

Evaluating and Revising a Long-Term Monitoring Program for Vascular Plants: Lessons From Shenandoah National Park

Carolyn G. Mahan¹

Division of Mathematics and Natural Science

The Pennsylvania State University
3000 Ivy Side Drive
Altoona, PA 16601

Duane R. Diefenbach

U.S. Geological Survey
Pennsylvania Cooperative Fish and Wildlife Research Unit
The Pennsylvania State University
404 Resources Building
University Park, PA 16802

Wendy B. Cass

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

¹ Corresponding author:
cgm2@psu.edu

ABSTRACT: Monitoring programs have been established by agencies to assist in the conservation of biological diversity and to assess the impacts of a variety of threats to species and natural systems. However, poorly designed programs may fail to detect changes in the system they were intended to monitor. We evaluated and revised the long-term monitoring program for vascular plants at Shenandoah National Park (SHEN) and used our evaluation and revision to illustrate common problems associated with monitoring programs. Our evaluation of data collected through SHEN's 14-year monitoring program indicated that the design and sampling effort lacked the statistical power to detect changes in stem density of shrubs or saplings, although there was sufficient power to detect changes in tree basal area for some species. The inability of the program to detect changes was due, in part, to the lack of specific management and sampling objectives, stratifying the park according to forest cover types that changed over time, errors associated with misidentification of species, and an inappropriate temporal schedule for visiting sampling plots. Our revised sampling design attempted to correct these deficiencies by using strata that are unlikely to change over time (elevation, bedrock geology, and aspect), streamlining data collection to allow a greater number of sampling plots, and visiting all plots over a 2-year period (interpenetrating sampling) to increase sample size. Long-term monitoring programs should: (1) establish specific, quantifiable, and attainable management and statistical sampling objectives; (2) use permanent characteristics to define strata (e.g., elevation or bedrock geology), if stratification is warranted; and (3) perform a statistical evaluation of the monitoring program once sufficient data have been collected. Prompt evaluation of an implemented monitoring program will allow timely modifications of either sampling objectives or the sample design with minimal delay in collecting meaningful long-term trend information.

Index terms: forest plants, monitoring, national parks, power analysis, vascular plants, vegetation

INTRODUCTION

Many countries and agencies have initiated monitoring programs to assist in the conservation of biological diversity and to detect impacts of various threats to natural resources (Austin and Heyligers; Woodley et al. 1993; Stork et al. 1995; Gibbs et al. 1998; McDonald 2003). Effective monitoring programs set objectives that can be assessed quantitatively using a statistical sampling design. In the United States, many federal agencies have monitoring programs. The National Park Service (NPS), for example, is required to monitor natural resources to detect change and provide reference points for comparisons with other altered environments (Schmoldt et al. 1994; Freet and Turner 1999). In general, however, monitoring programs conducted by natural resource agencies often have been undertaken in a less than rigorous fashion.

In particular, many programs are initiated without identifying specific objectives, and defining management and sampling objectives is the most important step in designing a monitoring program (Schmoldt et al. 1994). Management objectives reflect what outcome or finding resource managers would like to see as a result of a particular monitoring program. Sampling objectives

are more specific than management objectives, and they link management objectives with statistical rigor, including effect sizes (e.g., changes in abundance over a specified time period) and statistical power (NPS 2005). Without clarifying objectives, researchers often end up with data that address the wrong question(s), too much or too little data, or data that are of no use (Gibbs 1998; NPS 2005).

Shenandoah National Park (SHEN) has natural resources of national importance and it, therefore, was one of the first national parks included in a long-term inventory and monitoring (LTEM) program to detect changes and quantify trends in resource condition and to link the changes to their causes (Schmoldt et al. 1994; Freet and Turner 1999). In theory, the LTEM program should provide the data necessary for the fundamental understanding of ecological processes and changes that occur within the park.

We evaluated, and consequently revised, the LTEM program for vascular plants at SHEN. The objectives of this revision and evaluation were threefold. One, specific management and sampling objectives were needed to assess whether the current monitoring effort was adequate for detecting desired trends. Two, once these objectives

were set, we conducted a statistical evaluation to assess whether the current program met objectives. Three, using our statistical evaluation of the original LTEM program, we developed a revised sampling design to meet the newly-formed management and sampling objectives. We contend that resource managers throughout the NPS system and other natural resource agencies should conduct periodic evaluations to assess whether their monitoring programs have identified specific objectives and, if so, determine whether the monitoring programs can meet these objectives. Periodic evaluations are particularly important for trees because vegetation requires monitoring time periods of decades or centuries due to their longevity.

METHODS

To establish specific and measurable management and sampling objectives, a one-day workshop was held at SHEN in March 2000. The goal of the workshop was to develop specific, appropriate, attainable, measurable, and statistically explicit management and sampling objectives for the park's LTEM program for vascular plants (NPS 2005). Scientists and natural resource managers from 10 organizations (universities, governmental [state and federal], nongovernmental) participated in the workshop. Workshop participants assisted park resource managers in determining what changes in vascular plant conditions, specifically forest plants, the monitoring program should detect. We focused on monitoring of trends in overstory trees, saplings, and shrubs, because these areas have the greatest applicability to other parks and resource management agencies that contain large tracts of forested land.

At the time of this study, SHEN had 14 years (1987-2000) of vascular plant data collected via the LTEM program. This original LTEM program was typical of many established monitoring programs – especially by placing plots within specific forest cover types. These original data were collected at 104 sampling sites distributed among 42 strata within the park (Smith and Torbert 1990). The original LTEM protocols used a stratified random sampling

design where 91 of the 104 LTEM sampling sites were randomly selected from the strata for vascular plant inventories, and an additional 13 sites were added as part of subsequent research projects. The original 42 strata were derived from eight forest cover types (cove hardwoods, pitch pine [*Pinus rigida*, Miller], Virginia pine [*Pinus virginiana*, Miller], eastern hemlock [*Tsuga canadensis*, Engelm.], chestnut oak [*Quercus prinus*, L.], black locust [*Robinia pseudoacacia*, L.], northern red oak [*Quercus rubra*, L.], and yellow poplar [*Liriodendron tulipifera*, L.]), three elevation ranges (low 381-533 m; mid 686-838 m; and high 991-1143 m), and two aspect ranges (moist 350-100 degrees azimuth; and dry 170-280 degrees azimuth). The original coverage of each stratum was determined using a Geographic Information System (GIS) that included vegetation mapping (D. Hurlbert, NPS, pers. comm.). Whenever possible, vascular plant sampling sites were distributed equally among each of the three park districts (north, central, and south).

Under the original LTEM design, at each sampling site three 24-m × 24-m plots were permanently established and diameter at breast height (dbh) was measured for all woody vegetation > 5 m tall within the plot. At three corners of this plot, 6-m × 6-m sapling-shrub sampling plots were established and number of woody stems 1-5 m tall was counted by species. Within each sapling-shrub plot, two 1-m × 1-m seedling plots were established where a species-specific count was made of all woody regeneration < 1 m tall (Smith and Torbert 1990). Because all plot measurements were based on horizontal-plane measurements, all horizontal distances along slopes exceeding 3% were corrected by multiplying the horizontal distance by a corresponding slope correcting factor (Smith and Torbert 1990; Kleinn et al. 2002). Sites that contained slopes exceeding 50% were not used in the LTEM program.

Estimates of variances and effect sizes are required before statistical power of a given parameter can be estimated. Therefore, the first step of the statistical evaluation of the original LTEM program for vascular plants was to generate estimated basal areas and

stem densities values for selected species. We used formulas for a stratified random design (Cochran 1977) to estimate means and variances for basal area (m²/ha) and stem density (stems/ha) for selected plant species. However, we only used data from one 24-m × 24-m sample plot because the three plots at each sample site were not independent. We calculated Satterthwaite degrees of freedom (Satterthwaite df) to obtain weighted degrees of freedom based on sample sizes among strata, area of strata, and variances among strata. The Satterthwaite approximation for the degrees of freedom is:

Satterthwaite df =

$$\frac{\left(\sum_{h=1}^L a_h s_h^2 \right)^2}{\sum_{h=1}^L \left(a_h s_h^2 \right)^2 / (n_h - 1)}$$

where

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

If all stratum sizes (N_h), sample sizes (n_h), and variances (s_h^2) are equal, then the degrees of freedom are $n - L$, where L is the total number of strata (Thompson 2002).

Estimates were calculated for total basal area (m²/ha) in each forest cover type at each sampling period, change in mean basal area between sampling periods, and change in total basal area between sampling periods for the following selected overstory tree species: northern red oak, red maple (*Acer rubrum*, L.), pine (pitch pine and Virginia pine), and black birch (*Betula lenta*, L.). Estimates also were calculated for stem density (stems/ha) of shrubs and saplings (1-5 m tall) in each forest cover type at each sampling period, and changes in mean stem density (stems/ha) between sampling periods for each of the following selected species: mountain laurel (*Kalmia latifolia*, L.), sassafras (*Sassafras albidum*, Nees), brambles (*Rubus* spp.), spicebush (*Lindera benzoin*, Blume), and flowering dogwood (*Cornus florida*, L.). We used the

coefficient of variation (CV = standard error/mean $\times$ 100%) as a measure of precision of estimates for basal area and stems/ha based on the original LTEM sampling design for vascular plants at SHEN.

Statistical power to detect changes (e.g., mean difference of paired plots between sampling periods via a *t*-test) was estimated for tree basal area and shrub-sapling and seedling stem density. Because the variance of these parameters was positively correlated with the mean, the standard deviation (SD) was first modeled as a linear function of the mean change (Gerrodette 1993, Figure 1). From this model, the standard deviation could be predicted for a given absolute value of the change in the parameter of interest. For changes in basal area or stem density beyond the limits of the linear model, the estimate of

standard deviation from the largest change in basal area or stem density in the model was used.

We assumed that the distribution of mean change (mean of paired-plot differences over time) in the parameter of interest (θ ; i.e., basal area or stem density) could be described by a *t* distribution, in which the $SE(\theta)$ was a function of the mean and sample size. In the simulations, $\alpha = 0.20$. Satterthwaite df ranged from 2 to 10, basal area ranged from 0 to 9 m²/ha, and shrub-sapling stem density ranged from 0-5000 stems/ha. An $\alpha = 0.20$ was agreed upon by workshop participants in developing management and sampling objectives to detect general trends in vegetation at SHEN. Details of the power analysis are provided in Diefenbach and Mahan (2002).

After reviewing the results of the statistical evaluation of the data collected using the original LTEM sampling design for vascular plants, we created a revised sampling design based on a stratified random sampling with interpenetrating sampling over two years. Therefore, the plots were subdivided randomly into two sub-samples visited in successive years (i.e., split panel design; McDonald 2003). At the conclusion of the 2-year sampling process, all plots will be revisited beginning the following year.

Under the revised design, new strata were no longer based on forest cover type because forest cover types may change as a result of succession and disturbance regimes. New strata were based on elevation, geology, and aspect that were not expected to change except on a geological time scale. We divided the elevation gradient at SHEN into three elevation ranges that differed slightly from the ranges proposed under the original LTEM design. Under our revised design, most (384 km²) of SHEN is located in the middle elevation range (610-914 m), but 309 km² are in the low elevation range (213-609 m) and 80 km² are in the high elevation range (915-1144 m). The geology categories used in stratification were: basaltic, granitic, and siliciclastic (Gathright 1976). Aspects were divided into moist northeastern (315-124 degrees azimuth) and dry southwestern (125-314 degrees azimuth) throughout SHEN. These aspect categories differed slightly from those proposed under the original LTEM design (Smith and Torbert 1990).

When elevation, geology, and aspect were cross-classified, middle elevations consistently occupied the greatest area among all geologic types, followed in area by low elevations and high elevations. Six thousand two hundred and six unique polygons from 0.001 ha to 1174.8 ha comprise these cross-classified strata. 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 minus the 2 high-elevation siliciclastic strata that were incorporated into mid-elevation

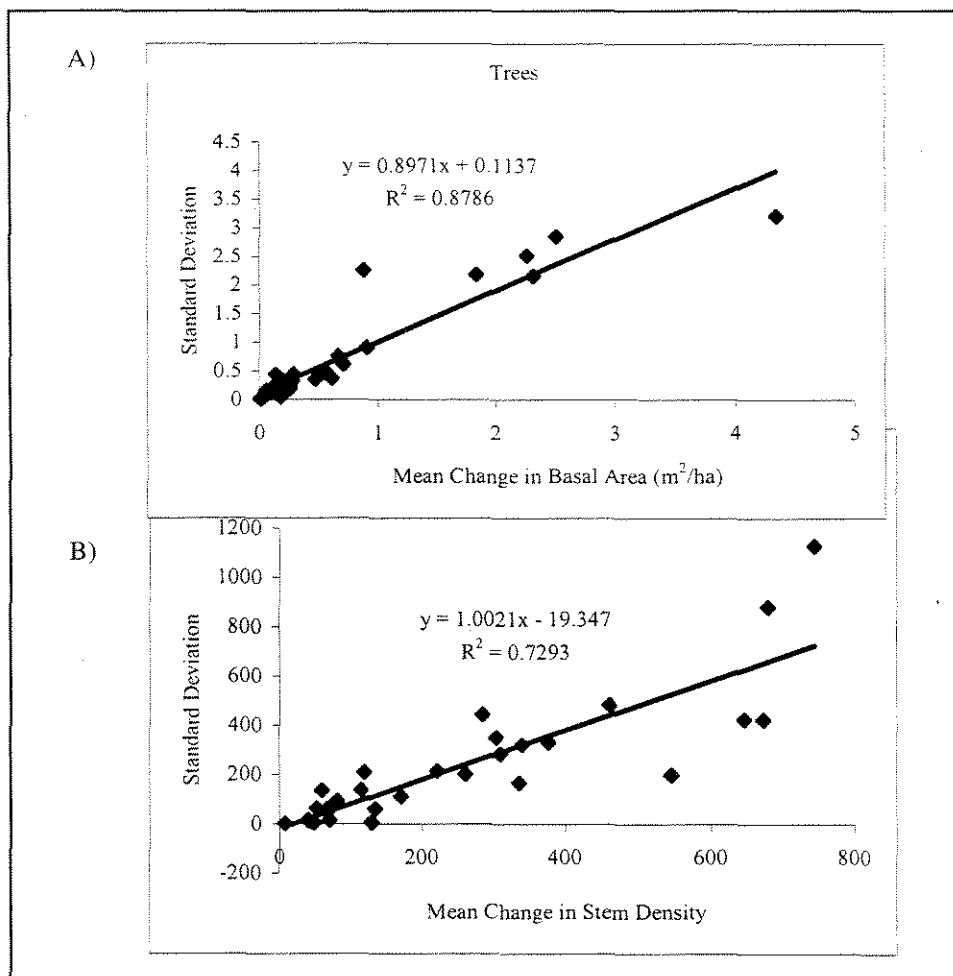


Figure 1. Scatterplot with regression line for the relationship between standard deviation and mean changes in (A) basal area of trees (m²/ha) and (B) stem density of shrubs or saplings (stems/ha) at Satterthwaite df = 4.

strata = 16 strata).

In the revised LTEM sampling design, plots were allocated among strata proportional to area. When possible, we retained plots used in the original sampling design and assigned each plot to its new stratum. These plots were retained because of the existing 14-year history of data collected on these plots. However, selection criteria were established before an existing plot was eligible to be retained. All plot centers in the new sampling design had to be ≥ 40 m from an established trail, ≥ 50 m from any administrative road or park boundary, ≥ 100 m from Skyline Drive (a paved 2-lane road) or any developed area, and have a slope $< 26.5^\circ$.

To evaluate the statistical precision of the new sampling design, we first re-classified 104 original LTEM plots into the 16 new strata and treated these data as pilot data from which to estimate sample sizes for the new sampling design. By stratifying these historical plots under the new sampling design, six strata contained only 2-4 plots, five strata contained 5-7 plots, four strata contained 8-10 plots, and one stratum contained 14 plots. 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 to simulate data under the new sampling design. 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 data collected under the original LTEM sampling design.

We evaluated the precision of mean basal area and stem densities for the selected overstory (northern red oak, red maple, pine, and black birch) and shrub/sapling species (mountain laurel, spicebush, sassafras, flowering dogwood, and *Rubus*) for sample sizes of 100, 140, 180, 220, and 260 plots. For each overstory and shrub/sapling 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 df (Thompson 2002).

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 that was collected using the original LTEM design 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 sampling design. Second, we 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 the statistical evaluation of the original LTEM data to assess which sample sizes would provide reasonable precision of parameter estimates. We believe this was a reasonable approach to choosing sample sizes that would be likely to provide parameter estimates with sufficient precision.

RESULTS

We used the following management and sampling objectives developed by workshop participants:

Management Objective: To be able to detect a 50% change in the density of any one species of tree (overstory tree; sapling or shrubs) within any stratum over a five-year period.

Sampling Objective: Data collected for the LTEM program should ensure a 90% probability of detecting a $> 50\%$ change in the basal area or stem density of any vascular plant species (in a given size class [overstory, sapling or shrub]) within any stratum over a five-year period ($\alpha = 0.20$).

Based on data collected from 1987-2000 under the original LTEM sampling design, CVs of estimated basal area (mean and total) for overstory trees in plots paired over time were highly variable, and ranged from

26-204% among selected species (northern red oak [CVs = 28-157%], red maple [CVs = 35-165%], Virginia and pitch pine [CV = 26% for pine forest type only], and black birch [CVs = 43-204%]) in all forest cover types. Poor precision was expected for some situations (e.g., northern red oak in pine stands, CV = 157%), but CVs were generally $< 40\%$ for species in vegetation types where they were most abundant (e.g., northern red oak in chestnut oak and northern red oak cover type, CV = 28%).

In contrast to the basal area estimates, few changes in stem density were detected for shrubs and saplings in plots paired over time. CVs of estimated stems/ha for selected species (flowering dogwood [CVs = 31-61%], spicebush [CVs = 37-205%], sassafras [CVs = 46-573%], *Rubus* spp. [CVs = 50-88%], and mountain laurel [CVs = 38-100%]) were highly variable and most CVs were $> 50\%$ (range 31-573%) in all forest cover types.

We found that given the stratum sizes, variances, and sample sizes of the sampling design, the 104 plots resulted, in general, in four Satterthwaite df. Thus, the graphs of estimated statistical power for changes in mean basal area (Figure 2) and stem density (Figure 3) at Satterthwaite df = 4 provide a measure of the statistical power of the sampling effort under the original LTEM sampling design for vascular plants at SHEN. For example, at Satterthwaite df = 4, we should detect a change of 6 m²/ha with 90% power in overstory trees, which represents a 10% change at 60 m²/ha, 20% change at 30 m²/ha, and 50% at 12 m²/ha (Figure 2). Because most basal area measurements are > 20 m²/ha for overstory species in their primary forest cover types (e.g., northern red oak in chestnut oak cover type), sampling effort under the original LTEM sampling design for vascular plants has $> 90\%$ power to detect changes in basal area of 50% for dominant species of overstory trees.

Under the sampling effort at Satterthwaite df = 4 using the original LTEM design, statistical power was estimated $> 90\%$ for changes in shrub and sapling stem density of ~ 2000 stems/ha or greater (Figure 3). However, the ability to detect smaller

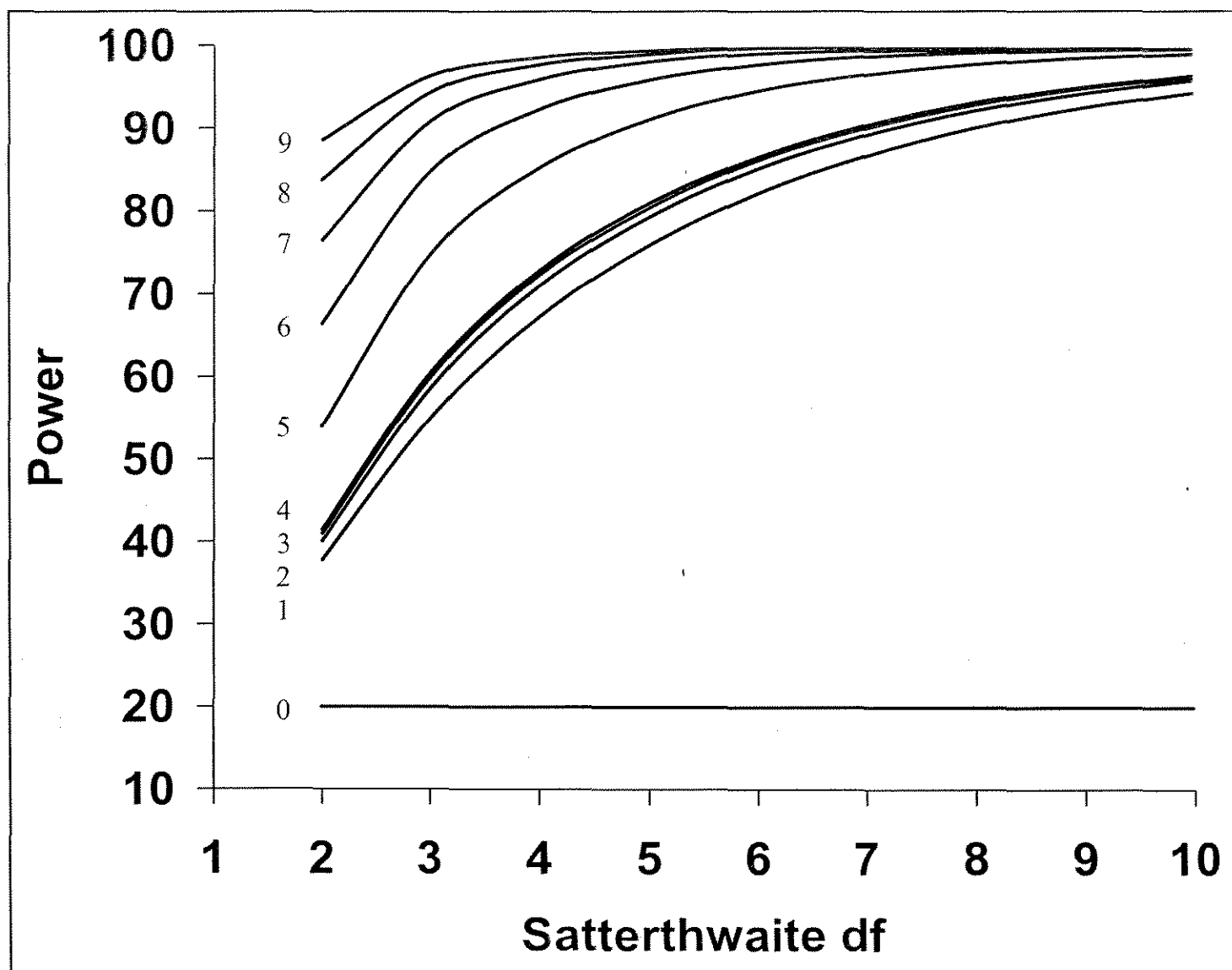


Figure 2. Estimated power to detect a change in tree basal area (m^2/ha) according to sample size (Satterthwaite df; $\alpha = 0.20$). Curves from bottom to top represent mean changes in basal area.

changes with 90% power would require a doubling of sampling effort (208 sample plots). Only six of 74 estimates of stem density for shrubs and seedlings were > 1000 stems/ha which indicates that current sampling effort has low power to detect even 50% changes in stem density (Figure 3).

Under our revised sampling design, estimates of basal area for black birch, Virginia and pitch pine, red maple, and northern red oak all had CVs $< 20\%$ for sample sizes ≥ 100 plots. Sample sizes of 140-180 plots produced CVs of 10-15% (Table 1). The mean Satterthwaite df for the redesigned

sampling design was > 16 for all species and sample sizes which should result in $> 80\%$ power to detect even small changes in basal area ($< 2 \text{ m}^2/\text{ha}$) (Table 1). The greater Satterthwaite df primarily was a result of fewer strata and more equitable sample sizes among strata.

As expected, CVs of stem density still were greater than for basal area, but were $< 40\%$ for all shrub and sapling species examined for sample sizes ≥ 100 plots (Table 2). Sample sizes of 140-180 plots produced CVs of 11-35%. The mean Satterthwaite df for the redesigned sampling design was > 8 for all sapling and shrub species and

sample sizes ≥ 100 plots, which should result in $> 80\%$ power to detect changes in shrub and sapling stem density of 300-400 stems/ha (Table 2).

DISCUSSION

The management and corresponding sampling objectives generated by workshop participants primarily relate to forest regeneration and succession. The measurement of succession and regeneration is based on the basal area and/or number of stems per hectare and the change in density of different species of overstory trees and shrubs and saplings over time within a

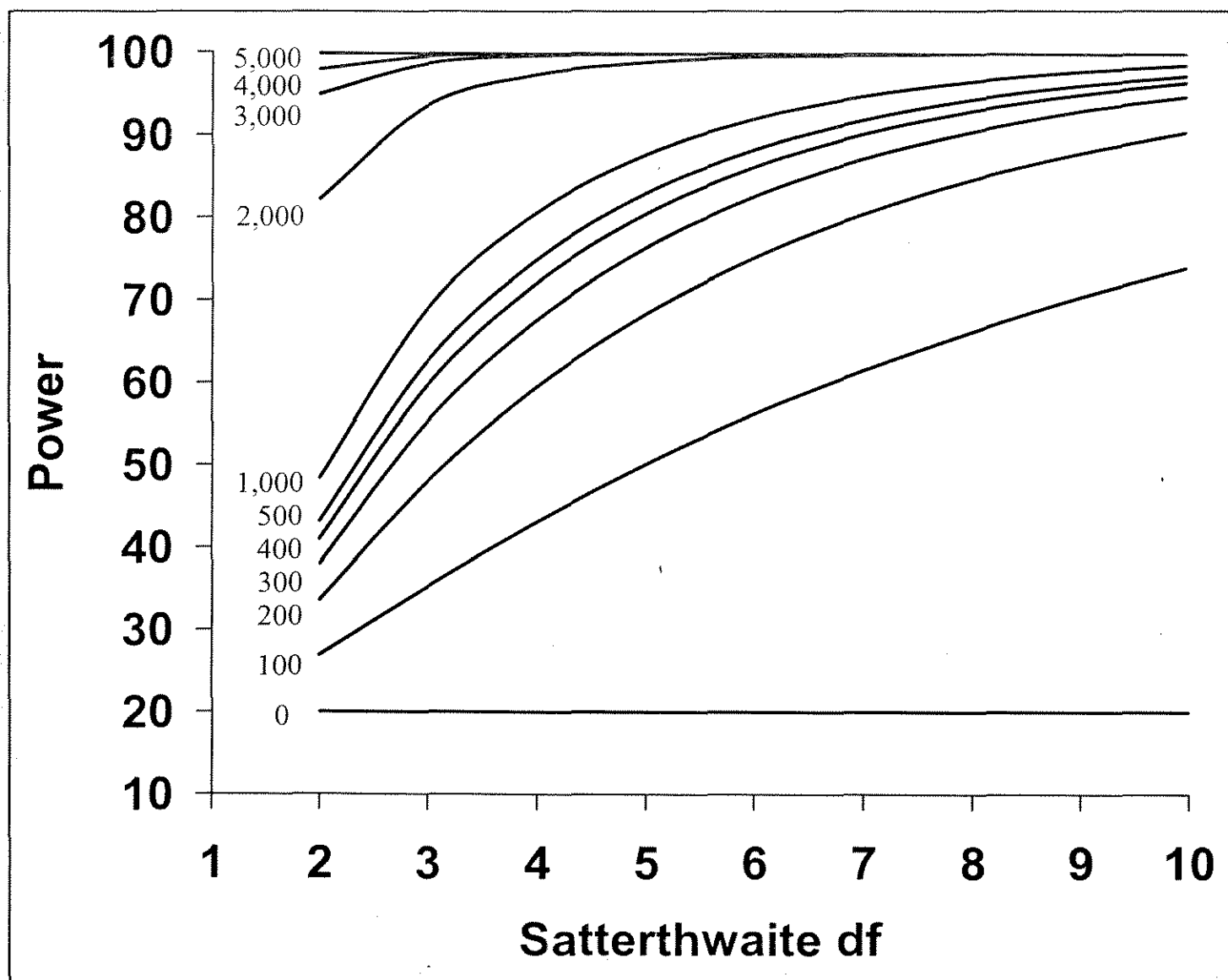


Figure 3. Estimated power to detect a change in shrub or sapling stem density (stems/ha) according to sample size (Satterthwaite df; $\alpha = 0.20$). Curves from bottom to top represent mean changes in stem density.

Table 1. Simulated mean basal area (m^2/ha), Satterthwaite degrees of freedom (df), and coefficient of variation (CV) for black birch, Virginia and pitch pine, red maple, and northern red oak 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			Northern red oak		
	$\bar{x}$	df	CV	$\bar{x}$	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	3.34	20.0	13.9
140	0.78	26.1	15.8	2.92	28.4	17.2	1.50	41.3	13.0	3.36	31.2	12.0
180	0.80	31.8	14.5	2.91	38.6	15.1	1.49	56.1	11.5	3.33	45.9	10.6
220	0.79	41.6	13.0	2.93	49.8	13.8	1.48	69.5	10.4	3.34	60.1	9.6
260	0.78	51.6	11.9	2.91	60.1	12.9	1.50	86.3	9.6	3.34	78.1	8.7

Table 2. Simulated mean stem density (stems/ha; 1–5 m tall), Satterthwaite degrees of freedom (df), and coefficient of variation (CV) for mountain laurel, spicebush, sassafras, flowering dogwood, and hrambles (*Rubus* spp.) 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	Mountain Laurel			Spicebush			Sassafras			Flowering Dogwood			<i>Rubus</i> spp.		
	$\bar{x}$	df	CV	$\bar{x}$	df	CV	$\bar{x}$	df	CV	Stem density	df	CV	Stem density	df	CV
100	6746	13.6	18.7	2655	16.2	24.8	692	25.1	15.0	516	12.2	21.7	5548	10.7	38.0
140	6743	19.3	16.3	2652	23.4	21.8	693	38.2	12.9	520	19.9	18.7	5578	14.8	34.2
180	6699	26.3	14.5	2607	32.5	19.3	689	56.0	11.3	521	27.4	16.6	5579	20.4	30.6
220	6804	33.8	13.1	2623	40.7	17.5	694	72.1	10.3	520	34.3	15.2	5629	26.6	27.9
260	6809	41.1	12.2	2670	48.4	16.5	692	87.9	9.5	521	41.4	14.0	5585	33.7	26.0

particular stratum. When focusing on a particular species within a stratum, the investigator must keep in mind that the density of one species is not independent of the density of another. Furthermore, variation in the number of stems per acre is usually large and dependent on stand dynamics. Due to this inherent variability in the data, workshop participants chose an $\alpha = 0.20$ in our sampling objective so that the number of sample sites (e.g., sample size or panel) needed in the monitoring program likely would be feasible. National parks like SHEN may be willing to accept a relatively high error rate because sampling objectives must be formulated that are not only measurable and specific but also achievable (NPS 2005).

Formulating specific management and sampling objectives for the vascular plant LTEM program at SHEN permitted statistical evaluation of the program. Estimating vegetation characteristics using LTEM data collected from 1987–2000 and the specified sampling design identified several problems with the original monitoring program at SHEN. First, all strata were sampled ≥ 2 times during 1987–2000, but not all at the same time. For example, northern red oak sites were sampled in one year, followed by sampling at cove hardwood sites the next year. This type of data collection protocol permitted estimates of changes in vegetation between two time periods (within a given forest cover type), but it did not permit an estimate of a given parameter (e.g., basal area of northern red oak) for a given year across all forest cover types. Second, not all strata contained > 1 sample plot, which made it impossible to calculate variances for some strata. For instance, it was not possible to estimate stand characteristics (e.g., variance) in the eastern hemlock vegetation types even though most stands were sampled every year, because there was only one sample plot. Third, the strata defined by the GIS could not separate the various pine stands, so pitch pine and Virginia pine were analyzed as if they occurred in a single

forest cover type (pine). Finally, some inconsistencies existed between strata and allocation of sampling sites. For example, the GIS analysis provided 27.2 ha in the high elevation yellow poplar stratum and 46.2 ha in the high elevation pine stratum, but these strata were not sampled in the original LTEM sampling design, possibly because of their small area ($< 0.2\%$ of total area of the park).

The power analysis of the vascular plant data collected under the original LTEM design indicated that precision of estimates of mean shrub and sapling densities were not sufficient to detect statistically significant changes. Our estimates of power assumed that the estimated change followed a t distribution, and that variance was positively correlated with the mean. Consequently, the estimates of power that we presented contain some unknown bias and precision; however, bias is likely low, although precision may be poor (Gerard et al. 1998).

Power analyses cannot be used to interpret results, and we do not recommend applying power curves to determine the “statistical power” of an estimate of change (Gerard et al. 1998). Rather, once data have been collected and estimates calculated, confidence intervals (CI) should be used to assess whether changes have occurred (e.g., whether the CI encompasses zero, and CVs, or the lengths of confidence intervals, should be used to assess the precision of estimates. The power analysis we conducted, however, indicated that the original LTEM sampling design for vascular plants was inadequate to detect specified changes in basal area or stem density for most species. In addition power curves that we generated suggested that only relatively large changes in shrub or sapling stem density had a reasonable chance of being detected under the original LTEM sampling design.

Errors associated with misidentification of species created difficulties in assessing whether the changes detected in basal area or stem density were caused by recording errors, environmental perturbations or reflected differences in life-history characteristics. In addition, missing data

were encountered when we reviewed the data collected under the original LTEM sampling design. These types of data collection errors are unavoidable, but can be minimized. Permanently marking trees with unique identifiers within each permanent plot will greatly reduce misidentification errors. Implementing a field-based data-entry system (Krueger and Rich 2001) can greatly reduce errors by prompting technicians to document the status of trees measured in previous years, checking for data-entry errors, and eliminating transcription errors from paper datasheets.

Despite the data recording errors, our statistical evaluation of the data collected under the original LTEM design indicated that the most needed change was to implement a sampling design that will permit regular estimates of park-wide parameters (e.g., an estimate of basal area), yet also permit estimates of trends over time (Urquhart et al. 1998). This type of sampling design would greatly improve the inferences that can be obtained from LTEM regarding changes in the vegetative communities in the park.

Overall, we provided the following recommendations for the LTEM program for vascular plants at SHEN using proposed management and sampling objectives:

- Strata should be defined by elevation, geology, and aspect in 16 categories.
- Samples should be allocated among strata proportional to the area of each stratum. This also will ensure a proper spatial distribution of sample sites.
- Each sample site within a stratum should consist of a single vascular plant plot, 24 m × 24 m, demarcated by four corner stakes, to record overstory tree species and dbh. In addition, percent coverage of ground cover, target exotic species, and herbaceous vegetation should be collected. Along two sides of the plot will be a 2-m × 24-m strip transect for sampling sapling and shrub stem density. We recommend using strip transects to sample sapling and shrub stem density

because they are easier to establish, and because strip transects are better suited to describing the density of species with clumped stem distributions (Elzinga et al. 1998). A 1-m × 12-m strip transect for sampling seedling density also will be established along two sides of the large (24 m × 24 m) vascular plant plot. Although seedling data will be collected in a quantitative manner, they will not be expected to provide statistically precise results for predicting biologically significant trends.

- Overstory trees (> 5 m tall) will be permanently marked to reduce data collection errors and improve repeatability of dbh measurements.
- All plots that fall on slopes of 3-26.5 % will be corrected for slope by multiplying the horizontal distance of a plot line by a slope correction factor (Kleinn et al. 2002). Plots that fall on slopes that exceed 26.5% will be excluded from the LTEM program due to difficulties in plot establishment on steeper slopes.
- The sampling effort will require two years to visit all plots. The total number of plots will be subdivided randomly into two sub-samples visited in successive years (i.e., interpenetrating sampling or split panel design; McDonald 2003). Therefore, a total of 160 plots (80/yr) is feasible and will provide sufficient precision to meet stated sampling objective. However, a rest period of up to five years between sampling events may be appropriate given the relatively slow growth and persistence of woody vegetation in SHEN.

We strongly recommend that, upon initial completion of all 160 plots, data be analyzed to estimate basal area and stem density for selected overstory trees and sapling/shrub species. Such an analysis would indicate if the sample sizes and sampling design would provide the desired precision of estimates of basal area and stem density.

CONCLUSIONS

For agencies considering long-term monitoring programs, we believe there are several important lessons to be learned from the vegetation-monitoring program at SHEN. First, a monitoring program should be based on specific, quantifiable, and attainable management and statistical objectives. Second, the sampling design should use strata, if warranted, that are unlikely to change during the monitoring period. Third, most people conduct and view monitoring or sampling as an instantaneous or at least a within-year effort. However, by considering time in units others than one year (e.g., a multi-year sampling interval), although there are some resulting restrictions on inferences, greater sample sizes can be achieved because of the longer sampling period. We recognize that although some events (e.g., fire, insect irruption) can cause large changes in forest conditions in a single year, this monitoring program was designed with interest in detection of long-term changes. Hence, changes that occur within a sampling period (two years) should be relatively unimportant compared to changes that may occur over decades or longer. We believe this is reasonable for vegetation monitoring because of the longevity of woody plants. Fourth, a statistical evaluation of the proposed sampling design should be conducted to assess whether it is likely to meet specified statistical objectives. Preferably, pilot data would be available to provide estimates of expected variability in the parameters being estimated. Fifth, an evaluation of the monitoring program should be done as soon as practicable to assess whether stated objectives could be met. If objectives are not met, then either management and sampling objectives or the sampling design can be modified. Sixth, our choices for a revised sampling design were limited by the historical data and sampling sites that we wanted to incorporate, where possible, into our new design. However, there are other approaches to placing plots on a landscape that resource managers may want to consider when implementing a monitoring program (e.g., McDonald 2002; Stevens and Olson 2004). Finally, annual (or some other recurring time interval) reports should be provided to administrators to ensure that

data are being analyzed, the monitoring program is meeting stated objectives, and that administrators, policy makers, and the public understand the importance and value of the monitoring program.

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Carolyn Mahan is an Associate Professor of Biology and Environmental Studies at The Pennsylvania State University, Altoona College. Her research interests center on threats to forested ecosystems, public lands management, and sciurid ecology and conversation.

Duane Diefenbach is Assistant Unit Leader of the Pennsylvania Cooperative Fish and Wildlife Research Unit and adjunct associate professor of wildlife ecology at The Pennsylvania State University. His research interests focus on estimation of wildlife population parameters.

Wendy Cass is the Botanist for Shenandoah National Park. She manages the Park's long-term forest monitoring program, and works to monitor and protect rare plant species and communities throughout the park.

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