

## Detection and Monitoring of Invasive Exotic Plants: A Comparison of Four Sampling Methods

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**Abstract** - The ability to detect and monitor exotic invasive plants is likely to vary depending on the sampling method employed. Methods with strong qualitative thoroughness for species detection often lack the intensity necessary to monitor vegetation change. Four sampling methods (systematic plot, stratified-random plot, modified Whittaker, and timed meander) in hemlock and red oak forests in the Delaware Water Gap National Recreation Area were compared for their ability to detect and monitor understory exotic invasive plant species. The timed-meander method best detected exotic invasive plants and documented richness. The stratified-random method was similar to the timed-meander method in terms of detection of exotic invasives and defining richness, but also provided estimates of species abundances and diversity. An initial combination of the timed-meander and stratified-random sampling designs followed by monitoring with the stratified-random method is suggested as a standard approach.

### Introduction

Successful early detection and subsequent monitoring of exotic invasive plant species in a forested area depend on the chosen sampling design. Methods that best measure richness of an area (e.g., timed meander) are limited by a qualitative estimate of species importance and an inability to define other vegetation patterns (Goff et al. 1982, Palmer 1995, Palmer et al. 1995). Likewise, those methods that enable a researcher to quantify the relative importance of each species and other patterns (e.g., systematic plots/grids) are limited by cost and time to adequately sample enough area for a full flora record (Peet et al. 1998, Stohlgren et al. 1998, Yorks and Dabydeen 1998). A sampling design that detects rare species, such as early establishing exotics, but is also capable of defining vegetation patterns and individual species' relative importance, would be optimal. Such a standard design could serve as a method for both early detection and long-term monitoring of invasions and impacts on associated native species (Etchberger and Krausman 1997, Peet et al. 1998, Stohlgren et al. 1998, Stokes and Yeaton 1994, Yorks and Dabydeen 1998).

In this paper, detection is defined as the ability to document the presence of a species, especially one that is rare in abundance compared to other species. Monitoring is defined as documentation of species' relative abundance over time. The goal of this research is to compare the utility of four methods to accurately describe all species present and their relative abundance, with particular interest in each method's ability to detect early-establishing exotic

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invasive or rare species. While mapping and survey methods that focus on particular species can efficiently describe the distribution of those species and monitor them for adaptive management purposes (Dewey and Anderson 2004), such methods do not accurately describe the relative abundance of the focal species nor are they designed to detect any non-focal species.

Sampling-method performance is dependent on the heterogeneity of the sampled vegetation type and the scale of the study. The required sampling intensity is determined in part by whether one defines a sample area's boundary by dominant vegetation homogeneity or by deliberate inclusion of the maximum amount of variation (i.e., sampling across an environmental gradient). Researchers seeking to classify vegetation types, or compare impacts of a treatment to *a priori* defined vegetation types, often stratify the sample area into homogeneous vegetation types (Barnes et al. 1982), which may also follow one or more resource gradients (Sardinero 2000). Researchers or land managers who wish to survey a defined area (such as a National Park or natural area) often focus on potential variation found across several resource gradients instead of nested homogeneous areas (Austin and Heyligers 1989). Focusing on heterogeneity, especially in large areas, may result in a loss of information in presumed homogeneous areas (Taylor et al. 1984). This study focuses on relatively small homogeneous forested areas (less than 5 ha). However, seemingly homogeneous forests, usually defined by the dominant tree species, are often quite heterogeneous at micro-topographic scales.

The homogeneity of a vegetation type may be impacted by different disturbances, and these effects may differ by forest stratum. For instance, while the vegetation is defined by an existing dominant canopy species, such as hemlock or oak, new canopy openings and changes in soil nutrients caused by tree death and insect or pathogen defoliation may result in a more heterogeneous understory (Beatty 2003, Orwig and Foster 1998, Yorks et al. 2001). The understory is where most of the early establishing exotic invasive species are likely to be found. Certain disturbances, such as early stages of insect defoliation, gap formation, and patchy burns, make defining homogeneous areas difficult. A more intense sampling design may be necessary to detect exotic plant species in early stages of establishment in forests, because exotics tend to respond positively to disturbances (Hobbs and Huenneke 1992, Lonsdale 1999).

The purpose of this study is to compare the effectiveness of four sampling methods of varying intensity—systematic plot, stratified-random plot with two scales, modified Whittaker, and timed meander—in detecting and monitoring exotic invasive plant species in relation to associated species within two forest types of the northeastern United States. Each of the four methods is commonly used to sample eastern deciduous forest understory vegetation (Elzinga et al. 2001, Goff et al. 1982).

Two questions are addressed: 1) Which of the four methods best detects exotic invasive species and defines the true species composition or flora? and 2) which method best describes plant species' relative abundance and,

consequently, may monitor vegetation change (i.e., invasion) more accurately? It is hypothesized that the stratified-random plot or modified Whittaker methods will be best at detecting and monitoring early-establishing exotics because both combine the positive quantitative aspect of the systematic-plot method and the qualitative thoroughness of the timed-mean-der method.

## Materials and Methods

### Study area

The Delaware Water Gap National Recreation Area (DWGNRA) is located in Pennsylvania and New Jersey, 60 km on either side of the Delaware River (41°00'00" to 41°22'30"N and 74°52'30" to 75°02'30"E). Within the DWGNRA, there are approximately 22,000 ha of forested land, 6% of which is evergreen (*Pinus strobus* L. [white pine] and *Tsuga canadensis* (L.) Carrière [eastern hemlock]), 85% deciduous (*Quercus rubra* L. [northern red oak], *Acer saccharum* Marshall [sugar maple], *Q. montana* Willd [chestnut oak], *A. rubrum* L. [red maple], and *Betula lenta* L. [yellow birch]), and 9% mixed deciduous and evergreen (Young et al. 2002).

Using a 1981 National Park Service database of the DWGNRA vegetation cover (Myers and Irish 1981), three hemlock stands and three red oak stands with at least 80% canopy cover and at least two ha in size, but no larger than five ha, were randomly selected and ground truthed for size, dominant vegetation, and degree of disturbance. The hemlock stands were infested with hemlock woolly adelgid, and moderate (25–50%) levels of defoliation were evident in a few trees within each stand (Royle and Lanthrop 1997). The red oak stands may have had a history of *Lymantria dispar* L. (gypsy moth) defoliation, but no defoliation was currently evident. Both forest types were located in a landscape impacted by current and historic human disturbances, such as fragmentation, roads, agriculture, harvesting, and recreation. All selected stands were at least 200 m long and 100 m wide; this criterion eliminated several steep narrow hemlock slopes.

### Sampling methods

The systematic-plot method, hereafter referred to as the systematic method, contained 32 one-m<sup>2</sup> plots arranged along a 200-m central transect. Four plots placed at each cardinal direction were arrayed 1 m away from a point 15 m on either side of the transect, at 50-m intervals along the transect (Fig. 1a). Percent cover of herbs, shrubs, and vines rooted in the plots, and percent cover and density of the tree seedlings under 1 m in height and rooted in the plots were measured for all plots. Cover was estimated to the 0.25% level using a plastic Mylar circle that was 0.5% of the 1-m<sup>2</sup> area. There was a < 0.25%-cover category arbitrarily given a value of 0.13%. This method sampled 0.2% of each site.

The stratified-random plot method, hereafter referred to as the random method, was composed of 60 plots, 40 of which were 1 m<sup>2</sup> in size and 20 of

which were 10 m<sup>2</sup> in size. These plots were stratified every 10 m along the 200-m central transect and at random distances (within the boundaries of the plot and not overlapping the plots on the transect) perpendicular to the transect (Fig. 1b). Percent cover in all 1-m<sup>2</sup> plots was estimated as described in the systematic method. In the 10-m<sup>2</sup> plots, a 0.5% Mylar circle was used to

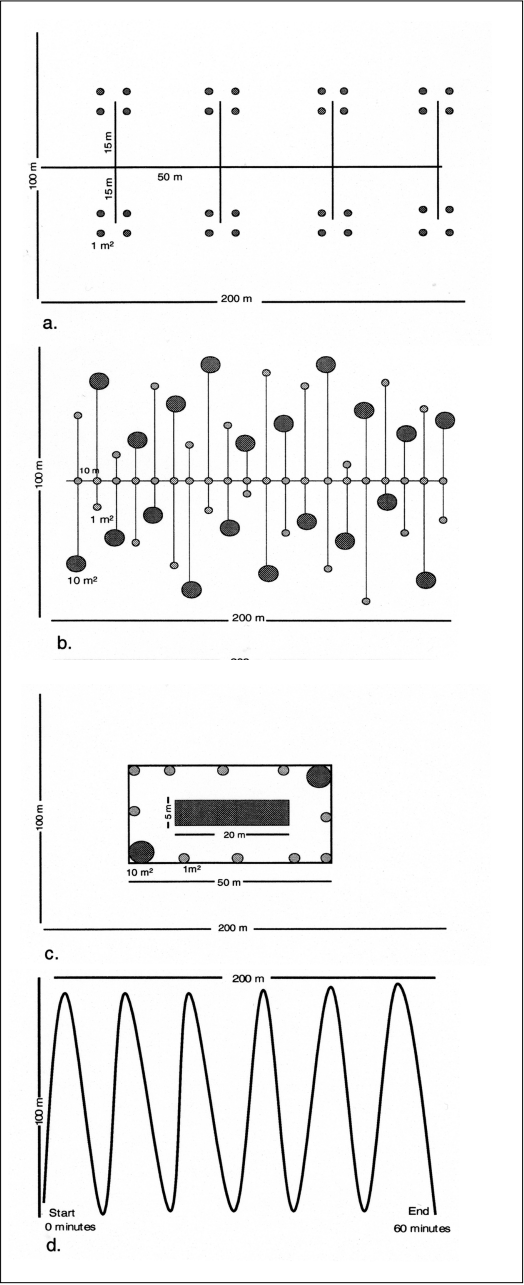


Figure 1. The four sampling methods: a. systematic plot method, b. stratified-random plot method, c. modified Whittaker method, and d. timed-meander method.

estimate cover of each herb, shrub, vine, and tree seedling species rooted in the plot, and I also calculated for each tree species the density of seedlings under 1 m in height and rooted in the plot. All site averages for species importance values were calculated per 1 m<sup>2</sup> (i.e., the differences in plot areas were taken into account before determining species importance). The random plot method may suffer less from autocorrelation bias associated with many transect and quadrat methods (Barnett and Stohlgren 2003, Stohlgren et al. 1998) because two-thirds of the plots are randomly located on either side of the central transect. This method sampled 0.7% of each site.

The modified Whittaker method included one large 1000-m<sup>2</sup> rectangular plot centrally located in the stand with one rectangular 100-m<sup>2</sup> plot, two circular 10-m<sup>2</sup> plots, and 10 circular 1-m<sup>2</sup> plots nested within the 1000-m<sup>2</sup> plot (Shmida 1984; Stohlgren et al. 1995, 1997a; Yorks and Dabydeen 1998). This design differs from the literature because the 1-m<sup>2</sup> and 10-m<sup>2</sup> plots were circular (as in the plot and random methods) instead of square as in the literature (Fig. 1c). Percent cover of each herb, shrub, vine, and tree seedling species, as well as density of each tree seedling species rooted in the plot, were estimated in the 1-m<sup>2</sup> plots as in the previous two methods. Herbs, shrubs, vines, and tree seedlings under 1 m present in the other plots were recorded. If species were present in any of the nested plots, they were not counted again in the 1000-m<sup>2</sup> area. All site averages for species importance values were calculated per 1 m<sup>2</sup>, so that differences in plot areas were taken into account before determining species importance. This method sampled 5% of each site.

The timed-meander method entailed thoroughly walking each site (within the 2-ha area) for one hour noting the time every 10 minutes as new species were tallied (Goff et al. 1982; Fig. 1d). If the number of new species listed did not decrease to zero in the last 10 minutes of walking, additional time would have been added, but this was not necessary. Because this is a plotless method, any variables based on plots could not be analyzed. This method sampled 100% of each site.

Importance values were calculated using relative cover for the herbs, shrubs, and vines, and relative cover and relative density for the tree seedlings for all measurable plots in each method. In the modified Whittaker plots that had only presence or absence information, each present species was arbitrarily given a value of 0.13 (similar to the more rare species that have a cover value of < 0.25%) before combining importance value estimates for each site. For the timed-meander method, importance values could only be based on species presence or absence in each site; relative values based on the number of other species present in each site were then calculated. Species importance values were pooled for all three sites in each forest type within each method (Appendix 1).

## Variables

Fifteen site-vegetation variables were evaluated: (1) richness, (2) number and (3) abundance of exotic invasives, (4) number and (5) abundance of

exotics that are not invasive (referred to as “exotics”), (6) number and (7) abundance of native invasives, (8) number and (9) abundance of native weeds/early successional species (referred to as “native weeds”), (10) number and (11) abundance of native species that are mutually exclusive of the other categories (referred to as “natives”), (12) species diversity, (13) species evenness, (14) number of predicted species from the species-area curve (referred to as “predicted species”), and (15) percent empty plots. Question 1, which asks which method best detects exotic invasive species and defines a true flora, was addressed by comparing richness and number of species within each species category using all four methods. The method that documents the highest number of species overall and within each category is considered the best. Question 2, which asks which method best describes plant species’ relative abundance and vegetation patterns, was addressed by comparing the abundance (percent cover) estimates of each of the above five species categories as well as species diversity, species evenness, predicted species, and percent empty plots using all methods but the timed-meander method. The method that samples the most area and whose predicted species (based on species area curves) is most similar to the highest number of actual species documented is considered the best method. Differences in forest type were also evaluated using the same 15 variables in order to help explain any potential interactions with sampling method.

Shannon’s index ( $H'$ ) was used to estimate the diversity for each site, and evenness was calculated by dividing  $H'$  by the natural log of each site’s richness (McCune and Mefford 1999). The Simpson index gave similar results and will not be presented. These diversity indices should be scrutinized further because their results are dependent on both number of species and the abundance of each species. For instance, sites with a high species number but few individuals (or low overall cover) tend to show only intermediate values of  $H'$  as a mathematical artifact of how  $H'$  is calculated (Austin 1999). Because the methods are being compared within the same area at one time period, species cover should not differ. However, when comparing forest types, the potential differences in species cover may influence any noted significant differences in  $H'$ ; i.e., oak-dominated sites may show higher  $H'$  values than the hemlock sites because most of the understory species in the oak stands may tend to have higher overall cover values.

Species-area curves and estimates of predicted species richness using the first-order jackknife estimator (Chiarucci et al. 2001) were calculated in PCORD v. 4 (McCune and Mefford 1999). Predicted species richness for modified Whittaker data was also calculated as a linear regression using  $S = b + d \log_{10} A$ , where  $S$  = number of species,  $b$  = the y intercept,  $d$  = the slope of the regression line, and  $A$  = the sample areas (1 m<sup>2</sup>, 10 m<sup>2</sup>, 500 m<sup>2</sup>, and 1000 m<sup>2</sup>; Stohlgren et al. 1995, 1997a, 1997c).

Exotic species were defined using several published state and regional flora (Fernald 1970, Gleason and Cronquist 1991, Rhoads and Block 2000). Determination of invasive exotic species was conservative, being

based on shared species included on Mid-Atlantic state exotic invasive plant species lists (Harmon 1999, Invasive Plant Council of New York 2003, McAvoy 2001, Native Plant Society of New Jersey 2003, Pennsylvania Department of Conservation and Natural Resources 2000, Virginia Department of Conservation and Recreation and Virginia Native Plant Society 2001), a USDA Forest Service list (USDA Forest Service, Eastern Region 1998), and published flora (Gleason and Cronquist 1991, Rhoads and Block 2000). Native invaders were defined by documentation in the literature on each species' invasiveness (de la Cretaz and Kelty 1999, Hill and Silander 2001, Luken 2003). The native weeds/early successional/gap species category may be the most subjective because it is based on a combination of information in flora and general ecological literature (Fernald 1970, Gleason and Cronquist 1991, Rhoads and Block 2000, Spurr and Barnes 1980). Nomenclature follows Gleason and Cronquist (1991) and Rhoades and Block (2000). All sampling was conducted by the author and a botanist trained (over the past five years) by the author to ensure consistency and accuracy (Helm and Mead 2003, Kercher et al. 2003). All sites were sampled between July 17 and July 29, 2002, and each took approximately 1.5–2 days to sample using all four methods, starting with the random method, followed by the plot method, then the modified Whittaker, and finally the timed meander.

### Statistical analysis

All comparisons were made at the site level (plot information being averaged in all but the timed-meander method). Herbs, vines, and shrubs were analyzed as a group separately from the tree seedlings. Percent similarity of species composition based on presence/absence data was determined using the Sorensen coefficient of similarity for each method-pair comparison for all sites and within each forest type (Kent and Coker 1992, van Tongeren 1987). Differences in Sorensen similarity for paired methods were tested using a one-way ANOVA, and multiple comparisons were made using Tukey's tests of significance; normality and homogeneous variance assumptions were met (Proc GLM in SAS 9.1).

A mixed-model repeated measures analysis (site as the random effect, method and forest type as the fixed effects) with an unstructured covariance model was used to test for differences among methods and forest types, as well as any interactions between methods and forest types, for each of the 15 vegetation variables (Proc Mixed in SAS 9.1). The abundance estimates of exotic invasives, exotics, native invasives, and native weeds for the herbs, vines, and shrubs were transformed ( $\log_{10}$ ) to ensure normality; a nonparametric smoothing function was incorporated in the mixed ANOVA models for the counts of exotic invasives, exotics, native weeds, and native invasives of the herbs, vines, and shrubs using a quadratic regression spline model and a toeplitz covariance structure (Proc Mixed in SAS 9.1; Pedan 2003). The same nonparametric smoothing procedure was used on the seedling count and abundance estimates for exotic invasives and native weeds as

well as percent empty plots. Multiple comparisons were based on the likelihood-ratio statistic using the SLICE option in Proc Mixed (Proc Mixed in SAS 9.1; Littell et al. 1998).

Results

The timed-meander method took a half hour, the systematic method 1–2 hours, the random method 2–4 hours, and the modified Whittaker 2–3 hours for two botanists to complete. Sampling time included plot set up.

Which method best detects exotic invasive species and defines a true composition or flora?

There were a total of 236 herb, shrub, and vine species (methods and forest types combined), with 82, 152, 119, 184 species found using the systematic, random, modified Whittaker, and timed-meander methods, respectively, and 176 and 160 species in the hemlock and oak stands, respectively. There were a total of 38 tree seedling species (methods and forest types combined), with 27, 31, 29, and 31 species found using the systematic, random, modified Whittaker, and timed-meander methods, respectively, and 31 and 34 species in the hemlock and oak stands, respectively.

*Description of exotic invasive species found.* There were a total of 12 different invasive exotic herb, shrub, and vine species (methods and forest types combined), with 6, 8, 8, and 8 different species detected using the systematic, random, modified Whittaker, and timed-meander methods, respectively. The methods differed within each forest type in terms of the exotic invasive plants they defined as most important (1 indicating highest ranking invasive exotic species by relative importance value; Table 1). Despite a lack of pattern among the methods and forest types, *Alliaria petiolata* (Bieb.) Cavara & Grande (garlic mustard), *Berberis*

Table 1. Exotic invasive herb, vine, and shrub species ranking by method and forest type. T = *Tsuga canadensis* (hemlock) forests and Q = *Quercus rubra* (red oak) dominated forests. Ranks are based on site-level importance values. Highest ranking species = 1; species with equal rankings have equal relative importance values; - = not present.

| Species                                           | Systematic |   | Random |   | Modified Whittaker |   | Timed meander |   |
|---------------------------------------------------|------------|---|--------|---|--------------------|---|---------------|---|
|                                                   | T          | Q | T      | Q | T                  | Q | T             | Q |
| <i>Alliaria petiolata</i> (Bieb.) Cavara & Grande | -          | 1 | 3      | 1 | 3                  | - | 1             | 1 |
| <i>Anthoxanthum odoratum</i> L.                   | -          | 1 | -      | - | 3                  | - | 3             | - |
| <i>Berberis thunbergii</i> D.C                    | -          | 2 | 1      | 4 | 1                  | 1 | 2             | 2 |
| <i>Berberis</i> cf. <i>vulgaris</i> L.            | -          | - | -      | 6 | -                  | - | -             | - |
| <i>Celastrus orbiculatus</i> Thunb.               | -          | - | -      | 3 | -                  | 3 | -             | - |
| <i>Elaeagnus umbellata</i> Thunb.                 | -          | - | -      | - | -                  | - | -             | 2 |
| <i>Euonymus alatus</i> (Thunb.) Siebold           | -          | - | -      | 5 | -                  | - | -             | - |
| <i>Lonicera morrowii</i> A. Gray                  | -          | - | -      | 6 | -                  | 1 | 5             | 3 |
| <i>Microstegium vimineum</i> (Trin.) A. Camus     | -          | 3 | 2      | - | 3                  | 2 | 1             | 1 |
| <i>Poa compressa</i> L.                           | 1          | 2 | -      | - | -                  | - | -             | - |
| <i>Rosa multiflora</i> Thunb.                     | -          | 3 | 4      | 2 | -                  | 3 | -             | 2 |
| <i>Rumex acetosella</i> L.                        | -          | - | -      | - | 2                  | - | 4             | - |



*thunbergii* DC. (Japanese barberry), and *Microstegium vimineum* (Trin.) A. Camus (Japanese stiltgrass) appeared to occur more commonly among the 12 exotic invasive species present. *Rumex acetosella* L. (sheep sorrel) was found only in hemlock forests, and *Celastrus orbiculatus* Thunb. (oriental bittersweet), *Elaeagnus umbellata* Thunb. (Autumn olive), and *Euonymus alatus* (Thunb.) Siebold (winged euonymus) were found only in oak forests. *Ailanthus altissima* (Miller) Swingle (tree of heaven) was the single exotic invasive tree seedling present, occurring only in the hemlock stands, but was detected by all methods. The systematic, random, modified Whittaker, and timed-meander methods detected 2, 5, 6, and 7 exotic invasive species, respectively, in hemlock forests, and 6, 7, 5, and 6 exotic invasive species, respectively, in oak forests, which suggests that sampling method choice for detection of exotic invasives may be more important in hemlock forests. *Epipactis helleborine* (L.) Crantz (bastard hellebore), an orchid species categorized as a non-invasive exotic, ranked relatively high, which may indicate it could become invasive. It was detected by all methods in the hemlock sites in which it was more common, but only the random and plot methods detected this species in the oak sites.

**Overview of species composition.** When comparing all sites for herbs, shrubs, and vines, none of the composition similarity values for each

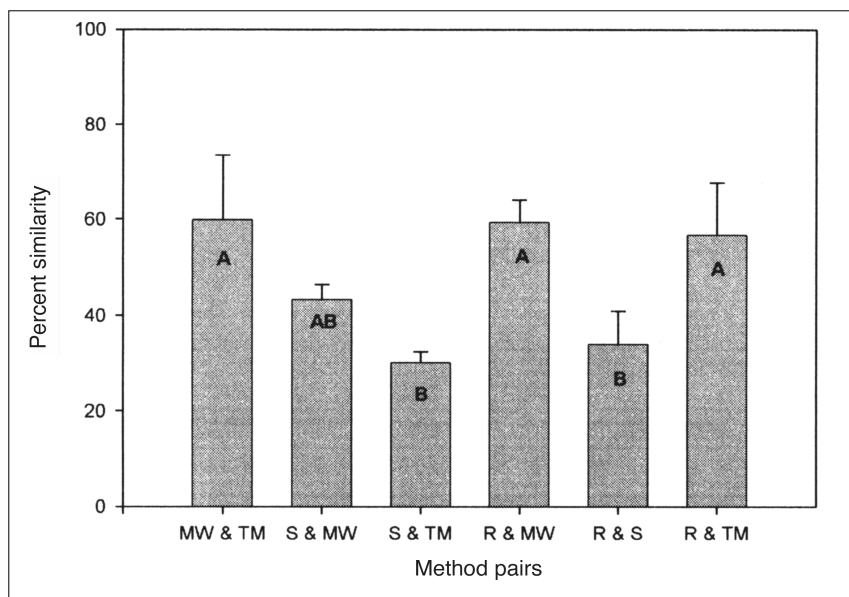


Figure 2. Percent similarity of method pairs based on presence/absence vegetation composition data for the hemlock forests. The Sorensen coefficient of similarity was used to compare each method pair. S = systematic plot method, R = stratified-random method, MW = modified Whittaker method, TM = timed-meander method. Method pairs with different letters are significantly different at  $\alpha \leq 0.05$ .

method pair were significantly different, though there was a trend for the random, modified Whittaker, and timed-meander methods to be more similar to each other than to the systematic method. The tree-seedling composition showed greater overall similarity among all methods for combined forest types (range = 65–80%) and within each forest type (range = 45–80%), with higher percent similarity values than noted for the herbs, shrubs, and vines (combined forest types range = 40–50%; separate forest types range = 30–60%).

A comparison of composition similarity of method pairs within each forest type for herbs, shrubs, and vines showed that there were significant differences in similarity among the methods within the hemlock forests ( $F = 8.11$ ,  $df = 5$ ,  $P < 0.001$ ; Fig. 2), but not the oak-dominated forests. The random, modified Whittaker, and timed-meander methods were much more similar to each other than they were to the systematic method in hemlock forests, though the modified Whittaker method was not significantly different from the systematic method. There were no significant differences in similarity among methods for either forest type for tree seedlings, though in both forest types the compositions resulting from the random, modified Whittaker, and timed-meander methods tended to be more similar to each than to the systematic method.

Table 2. Herb, shrub, and vine variable means for all sites by method. Means with different superscript letters are significantly different ( $\alpha \leq 0.05$ ). Standard errors are in parentheses. Not applicable (NA) designates those parameters which cannot be compared due to missing plot measures. Richness is observed counts of different species. Predicted species is the observed richness adjusted for sample size. Abundance equals the average actual percent cover per 1-m<sup>2</sup> plot for each site. Diversity is calculated using Shannon's index  $H'$ . Evenness is  $H'$  divided by the natural log of each site's observed richness.

| Variable            | Systematic                | Random                    | Modified Whittaker        | Timed meander            |
|---------------------|---------------------------|---------------------------|---------------------------|--------------------------|
| Richness            | 24.2 <sup>B</sup> (4.70)  | 49.5 <sup>A</sup> (8.74)  | 35.5 <sup>B</sup> (9.40)  | 65.0 <sup>C</sup> (6.83) |
| Exotic invasives    |                           |                           |                           |                          |
| Number              | 1.5 <sup>A</sup> (0.50)   | 2.3 <sup>A</sup> (0.88)   | 2.2 <sup>A</sup> (0.87)   | 4.3 <sup>B</sup> (0.56)  |
| Abundance           | 0.027 (0.013)             | 0.020 (0.015)             | 0.042 (0.036)             | NA                       |
| Exotics             |                           |                           |                           |                          |
| Number              | 0.33 (0.21)               | 0.83 (0.40)               | 0.67 (0.21)               | 1.33 (0.42)              |
| Abundance           | 0.0039 (0.0039)           | 0.0072 (0.0045)           | 0.00016 (0.00015)         | NA                       |
| Native invasives    |                           |                           |                           |                          |
| Number              | 2.2 <sup>A</sup> (0.65)   | 3.5 <sup>AB</sup> (0.56)  | 2.2 <sup>A</sup> (0.60)   | 4.0 <sup>B</sup> (0.36)  |
| Abundance           | 2.30 (1.73)               | 1.41 (0.89)               | 0.63 (0.63)               | NA                       |
| Native weeds        |                           |                           |                           |                          |
| Number              | 1.0 (0.47)                | 1.8 (0.37)                | 1.5 (0.47)                | 2.0 (0.45)               |
| Abundance           | 0.027 (0.016)             | 0.016 (0.012)             | 0.002 (0.001)             | NA                       |
| Natives             |                           |                           |                           |                          |
| Number              | 17.5 <sup>B</sup> (3.08)  | 36.8 <sup>A</sup> (6.41)  | 27.2 <sup>B</sup> (6.24)  | 48.8 <sup>C</sup> (5.20) |
| Abundance           | 5.35 (2.48)               | 3.07 (1.26)               | 4.07 (2.08)               | NA                       |
| Predicted species   | 36.0 <sup>B</sup> (6.4)   | 72.3 <sup>A</sup> (11.7)  | 59.8 <sup>AB</sup> (14.3) | NA                       |
| Diversity           | 2.19 <sup>B</sup> (0.203) | 2.81 <sup>A</sup> (0.264) | 2.82 <sup>A</sup> (0.316) | NA                       |
| Evenness            | 0.72 (0.057)              | 0.74 (0.059)              | 0.82 (0.067)              | NA                       |
| Percent empty plots | 31.3 (10.1)               | 27.2 (9.40)               | 33.3 (10.3)               | NA                       |

*Comparison of the related vegetation variables—herbs, shrubs, and vines.* The mixed-model repeated measures analysis of the herb, vine, and shrub data showed that the methods were significantly different without any forest and method interactions for richness ( $F = 128$ ,  $df = 3$ ,  $P < 0.001$ ), number of invasive exotics ( $F = 4.56$ ,  $df = 3$ ,  $P = 0.018$ ), native invasives ( $F = 3.41$ ,  $df = 3$ , and  $P = 0.043$ ), and number of natives ( $F = 108$ ,  $df = 3$ ,  $P = < 0.001$ ). The timed-meander method showed significantly higher herb, shrub, and vine richness than the systematic ( $P < 0.001$ ), random ( $P = 0.016$ ), modified Whittaker ( $P = 0.001$ ) methods, but the random method also had significantly higher richness than the systematic ( $P = 0.022$ ) and modified Whittaker methods ( $P = 0.003$ ) (Table 2). There were significantly more exotic invasive herbs, shrubs, and vines found using the timed-meander method compared to the systematic ( $P = 0.008$ ), random ( $P = 0.012$ ), and modified Whittaker ( $P = 0.007$ ) methods. More native invasive herb, shrub, and vine species were found using the timed-meander method than the systematic ( $P = 0.021$ ) and modified Whittaker ( $P = 0.021$ ) methods.

*Comparison of the related vegetation variables: tree seedlings.* The mixed-model repeated-measures analysis results for the tree-seedling data showed that the methods were significantly different without any significant interactions with forest type for richness ( $F = 8.81$ ,  $df = 3$ ,  $P = 0.031$ ) and number of native species ( $F = 82.6$ ,  $df = 3$ ,  $P = < 0.001$ ). Tree seedling richness and the number of native species were significantly lower for the

Table 3. Tree-seedling variable means for all sites by method. Means with different letters are significantly different ( $\alpha \leq 0.05$ ). Standard errors are in parentheses. Not applicable (NA) designates those parameters which cannot be compared due to missing plot measures. Richness is observed counts of different species. Predicted species is the observed richness adjusted for sample size. Abundance is the averaged actual percent cover per 1-m<sup>2</sup> plot for each site. Diversity is calculated using Shannon's index  $H'$ . Evenness is  $H'$  divided by the natural log of each site's observed richness.

| Variables           | Systematic               | Random                   | Modified Whittaker        | Timed meander            |
|---------------------|--------------------------|--------------------------|---------------------------|--------------------------|
| Richness            | 11.3 <sup>B</sup> (1.67) | 15.3 <sup>A</sup> (1.17) | 13.7 <sup>AB</sup> (1.45) | 16.8 <sup>A</sup> (1.17) |
| Exotic invasives    |                          |                          |                           |                          |
| Number              | 0.17 (0.17)              | 0.17 (0.17)              | 0.17 (0.17)               | 0.33 (0.21)              |
| Abundance           | 0.011 (0.011)            | 0.0015 (0.0015)          | 0.0060 (0.0060)           | NA                       |
| Exotics             | 0                        | 0                        | 0                         | 0                        |
| Native invasives    | 0                        | 0                        | 0                         | 0                        |
| Native weeds        |                          |                          |                           |                          |
| Number              | 3.3 (0.56)               | 3.7 (0.21)               | 3.2 (0.31)                | 3.5 (0.34)               |
| Abundance           | 0.31 (0.064)             | 0.44 (0.12)              | 0.50 (0.10)               | NA                       |
| Natives             |                          |                          |                           |                          |
| Number              | 7.83 <sup>B</sup> (1.38) | 11.3 <sup>A</sup> (1.20) | 10.3 <sup>AB</sup> (1.48) | 13.0 <sup>A</sup> (1.24) |
| Abundance           | 1.13 (0.470)             | 1.26 (0.433)             | 1.25 (0.263)              | NA                       |
| Predicted species   | 16.3 (3.07)              | 18.3 (1.28)              | 20.6 (2.42)               | NA                       |
| Diversity           | 1.9 (0.15)               | 2.1 (0.12)               | 2.2 (0.13)                | NA                       |
| Evenness            | 0.78 (0.04)              | 0.78 (0.03)              | 0.84 (0.04)               | NA                       |
| Percent empty plots | 40.6 (7.96)              | 38.9 (8.08)              | 38.1 (5.73)               | NA                       |

systematic method compared to the timed-meander ( $P = 0.011$ ,  $P = < 0.001$ , respectively) and random ( $P = 0.022$ ,  $P = 0.008$ , respectively) methods (Table 3).

**Which method best describes plant species relative abundance (i.e., relative importance) and, consequently, may monitor vegetation change (i.e., invasion) more accurately?**

*Overview of species relative abundance.* In each forest type, the methods differed in what they revealed to be the most important species (Appendix 1). The oak forests showed less dissimilarity of important species among the methods than the hemlock forests. While *Dennstaedtia punctilobula* was the most important species of hemlock forests using the random method, *Dryopteris marginalis* (marginal wood fern) and *Chimaphila maculata* (spotted wintergreen) were the most important using the systematic and modified Whittaker methods, respectively. The most important species for the timed-meander method in hemlock forests could be any of 14 species, but *D. marginalis* was not among these. The random and modified Whittaker methods shared *Vaccinium pallidum* (low-bush blueberry) as their most important species in oak forests, while the systematic method had *D. punctilobula* as its most important species. Both species were among the highest ranking species for the timed-meander method.

*Comparison of the related vegetation variables: herbs, vines, and shrubs.* The mixed-model repeated-measures analysis of the herb, vine, and shrub data showed that the methods were significantly different without any forest and method interactions for diversity ( $F = 15.2$ ,  $df = 2$ ,  $P = 0.014$ ) and predicted number of species ( $F = 14.4$ ,  $df = 2$ ,  $P = 0.015$ ) (Table 2). The systematic method had significantly higher native weed species abundance values than the modified Whittaker method, but this was only within oak forests (i.e., there was a significant forest interaction). Diversity of herbs, shrubs, and vines was significantly greater for the random and modified Whittaker methods compared with the systematic method ( $P = 0.009$  and  $P = 0.034$ , respectively). The random method had significantly more predicted herb, shrub, and vine species than the systematic method ( $P = 0.024$ ), surpassing the actual number (65) found by the timed-meander method (Table 2) and coming closest to the total number of species found (236; not averaged by site) for all methods.

The species-log area model for the modified Whittaker method (Stohlgren et al. 1997a, c) comparatively underestimated the possible number of species (i.e., it predicted an average of 48.3 herb, shrub, and vine species for 2 ha using all sites, 52.1 for hemlock sites, and 44.5 for red oak sites). Consequently, this method was not viewed as any more reliable than the first-order jackknife estimator, and the use of various species-area curve models to compare the four methods was not justified. The first-order jackknife estimated values for predicted number of herb, shrub, and vine species in the modified Whittaker method was most similar to the actual

richness values of the timed-meander method (i.e., 59.8 for all sites, 67.5 species for hemlock sites, and 52.1 species for red oak sites). Based on the species area curves, only 22 1-m<sup>2</sup> plots, instead of 60, were needed to achieve the same richness for the herbs, shrubs, and vines using the random method, while the systematic and modified Whittaker methods required 21 (instead of 32) and 9 (instead of 14), respectively.

*Comparison of the related vegetation variables tree seedlings.* The mixed-model repeated-measures analysis results for the tree-seedling data showed that the methods were not significantly different, with no significant interactions with forest type for any of the abundance or plot area variables (Table 3). The species-area curve showed that 25, 34, and 11 plots, instead of 32, 60, and 14 plots, were needed to reach the predicted species richness of the systematic, random, and modified Whittaker methods, respectively.

## Discussion

### **Which method best detects exotic invasive species and defines a true composition or flora?**

The timed-meander method and, to a lesser extent, the random method resulted in the highest estimates of species and, thus, best defined the flora and invasive exotic species of each site for herbs, vines, shrubs, and tree seedlings; however, the random method required much more effort. If the management goals of a site require only documentation of all species present and information on the relative abundance of such species is not important, the timed-meander method is the best of the four methods. These results are well supported by other floristic studies (Goff et al. 1982, Palmer 1995, Palmer et al. 1995). These two methods may sample the edges of the sites more effectively than the centrally based systematic-plot and modified Whittaker methods. However, most of the exotic species found in the sites were located throughout the sites' interiors and were often associated with canopy gaps.

Because of the inherent patchiness of forest understory vegetation (Beatty 2003), sampling a larger percentage of a site will logically result in better detection of the less common species. Despite their small size, the sites' understories (especially those of the hemlock forests) were heterogeneous compared to their overstories, which is supported by other studies in which sites were subjected to intermediate levels of disturbance (Sagers and Lyon 1997, Williams et al. 1999). However, it is important to point out that while the timed-meander method tended to detect more species of all species categories than any other method, it (like each of the other methods) did not detect all known species in each site. Species that were detected by one of the other three methods, but missed by the timed-meander method, included some sedges and grasses, which may have been more difficult to see while walking as opposed to bending over a plot at ground level. However, small

stature does not explain why the relatively large *Epipactis helleborine* was missed in the oak sites by both the timed-meander and modified Whittaker methods. The relatively dense ground cover in the oak sites may have influenced detection ability of the timed-meander method. The results of the timed meander could potentially vary greatly among data collectors if botanical skill level varies. In order for this method to be effective, those conducting the timed meander should be skilled field botanists who are already familiar with the site's flora. This condition may limit the timed-meander method's applicability.

The methods generated significantly different species compositions (e.g., a different flora) in the hemlock forests, but not in the oak forests, which suggests that forest type or degree of disturbance may influence the effectiveness of a sampling method in terms of documenting accurate composition. It is well-supported that a sampling design should reflect the vegetation structure (Bonham 1989, Chambers and Brown 1983, Elzinga et al. 2001, Kent and Coker 1992, Ohmann 1973). However, sampling-design choice often does not factor in additional disturbance-related factors that impact the vegetation structure and influence light, water, or nutrient availability. Given the depauperate understory of healthy hemlock forests (Hadley 2000, Orwig and Foster 1998), these results either reflect potential sampling weaknesses in previous studies of healthy hemlock forests or how hemlock forest understories compositions have changed in response to an overstory disturbance (i.e., adelgid infestations). In this study, two exotic species, *Rumex acetosella* and *Ailanthus altissima*, were more likely to invade the hemlock forests than the red oak forests. Both of these species show greater competitive ability in poor soils and may, in the case of *R. acetosella*, prefer such soils (Banasova 1989, Hu 1979, Kowarik 1995). The invasion or colonization of all these sites by both exotic and native species is still sparse and patchy, resulting in a very heterogeneous understory. The timed-meander and random methods were the best at detecting species of all categories in such a heterogeneous understory. Forest understories, in general, may become more heterogeneous as larger areas respond to new invasive insects and pathogens in conjunction with natural and anthropogenic overstory tree removals, and sampling designs ideally should be able to document these responses effectively.

Although the modified Whittaker method sampled 5% of each site, it was not able to detect as many native species as the random method, which only sampled 0.7% of each site. In this case, sampling a greater percentage of the area did not result in greater detection ability. The centrally based design of this method appeared to have missed several patches of native species at each site.

The random method's greater sampling intensity may explain its ability to detect more species. Approximately half of the 60 plots were needed to achieve the 49.5 herb, shrub, and vine species richness and

15.3 tree-seedling species richness based on the species-area curves. This suggests that the two scales (1 m<sup>2</sup> and 10 m<sup>2</sup>) used may be more important than the number of plots. The smaller plot size is best suited for the patches of vegetation that are relatively dense, while the larger plots are more likely to detect species in widely spaced vegetation (Chambers and Brown 1983, Mosley et al. 1989), and the forests sampled (especially the hemlock forests) in this study have both types of understory vegetation patterns. Thus, these results support the use of variable plot sizes to increase intensity, instead of increasing the number of plots (Barnett and Stohlgren 2003, Frischknecht 1981, Stohlgren et al. 1997a).

**Which method best describes plant species relative abundance (i.e., relative importance) and, consequently, may monitor vegetation change (i.e., invasion) more accurately?**

Because the random method, of the four methods, estimated species cover from a larger area than the systematic and modified Whittaker methods, and it predicted more species (based on species-area curves) than the systematic method, I infer that it came closer to defining true diversity, evenness, and species abundance. While the modified Whittaker method sampled 5% of each site, only 0.05% occurred in plots in which species percent cover was estimated. The timed-meander method is clearly limited in its ability to detect changes in species abundance and their relative importance because of its reliance on presence-absence data. The modified Whittaker method showed lower abundance values of native invasive and native weedy herb, vine, and shrub species compared to the random and systematic methods. This is not too surprising considering many relatively abundant species in the larger modified Whittaker plots were arbitrarily given a small cover estimate when all plots were standardized to 1 m<sup>2</sup>. The ten 1-m<sup>2</sup> plots, on which cover was measured, failed to document the importance of some of the dominant species within the native invasives and native weeds categories when compared to the random method.

The exotic invasives and exotics were low in abundance, so that differences were statistically difficult to detect. While invasion has occurred in both forest types of the DWGNRA, invasion is still in the establishment stage because few invasive exotic plants make the top 20 most important species in any of the methods (Appendix 1). One or a few of the currently rare species could be sampled more effectively using adaptive cluster sampling or two-stage sampling (Elzinga 2001; Thompson 1991, 1994), but these methods are not suitable for community-level studies. If abundance of the invasive exotic species increases over time with a subsequent decrease in abundance of associated native species, the random method will be the best of the four methods to capture this change. It is expected that the exotic invasive species will behave much like the native weeds in response to disturbances and changes in resource availability (Attiwill and Adams 1993, Boring et al. 1981, Gilliam 2002, Phillips and Shure 1990). Consequently,

the tendency for the systematic method to overestimate the abundance of native weeds, at least in oak forests, and the modified Whittaker method to underestimate their abundance and importance when compared to the random method, is of concern. The native species showed no significant difference in abundances estimated by each method because most of the native species were relatively rare.

The random method's greater sampling intensity may place more credence on its estimate of species abundance. Moreover, inclusion of a larger plot size also ensures a more accurate measure of larger vegetation such as shrubs, vines, and highly clonal perennial herbs. The modified Whittaker method is also composed of multiple scales and did comparatively well in estimating richness, but its abundance estimates and importance values are based on a much smaller sample area compared to the random method. Consequently, this method, which has been suggested as a standard sampling method (Barnett and Stohlgren 2003; Chong et al. 2001; Stohlgren et al. 1995, 1997b), is considered unsuitable for monitoring. However, modifications of the modified Whittaker method, such as estimating cover in the 10-m<sup>2</sup> plots, using two (or more) 1000-m<sup>2</sup> areas instead of one (indeed, Stohlgren et al. [1997a] suggests using one modified Whittaker plot per actual 1000 m<sup>2</sup> of area), and adding more 1-m<sup>2</sup> and 10-m<sup>2</sup> plots, may result in vegetation variable estimates similar to that of a combined random and timed-meander approach. These changes would increase the effort required considerably. Also, some areas may be of a shape not conducive to the modified Whittaker plot layout. In contrast, the random method can be manipulated by dissecting the transect to fit existing land forms, being careful to avoid overlap of plots.

If plots of a different scale were added to the systematic plot design, it may perform more similarly to the random method in terms of species abundances. However, there is an additional benefit to the random method shared by the timed-meander method in that permanent plot establishment is not required for monitoring. Choosing random plots each sampling period predictably will increase the variance (i.e., decrease the sampling precision), possibly requiring that all 60 plots (or more) always be sampled. Nonetheless, the cost and effort associated with maintaining the permanent plots over a long period may make sampling more random plots worthwhile. If colonization by new species is occurring and changes in species cover or composition is expected, i.e., after a disturbance event, the relative precision of permanent plots may decrease. Maintenance of the permanent plots may not be warranted with very weak year-to-year plot correlations. Permanent plots are also more likely to suffer from impacts caused by data collectors, who make repeated visits to the plots, or wildlife attracted to the markers (Elzinga et al. 2001).

## **Conclusions**

A standard method of sampling vegetation for both detection and monitoring needs to be both flexible and intensive enough to address differences



in patterns of various forest types. Combining the random method and the timed-meander method ensures that most species will be found and that vegetation patterns are detected; these are proposed as potential standard sampling methods.

The results of this study indicate that four sampling methods used to evaluate the same area produce four different results. While it is comforting to know that overall compositional differences among the methods were insignificant in one of the two forest types, conclusions that one would make about the most important exotic invasive species (or species in general), richness, number and abundance of natives and exotics, diversity, and evenness would differ depending on the method employed. If the goal is solely to detect the presence of invasive exotic species (or all species), the timed-meander method (or a similar method) is most suitable. However, detection is rarely sufficient when evaluating success or failure of control strategies and management or impacts of invasion. Such assessments require monitoring, and the random method (or a method of similar intensity) is the strongest for estimating changes in relative abundance. Consequently, an initial combined effort of the timed-meander and random methods, followed by subsequent monitoring using the random method, is most prudent. If significant changes in composition are suspected (i.e., after a disturbance or environmental stress event), it is advisable to use the timed-meander method periodically to assess the detection strength of the random method.

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**Appendix 1.** The top 20 most important herb, shrub, and vine species and top 10 tree-seedling species pooled for all three sites in each forest type and within each method. \* = exotic; \*\* = invasive exotic; + = native invasive; ++ = native weed (or early successional/gap species); no mark = native exclusive of the other categories. A dash is used to indicate that a species was not present in the top 20. The highest rank is “1.” Equivalent ranks within a method are possible and occur more often within the timed-meander method. S = systematic, R = random, MW = modified Whittaker, T-m = timed meander.

### Eastern Hemlock Forest – Herbs, Shrubs, and Vines

| Species                                                                        | S  | R  | M-W | T-m |
|--------------------------------------------------------------------------------|----|----|-----|-----|
| <i>Dryopteris marginalis</i> (L.) A. Gray. (marginal fern)                     | 1  | -  | -   | 2   |
| <i>Eupatorium rugosum</i> Houttuyn. (white snakeroot)                          | 2  | -  | 5   | 1   |
| * <i>Verbascum thapsus</i> L. (common mullein)                                 | 3  | -  | -   | -   |
| <i>Osmunda claytoniana</i> L. (interrupted fern)                               | 4  | -  | 12  | -   |
| <i>Vaccinium</i> L. sp. (blueberry)                                            | 5  | -  | -   | -   |
| <i>Potentilla simplex</i> Michx. (old-field cinquefoil)                        | 6  | -  | -   | -   |
| <i>Collinsonia canadensis</i> L. (northern horse-balm)                         | 7  | -  | -   | -   |
| * <i>Epipactis helleborine</i> (L.) Crantz. (helleborine)                      | 8  | 13 | 12  | -   |
| <i>Aster puniceus</i> L. ssp. <i>firmus</i> (Nees) A.G. Jones. (bristly aster) | 9  | -  | -   | -   |
| <i>Plantago</i> L. sp. (plantain)                                              | 10 | -  | -   | -   |
| <i>Carex cephalophora</i> Muhl. (sedge)                                        | 11 | -  | -   | -   |
| <i>Rubus</i> L. sp. (bramble)                                                  | 12 | -  | -   | -   |
| <i>Carex festucacea</i> Schk. (sedge)                                          | 13 | -  | -   | -   |
| <i>Monotropa uniflora</i> L. (Indian pipe)                                     | 13 | -  | -   | 1   |
| ++ <i>Phytolacca americana</i> L. (pokeweed)                                   | 14 | 16 | 12  | -   |
| <i>Osumunda cinnamomea</i> L. (cinnamon fern)                                  | 15 | -  | -   | -   |
| <i>Carex</i> L. sp. (sedge)                                                    | 16 | -  | -   | -   |
| + <i>Thelypteris noveboracensis</i> (L.) Nieuwl. (New York fern)               | 17 | -  | -   | -   |
| <i>Vaccinium angustifolium</i> Aiton. (lowbush blueberry)                      | 17 | 8  | -   | -   |
| <i>Tiarella cordifolia</i> L. (foam flower)                                    | 18 | -  | -   | -   |
| <i>Dennstaedtia punctilobula</i> (Michx.) Moore. (hayscented fern)             | -  | 1  | 7   | 1   |
| <i>Vaccinium stamineum</i> L. (deerberry)                                      | -  | 2  | 4   | -   |
| <i>Vaccinium pallidum</i> Aiton. (hillside blueberry)                          | -  | 3  | 2   | 1   |
| <i>Carex pensylvanica</i> Lam. (sedge)                                         | -  | 4  | 3   | 1   |
| <i>Mitchella repens</i> L. (partridge berry)                                   | -  | 5  | 10  | 1   |
| <i>Polystichum acrostichoides</i> (Michx.) Schott. (Christmas fern)            | -  | 6  | 11  | 2   |
| ++ <i>Erechtites hieraciifolia</i> (L.) Raf. (fireweed)                        | -  | 7  | 12  | 2   |
| <i>Chimaphila maculata</i> (L.) Pursh. (spotted wintergreen)                   | -  | 9  | 1   | 1   |
| <i>Diphasiastrum digitatum</i> (Dill. Ex A. Braun) Holub. (ground cedar)       | -  | 10 | -   | -   |
| <i>Carex striatula</i> Michx. (sedge)                                          | -  | 11 | -   | -   |
| <i>Dryopteris intermedia</i> (Muhl.) A. Gray. (wood fern)                      | -  | 12 | 12  | 2   |
| <i>Aster divaricatus</i> L. (white heart-leaved aster)                         | -  | 14 | 12  | 1   |
| <i>Viola blanda</i> Willd. (sweet white violet)                                | -  | 15 | -   | -   |
| <i>Carex swanii</i> (Fern.) Mackenzie (sedge)                                  | -  | 17 | -   | -   |
| <i>Carex bromoides</i> Willd. (sedge)                                          | -  | 18 | -   | -   |
| <i>Solidago caesia</i> L. (blue-stemmed goldenrod)                             | -  | 19 | -   | -   |
| <i>Panicum acuminatum</i> Sw. (panic grass)                                    | -  | 20 | -   | -   |

| Species                                                                   | S | R | M-W | T-m |
|---------------------------------------------------------------------------|---|---|-----|-----|
| <i>Carex digitalis</i> Willd. (sedge)                                     | - | - | 6   | -   |
| <i>Maianthemum canadense</i> Desf. (Canada mayflower)                     | - | - | 7   | 1   |
| ** <i>Berberis thunbergii</i> DC. (Japanese barberry)                     | - | - | 8   | -   |
| <i>Parthenocissus quinquefolia</i> (L.) Planchon.<br>(Virginia creeper)   | - | - | 9   | 1   |
| <i>Hamamelis virginiana</i> L. (witchhazel)                               | - | - | 10  | -   |
| + <i>Vitis</i> L. sp. (grape)                                             | - | - | 10  | 1   |
| ** <i>Alliaria petiolata</i> (Bieb.) Cavara & Grande<br>(garlic mustard)  | - | - | -   | 1   |
| ** <i>Microstegium vimineum</i> (Trin.) A. Camus<br>(Japanese stiltgrass) | - | - | -   | 1   |
| + <i>Toxicodendron radicans</i> (L.) Kuntze. (poison ivy)                 | - | - | -   | 1   |
| <i>Deschampsia flexuosa</i> (L.) Trin. (hairgrass)                        | - | - | -   | 2   |
| <i>Polygonatum pubescens</i> (Willd.) Pursh. (Solomon's seal)             | - | - | -   | 2   |

### Red-Oak Dominated Forest – Herbs, Shrubs, and Vines

| Species                                                                 | S  | R  | M-W | T-m |
|-------------------------------------------------------------------------|----|----|-----|-----|
| + <i>Dennstaedtia punctilobula</i> (Michx.) Moore.<br>(hayscented fern) | 1  | 2  | 8   | 1   |
| <i>Vaccinium stamineum</i> L. (deerberry)                               | 2  | 3  | 3   | -   |
| + <i>Thelypteris noveboracensis</i> (L.) Nieuwl. (New York fern)        | 3  | 12 | -   | -   |
| <i>Polystichum acrostichoides</i> (Michx.) Schott.<br>(Christmas fern)  | 4  | 6  | 13  | -   |
| <i>Deschampsia flexuosa</i> (L.) Trin. (hairgrass)                      | 5  | 5  | 4   | 1   |
| <i>Vaccinium pallidum</i> Aiton. (hillside blueberry)                   | 6  | 1  | 1   | 1   |
| <i>Gaylussacia baccatta</i> (Wangenh.) K. Koch. (huckleberry)           | 7  | 4  | 2   | -   |
| <i>Osmunda cinnamomea</i> L. (cinnamon fern)                            | 8  | 14 | -   | -   |
| <i>Osmunda claytoniana</i> L. (interrupted fern)                        | 9  | -  | -   | -   |
| <i>Chimaphila maculata</i> (L.) Pursh. (spotted wintergreen)            | 10 | 7  | 6   | 1   |
| <i>Podophyllum peltatum</i> L. (mayapple)                               | 11 | 8  | 15  | -   |
| <i>Aralia nudicaulis</i> L. (sarsaparilla)                              | 12 | -  | -   | 1   |
| <i>Mitchella repens</i> L. (partridge berry)                            | 13 | -  | -   | -   |
| <i>Maianthemum canadense</i> Desf. (Canada mayflower)                   | 14 | 13 | 12  | -   |
| <i>Eupatorium rugosum</i> Houttuyn. (white snakeroot)                   | 15 | -  | -   | 1   |
| <i>Rubus flagellaris</i> Willd. (northern dewberry)                     | 16 | 18 | 10  | -   |
| ** <i>Anthoxanthum odoratum</i> L. (sweet vernal grass)                 | 17 | -  | -   | -   |
| + <i>Toxicodendron radicans</i> (L.) Kuntze. (poison ivy)               | 18 | 16 | -   | 1   |
| + <i>Pteridium aquilinum</i> (L.) Kuhn. (bracken fern)                  | 19 | -  | -   | -   |
| <i>Quercus ilicifolia</i> Wangenh. (bear oak)                           | 19 | -  | -   | -   |
| <i>Viburnum acerifolium</i> L. (maple-leaf viburnum)                    | -  | 9  | 9   | 1   |
| <i>Lindera benzoin</i> (L.) Blume. (spice bush)                         | -  | 10 | -   | -   |
| <i>Parthenocissus quinquefolia</i> (L.) Planchon.<br>(Virginia creeper) | -  | 11 | -   | 1   |
| <i>Carex pensylvanica</i> Lam. (sedge)                                  | -  | 11 | 5   | 1   |
| <i>Desmodium nudiflorum</i> (L.) DC. (naked tick-trefoil)               | -  | 15 | 15  | 1   |
| <i>Vaccinium angustifolium</i> Aiton. (lowbush blueberry)               | -  | 17 | 7   | -   |
| <i>Carex</i> L. sp. (sedge)                                             | -  | 17 | -   | -   |
| <i>Carex cephalophora</i> Muhl. (sedge)                                 | -  | -  | 11  | -   |
| <i>Carex digitalis</i> Willd. (sedge)                                   | -  | -  | 14  | -   |
| <i>Uvularia perfoliata</i> L. (bellwort)                                | -  | -  | 16  | -   |
| <i>Cypripedium acaule</i> Aiton. (pink lady-slipper)                    | -  | -  | 17  | -   |

| Species                                                                   | S | R | M-W | T-m |
|---------------------------------------------------------------------------|---|---|-----|-----|
| ** <i>Berberis thunbergii</i> DC. (Japanese barberry)                     | - | - | 18  | -   |
| <i>Carex swanii</i> (Fern.) Mackenzie (sedge)                             | - | - | 18  | 1   |
| ** <i>Alliaria petiolata</i> (Bieb.) Cavara & Grande<br>(garlic mustard)  | - | - | -   | 1   |
| <i>Galium circaezans</i> Michx. (wild licorice)                           | - | - | -   | 1   |
| ** <i>Microstegium vimineum</i> (Trin.) A. Camus<br>(Japanese stiltgrass) | - | - | -   | 1   |
| <i>Monotropa uniflora</i> L. (Indian pipe)                                | - | - | -   | 1   |
| <i>Polygonatum biflorum</i> (Walter) Elliott. (Solomon's seal)            | - | - | -   | 1   |
| <i>Potentilla simplex</i> Michx. (old-field cinquefoil)                   | - | - | -   | 1   |
| * <i>Veronica officinalis</i> L. (common speedwell)                       | - | - | -   | 1   |
| + <i>Vitis</i> L. sp. (grape)                                             | - | - | -   | 1   |

### Eastern Hemlock Forests – Tree Seedlings

| Species                                                          | S  | R  | M-W | T-m |
|------------------------------------------------------------------|----|----|-----|-----|
| ++ <i>Betula</i> L. sp. (birch)                                  | 1  | 2  | -   | -   |
| <i>Carpinus caroliniana</i> Walter. (blue beech)                 | 2  | 6  | 3   | -   |
| ++ <i>Acer rubrum</i> L. (red maple)                             | 3  | 1  | 4   | 1   |
| <i>Tsuga canadensis</i> (L.) Carrière (eastern hemlock)          | 4  | 4  | 8   | 1   |
| ++ <i>Prunus serotina</i> Ehrh. (black cherry)                   | 5  | 9  | 6   | 1   |
| <i>Quercus montana</i> Willd. (chestnut oak)                     | 6  | 3  | 1   | 2   |
| <i>Amelanchier arborea</i> (Michx. f.) Fern. (serviceberry)      | 7  | 7  | 5   | 1   |
| <i>Quercus rubra</i> L. (northern red oak)                       | 8  | 8  | 2   | -   |
| <i>Quercus alba</i> L. (white oak)                               | 9  | -  | -   | 1   |
| ++ <i>Liriodendron tulipifera</i> L. (tulip poplar)              | 10 | -  | 10  | -   |
| ++ <i>Betula lenta</i> L. (sweet birch)                          | -  | 5  | 7   | -   |
| <i>Carya glabra</i> (Miller) Sweet. (pignut hickory)             | -  | 10 | 9   | 1   |
| <i>Acer saccharum</i> Marshall. (sugar maple)                    | -  | -  | -   | 1   |
| <i>Fagus grandifolia</i> Ehrh. (American beech)                  | -  | -  | -   | 1   |
| ** <i>Ailanthus altissima</i> (Miller) Swingle. (tree of heaven) | -  | -  | -   | 2   |

### Red-Oak Dominated Forests — Tree Seedlings

| Species                                                     | S  | R  | M-W | T-m |
|-------------------------------------------------------------|----|----|-----|-----|
| <i>Acer saccharum</i> Marshall. (sugar maple)               | 1  | 2  | 1   | -   |
| <i>Quercus montana</i> Willd. (chestnut oak)                | 2  | 1  | 3   | -   |
| ++ <i>Acer rubrum</i> L. (red maple)                        | 3  | 3  | 2   | 1   |
| <i>Fraxinus americana</i> L. (white ash)                    | 4  | 6  | 9   | 1   |
| <i>Quercus alba</i> L. (white oak)                          | 5  | 4  | 4   | -   |
| <i>Quercus rubra</i> L. (northern red oak)                  | 6  | 8  | 7   | 2   |
| <i>Fagus grandifolia</i> Ehrh. (American beech)             | 7  | 5  | 6   | 1   |
| <i>Amelanchier arborea</i> (Michx. f.) Fern. (serviceberry) | 8  | 9  | 8   | 1   |
| <i>Quercus velutina</i> Lam. (black oak)                    | 9  | -  | -   | 1   |
| ++ <i>Betula</i> L. sp. (birch)                             | 10 | -  | 5   | -   |
| <i>Carya glabra</i> (Miller) Sweet. (pignut hickory)        | -  | 7  | -   | -   |
| <i>Ostrya virginiana</i> (Miller) K. Koch. (ironwood)       | -  | 10 | -   | 2   |
| <i>Carpinus caroliniana</i> Walter. (blue beech)            | -  | -  | 10  | -   |
| <i>Carya</i> Nutt. sp. (hickory)                            | -  | -  | -   | 2   |
| <i>Pinus strobus</i> L. (white pine)                        | -  | -  | -   | 3   |
| ++ <i>Prunus serotina</i> Ehrh. (black cherry)              | -  | -  | -   | 3   |