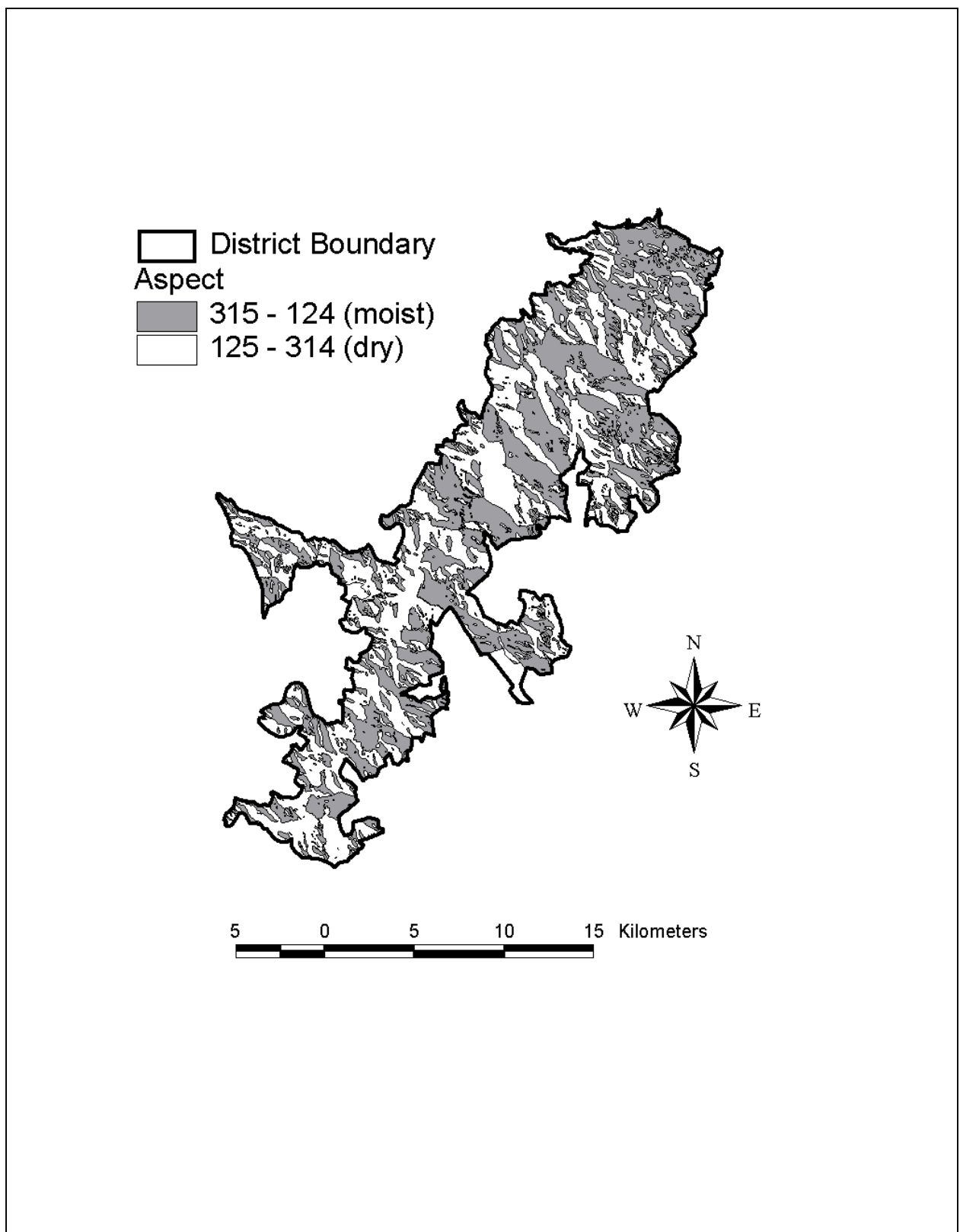


Figure 9. Aspect (NE = 315 - 124 degrees, SW = 125 - 314) in the central district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program.

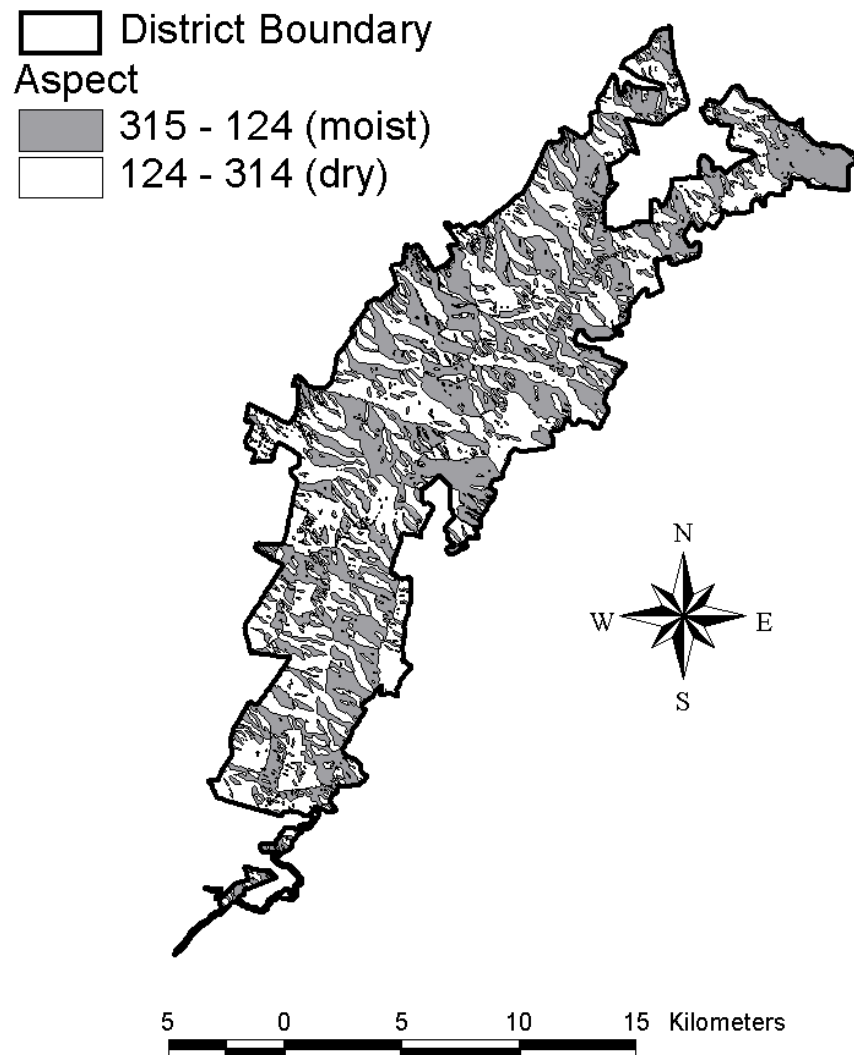


Figure 10. Aspect (NE = 315 - 124 degrees, SW = 125 - 314) in the southern district of Shenandoah National Park (SNP), one of three classification strata used to stratify vegetation sampling plots for a long-term vegetation monitoring program.

Table 2. Area (ha) of geologic, aspect, and elevation strata cross-classified to stratify plot selection for long-term vegetation monitoring at Shenandoah National Park, 2003.

Geology	Strata		Area (ha)
	Aspect ^a	Elevation (m)	
Basaltic	NE	0–609	3,733.6
Basaltic	NE	610–914	6,662.2
Basaltic	NE	915–1,144	2,453.5
Basaltic	NE	>1,144 ^b	48.3
Basaltic	SW	0–609	4,139.8
Basaltic	SW	610–914	8,351.2
Basaltic	SW	915–1,144	2,798.6
Basaltic	SW	>1,144 ^b	70.7
Granitic	NE	0–609	5,669.0
Granitic	NE	610–914	6,470.5
Granitic	NE	915–1,144	1,264.5
Granitic	NE	>1,144 ^b	9.4
Granitic	SW	0–609	4,934.1
Granitic	SW	610–914	5,602.3
Granitic	SW	915–1,144	1,293.1
Granitic	SW	>1,144 ^b	6.0
Siliciclastic	NE	0–609	4,867.8
Siliciclastic	NE	610–1,114	5,179.0
Siliciclastic	NE	>1,144 ^b	4.2
Siliciclastic	SW	0–609	6,027.2
Siliciclastic	SW	610–1,114	6,200.6
Siliciclastic	SW	>1,144 ^b	3.3

^a Northeast = 315–124 degrees, southwest = 125–314 degrees.

^b Elevations >1,144 meters were excluded from plot selection criteria.

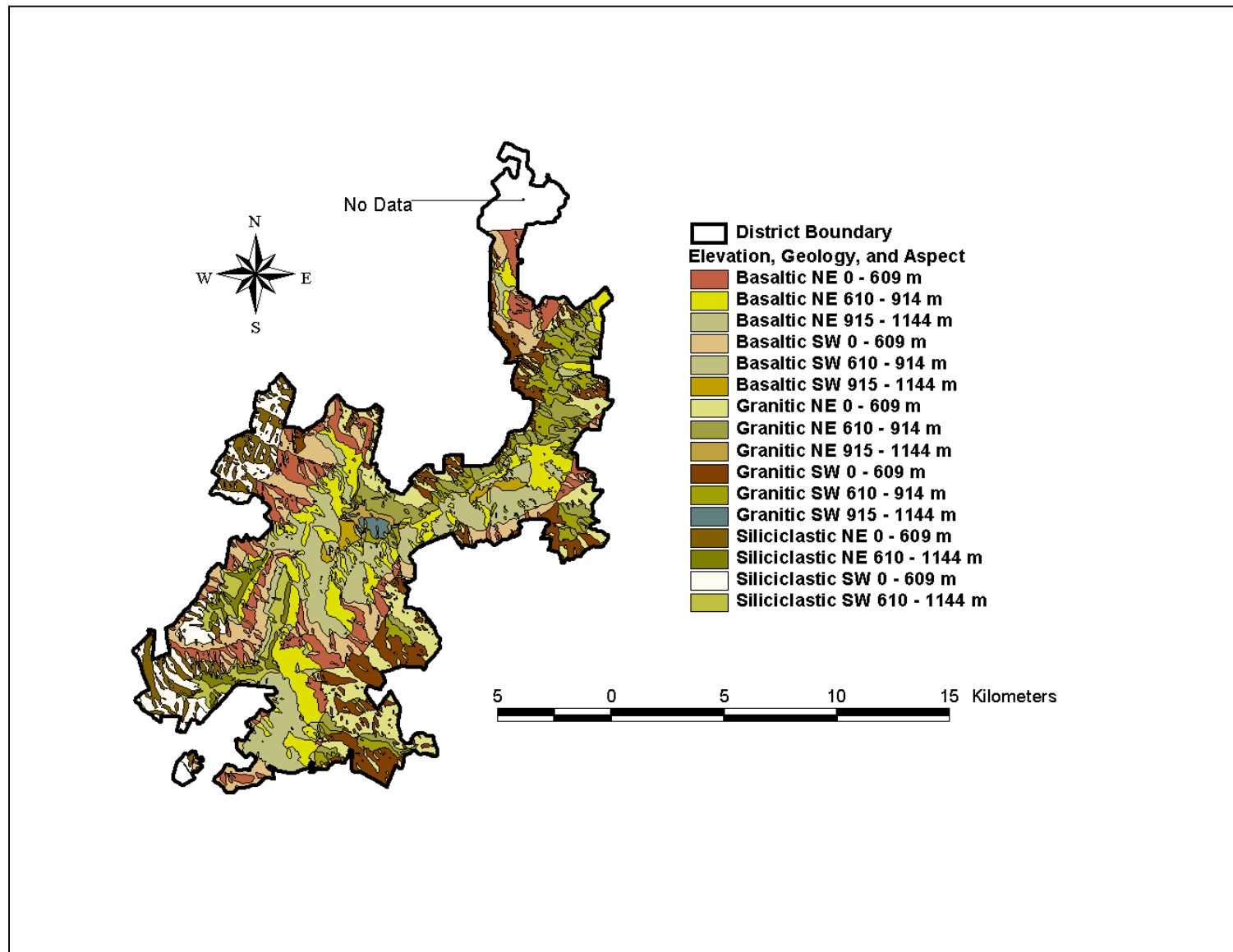


Figure 11. Cross-classification of geology, aspect, and elevation strata in the northern district of Shenandoah National Park (SNP), 2003.

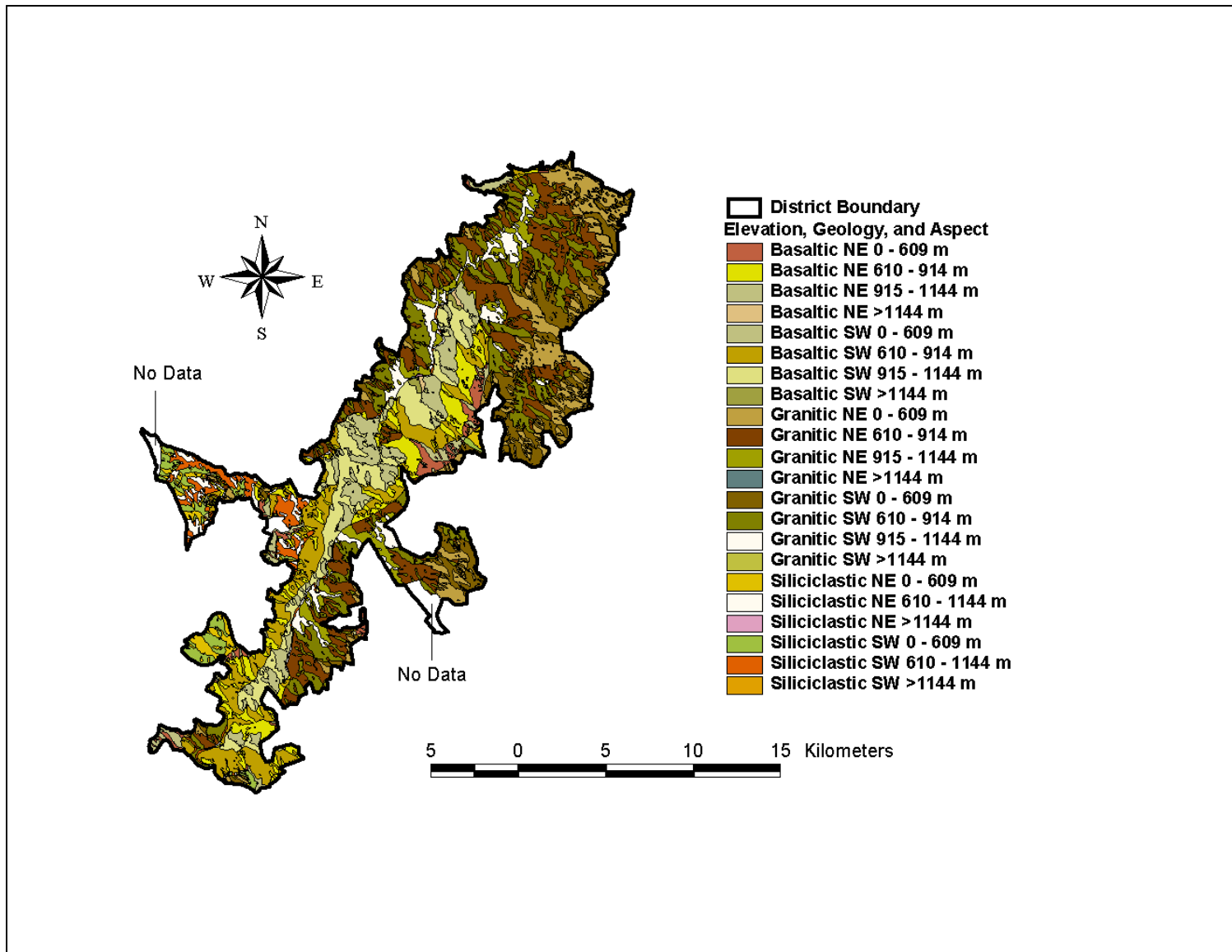


Figure 12. Cross-classification of geology, aspect, and elevation strata in the central district of Shenandoah National Park (SNP), 2003.

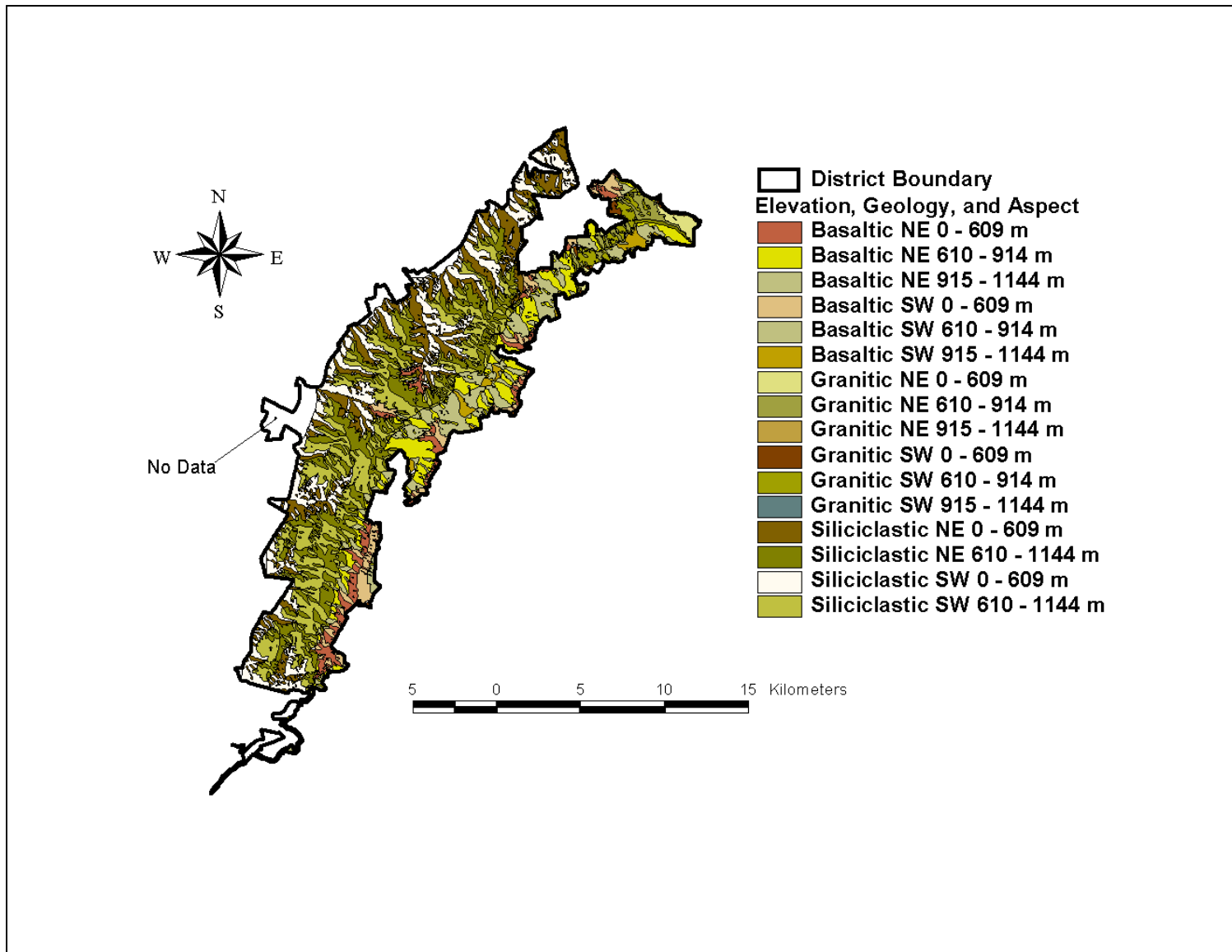


Figure 13. Cross-classification of geology, aspect, and elevation strata in the southern district of Shenandoah National Park (SNP), 2003.

Geology, SNP boundary, and road data were obtained from NPS Geography and Mapping Technologies (http://www.nps.gov/gis/park_gisdata/virginia/shen.htm). John Young (U.S. Geological Survey, Leetown Science Center, Aquatic Ecology Laboratory) provided elevation and aspect data in 10-m grid-cell resolution. Alan Williams (Ecologist and Data Manager, SNP) and Wendy Cass (Botanist, SNP) provided spatial and attribute information for existing LTEM plots. Aspect and elevation grids were transformed to polygon themes to permit spatial merges among aspect, elevation, and geology themes. Majority filters and neighborhood statistics were used to eliminate small patches of cells in the aspect stratum. All data were manipulated in North American Land Datum of 1927.

Power Analysis

We re-classified 103 existing plots into the 16 new strata which we used to calculate estimates of the mean and variance for various species and size classes (shrub-sapling and trees) under the new sampling design. Tables 3 – 5 provide estimates of the mean and standard deviation, by stratum, of basal area of trees and stem density of shrubs and saplings for selected species. These tables should be interpreted with caution because the plots were selected under a different method of stratification and sample sizes within strata are generally small; however, they are the only available data upon which to optimize a sampling design.

Six strata contained only 2–4 plots, five strata contained 5–7 plots, four strata contained 8–10 plots, and only one strata contained 14 plots (Tables 3 – 5). Bryan F. J. Manly (Statistician, West, Inc.; Appendix A) recommended that a resampling approach with pilot data be used to evaluate the statistical power of various sampling designs, with which we concurred. However, sample sizes of pilot data were too small so we modeled the data as distributed under a gamma distribution. We used a random generating function (RANGAM in software SAS, Statistical Analysis System, Inc., Cary, North Carolina) with the scale parameter, β , defined as the variance divided by the mean and the shape parameter, α , defined as the squared mean divided by the variance. This parameterization of the gamma distribution provided an asymmetric distribution (right-skewed) from which to draw samples with the same mean and variance as the pilot data.

For the power analysis, we investigated the precision of basal area and stem densities for the species listed in Tables 3 – 5 under sampling designs in which the sample sizes were 100, 140, 180, 220, and 260 plots. Plots were allocated among strata in proportion to strata areas. For each species, we created 999 datasets and calculated park-wide means, SE, and CV for each sample size (100 – 260 plots). We used standard formulae for calculating means and variances (Cochran 1977) and Satterthwaite degrees of freedom (Appendix B).

We did not estimate statistical power ($1 - \beta$) to detect specific changes in basal area and stem density for several reasons. First, we relied on existing data to make inferences regarding effect size (means) and variability (SD) of data for the species being monitored and these data were limited by small sample sizes and were obtained under a different

Table 3. Mean and SD of basal area (m²/ha) for selected tree species in Shenandoah National Park, 1987-2000, based on 103 plots originally stratified by forest vegetation type and re-organized into strata based on geology, elevation, and aspect.

Stratum ^a	n ^b	Black Birch		Virginia Pine Pitch Pine		All Red Oaks		All White Oaks		All Oaks		Northern Red Oak		Red Maple	
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
B-H-SW	10	0.7	1.11	0.5	1.48	6.3	7.76	2.5	4.94	9.5	11.97	6.3	7.76	0.5	1.19
B-H-NE	6	0.5	0.89	0.1	0.18	9.9	9.56	4.4	5.59	14.5	8.97	9.9	9.56	0.2	0.67
B-M-SW	14	0.2	0.52	0.0		4.1	6.07	6.5	7.90	9.7	10.49	3.8	5.74	1.9	2.42
B-M-NE	10	3.1	4.04	1.9	3.44	3.6	5.14	4.7	9.03	8.3	10.81	3.6	5.15	1.2	1.62
B-L-SW	7	0.2	0.32	2.1	5.41	3.2	2.95	9.0	11.07	12.6	12.09	2.4	2.94	0.7	0.90
B-L-NE	6	1.2	1.91	0.6	1.45	2.9	4.42	0.0		2.8	4.42	2.8	4.42	3.3	
G-H-SW	2	1.7	2.40	0.0		21.5	2.19	0.0		21.5	2.19	21.5	2.19	0.1	0.04
G-H-NE	4	0.3	0.53	0.0		10.1	12.30	5.9	11.47	16.0	13.15	10.1	12.30	0.0	
G-M-SW	4	0.6	0.72	5.2	10.46	2.4	2.89	13.6	12.35	16.1	12.16	0.9	1.45	3.1	4.09
G-M-NE	10	0.7	1.09	0.0		1.9	3.32	3.8	7.36	6.7	10.42	1.8	3.34	2.0	2.19
G-L-SW	5	0.1	0.04	0.3	0.59	2.2	2.72	11.1	14.91	12.2	14.01	2.2	2.72	0.2	1.07
G-L-NE	8	3.2	2.47	0.5	1.04	1.8	2.95	3.8	6.14	3.3	5.44	1.8	2.95	2.8	5.19
S-M-SW	3	0.0		11.7	8.67	1.1	1.10	2.2	3.05	3.3	3.94	0.4	0.70	0.5	0.99
S-M-M	3	0.0	0.04	1.9	3.29	7.7	7.41	3.8	4.12	11.6	10.06	6.1	7.72	0.4	0.70
S-L-SW	7	0.0		9.1	15.35	3.8	3.93	3.0	3.14	6.9	6.63	0.6	0.84	1.6	2.27
S-L-NE	4	0.0		5.7	7.87	4.9	2.70	12.5	7.33	17.5	6.42	2.5	3.80	0.6	0.64
All ^c	103	0.9	0.16	1.9	0.53	4.5	0.56	5.3	0.78	9.7	0.98	4.0	0.54	1.5	0.23

^a Stratum definitions: geology (B = basaltic, G = granitic, S = siliciclastic), elevation (H = high, M = middle, L = low), aspect (NE = 315–124 degrees, SW = 125–314 degrees).

^b Statistics for All strata ($n = 103$) are the mean and SE.

Table 4. Mean and SD of stem density (stems/ha; 1–5 m tall) for tree-of-heaven (*Ailanthus altissima*), mountain laurel (*Kalmia latifolia*), spicebush (*Lindera benzoin*), and sassafras (*Sassafras albidum*) in Shenandoah National Park, 1987-2000, based on 103 plots originally stratified by forest vegetation type and re-organized into strata based on geology, elevation, and aspect.

Stratum ^a	<i>n</i> ^b	Tree-of-heaven		Mountain Laurel		Spicebush		Sassafras	
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
B-H-SW	10	0.00		0.00		0.00		0.00	
B-H-NE	6	0.00		0.00		0.00		0.00	
B-M-SW	14	357.14	874.54	19.84	74.24	3670.63	6203.82	59.52	118.28
B-M-NE	10	0.00		83.33	263.52	861.11	1768.74	83.33	263.52
B-L-SW	7	79.37	209.98	39.68	104.99	2500.00	3908.68	119.05	148.48
B-L-NE	6	5,138.89	9,984.17	0.00		10879.63	22322.29	46.30	113.40
G-H-SW	2	0.00		3,472.22	4,910.46	0.00		0.00	
G-H-NE	4	0.00		17,638.89	35,277.78	138.89	277.78	416.67	833.33
G-M-SW	4	694.44	1,388.89	9,791.67	10,171.81	1875.00	3750.00	972.22	1,312.73
G-M-NE	10	194.44	614.89	2,138.89	4,027.62	7638.89	12227.31	1,055.56	1,941.36
G-L-SW	5	111.11	248.45	1,166.67	2,608.75	1111.11	1495.88	1,388.89	1,257.69
G-L-NE	8	520.83	1,033.37	1,597.22	3,272.43	8333.33	12083.45	277.78	514.34
S-M-SW	3	0.00		30,185.19	25,694.57	0.00		740.74	1,051.65
S-M-NE	3	0.00		28,518.52	36,346.81	0.00		2,129.63	2,009.49
S-L-SW	7	0.00		6,984.13	8,108.75	0.00		1,349.21	1,267.15
S-L-NE	4	0.00		2,013.89	3,494.37	0.00		1,319.44	1,048.59
All ^b	103	444.98	243.38	3,797.20	1,070.40	2907.23	775.92	498.92	91.83

^a Stratum definitions: geology (B = basaltic, G = granitic, S = siliciclastic), elevation (L = 0 – 609 m, M = 610 – 914 m, H = 915 – 1144 m), aspect (NE = 315–124 degrees, SW = 125–314 degrees).

^b *n* = number of plots.

^c Statistics for All strata (*n* = 103) are the mean and SE.

Table 5. Mean and SD of stem density (stems/ha; 1–5 m tall) for flowering dogwood (*Cornus florida*), ash (*Fraxinus* spp.), and *Rubus* species in Shenandoah National Park, 1987-2000, based on 103 plots originally stratified by forest vegetation type and re-organized into strata based on geology, elevation, and aspect.

Stratum ^a	n ^b	Flowering Dogwood		Ash		<i>Rubus</i> spp.	
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
B-H-SW	10	27.78	87.84	277.78	320.75	500.00	1,086.14
B-H-NE	6	0.00		231.48	567.01	138.89	340.21
B-M-SW	14	337.30	535.74	873.02	1,655.44	12,718.25	40,408.67
B-M-NE	10	55.56	117.12	916.67	1,587.90	1,861.11	4,111.88
B-L-SW	7	2,738.10	3,399.91	238.10	191.68	1,150.79	3,044.71
B-L-NE	6	1,296.30	1,334.10	138.89	232.41	1,111.11	2,459.55
G-H-SW	2	0.00		277.78	392.84	138.89	196.42
G-H-NE	4	0.00		0.00		27,777.78	55,555.56
G-M-SW	4	69.44	138.89	0.00		69.44	138.89
G-M-NE	10	166.67	374.97	388.89	819.85	611.11	1,124.91
G-L-SW	5	1,444.44	2,146.27	611.11	534.32	0.00	
G-L-NE	8	277.78	257.17	69.44	196.42	2,743.06	7,758.53
S-M-SW	3	0.00		0.00		0.00	
S-M-NE	3	185.19	160.38	0.00		42,500.00	73,612.16
S-L-SW	7	1,746.03	2,569.58	0.00		515.87	1,364.87
S-L-NE	4	69.44	138.89	0.00		0.00	
All ^c	103	552.86	125.46	350.59	84.51	4,738.40	2,217.42

^a Stratum definitions: bedrock geology (B = basaltic, G = granitic, S = siliciclastic), elevation (L = 0 – 609 m, M = 610 – 914 m, H = 915 – 1144 m), aspect (NE = 315–124 degrees, SW = 125–314 degrees).

^b n = number of plots.

^c Statistics for All strata (n = 103) are the mean and SE.

sampling design. Second, the decision to select the total number of plots under the new sampling design had to consider changes being implemented in the sampling protocols, future staff availability, and the logistics of visiting a given number of plots each summer. Third, we could compare the sample size (Satterthwaite df) versus precision (e.g., CV) of results of Diefenbach and Mahan (2002) to assess whether the sample sizes in this power analysis would provide reasonable power to detect changes as specified in established monitoring objectives (Diefenbach and Mahan 2002). Given the data available, an assessment of the estimated precision of resulting estimates of basal area and stem density, in conjunction with logistical issues, is a reasonable approach to choosing sample sizes that are likely to provide useful parameter estimates as well as be logistically feasible to accomplish in the field.

Results of Simulations

Estimates of basal area for black birch, Virginia and pitch pine, red maple, northern red oak, and groups of oak species all had CVs < 20% for sample sizes ≥ 100 plots (Tables 6 and 7). Sample sizes of 140 – 180 plots produced CVs of 10 – 15%.

As expected, CVs of stem density were greater than for basal area, but were <40% for all species examined for sample sizes ≥ 100 plots (Tables 8 and 9). Sample sizes of 140 – 180 plots produced CVs of 11 – 35%.

Under the existing sampling design, the mean Satterthwaite degrees of freedom (df) was approximately 4.0 for all species for both basal area and stem density estimates (Diefenbach and Mahan 2002:24). Based on this sample size, Diefenbach and Mahan (2002) estimated statistical power was approximately 80% to detect a mean change in basal area of 5 m²/ha ($\alpha = 0.20$). The mean Satterthwaite df for the proposed sampling design was >16 for all species and sample sizes (Tables 7 and 8), which should result in >80% power to detect even small changes in basal area (<2 m²/ha).

For stem density, only changes of 1,000 – 2,000 stems/ha were expected to have >80% chance of being detected ($\alpha = 0.20$, Satterthwaite df = 4) under the existing sampling design. Tables 8 and 9 indicate Satterthwaite df > 8 for the proposed sampling design for all species and sample sizes ≥ 100 plots, which should result in >80% power to detect changes in stem density of 300 – 400 stems/ha.

Table 6. Simulated mean basal area (m^2/ha), Satterthwaite degrees of freedom (df), and CV for black birch (*Betula lenta*), Virginia (*Pinus virginiana*) and pitch pine (*P. rigida*), and red maple (*Acer rubrum*) under different sample sizes in a stratified random sampling design. Parameters were simulated using 999 replications based on empirical data collected in Shenandoah National Park, 1987-2000.

Sample size	Black birch			Virginia and pitch pine			Red maple		
	$\bar{x}$	df	CV	$\bar{x}$	df	CV	$\bar{x}$	df	CV
100	0.78	16.1	18.7	2.90	18.4	19.8	1.48	27.0	15.1
140	0.78	26.1	15.8	2.92	28.4	17.2	1.50	41.3	13.0
180	0.80	31.8	14.5	2.91	38.6	15.1	1.49	56.1	11.5
220	0.79	41.6	13.0	2.93	49.8	13.8	1.48	69.5	10.4
260	0.78	51.6	11.9	2.91	60.1	12.9	1.50	86.3	9.6

Table 7. Simulated mean basal area (m^2/ha), Satterthwaite degrees of freedom (df), and CV for northern red oak (*Quercus rubra*) and various groups of oak tree species under different sample sizes in a stratified random sampling design. Parameters were simulated using 999 replications based on empirical data collected in Shenandoah National Park, 1987-2000.

Sample size	Northern red oak			Red oak species			White oak species			All oak species		
	$\bar{x}$	df	CV	$\bar{x}$	df	CV	$\bar{x}$	df	CV	$\bar{x}$	df	CV
100	3.34	20.0	13.9	4.90	26.0	12.5	5.73	28.2	13.4	9.68	36.2	9.8
140	3.36	31.2	12.0	4.95	39.4	10.8	5.81	43.5	11.5	9.65	54.6	8.4
180	3.33	45.9	10.6	4.92	57.7	9.5	5.77	62.8	10.1	9.65	83.2	7.3
220	3.34	60.1	9.6	4.92	76.6	8.6	5.78	82.5	9.1	9.66	110.8	6.6
260	3.34	78.1	8.7	4.92	95.6	7.9	5.78	101.7	8.5	9.66	138.1	6.1

Table 8. Simulated mean stem density (stems/ha; 1–5 m tall), Satterthwaite degrees of freedom (df), and CV for tree-of-heaven (*Ailanthus altissima*), mountain laurel (*Kalmia latifolia*), spicebush (*Lindera benzoin*), and sassafras (*Sassafras albidum*) under different sample sizes in a stratified random sampling design. Parameters were simulated using 999 replications based on empirical data collected in Shenandoah National Park, 1987-2000.

Sample size	Tree-of-heaven			Mountain Laurel			Spicebush			Sassafras		
	$\bar{x}$	df	CV	$\bar{x}$	df	CV	$\bar{x}$	df	CV	$\bar{x}$	df	CV
100	410	8.6	39.5	6746	13.6	18.7	2655	16.2	24.8	692	25.1	15.0
140	407	11.4	35.5	6743	19.3	16.3	2652	23.4	21.8	693	38.2	12.9
180	403	14.0	32.9	6699	26.3	14.5	2607	32.5	19.3	689	56.0	11.3
220	404	16.5	30.4	6804	33.8	13.1	2623	40.7	17.5	694	72.1	10.3
260	409	19.7	28.8	6809	41.1	12.2	2670	48.4	16.5	692	87.9	9.5

Table 9. Simulated mean stem density (stems/ha; 1–5 m tall), Satterthwaite degrees of freedom (df), and CV for flowering dogwood (*Cornus florida*), ash species (*Fraxinus* spp.), and *Rubus* species under different sample sizes in a stratified random sampling design. Parameters were simulated using 999 replications based on empirical data collected in Shenandoah National Park, 1987-2000.

Sample size	Flowering Dogwood			Ash spp.			<i>Rubus</i> spp.		
	Stem density	df	CV	Stem density	df	CV	Stem density	df	CV
100	516	12.2	21.7	305	19.8	24.3	5548	10.7	38.0
140	520	19.9	18.7	307	29.7	20.9	5578	14.8	34.2
180	521	27.4	16.6	304	39.5	18.8	5579	20.4	30.6
220	520	34.3	15.2	304	49.0	17.3	5629	26.6	27.9
260	521	41.4	14.0	303	60.8	15.9	5585	33.7	26.0

Conclusions and Recommendations

Based upon the recommendations of Diefenbach and Mahan (2002) and the findings of this study, the following changes to the vegetation monitoring program at SNP have been adopted:

1. Each sample site will consist of a single plot, 24 m × 24 m, demarcated by four corner stakes, to record tree species and diameter at breast height (dbh), and coverage of ground cover, target exotic species, and herbs. The plot size will be corrected for slope. Along two sides will be a 2 m × 24 m strip transect for sampling shrub stem density, and a 1 m × 12 m strip transect for sampling seedling density.
2. Trees will be permanently marked to reduce data collection errors and provide more consistent dbh measurements.
3. Strata will be defined by elevation, geology, and aspect (Table 2) in 16 categories.
4. All statistical objectives for basal area and stem density will be retained (Diefenbach and Mahan 2002), but the objectives for stem densities of seedling species will be eliminated because of the inability to detect biologically important changes. Instead seedling data will continue to be collected in a quantitative manner (1 m × 12 m strip transect; see #1 above), because data collection will be more consistent than qualitative assessments of abundance, but will not be expected to provide statistically precise results.
5. A stratified random sampling design will be used to estimate basal area of tree species and stem density of sapling and shrub species. Samples will be allocated among strata proportional to the area of each stratum. Appendix B provides the formulae necessary to calculate means, totals, and corresponding variances (and other measures of precision, e.g., CIs).
6. Plot centers selected will be ≥40 m from an established trail, ≥50 m from any administrative road or park boundary, ≥100 m from Skyline Drive and any developed area, and have a slope <26.5 degrees. If upon actual visitation to a selected plot location these criteria are not met the site will not be incorporated into the sampling design and another randomly-selected site will be used.
7. The sampling effort will require two years to visit all plots (i.e., interpenetrating sampling). A total of 160 plots (80/yr) was decided upon as being logistically feasible and providing sufficient precision (Tables 6 – 9). Appendix C provides plots included in the new sampling design. In addition, this appendix includes extra plots in case some selected plots are not acceptable (e.g., too steep).

During summer 2003, fieldwork was begun to collect data under this new sampling design. Because of unusually wet weather and the additional time and effort involved in establishing new sampling plots (i.e., locating the plot, plot boundary, and installing corner markers), it will likely take >2 years to visit all 160 plots for the first time. However, once all plots are installed, it should be possible to visit all 160 plots within a two-year time interval (W. Cass, personal communication).

We strongly recommend that, upon initial completion of all 160 plots, data be analyzed to estimate basal area and stem density for at least the species analyzed in Diefenbach and Mahan (2002). This would indicate if the simulations presented in this report are reasonable and whether the selected sample size and sampling design will provide the desired precision of estimates of basal area and stem density.

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Appendix A

Memo Summarizing Reviewer Comments for Revised Sampling Design for Vegetation Monitoring in Shenandoah National Park



TO: John Karish, National Park Service
Wendy Cass, Shenandoah National Park

FROM: Duane R. Diefenbach, Assistant Unit Leader

SUBJECT: Summary of Reviewer Comments and Decisions for Shenandoah's
Revised Sampling Design for Vegetation Monitoring

DATE: January 31, 2003

On 30 January 2003, John Karish, Wendy Cass, and Duane Diefenbach met to discuss reviewer comments regarding proposed changes to the Vegetation and Inventory Monitoring Program at Shenandoah National Park. The purpose of this memo is to summarize the comments of reviewers and explain why we decided to incorporate recommendations into the proposed sampling re-design. The following people provided comments:

- Dr. Mike Jenkins, Ecologist, Great Smokey Mountains National Park
- Dr. Jeffrey S. Hatfield, Statistician, U.S. Geological Survey, Patuxent Wildlife Research Center
- Sylvia Haultain, Plant Ecologist, Sequoia and Kings Canyon National Parks
- Dr. Peggy Moore, Ecologist, U.S. Geological Survey, WERC, Yosemite Field Station
- Dr. Paul Geissler, Statistician, U.S. Geological Survey, Coordinator of the National Park Monitoring Project
- Dr. Bryan F. J. Manly, Statistician, University of Wyoming and Western EcoSystems Technology

The comments received from reviewers included comments about the vegetation data to be sampled as well as the sampling design. This memo will only address those comments directly related to statistical issues of the sampling design.

Review from Dr. Mike Jenkins

Below is a summary of the recommendations and comments provided (in bold) and our response:

- **Use a standardized protocol to enhance the comparability of SNP data to other inventory programs (e.g., USDA FIA program).**

I have interpreted that Dr. Jenkins' comments regarding a standardized sampling protocol refer to the methods of data collection at the sampling plot, and thus are not directly related to the statistical sampling design. Wendy Cass will be investigating these suggestions

- **Continue to collect seedling data because regeneration issues are early warning signs of future problems for the forest.**

We discussed the issue of collecting regeneration data, especially because other reviewers commented on this topic, and concluded that obtaining quantitative data is not possible. The Diefenbach and Mahan (2002) report analyzed statistical power to detect changes using seedling counts from plots 2-m² in size. Additional effort is not possible given time, personnel, and funding constraints, and thus the value of seedling stem densities is doubtful. Instead, the sampling protocol will record abundance rankings (e.g., trace, <5%, 5-25%, >25-75%, >75%) of selected species.

- **Classify trees and saplings/shrubs according to diameter at breast height (dbh) rather than height.**

The revised protocols likely will have revised classifications for seedlings, saplings/shrubs, and trees so they are defined on a height and dbh basis. For example, seedlings will be ≤1.5 m tall, small saplings will be >1.5 m tall and <1.4 cm in dbh, large saplings will be >1.5 m tall and >1.4-11.4 cm in dbh, and trees will be >11.4 cm dbh. I will attempt to subdivide existing shrub, sapling, and tree data into these categories when conducting power analyses for the new sampling design. This change should streamline the data collection process because determining height (for the 5 m cutoff) is time consuming.

- **Agreed that the proposed strata (bedrock, elevation, and aspect) were reasonable.**

The general consensus of reviewers was that the new strata are reasonable.

- **Recommended ensuring that some sampling plots were located in spatially-small but biologically important habitats.**

NPS staff decided that monitoring of biologically important habitats would best be accomplished via independent sampling efforts. For example, Big Meadow and hemlock stands are already monitored with separate inventory and monitoring protocols.

- **Suggested that the sampling design needs to be flexible, because, for example, certain plots may need to be sampled because of immediate concerns regardless of the sampling protocol.**

The consensus of NPS staff was that the purpose of the long-term monitoring program was to detect issues of special concern (e.g., vegetation mortality caused by disease or insect irruptions). If additional sampling were required to obtain more detailed information (e.g., regarding an insect outbreak), it would have to be in addition to long-term monitoring efforts. Otherwise, the ability of the monitoring program to provide comparable data over time could be compromised.

Review from Dr. Jeffrey S. Hatfield

The concern expressed by Dr. Hatfield was whether the interpenetrating sampling would complicate analyses because of missing values. For example, if 80 plots were visited in Year 1 and another 80 plots were visited in Year 2, year-to-year comparisons would be problematic. However, I do not believe this will be an issue if you simply analyze the data as if sampling intervals were two years long. That is, one would compare 2003-04 data with 2005-06 rather than 2003-04 or 2004-05. I believe this is a reasonable approach because changes in such parameters as dbh would be limited from year to year.

Although interpenetrating samples may not fully detect, for example, tree mortality caused by gypsy moth, a measure of tree mortality would be possible for a given year, and a more precise estimate could be obtained for any two-year period. I believe interpenetrating samples are the best compromise for increasing sample size under a constrained budget.

Review from Sylvia Haultain

Most of Sylvia Haultain's comments were directed more towards the vegetation sampling than the statistics design proposed. The focus of my report was on woody species because they are the only ones in which quantitative data are available, and for which explicit statistical objectives could be identified. Wendy Cass will be giving more thought about what to measure regarding herbaceous species.

Ms. Haultain recognized the benefit of using permanent strata, but was concerned about being able to make inferences regarding specific vegetation cover types. This issue was discussed, but because of the ephemeral nature of vegetation cover types (relative to the timeframe of the monitoring program), it is not practical to consider stratifying by cover type. Presently, USGS scientists with the Leetown Science Center are creating a vegetation cover map of the park. When this is completed, it may be possible to overlay this cover map and use post-stratification to obtain characteristics by cover type. In contrast, the previous sampling design had so many strata that few individual strata had enough samples within them to provide estimates with precision.

Review from Dr. Peggy Moore

Below is a summary of recommendations and comments provided (in bold) and our response:

- **Reducing the number of plots at a sampling site is reasonable.**
- **Eliminating the collection of quantitative information on seedling densities is warranted given the difficulty of obtaining sufficient sample sizes.**

Although we do not plan to collect quantitative data (i.e., stem densities), NPS staff still plan to collect abundance estimates (as described heretofore).

- **Was concerned about variances within the proposed strata – could pilot data be obtained?**

I plan to use data collected 1987-2000 data to assess the statistical power of the proposed sampling design and make recommendations for sample sizes (i.e., no. of plots).

- **Supported the proposal to use interpenetrating sampling to allocate sampling across years and increase effective sample size.**
- **Expressed reservations about a sampling with partial replacement (SPR) design because of the complexity. The complexity could complicate inferences and may become impractical given funding.**

This issue was discussed and it was decided to use a simpler sampling design with, at most, allocation of samples proportional to stratum area. One reason for this decision is that it was decided that request for trends in vegetation changes could occur for any number of possible methods of post-stratification. An SPR design would make it difficult to provide estimates based on post-stratification, or would at least require some samples to be excluded when estimating parameters of interest.

Review from Dr. Paul Geissler

Below is a summary of the recommendations and comments provided (in bold) and our response:

- **Suggested that we consider optimizing plot location with travel time, even though the plots would not necessarily be independent.**

The current plot layout places 3 plots adjacent to each other. We considered a multi-stage sampling design in which a cluster was selected and then within that cluster several plots may be located. The problem with this design is that the spatial distribution of plots is compromised. SNP staff believe that once plots are located on the park, the most efficient travel routes can be identified. Moreover, because of topography, plots located close in space do not necessarily have the least travel time between them. Thus, we concluded that a simple random sample of plots within strata was the best approach.

- **Recommended against changing strata, and to instead change the names because they no longer represented vegetation cover types.**

This idea was discussed, but was rejected primarily because the loss of comparability to 1987-2000 data because of redefined strata will be minimal. First, boundaries of the existing vegetation strata are not available in an accurate map. Thus, we cannot add new sampling points because we do not necessarily know where to put them in the correct stratum – all we know is in what stratum the existing plots were placed. Second, during 1987-2000 only a single vegetation cover type was visited each year. In the new sampling design we will obtain park-wide estimates for given parameters, but will not necessarily be able to directly compare them to estimates from 1987-2000 data because of the temporal sampling issues of the prior data. Third, some of the vegetation cover types from 1987-2000 no longer exist. Fourth, there were too many strata (approx. 72).

- **Supported the use of interpenetrating samples.**
- **Suggested that seedling data be collected qualitatively rather than quantitatively because information on forest regeneration is important for any forest monitoring program.**

This recommendation was accepted, and is discussed heretofore in this memo with respect to similar comments provided by Dr. Jenkins.

Review from Dr. Bryan F. J. Manly

Below is a summary of the recommendations and comments provided (in bold) and our response:

- **Agreed that the three 24 m x 24 m plots were not true replicates and that a single plot was appropriate.**
- **Supported the change of stratification.**
- **Recommended that at least 2 or 3 plots be located in each stratum.**

This likely will not be a problem because we anticipate that as many as 80 plots can be visited per summer, and that with an interpenetrating sampling design we could have as many as a 240 independent samples collected over a three year period. We do not expect that a minimum sample size per stratum will be necessary.

- **Warned that post-stratification may not be appropriate if sample allocation is stratified. Requiring a minimum sample size per stratum would further exacerbate this problem.**

This issue will be given further consideration and investigation. The strata were chosen because we know that bedrock, elevation, and aspect all are important factors that influence vegetation type; thus, these strata have the potential to reduce variability in the parameter estimates. Also, by using these strata we will ensure that sampling plots will be distributed across the park (i.e., provide ‘even’ spatial distribution of plots). Therefore, it is likely that despite the technical problems that arise when post-stratification is attempted using stratified data, the park will still employ a stratified sampling design for its long-term monitoring as well as use post-stratification to conduct retrospective analyses of changes in vegetation.

- **Supported interpenetrating sampling.**
- **Recommended using a bootstrap approach to assessing statistical power rather than relying on the assumption of some underlying distribution for the data.**

This suggestion will be used for the upcoming power analyses for making sample size recommendations.

Appendix B

Formulas to Estimate Means and Variances

The formulas used to estimate population means and totals are standard formulas that can be found in Cochran (1977) and Thompson (1992). However, we have not included finite population correction factors (fpc) in the calculation of variances because the fpc reduces the variance by approximately 0.2%, which would have a negligible effect on estimates of precision (i.e., SEs and CIs). In addition, eliminating the fpc greatly simplifies calculations.

The formulas in this appendix can be programmed in a spreadsheet quite easily, or developed in a statistical software package such as SAS (SAS, Inc., Cary, North Carolina). In addition, some software packages have canned procedures that provide stratified sampling estimates (e.g., PROC SURVEYMEANS in SAS). However, note that these canned packages will incorrectly calculate the fpc, although this introduced error will be negligible.

To estimate the population mean, the following formula (Cochran 1977:90-91) is used:

$$\hat{y} = \frac{1}{N} \sum_{h=1}^L N_h \sum_{i=1}^{n_h} \frac{y_{hi}}{n_h}$$

where N_h = number of hectares in stratum h , L = number of strata, y_{hi} = value for plot i in stratum h or the difference between time 1 and time 2 of plot i in stratum h (expressed on a per ha basis), n_h is the number of plots, and

$$N = \sum_{h=1}^L N_h.$$

To estimate the population variance of the mean, the following formula is used (Cochran 1977:95)

$$\hat{\text{var}}(\hat{y}) = \frac{1}{N^2} \sum_{h=1}^L N_h^2 \frac{s_h^2}{n_h}$$

where n_h = number of plots in stratum h and s_h^2 is the standard formula for a sample standard deviation

$$s_h^2 = \frac{1}{n_h - 1} \sum_{i=1}^{n_h} (y_{hi} - \hat{y}_h)^2.$$

The estimated standard errors are calculated as

$$SE = \sqrt{\hat{\text{var}}(\hat{y})}.$$

Population totals and their associated variances are calculated as

$$\hat{Y} = N \hat{\bar{y}}$$

$$\hat{\text{var}}(\hat{Y}) = N^2 \text{var}(\hat{\bar{y}}).$$

To calculate confidence intervals for population means, or totals for a difference (e.g., difference in basal area between time 1 and time 2), the following formula is used

$$\hat{\tau} \pm t_{\alpha/2, df} \sqrt{\hat{\text{var}}(\hat{\tau})}$$

where $\hat{\tau}$ represents the estimate of either the population mean ($\hat{\bar{y}}$) or total ($\hat{Y}$), the t -distribution is based on the upper $\alpha/2$ percentile, and the Satterthwaite degrees of freedom (df) are calculated as

$$\text{Satterthwaite } df = \left(\sum_{h=1}^L a_h s_h^2 \right)^2 / \left[\sum_{h=1}^L (a_h s_h^2)^2 / (n_h - 1) \right]$$

and

$$a_h = N_h (N_h - n_h) / n_h.$$

For estimates of population totals or means, in which the statistic of interest (e.g., basal area, stems/ha, etc.) was ≥ 0 , confidence intervals based on a log-normal distribution are calculated using the following formula (Burnham et al. 1987)

$$95\% \text{ CI} = [\hat{\tau} / C, \hat{\tau} C]$$

where

$$C = \exp \left\{ t_{\alpha/2, df} \sqrt{\ln \left(1 + \frac{\hat{\text{var}}(\hat{\tau})}{\hat{\tau}^2} \right)} \right\}.$$

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Appendix C

Description of Sampling Points

This appendix provides a summary of the status of plots after the 2003 field season. Fieldwork to collect data under the new sampling design was initiated in summer 2003. However, wet weather conditions delayed fieldwork and the additional work required to establish new sampling plots (locate the site, establish corner posts, etc.) was more time consuming than expected. Initial visits to all 160 plots likely will require three field seasons, but 160 plots visited every two years still is likely to be logistically possible (W. Cass, personal communication).

Table A1 provides a summary of plot characteristics (stratum, identification code, UTM coordinates from Zone 17 North, sequence in which a plot is to be visited, and sample size by stratum). Also, additional sample locations are provided in case plots that have not yet been visited do not meet selection criteria. Sites sampled prior to December 2003 are noted.

The number of plots to be sampled were allocated among strata proportional to area. Whenever possible, we retained plots used in the previous sampling design (Diefenbach and Mahan 2002); however, existing plots had to meet selection criteria before they were eligible to be retained. Plot centers had to be ≥ 40 m from an established trail, ≥ 50 m from any administrative road or park boundary, ≥ 100 m from Skyline Drive and any developed area, and have a slope < 26.5 degrees. These same criteria were applied to all newly-selected plots.

Table A1. Visitation schedules and characteristics of long-term vegetation monitoring plots, Shenandoah National Park, 2003.

ELU Code ^a	Point ID	Easting ^b	Northing ^b	No. plots in stratum ^c	Year to Visit	Visited by December 2003?
B H NE	2L437-1-1	729026	4270194	5	1	yes
B H NE	2L110-3-1	729414	4275246	5	1	yes
B H NE	3L102-3-1	714078	4245934	5	2	no
B H NE	2L316-1-1	727606	4269141	5	2	no
B H NE	2L120-1-2	728546	4272625	5	2	no
B H NE	2L540-1-1	718943	4254580	5	extra	no
B H NE	2L528-1-1	725171	4266171	5	extra	no
B H NE	unassigned	719685	4255576	5	extra	no
B H NE	unassigned	723576	4264163	5	extra	no
B H NE	unassigned	721587	4264169	5	extra	no
B H NE	unassigned	724451	4265674	5	extra	no
B H NE	unassigned	723901	4267378	5	extra	no
B H NE	unassigned	727952	4268429	5	extra	no
B H NE	unassigned	728410	4271064	5	extra	no
B H NE	2L584-1-1	728682	4274294	5	extra	no
B H NE	unassigned	734964	4291964	5	extra	no
B H NE	unassigned	743374	4295372	5	extra	no
B H SW	2L103-2-1	723009	4267914	6	1	yes
B H SW	1L100-1-1	742787	4295139	6	1	yes
B H SW	3L117-1-1	713736	4245310	6	1	no
B H SW	2L431-1-1	728905	4273454	6	2	no
B H SW	3L552-1-1	700560	4232050	6	2	no
B H SW	3L104-0-c	703500	4235200	6	2	no
B H SW	3L545-1-1	713481	4245511	6	extra	no
B H SW	3L101-1-1	713958	4245513	6	extra	no
B H SW	2L116-0-c	722600	4263400	6	extra	no
B H SW	2L112-0-c	726700	4268900	6	extra	no
B H SW	3L604-1-1	703525	4234914	6	extra	no
B H SW	2L590-1-1	722524	4264280	6	extra	no
B H SW	unassigned	717294	4251933	6	extra	no
B H SW	unassigned	724248	4264419	6	extra	no
B H SW	unassigned	722110	4264907	6	extra	no
B H SW	unassigned	725663	4265780	6	extra	no
B H SW	unassigned	722484	4266560	6	extra	no
B H SW	unassigned	727519	4268486	6	extra	no
B H SW	unassigned	728288	4270356	6	extra	no
B H SW	unassigned	728335	4273566	6	extra	no
B H SW	unassigned	735994	4292687	6	extra	no
B L NE	3L114-3-1	711448	4248495	8	1	yes
B L NE	1L407-1-1	732979	4297292	8	1	yes

Table A1. Visitation schedules and characteristics of long-term vegetation monitoring plots, Shenandoah National Park, 2003 (continued).

ELU Code ^a	Point ID	Easting ^b	Northing ^b	No. plots in stratum ^c	Year to Visit	Visited by Nov. 2003?
B L NE	1L126-1-2	745110	4303061	8	1	yes
B L NE	1L409-1-1	733223	4296209	8	1	no
B L NE	3L121-0-c	695520	4221500	8	2	no
B L NE	3L111-0-c	701650	4233600	8	2	no
B L NE	1L569-1-1	731676	4294936	8	2	no
B L NE	unassigned	730829	4288189	8	2	no
B L NE	unassigned	695781	4220504	8	extra	no
B L NE	unassigned	707466	4237656	8	extra	no
B L NE	unassigned	730282	4267505	8	extra	no
B L NE	unassigned	730633	4287439	8	extra	no
B L NE	unassigned	731096	4288971	8	extra	no
B L NE	unassigned	733345	4296194	8	extra	no
B L NE	unassigned	732684	4296303	8	extra	no
B L NE	unassigned	732985	4296456	8	extra	no
B L NE	unassigned	736284	4296468	8	extra	no
B L SW	1L105-2-1	732392	4294771	9	1	yes
B L SW	3L120-1-1	697982	4224082	9	1	no
B L SW	1L318-2-1	734726	4288059	9	1	no
B L SW	2L595-1-1	712328	4249690	9	1	no
B L SW	1L576-1-1	731781	4282715	9	1	no
B L SW	1L113-0-c	736450	4288980	9	2	no
B L SW	1L112-3-1	732035	4290655	9	2	no
B L SW	1L478-1-1	743238	4301153	9	2	no
B L SW	1L572-1-1	742586	4293214	9	2	no
B L SW	unassigned	695348	4220134	9	extra	no
B L SW	unassigned	697804	4228498	9	extra	no
B L SW	unassigned	732037	4281869	9	extra	no
B L SW	unassigned	732344	4281896	9	extra	no
B L SW	unassigned	731658	4290158	9	extra	no
B L SW	unassigned	743818	4293753	9	extra	no
B L SW	unassigned	733941	4295402	9	extra	no
B L SW	unassigned	734390	4296339	9	extra	no
B L SW	unassigned	732777	4297269	9	extra	no
B M NE	2L443-1-1	726109	4266975	14	1	yes
B M NE	1L410-1-1	744028	4295887	14	1	yes
B M NE	1L123-0-c	733390	4283800	14	1	no
B M NE	3L113-1-1	704765	4235538	14	1	no
B M NE	2L133-3-1	716756	4253381	14	1	no
B M NE	3L600-1-1	708555	4243434	14	1	no
B M NE	1L571-1-1	733923	4293728	14	1	no

Table A1. Visitation schedules and characteristics of long-term vegetation monitoring plots, Shenandoah National Park, 2003 (continued).

ELU Code ^a	Point ID	Easting ^b	Northing ^b	No. plots in stratum ^c	Year to Visit	Visited by Nov. 2003?
B M NE	3L550-1-1	707181	4237714	14	2	no
B M NE	3L100-1-1	708827	4243120	14	2	no
B M NE	2L121-1-1	724641	4262947	14	2	no
B M NE	1L505-1-1	734261	4284946	14	2	no
B M NE	1L312-0-c-	733200	4291000	14	2	no
B M NE	1L302-0-c-	743820	4296230	14	2	no
B M NE	unassigned	701345	4231677	14	2	no
B M NE	unassigned	706593	4238231	14	extra	no
B M NE	unassigned	715605	4252794	14	extra	no
B M NE	unassigned	717552	4253080	14	extra	no
B M NE	unassigned	729703	4269691	14	extra	no
B M NE	unassigned	736411	4290411	14	extra	no
B M NE	unassigned	744778	4294562	14	extra	no
B M SW	3L115-2-1	708032	4241964	17	1	yes
B M SW	3L123-1-1	713528	4248561	17	1	yes
B M SW	2L119-1-3	714045	4249085	17	1	yes
B M SW	1L120-1-1	732813	4283472	17	1	yes
B M SW	1L115-1-1	731514	4283507	17	1	yes
B M SW	1L301-2-2	739755	4293622	17	1	yes
B M SW	1L413-1-1	740512	4294624	17	1	yes
B M SW	3L465-1-1	707812	4243016	17	1	no
B M SW	2L459-1-1	715405	4248992	17	1	no
B M SW	3L112-0-c	702900	4234200	17	2	no
B M SW	3L105-2-1	707121	4240372	17	2	no
B M SW	2L107-0-c	716350	4251400	17	2	no
B M SW	2L310-1-1	730965	4271901	17	2	no
B M SW	2L130-1-1	730489	4272517	17	2	no
B M SW	1L506-1-1	731260	4283865	17	2	no
B M SW	1L104-0-c	734600	4290900	17	2	no
B M SW	1L498-1-1	733932	4291756	17	extra	no
B M SW	1L495-1-1	740700	4293467	17	extra	no
B M SW	1L110-0-c	740600	4294000	17	extra	no
B M SW	1L479-1-1	745429	4299985	17	extra	no
B M SW	2L455-1-1	718963	4255510	17	extra	no
B M SW	2L450-1-1	720698	4259093	17	extra	no
B M SW	2L441-1-1	725890	4268134	17	extra	no
B M SW	1L416-1-1	742755	4293641	17	extra	no
B M SW	unassigned	696569	4225695	17	extra	no
B M SW	unassigned	700404	4230789	17	extra	no
B M SW	unassigned	700658	4230876	17	extra	no

Table A1. Visitation schedules and characteristics of long-term vegetation monitoring plots, Shenandoah National Park, 2003 (continued).

ELU Code ^a	Point ID	Easting ^b	Northing ^b	No. plots in stratum ^c	Year to Visit	Visited by Nov. 2003?
B M SW	unassigned	707063	4241757	17	extra	no
B M SW	unassigned	708822	4242573	17	extra	no
B M SW	3L601-1-1	708849	4242642	17	extra	no
B M SW	2L598-1-1	715690	4248417	17	extra	no
B M SW	unassigned	716033	4250702	17	extra	no
B M SW	unassigned	716526	4252767	17	extra	no
B M SW	unassigned	720860	4260604	17	extra	no
B M SW	unassigned	721837	4263483	17	extra	no
B M SW	unassigned	731405	4283125	17	extra	no
B M SW	unassigned	735118	4288929	17	extra	no
B M SW	unassigned	731134	4291612	17	extra	no
B M SW	unassigned	744348	4294662	17	extra	no
G H NE	2L452-1-1	721403	4258403	3	1	no
G H NE	1L106-3-1	736297	4293867	3	1	no
G H NE	2L115-2-1	728037	4272793	3	2	no
G H NE	2L517-1-1	730491	4274044	3	extra	no
G H NE	2L132-3-1	731487	4277669	3	extra	no
G H NE	2L591-1-1	723049	4261330	3	extra	no
G H NE	1L570-1-1	735908	4293936	3	extra	no
G H NE	unassigned	724290	4261077	3	extra	no
G H NE	unassigned	721310	4256157	3	extra	no
G H NE	unassigned	725748	4259289	3	extra	no
G H NE	unassigned	725211	4259987	3	extra	no
G H NE	unassigned	725042	4260424	3	extra	no
G H NE	unassigned	723623	4261246	3	extra	no
G H NE	unassigned	731768	4273800	3	extra	no
G H NE	unassigned	733298	4281243	3	extra	no
G H NE	unassigned	736228	4293174	3	extra	no
G H SW	2L435-1-1	725743	4270528	3	1	no
G H SW	2L104-0-c	724920	4261920	3	2	no
G H SW	2L518-1-1	731058	4273855	3	2	no
G H SW	1L102-1-1	737146	4293496	3	extra	no
G H SW	2L580-1-1	732584	4277856	3	extra	no
G H SW	unassigned	721183	4255898	3	extra	no
G H SW	unassigned	720081	4256010	3	extra	no
G H SW	unassigned	724735	4262013	3	extra	no
G H SW	unassigned	725536	4269483	3	extra	no
G H SW	unassigned	725875	4269968	3	extra	no
G H SW	unassigned	731447	4273984	3	extra	no
G H SW	unassigned	730871	4274375	3	extra	No

Table A1. Visitation schedules and characteristics of long-term vegetation monitoring plots, Shenandoah National Park, 2003 (continued).

ELU Code ^a	Point ID	Easting ^b	Northing ^b	No. plots in stratum ^c	Year to Visit	Visited by Nov. 2003?
G H SW	unassigned	728437	4275167	3	extra	no
G H SW	unassigned	736682	4293786	3	extra	no
G L NE	1L114-1-1	735839	4286203	12	1	yes
G L NE	2L440-1-1	735896	4268887	12	1	no
G L NE	2L113-1-1	732815	4274850	12	1	no
G L NE	2L126-1-1	738172	4279981	12	1	no
G L NE	1L124-1-1	735228	4286172	12	1	no
G L NE	1L417-1-1	739429	4288664	12	1	no
G L NE	2L523-1-1	735957	4268800	12	2	no
G L NE	2L117-0-c	723800	4269400	12	2	no
G L NE	2L106-1-1	736857	4275157	12	2	no
G L NE	2L578-1-1	737741	4281162	12	2	no
G L NE	unassigned	729425	4257867	12	2	no
G L NE	unassigned	729205	4258250	12	2	no
G L NE	unassigned	733349	4265987	12	extra	no
G L NE	unassigned	736306	4269122	12	extra	no
G L NE	unassigned	734560	4273406	12	extra	no
G L NE	unassigned	738353	4280629	12	extra	no
G L NE	unassigned	737176	4281294	12	extra	no
G L NE	unassigned	738243	4290179	12	extra	no
G L NE	unassigned	746353	4295363	12	extra	no
G L SW	1L402-1-1	742810	4300650	10	1	yes
G L SW	1L117-3-1	743854	4300896	10	1	yes
G L SW	2L109-1-1	722062	4253964	10	1	no
G L SW	2L529-1-1	732043	4266132	10	1	no
G L SW	unassigned	736544	4270157	10	1	no
G L SW	unassigned	733572	4265843	10	2	no
G L SW	2L511-1-1	738815	4280442	10	2	no
G L SW	3L608-1-1	697893	4223611	10	2	no
G L SW	1L565-1-1	733311	4297004	10	2	no
G L SW	unassigned	732224	4266316	10	2	no
G L SW	unassigned	736290	4269540	10	extra	no
G L SW	unassigned	736584	4274177	10	extra	no
G L SW	unassigned	736655	4274315	10	extra	no
G L SW	unassigned	734646	4274815	10	extra	no
G L SW	unassigned	737327	4280451	10	extra	no
G L SW	unassigned	738065	4287207	10	extra	no
G L SW	unassigned	742809	4301394	10	extra	no
G M NE	3L122-1-1	713474	4247548	14	1	yes
G M NE	2L108-1-1	733966	4279063	14	1	yes

Table A1. Visitation schedules and characteristics of long-term vegetation monitoring plots, Shenandoah National Park, 2003 (continued).

ELU Code ^a	Point ID	Easting ^b	Northing ^b	No. plots in stratum ^c	Year to Visit	Visited by Nov. 2003?
G M NE	3L462-1-1	714586	4246743	14	1	no
G M NE	2L456-1-1	720113	4255287	14	1	no
G M NE	2L448-1-1	723768	4262089	14	1	no
G M NE	2L111-1-1	730972	4275403	14	1	no
G M NE	2L430-1-1	733541	4278783	14	1	no
G M NE	3L547-1-1	710171	4244205	14	2	no
G M NE	3L546-1-1	712015	4245289	14	2	no
G M NE	2L129-0-c	726560	4259460	14	2	no
G M NE	2L536-1-1	726326	4259770	14	2	no
G M NE	2L525-1-1	725221	4267357	14	2	no
G M NE	2L314-0-c	731850	4271350	14	2	no
G M NE	1L109-0-c	744400	4297000	14	2	no
G M NE	1L415-1-1	738751	4293927	14	extra	no
G M NE	2L514-1-1	734975	4277266	14	extra	no
G M NE	2L516-1-1	735530	4276522	14	extra	no
G M NE	3L599-1-1	711746	4245502	14	extra	no
G M NE	2L587-1-1	733409	4268881	14	extra	no
G M NE	unassigned	714902	4246945	14	extra	no
G M NE	unassigned	722587	4257795	14	extra	no
G M NE	unassigned	725950	4259210	14	extra	no
G M NE	unassigned	723194	4261905	14	extra	no
G M NE	unassigned	732304	4272313	14	extra	no
G M NE	unassigned	732288	4274409	14	extra	no
G M NE	unassigned	736837	4276922	14	extra	no
G M NE	unassigned	735013	4277299	14	extra	no
G M NE	unassigned	735122	4278503	14	extra	no
G M NE	unassigned	731316	4279569	14	extra	no
G M NE	unassigned	737349	4294017	14	extra	no
G M NE	unassigned	745948	4301234	14	extra	no
G M NE	unassigned	744595	4301930	14	extra	no
G M SW	2L457-1-1	721545	4254390	12	1	no
G M SW	2L449-1-1	722780	4260857	12	1	no
G M SW	2L531-1-1	726197	4263859	12	1	no
G M SW	2L521-1-1	725260	4270479	12	1	no
G M SW	2L520-1-1	731957	4273150	12	1	no
G M NE	unassigned	722268	4258714	14	1	no
G M SW	1L128-0-c	736750	4283500	12	2	no
G M SW	1L108-0-c	745190	4298900	12	2	no
G M SW	2L592-1-1	726032	4260403	12	2	no
G M SW	2L577-1-1	734746	4281312	12	2	no

Table A1. Visitation schedules and characteristics of long-term vegetation monitoring plots, Shenandoah National Park, 2003 (continued).

ELU Code ^a	Point ID	Easting ^b	Northing ^b	No. plots in stratum ^c	Year to Visit	Visited by Nov. 2003?
G M SW	unassigned	722459	4257031	12	2	no
G M SW	unassigned	724404	4262402	12	2	no
G M SW	unassigned	721074	4265903	12	extra	no
G M SW	unassigned	733058	4267649	12	extra	no
G M SW	unassigned	727258	4271889	12	extra	no
G M SW	unassigned	734844	4281285	12	extra	no
G M SW	unassigned	745754	4293045	12	extra	no
S L NE	1L103-1-1	728024	4286990	10	1	yes
S L NE	3L107-0-c	708900	4249250	10	1	no
S L NE	1L480-1-1	732758	4299750	10	1	no
S L NE	3L125-1-1	709519	4251598	10	1	no
S L NE	unassigned	726746	4286867	10	1	no
S L NE	1L503-1-1	726738	4287331	10	2	no
S L NE	1L484-1-1	731174	4297423	10	2	no
S L NE	2L125-0-c	714520	4255480	10	2	no
S L NE	unassigned	726756	4287764	10	2	no
S L NE	unassigned	726885	4288168	10	2	no
S L NE	unassigned	726831	4288360	10	extra	no
S L NE	unassigned	730885	4295002	10	extra	no
S L NE	unassigned	732308	4296158	10	extra	no
S L NE	unassigned	732876	4299295	10	extra	no
S L NE	unassigned	732711	4299461	10	extra	no
S L SW	1L481-1-1	732366	4298371	13	1	no
S L SW	1L122-1-1	729556	4288481	13	1	yes
S L SW	1L405-1-1	731566	4297836	13	1	yes
S L SW	1L408-1-1	732395	4296291	13	1	no
S L SW	2L101-1-1	715013	4255026	13	1	no
S L SW	3L124-1-1	695345	4237128	13	1	yes
S L SW	1L129-0-c	727360	4285520	13	2	no
S L SW	1L504-1-1	726449	4287319	13	2	no
S L SW	1L485-1-1	731665	4297272	13	2	no
S L SW	1L564-1-1	731935	4298768	13	2	no
S L SW	unassigned	692851	4218607	13	2	no
S L SW	unassigned	728279	4284476	13	2	no
S L SW	unassigned	726459	4287183	13	2	no
S L SW	unassigned	727990	4287623	13	extra	no
S L SW	unassigned	726602	4288116	13	extra	no
S L SW	unassigned	731245	4294532	13	extra	no
S L SW	unassigned	730878	4294623	13	extra	no

Table A1. Visitation schedules and characteristics of long-term vegetation monitoring plots, Shenandoah National Park, 2003 (continued).

ELU Code ^a	Point ID	Easting ^b	Northing ^b	No. plots in stratum ^c	Year to Visit	Visited by Nov. 2003?
S L SW	unassigned	731380	4295905	13	extra	no
S L SW	unassigned	731770	4298780	13	extra	no
S L SW	1L561-1-1	732261	4299353	13	extra	no
S M NE	2L433-1-1	727828	4272062	11	1	yes
S M NE	2L432-1-1	728392	4272422	11	1	yes
S M NE	3L472-1-1	698128	4232324	11	1	no
S M NE	3L467-1-1	705132	4240556	11	1	no
S M NE	3L463-1-1	704796	4245126	11	1	no
S M NE	3L559-1-1	692965	4221495	11	2	no
S M NE	3L549-1-1	705586	4240489	11	2	no
S M NE	2L530-1-1	713554	4265810	11	2	no
S M NE	1L303-0-c-	745780	4301770	11	2	no
S M NE	3L607-1-1	695579	4225794	11	2	no
S M NE	unassigned	696258	4225460	11	2	no
S M NE	unassigned	696369	4226324	11	extra	no
S M NE	unassigned	697463	4230310	11	extra	no
S M NE	unassigned	694999	4232529	11	extra	no
S M NE	unassigned	695236	4233453	11	extra	no
S M NE	unassigned	697018	4233580	11	extra	no
S M NE	unassigned	702912	4237181	11	extra	no
S M NE	unassigned	705094	4239451	11	extra	no
S M NE	unassigned	704037	4241724	11	extra	no
S M NE	unassigned	718869	4260418	11	extra	no
S M NE	unassigned	714026	4265593	11	extra	no
S M SW	3L474-1-1	695641	4227206	13	1	no
S M SW	2L131-0-c	719790	4262200	13	1	no
S M SW	3L464-1-1	705490	4244425	13	1	no
S M SW	3L560-1-1	692093	4219535	13	1	no
S M SW	3L558-1-1	693692	4224204	13	1	no
S M SW	3L555-1-1	694856	4225002	13	1	no
S M SW	3L553-1-1	694494	4228130	13	1	no
S M SW	3L119-0-c	697540	4231500	13	2	no
S M SW	3L470-1-1	696496	4238174	13	2	no
S M SW	3L551-1-1	696763	4232189	13	2	no
S M SW	2L535-1-1	713815	4260875	13	2	no
S M SW	2L533-1-1	718947	4263534	13	2	no
S M SW	3L602-1-1	699181	4238779	13	2	no
S M SW	2L589-1-1	715623	4265096	13	extra	no
S M SW	unassigned	692244	4220787	13	extra	no

Table A1. Visitation schedules and characteristics of long-term vegetation monitoring plots, Shenandoah National Park, 2003 (continued).

ELU Code ^a	Point ID	Easting ^b	Northing ^b	No. plots in stratum ^c	Year to Visit	Visited by Nov. 2003?
S M SW	unassigned	694249	4227802	13	extra	no
S M SW	unassigned	694296	4227920	13	extra	no
S M SW	unassigned	699049	4235323	13	extra	no
S M SW	unassigned	699828	4237927	13	extra	no
S M SW	unassigned	703399	4240836	13	extra	no
S M SW	unassigned	712729	4244259	13	extra	no
S M SW	unassigned	720796	4261390	13	extra	no
S M SW	unassigned	716789	4264852	13	extra	no
S M SW	unassigned	731196	4291383	13	extra	no

^a Geology (B = basaltic, G = granitic, S = siliciclastic), elevation (L = 0–609 m, M = 610–914 m, H = 915–1,144 m), and aspect (NE = 315–124 degrees, SW = 125–314 degrees).

^b Universal transverse mercator coordinates (meters) in North American Datum 1927 of the Continental United States (NAD27CONUS), Zone 17 North.

^c This is the number of plots that need to be sampled in the given stratum. For example, stratum S M NE requires 11 plots. The first 11 plots will be sampled and used in the study design unless a given plot does not meet selection criteria. If a plot is rejected, then one of the extra plots will be visited to see if it meets the selection criteria.

Appendix D

Metadata

Defining Strata

Elevation data were received from John Young (Leetown Science Center, U.S. Geological Survey) as a 10-m floating-point digital elevation model (DEM; <http://edc.usgs.gov/guides/dem.html>). Elevations were reclassified to the three intervals defined in this report. Elevations >1,144 m were excluded because of their sensitive plant communities and because they are monitored under different protocols. For simplifying data querying and merging, the elevation grid was converted to a shapefile.

Aspect was derived from the DEM by John Young as compass direction that slopes face. It was derived by issuing the ArcInfo command `aspect = aspect(elevation)`. Aspect data were reclassified into northeast and southwest directions as defined in this report. Because the grid aspect data contained numerous patches of very few cells of a particular aspect embedded within larger regions of the other aspect, a majority filter (using orthogonals) to eliminate few-cell patches was performed 5 times. Further, neighborhood statistics with a 5-cell majority to additionally smooth patch edges and further eliminate few-cell patches was performed on the majority filter theme. No improvement in reduction of number of small patches or substantive smoothing of patch edges was gained by conducting the majority filter beyond 5 times. Further, 5-cell neighborhood statistics was an appropriate compromise between leaving a greater number of smaller patches (e.g., with a 3-cell neighborhood) and losing too much detail (e.g., with an 8-cell neighborhood) at the patch level. Majority filter and neighborhood statistics reduced the number of aspect polygons from 13,343 to 3,526. For simplifying data querying and merging, the aspect grid was converted to a shapefile.

Geologic strata initially were defined by nine soil series. These series were associated with the three parent material types (siliciclastic, granitic, basaltic; W Cass, pers. commun.) defined in this report. Within geoprocessing, geology was dissolved at the strata level to eliminate multi-part and orphan polygons.

Elevation, aspect, and geology shapefiles were merged in geoprocessing to create single 3-way cross-classification theme of all strata. High siliciclastic elevations combined into medium siliciclastic elevations.

Selecting Plot Locations

Sampling plots were a collection of sites grandfathered from earlier LTEM plots (selection of individual sites conducted by Wendy Cass et al., SNP) and plots generated via stratified random sampling. Random sites were selected by generating 10,000 random points throughout SNP. Strata characteristics were associated with sample points using the spatial join function in geoprocessing.