Measuring Tree Seedlings and Associated Understory Vegetation in Pennsylvania's Forests

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Abstract.—The Northeastern Research Station's Forest Inventory and Analysis (NE-FIA) unit is conducting the Pennsylvania Regeneration Study (PRS) to evaluate composition and abundance of tree seedlings and associated vegetation. Sampling methods for the PRS were tested and developed in a pilot study to determine the appropriate number of 2-m microplots needed to capture variability in seedling abundance. The findings resulted in a decision to use one 2-m fixed-radius microplot per 7.3-m fixed-radius subplot of the NE-FIA design. Preliminary results indicate that one-half to two-thirds of the region's forests would require remedial treatment if preferred species are the management objective.

Forest inventory data are being used to monitor understory communities as part of the inventory of Pennsylvania by the Northeastern Research Station's Forest Inventory and Analysis (NE-FIA) unit (McWilliams *et al.* 2002). The primary objective of the landscape-level Pennsylvania Regeneration Study (PRS) is to determine the composition and abundance of tree seedlings and associated understory vegetation. The PRS is part of a larger research initiative by cooperating institutions to develop site- and species-specific stocking guidelines and other management criteria for the range of forest systems in the State. The results of a pilot study to test and evaluate sampling methods for tree seedlings and understory communities are presented along with preliminary results from the first year of data collection.

Methods

Study Region

The PRS region consists of the entire State and is excellent for regeneration measurements and assessments (fig. 1a), as complicated forest associations abound: mixed mesophytic in the southwest (Braun 1985); mixed oak throughout but concentrated in the Central Appalachians; Allegheny and northern hardwoods along the northern tier; coniferous systems mixed throughout; and several other cover types (see Fike 1999). Actual species composition and structure vary greatly due to interrelated factors such as topographic location, land use and disturbance history, anthropogenic forces, and geographic differences. An overpopulation of white-tailed deer (*Odocoileus virginianus* Zimmerman) that has devastated regeneration over vast areas adds a particularly complex factor to this mix (McWilliams *et al.* 1995). Current deer populations are well above the thresholds for healthy understory development (deCalesta and Stout 1997).

Determining the Number of Microplots to Measure

Sampling methods for the PRS were tested and developed from a pilot study using a subset of NE-FIA sample locations during the 2000 field season (McWilliams *et al.* 2001). Sample plots occupy 2,400-ha hexagons that mosaic the State. Because the NE-FIA sample is measured over 5 years, 20 percent of the sample locations are measured each year in an "interpenetrating" fashion; that is, no plots are measured in two adjacent hexagons in a given year. Regeneration was measured during the leaf-on season; the interpenetrating concept (fig. 1b) was

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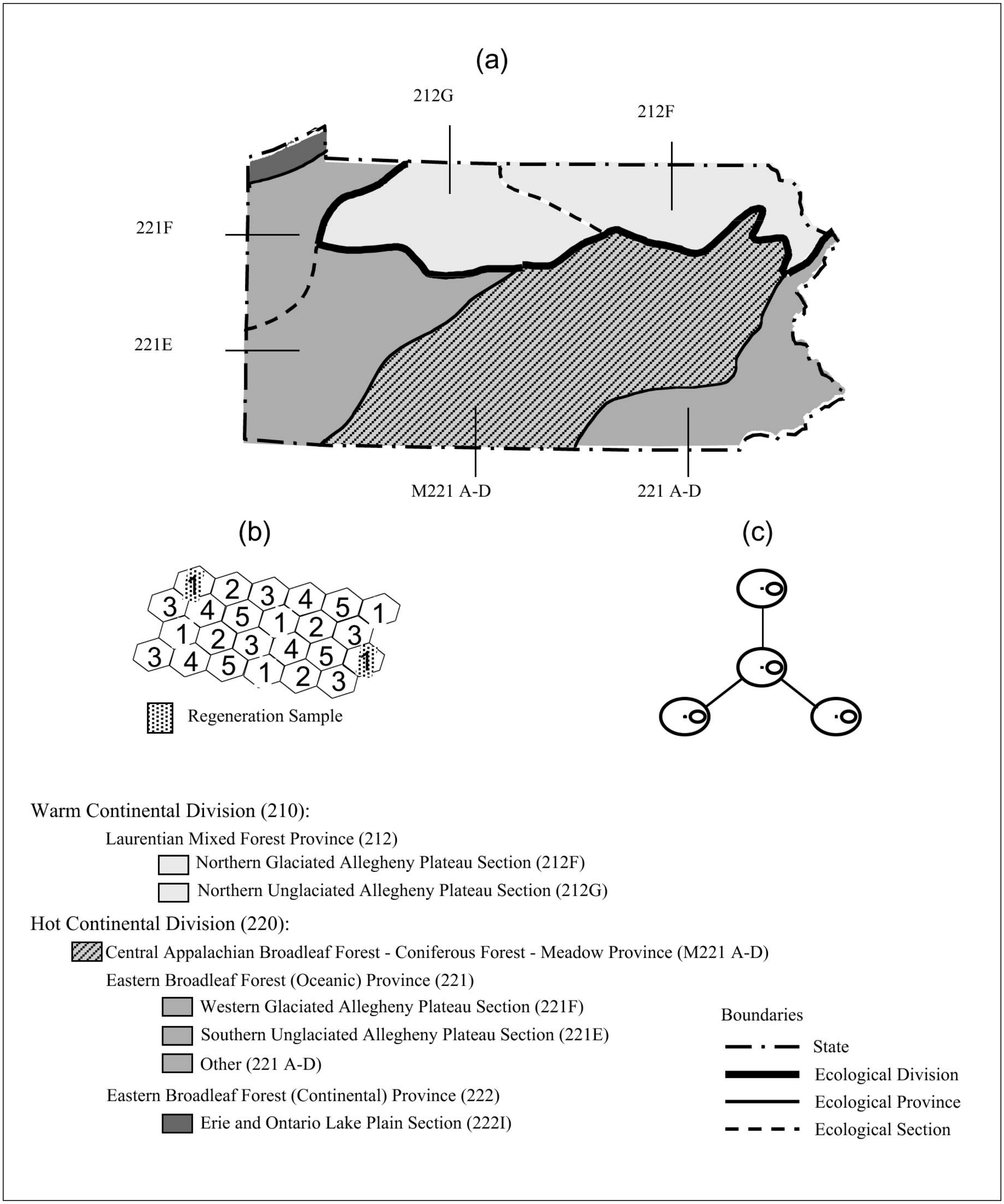
Figure 1.—*Ecoregions of the study region (a), systematic interpenetrating sample design (b), and sample location layout (c), Pennsylvania.*



used. Each year, about 300 regeneration plots are measured. The NE-FIA sample location consists of four 7.3-m fixed-radius subplots spaced 36.5 m apart with a 2-m fixed-radius microplot used for saplings (fig. 1c).

One objective of the pilot study was to determine the appropriate number of 2-m microplots needed to determine in situ variability in seedling abundance. A model was fit for every number and spatial combination of 16 microplots—the maximum that would fit onto the sample location, or four microplots per subplot.

A relative-variance function relates the plot and sampling design variables to the attribute of interest. A relative-variance function for a single plot of varying size (z) takes the form (Smith 1938):

$$R_i(z) = b_{0i} z^{b_{1i}} \quad (1)$$

where:

b_{1i} = a negative exponent relating the area sampled to the relative-variance of an attribute i such as species

b_{0i} = a coefficient

As b_{1i} approaches 0, little information is gained by increasing plot size, whereas as b_{1i} approaches -1, increasing the plot size provides new information. Scott (1993) extended Smith's formula to include the case of multiple subplots:

$$R_i(m, \overline{d}, z) = b_{0i} m^{b_{1i}} \overline{d}^{b_{2i}} z^{b_{3i}} \quad (2)$$

where:

m = the number of subplots

$\overline{d}$ = averaged paired distance between subplots

z = subplot size

In this application, the distance between the subplots and the size of the plots is fixed. Therefore, the only variable is the number of plots. The relative-variance was replaced by its square root, the coefficient of variation (CV).

$$CV_i\ (m) = b_{0i}\ m^{b_{1i}} \quad (3)$$

Using nonlinear regression, the coefficients b_{0i} and b_{1i} converged to 1 and 0 respectively for any combination of species, and subplots. Linearizing the coefficient of variation equation, by taking the natural log of both sides allowed a differentiation of the coefficients.

$$1\text{n}\ (CV_i\ (m)) = 1\text{n}\ (b_{0i}) + b_{1i}\ 1\text{n}(m) \quad (4)$$

The intercepts varied by species, but the slopes ranged from -0.6 to -0.16. Figure 2 shows the plotted function for all species combined. Individual species had similar curves. Since the curve was flat for four or more microplots, the decision is to use one 2-m microplot per 7.3-m subplot.

Sample Design

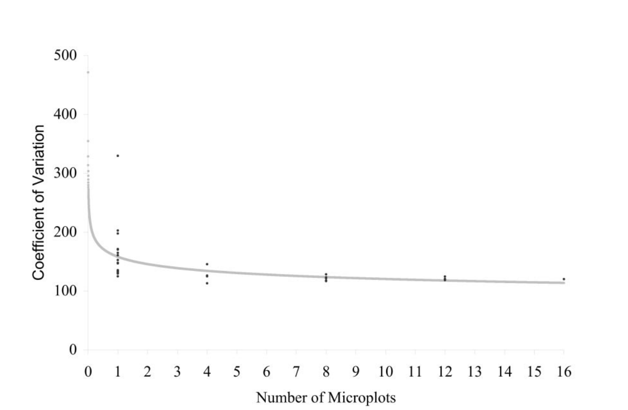
The overall nested plot design follows protocols used by Marquis (1994). A focus session with field staff following the pilot-study fieldwork resulted in suggestions for modifying tally procedures. For example, the number of tree-seedling height classes was reduced from eight to six without sacrificing scientific utility. The final design consists of a tally of all fully established seedlings (less than 2.5 cm in diameter) by species, source, and height class. Seedling source includes stump sprout, other seedling, and a "competitive" category for large-seeded deciduous species. The minimum threshold of 1.9-cm root-collar diameter for competitive status was based on Brose and Van Lear's (1998) findings for long-term stem survival. Microplot variables also include standard NE-FIA sapling measurements, presence of a large tree, and site limitations. Percentage cover of associated understory vegetation was estimated by species using the larger subplot. Marquis (1994) found that the 7.3-m size captured the variation of fern, grass, and other herbaceous vegetation. Associated understory vegetation was tallied using standard FIA codes for woody shrub species and three groups for other life forms: fern, grass, other herbaceous.

Preliminary Results

Indicators of Regenerative Capacity

Indicators used to analyze advance tree seedlings were developed to provide results that span a range of stocking that

Figure 2.—*Coefficient of variation for numbers of tree seedlings as a function of numbers of microplots used.*



reflects both standard guidelines (Gingrich 1967, Sander *et al.* 1976) and those for the high deer impact-conditions of Pennsylvania (Marquis and Bjorkbom 1982). The standard guideline for acceptable stocking is 25 seedlings per 2-m microplot versus 100 for high deer-impact conditions. Each sample tree is weighted by height class before the thresholds are applied:

Height Class	Weight
5.1 cm to 14.7 cm	1
14.7 cm to 0.3 m	1
0.3 m to 0.9 m	2
0.9 m to 1.5 m	20
1.5 m to 3.1 m	50
Greater than 3.1 m	50

Any combination of weighted stems that meets or exceeds the minimum number required is considered adequate stocking. For example, one seedling from 1.5 to 3.1 meters in height represents 50 seedlings. The indicators also used the tally of saplings (2.5 to 12.5 centimeters in diameter) to fully account for understory tree stocking. The results were partitioned by species groupings that reflect a range of management objectives: preferred, commercial, or woody (McWilliams *et al.* 1995).

Advance Tree-seedling Component

Applying the stocking thresholds to the sample data provides estimates of the proportion of forest that met or did not meet accepted silvicultural guidelines for advance tree-seedling stocking (table 1). The sample data were filtered to include only forested sample locations within the range of stocking where silvicultural guidelines indicate sufficient light for tree-seedling establishment (from 40- to 75-percent stocked with overstory trees). The findings indicate from one-third to one-half of the region's forests would need some form of remedial treatment if commercially acceptable species are the management objective; one-half to two-thirds require remedial treatment if preferred species are desired. Estimates for the indicators were lower for the Laurentian Mixed Forest Province and the Eastern Broadleaf Forest (Oceanic) Province (East) than for the Central Appalachian Broadleaf-Coniferous Forest-Meadow Province and Eastern Broadleaf Forest (Oceanic) Province (West) (Bailey 1995). Data from future samples should reveal additional spatial information, for example, test results of ecoregions and deer management zones for detectable differences in regenerative capacity; and data specific to natural and managed systems, advance- and post-disturbance regeneration, and composition of understory communities.

Associated Understory Vegetation

Tree seedlings and associated understory vegetation compete for growing space (Lorimer *et al.* 1994). Using percentage cover as a surrogate for growing space allows us to compare cover for samples that did and did not meet the tree-seedling stocking thresholds. Results for the two stocking guidelines by vegetative component are shown in table 2. Samples that did not meet the thresholds had more growing space allocated to associated understory vegetation than those that did. Fern was particularly opportunistic. The most common ferns in Pennsylvania, rhizomous, are not preferred deer food, and quickly spread across the forest floor in the absence of competition for available light.

Conclusions

The PRS results are commonly cited in policy discussions within Pennsylvania's environmental community because the implications for forest management are controversial. These include significantly reducing the State's doe herd, installing and maintaining deer fencing, applying herbicides and other control measures, and introducing prescribed fire in areas where species such as *Quercus* spp. are desired future stand cohorts. The PRS sampling protocols and indicators are useful for characterizing understory vegetation. Future work will be directed toward refining existing methods with the study team focusing on reviewing and expanding specific indicators to address a wider range of questions.

The detailed understory measurements collected in this study can be used to address additional research questions. Extensions include developing models for prospective vegetational changes based on overstory-understory relationships, gaining insight into differences between advance- and post-disturbance regeneration, additional indicator development, and improving stocking guidelines for managed and unmanaged eastern hardwood forests. Understory measurements also will improve estimates of understory biomass and carbon by vegetational component.

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Table 1.—*Percentage of samples that met regeneration indicator thresholds by species group, stocking guideline, and ecoregion, Pennsylvania, 2001*

Species group	Stocking guideline	Ecoregion[a]				
		All	EBF-W	PLAT	C APP	EBF-E
Preferred	Standard	48	58	45	44	50
	High deer	31	45	24	30	22
Commercial	Standard	66	69	65	64	61[b]
	High deer	51	57	46	52	39
Woody	Standard	72	77	68	72	67[b]
	High deer	56	66	47	58	50

[a] EBF-W=Eastern Broadleaf Forest (Oceanic) Province - West; PLAT=Laurentian Mixed Forest Province (Plateau); C APP=Central Appalachian Broadleaf - Coniferous Forest - Meadow Province; EBF-E=Eastern Broadleaf Forest (Oceanic) Province - East.
[b] Indicates nonsignificant differences between standard and high deer guidelines for H_0: $P_s > P_{hd}$ at the 95% confidence level.

Table 2.—*Mean percentage cover by threshold status, vegetative component, stocking guideline, and species group, Pennsylvania, 2001*

	Vegetative Component[a]							
	F	FGH	SB	All	F	FGH	SB	All
Threshold status	Standard				High deer			
				Preferred				
Met	23[b]	21[b]	17[b]	18 [b]	20	21 [b]	16 [b]	18 [b]
Not met	28	25	16	22	27	24	16	21
				Commercial				
Met	22	20	16 [b]	18	20	19	16 [b]	18
Not met	31	29	17	24	31	27	16	23
				Woody				
Met	23	20	16 [b]	18	19	19	16 [b]	18
Not met	32	29	18	25	33	27	17	23

[a] F=fern; FGH=fern, grass, and other herbaceous; SB=woody shrubs and vines.
[b] Indicates nonsignificant differences between vegetative components for H_0: $P_{NOT} > P_{MET}$ at the 95% confidence level.

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