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Can Cover Data Be Used as a Surrogate for Seedling Counts in Regeneration Stocking Evaluations in Northern Hardwood Forests?

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Abstract

Assessment of regeneration can be time-consuming and costly. Often, foresters look for ways to minimize the cost of doing inventories. One potential method to reduce time required on a plot is use of percent cover data rather than seedling count data to determine stocking. Robust linear regression analysis was used in this report to predict seedling count data from percent cover data based on 3,800 plots on which both count and cover data were collected. Results showed very poor relationships of cover data to seedling counts overall. The weakest relationships were found in plots that had received a shelterwood seed cut without any other regeneration preparation in the past. The better relationship came from plots where competition was reduced through herbicide application and shelterwood seed cutting. Immediately following herbicide application, when total seedling numbers were lowest, the relationship of cover to counts was best, with r-squared values as high as 0.8 for black birch, and between 0.4 and 0.6 for the smallest black cherry and red maple. These numbers quickly declined as seedlings developed. Cover data cannot reliably serve as a surrogate for seedling counts.

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INTRODUCTION

Accurate assessment of seedling stocking on sample plots is essential to prescribing treatments to meet landowner regeneration objectives for a stand (Marquis et al. 1992). Sampling requires substantial time to complete, especially in large stand areas. Stocking criteria for regeneration often are based on species identity, size, and stem counts and when numbers of desired species are present above a certain threshold size and count, a plot is considered stocked (Grisez and Peace 1973, Leak 1969, Marquis et al. 1992, Sander 1971). Some foresters looking for ways to minimize the time required for regeneration assessment have considered the potential of simply quantifying cover by species and height class on sample plots. When stocking criteria based directly on percent cover are not available, this approach requires conversion equations that can accurately predict seedling counts from percent cover data.

The SILVAH stand inventory, analysis, and prescription decision support system requires stem counts by species and height class from either 6-foot-radius or milacre regeneration sample plots. The stocking standards for these plots were developed over time for Allegheny and northern hardwoods (Grisez and Peace 1973, Marquis 1974, Marquis et al. 1992) and through a collaborative expert synthesis of research conducted elsewhere for mixed oak forests (Brose et al. 2008, Stout et al. 2007). McWilliams et al. (1995) extended the SILVAH approach for use with intensive regeneration data collected on U.S. Department of Agriculture, Forest Service Forest Inventory and Analysis (FIA) plots across Pennsylvania. Later the Pennsylvania Game Commission began to use these FIA data as a key measure related to its third deer management objective of managing deer "for healthy and sustainable forest habitat" (Rosenberry et al. 2009: 65).

Recently, some users of the SILVAH stand inventory, analysis, and prescription decision support system (Brose et al. 2008, Marquis et al. 1992) and its extensions in the policy arena have asked for equations to convert percent cover data to estimates of stocking. In other words, they ask if we can translate the required stem count thresholds into percent cover thresholds, or provide equations that reliably predict stem counts from percent cover. To answer these questions, we used study data collected over 12 years on the Allegheny National Forest in northwestern Pennsylvania that included both percent cover and seedling count data in broad size classes on the same plots. The purpose of this analysis was to determine whether seedling counts can be accurately predicted from percent cover data.

METHODS

Data from a long-term regeneration study were used to construct robust linear regression models in SAS (SAS Institute Inc. 2011). The study was conducted at 10 sites on the Allegheny National Forest to study nontarget effects of a one-time herbicide application using glyphosate and sulfometuron methyl (Ristau et al. 2011, Stoleson et al. 2011, Trager et al. 2013). In this study, development of regeneration after a shelterwood seed cut with no further preparation of regeneration was contrasted with development following a shelterwood seed cut and a one-time herbicide treatment to reduce competition from understory vegetation known to limit regeneration development, such as ferns, American beech (*Fagus grandifolia* Ehrh.), and striped maple (*Acer pensylvanicum* L.) (Horsley and Bjorkbom 1983, Horsley and Marquis 1983). Data from both the shelterwood only and the shelterwood and herbicide plots were used for this analysis, with each analysis run separately.

Thirty temporary circular milacre sample plots were established in each sample year (1992, 1994, 1995, 1996, 1998, and 2000) on a systematic grid to adequately cover the area. In 2002 and 2004, 20 plots per site were sampled rather than 30 because within-stand variability decreased as stand development progressed. Plants ≤5 feet tall within the plot, or with parts leaning into the plot, were identified and the percentage of the plot covered by each species was recorded. Height classes were <1 foot, 1 - 3 feet, and >3 - 5 feet. Cover in each of the three height categories was estimated visually in 1-percent intervals up to 5 percent, then by 5-percent intervals up to 100 percent. Because plants occurred in overlapping layers, the total cover on a plot could exceed 100 percent. Species present on the plot, but covering <1 percent of plot area, were recorded as 1 percent cover to indicate their presence.

Using the same plot centers, we counted seedlings by species in the same three height classes used for percent cover. There were eight sample years: 1992 and 1994 pretreatment and 1995, 1996, 1998, 2000, 2002, and 2004 post-treatment. Herbicide was applied in mid-August 1994. A total of 3,800 (1,600 treated and 2,200 control) plots with both seedling counts and percent cover data served as the basis for regression analyses. Sample plots from different years were considered independent because temporary plot locations were used rather than permanently marked plot centers. Regression was run with the PROC ROBUSTREG procedure in SAS (SAS Institute Inc. 2011).

The robust regression technique removed outliers and down-weighted high leverage points by using the mm estimation option, which uses high breakdown value estimation and efficient estimation techniques. Percent cover data were transformed with the arcsine (square root) transformation typically used with proportion data ranging from 0 to 1, and count data were transformed with a square root transformation as is typical with count data to ensure normality and homogeneous variance. Data were tested for normality before and after transformation and found to have normally distributed residuals after the transformation. Within a species and size class, any data points where both cover and count were equal to zero were eliminated from the regression because there were so many of these points in the data set. Regression lines were forced through the origin by using the NOINT option because when cover is zero, count is also zero for any species and size class. Equations were of the form:

$$\sqrt{\boldsymbol{seedling\ count\ (species\ x)}} = \beta_1 * \sin^{-1}\sqrt{\boldsymbol{percent\ cover\ (species\ x)}}$$

where β_1 is the slope, and intercept was forced through zero. In addition to pooled plot regressions across years, data were separated by height classes and years to determine if regressions of a particular size class or time since disturbance produced stronger relationships than the pooled data.

RESULTS

Data from this study included 12 tree seedling species, of which 5 were consistently present and able to be used for regression analysis. Overall, the relationship between cover and counts was poor, especially in the shelterwood-only plots (Table 1). On these plots r-squared values ranged from 0.043 to 0.456 (Table 1). Black cherry (*Prunus serotina*) <1 foot tall had the best relationship ($r^2 = 0.456$), followed by red maple (*Acer rubrum*) ($r^2 = 0.435$) and black birch (*Betula lenta*) ($r^2 = 0.211$). On shelterwood-herbicided plots r-squared values ranged from 0.006 to 0.554 following treatment (Table 2). The best relationship between cover of seedlings and counts of seedlings was that of <1 foot red maple ($r^2 = 0.554$), followed by <1 foot black cherry ($r^2 = 0.510$) (Table 2). A scatter plot and associated regression line (Fig. 1) show that the data had strongest representation from plots with low cover and low counts and data were highly variable.

If regression data were separated by year, seedling size class, and species, the proportion of variability accounted for by the regression varied with time (Figs. 2-3). Best regressions on shelterwood-only plots were for <1 foot black cherry ($r^2 \approx 0.500$) in all years and <1 foot and 1-3 foot red maple in 1995 and 1996 ($r^2 \approx 0.600$) (Fig. 2), both of which responded to additional light created by shelterwood seed cutting. On shelterwood-herbicide plots r-squared values were as high as 0.8 for black birch very shortly after the herbicide treatment (Fig. 3). All herbicide and shelterwood plot regressions were strongest for the five species in the first 2 years after treatment (1995 and 1996). However, red maple and black cherry <1 foot maintained similar relationships throughout the study ($r^2 \approx 0.600$), and 1-3 foot red maple and black cherry increased their proportion of variability accounted for by the regressions through time (Figs. 2-3).

Table 1.—Results from regression analysis[a] of 2,200 sample plots following shelterwood seed cutting

Species	Height (feet)	N	Slope	r-squared
Acer pensylvanicum	<1	524	2.764	0.126
	1 – 3	416	2.022	0.143
	3 – 5	347	0.600	0.045
Acer rubrum	<1	2,145	18.140	0.435
	1 – 3	332	5.109	0.142
Betula lenta	<1	1,331	5.352	0.211
	1 – 3	806	3.434	0.213
Fagus grandifolia	<1	1,198	1.392	0.097
	1 – 3	1,234	1.535	0.161
	3 – 5	990	0.461	0.043
Prunus serotina	<1	1,634	19.411	0.456
	1 – 3	329	2.909	0.073

[a] The regression analysis compared percent cover by species and height class (x) and seedling counts (y) on the same plot through time. Only non-zero plots for a given species and size class are included, with number of plots shown as N. Equations were of the form:
$\sqrt{\textit{seedling count}(\textit{species } x)} = \beta_1 * \sin^{-1}\sqrt{\textit{percent cover }(\textit{species } x)}$, where β_1 is the slope, and intercept was forced through the origin.

Table 2.—Results from regression analysis[a] of 1,600 sample plots following shelterwood seed cutting and treatment with glyphosate and sulfometuron methyl herbicides

Species	Height (feet)	N	Slope	r-squared
Acer pensylvanicum	< 1	424	3.307	0.112
	1 – 3	259	1.418	0.058
	3 – 5	105	0.306	0.010
Acer rubrum	< 1	1576	18.210	0.554
	1 – 3	479	6.850	0.296
Betula lenta	< 1	999	3.165	0.146
	1 – 3	476	2.920	0.205
Fagus grandifolia	< 1	482	1.022	0.041
	1 – 3	324	0.724	0.030
	3 – 5	106	0.178	0.006
Prunus serotina	< 1	1,584	19.738	0.510
	1 – 3	484	7.076	0.212

[a] The regression analysis compared percent cover by species and height class (x) and seedling counts (y) on the same plot through time. Only non-zero plots for a given species and size class are included, with number of plots shown as N. Equations were of the form:
$\sqrt{\boldsymbol{seedling\ count(species\ x)}} = \beta_1 * \sin^{-1}\sqrt{\boldsymbol{percent\ cover\ (species\ x)}}$, where $\beta 1$ is the slope, and intercept was forced through the origin.

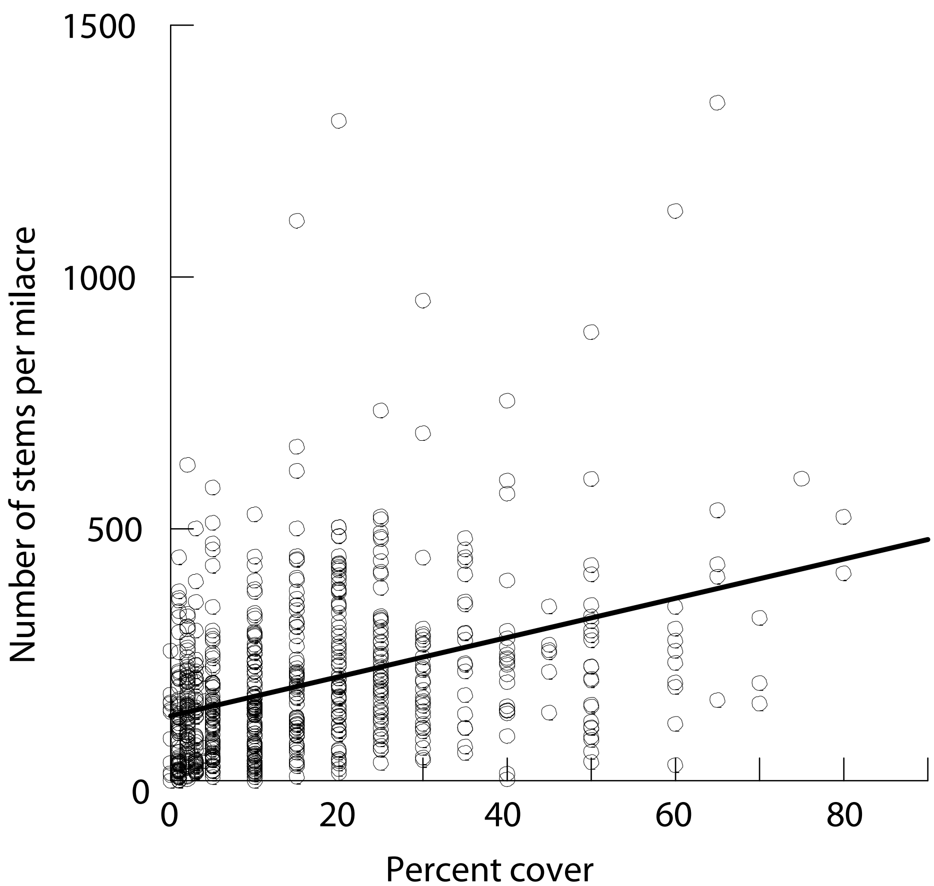

Figure 1.—Scatter plot of percent cover of <1 foot black cherry versus number of stems and associated simple linear regression line per milacre plot. Data are from 1,600 milacre plots in shelterwood seed cut and herbicided stands.

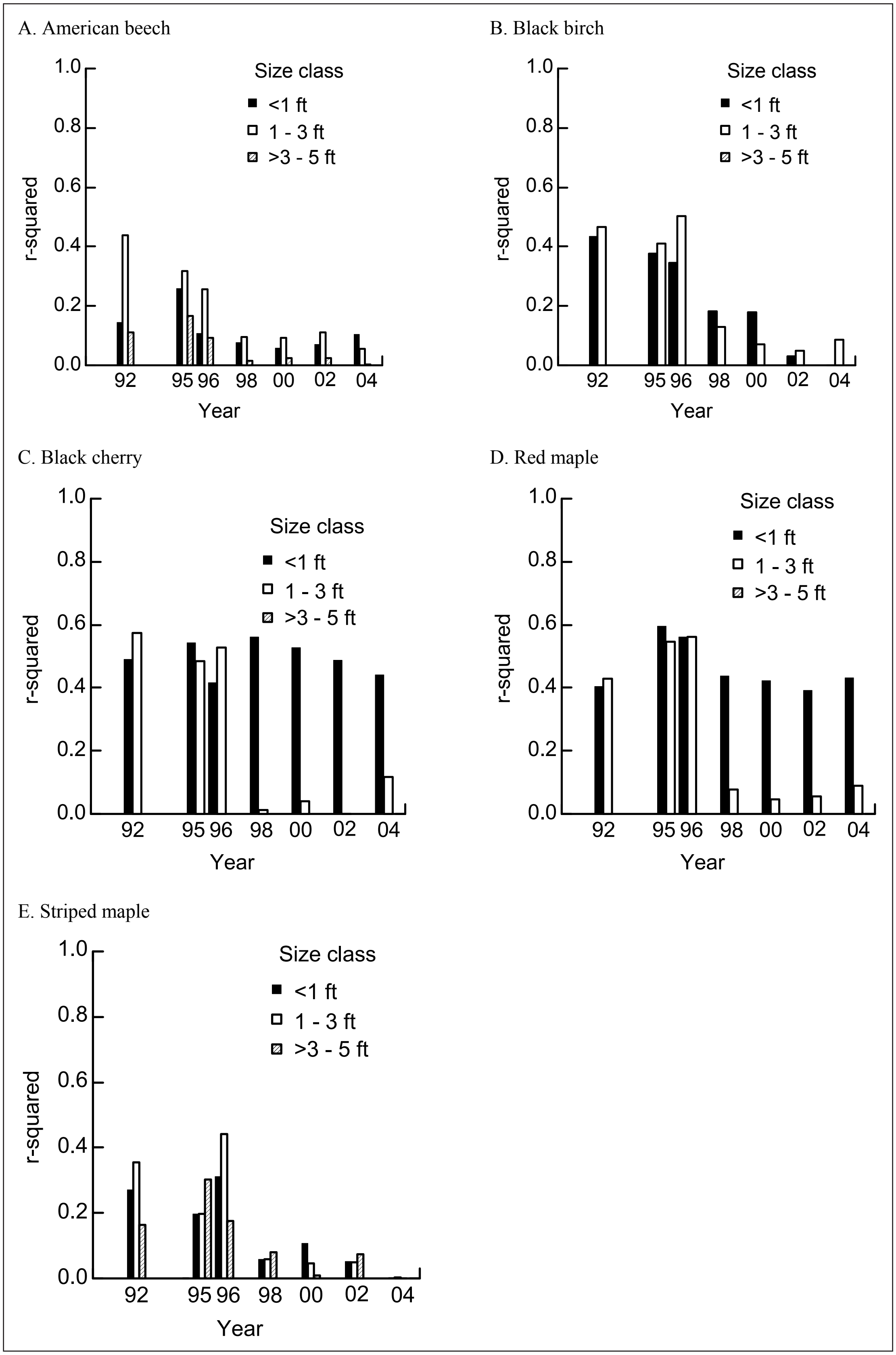

Figure 2.—R-squared values by species and size class over time for the equation: $\sqrt{\textbf{\textit{seedling count}}(\textbf{\textit{species x}})} = \beta_1 * \sin^{-1}\sqrt{\textbf{\textit{percent cover}}\ (\textbf{\textit{species x}})}$, where β_1 is the slope, and intercept was forced through the origin. Data are from 2,200 milacre plots in shelterwood seed cut-only stands.

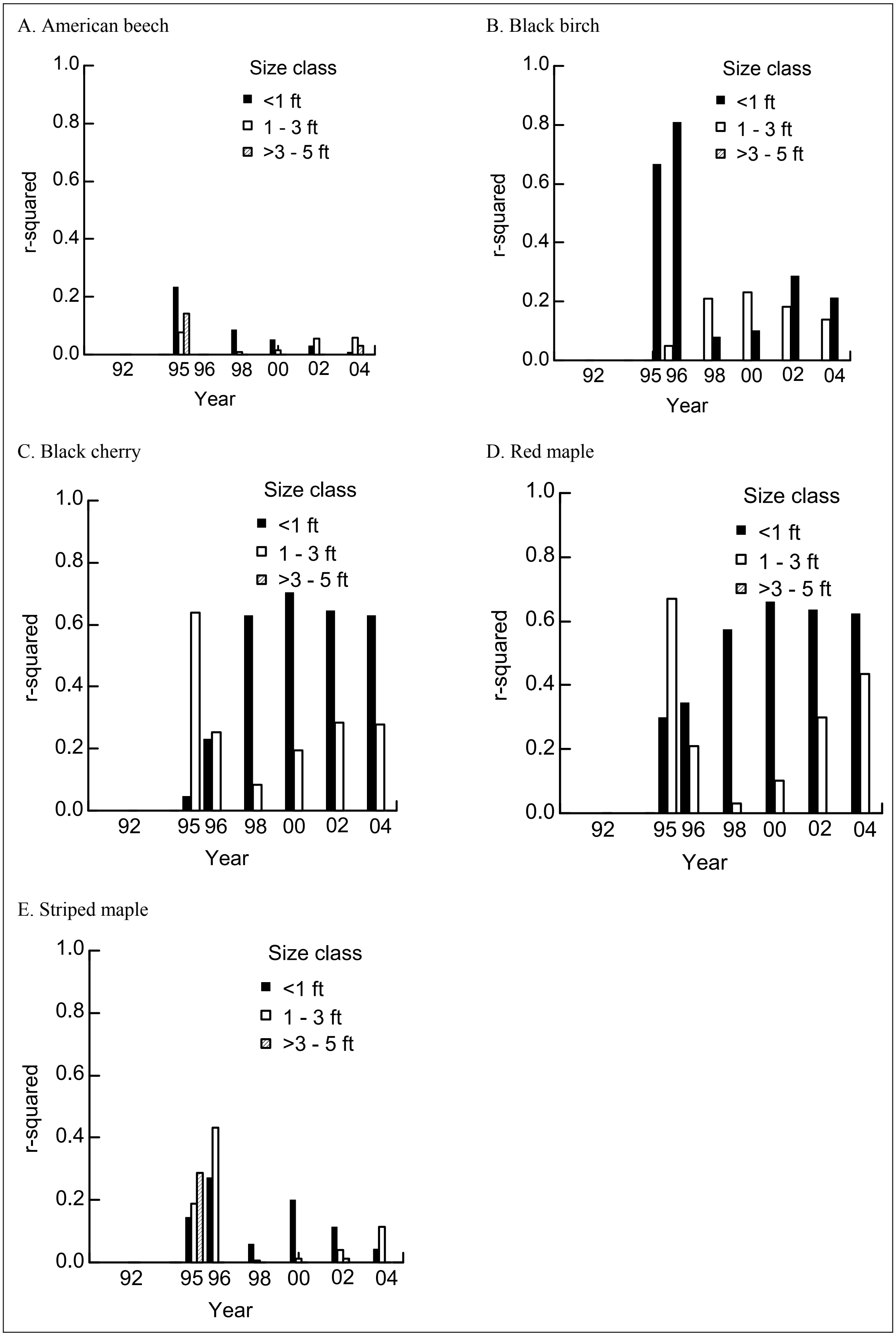

Figure 3.—R-squared values by species and size class over time for the equation: $\sqrt{\textit{seedling count}(\textit{species } x)} = \beta_1 * \sin^{-1}\sqrt{\textit{percent cover }(\textit{species } x)}$, where β_1 is the slope, and intercept was forced through the origin. Data are from 1,600 milacre plots in shelterwood seed cut and herbicided stands.

DISCUSSION

The conditions in the shelterwood-only plots are representative of much of Pennsylvania's forest. McWilliams et al. (2007) report that grasses, forbs, and rhizomatous ferns dominate Pennsylvania forest understories. In these conditions, there is very little relationship between percent cover and stem counts of a species by height class. Where key sources of variation in this relationship—competing plants—are removed by herbicide treatment, a short window opens in which percent cover and stem counts are much more strongly related. This relationship is best for shade-intolerant or intermediate species like black cherry, red maple, and birch. But due to the other sources of variation in the relationship, the ability to predict counts from cover data does not persist for long.

One major reason for high variability is that seedling sizes within the broad size classes can vary greatly. A size class <1 foot may contain mostly seedlings nearly 1 foot in height and high cover, or perhaps the same number of very small seedlings and low cover. Time since establishment is often unknown when stocking is being assessed during prescription development, but can be a source of substantial variation in seedling size within a size class. Variability in size of individuals within a species can result from many other factors as well. Nutrient availability at a microscale, light availability, and water availability can all affect the size of individual seedlings (Beatty 1984, Grubb 1977, Watt 1947). Genetic variations and phenotypic plasticity differences among species and environment also play a substantial role in seedling size (Rice et al. 1993). High variability was likely a result of many factors combined.

Prediction of seedling counts from percent cover data by height classes is not reliable and cannot serve as a substitute for careful seedling count data collected on plots. Our data were collected on the Allegheny National Forest, where regeneration was dominated by red maple and black cherry with associated American beech, black birch, and striped maple. These species represent the range of shade tolerance classes found in any forest. Leaf morphology and variability in plant sizes seen in our study certainly exist elsewhere and we expect that our results apply broadly to any forested situation.

Assessments of advance regeneration stocking are implicitly predictions of stocking through stand development. The stem count methods used in SILVAH have been proven by adoption over a wide geographic area. Our results suggest that entirely new studies would be required in order for users to use percent cover data to predict future plot stocking. This approach may be possible, but the results from our work suggest it would not be as accurate as stocking standards and predictions based on seedling counts. Conversion of cover data to stem counts cannot be done accurately and reliably across species and size classes and through time. Despite the effort required to assess the adequacy of regeneration prior to silvicultural operations, stem counts remain critical to predicting and ensuring regeneration success.

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