How Planting Method, Weed Abatement, and Herbivory Affect Afforestation Success

Bernard W. Sweeney, Stephen J. Czapka, and L. Carol A. Petrow

ABSTRACT

The success of upland and riparian afforestation depends on landowners making informed decisions about key factors such as the quality of seedlings (species, size, and root stock), planting technique, site preparation, weed and herbivore control, and planting pattern for the plantation. We show here that the short-term (1 year) and longer-term (3 year) effects on seedling survivorship and growth due to planting technique (dibble-bar versus auger) did not differ significantly for the five test species (red maple [*Acer rubrum* L.], eastern redbud [*Cercis canadensis* L.], green ash [*Fraxinus pennsylvanica* Marsh], sweetbay magnolia [*Magnolia virginiana* L.], and sweet gum [*Liquidambar styraciflua* L.]). Weed treatment (tree mats, initial herbiciding, and annual herbiciding) also failed to significantly increase seedling survivorship or growth, a result hypothesized to be caused by high moisture and nutrient content of soils on the site. In contrast, tree shelters significantly increased seedling survivorship and growth after 1 and 3 years. For some species, 3-year survivorship was up to fivefold higher with shelters. Long-term weed control increased survivorship of sheltered seedlings but decreased survivorship for those without shelters because of increased exposure to deer. For this site, successful afforestation depends more on protecting seedlings from herbivory with tree shelters than on either the method of planting or the method of controlling weeds.

Keywords: afforestation, forest buffer, tree shelter, auger, dibble-bar, artificial regeneration, hardwood silviculture

The process of restoring forest to land that had been cleared and/or cultivated (afforestation) is now considered best management practice (i.e., conservation buffers sensu Bentrup et al. [2005]) for both highly erodible upland lands and riparian areas. Reestablishing the forest can (i) reduce the loss of sediment from watersheds (Bentrup et al. 2005; (ii) prevent pollutants from entering streams or rivers (US Environmental Protection Agency [EPA] 1995, Lowrance et al. 1997, Schoonover and Williard 2003); (iii) improve the quality of the stream ecosystem (Sweeney 1992, 1993); and (iv) provide upland and riparian wildlife corridors and additional habitat, food, and other benefits to terrestrial plants and animals (Cockle and Richardson 2003, Bentrup et al. 2005). Moreover, recent research has shown that riparian forests actually increase the ability of streams and rivers to process certain pollutants in situ (Sweeney et al. 2004) and that forests are likely to have been the natural vegetated state for most stream corridors in North America, including those running through grassland prairies (West and Ruark 2004).

In contemporary landscapes, however, afforestation efforts face unnaturally high levels of both herbivory (Marquis 1977, Marquis and Brenneman 1981) and competition with invasive weedy plants (Davies 1987, Harmer 2001). For example, estimates of pre-European settlement densities of white-tailed deer (*Odocoileus virginianus* Zimm.) in eastern North America range from 3.1 to 7.7 deer/km^2, whereas late-20th century estimates range from 7.7 to 14.8 deer/km^2 in heavily forested areas and up to more than 60 deer/km^2 in areas with mixed forest and agriculture land (see Horsley et al. [2003] for review). Moreover, introduced invasive plants now comprise anywhere from 8 to 47% of the total flora in the United States depending on location (Westbrooks 1998). During the past 10 years, several techniques have been used to increase the success of afforestation in upland and riparian areas, including fencing (Opperman and Merenlender 2000) and tree shelters (Lantagne 1995, West et al. 1999, Dubois et al. 2000) to protect seedlings from herbivory, and mulching, herbicides and tree mats to reduce competition from invasive plants (Stange and Shea 1998, Bendfeldt et al. 2001, Sweeney et al. 2002). Recent observations on seedling growth and survivorship on landscapes characterized by intense deer herbivory and plant competition suggest a need for site-specific prescriptions for afforestation because natural forest succession is either very slow or completely suppressed (Sweeney et al. 2002, Sweeney and Czapka 2004). Not only will the prescription vary from site to site, but it also will depend on a detailed knowledge of the afforestation choices available to landowners so they can maximize the growth and survivorship of seedlings and minimize the cost and time of regeneration.

Choosing the "right species" of plants for a location is complex because of constraints imposed by the site, the budget, objectives and tastes of the landowner, and the ecological characteristics of the region. Choices can be further limited by the complexity of both the primary goals (e.g., creation of wind breaks, reduction of soil erosion, and preventing nonpoint pollutants from entering a stream) and the secondary goals (e.g., food for wildlife, creating a migration corridor, and stabilizing stream banks). Factors such as soil type or

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classification, mineral and nutrient content, annual and seasonal moisture and temperature regimes, and more all limit the array of potential species at a given site, as does the need for species to be native and/or nonornamental. In addition, cost constraints, viewshed requirements (small stature trees versus tall stature trees), the investment potential of timber, and the landowner's time frame for completion of the project all influence the choice of the "right species" for a given site.

Thus, from the perspective of both the landscape and the landowner, the species are "right" if, and only if, they are successfully incorporated into the site being restored. Ultimately, the success of an afforestation project depends on correct landowner choices regarding root stock and size (age) of seedlings for each of the "right" species, the time and method of planting, and the protection of seedlings from competitors and predators. Root stock and size choices range from bareroot to containerized (potted) and from small (0.5 m) 1-year-old seedlings to large (2 m) 2- to 3-year-old seedlings. The seedlings can be planted with a dibble-bar, shovel, or auger during certain seasons specific to each root stock. Clearly, landowner choices have a huge impact on the timing and cost of the planting and on the overall effort needed to put the plants in the ground.

Given the importance of afforestation for controlling upland erosion, enhancing wildlife, and improving water and habitat quality in streams and rivers, all landowner choices need to be based on good science. In particular, we need scientific data on how each choice affects the success rates of afforestation. In this study, we evaluated the effects of two planting methods (dibble-bar and auger) on the short-term (1 year) and longer-term (3 years) survivorship and growth of potted seedlings of five species of deciduous trees native to eastern North America. In addition, our design included an experimental overlay to address the issues of repeated-versus-single herbicide treatments to reduce plant competition and the use of tree shelters to reduce herbivory.

Methods

This study was conducted on the Blaine property in southern Chester County, Pennsylvania. Treatments were applied in a split-plot design with the following variables: planting technique, species, tree shelter use, and weed treatment. Sixteen replicate plots (9 × 27 m each), in four blocks (i.e., randomized combination of each of the four weed treatment plots), were established in the floodplain along both sides of an unnamed tributary of the Red Clay Creek (39°51′74″ N; 75°45′79″ W). Weed treatments, applied at the plot level, consisted of tree mats (VisPore; Tredegar Corporation, Richmond, Virginia), a one-time application of herbicide (Roundup; Monsanto Company, St. Louis, Missouri) at planting, an application of herbicide at planting followed by annual treatments in early summer, or control (no treatment). Five tree species were planted in each plot: red maple (*Acer rubrum* L.), eastern redbud (*Cercis canadensis* L.), green ash (*Fraxinus pennsylvanica* Marsh), sweetbay magnolia (*Magnolia virginiana* L.), and sweet gum (*Liquidambar styraciflua* L.). All seedlings were 2-year-old stock in containers (i.e., plastic pots, 7.6 cm^2 square × 22.8 cm deep). We chose the more expensive containerized seedlings over cheaper bareroot seedlings because of greater flexibility in planting date, less problems with dessication due to handling during planting, and, most importantly, because we wanted to experimentally compare seedling growth and survivorship for auger versus dibble-bar planted seedlings. Thus, the planting technique alternated using either an auger or dibble-bar with every other seedling of the same species. Each plot was planted in four rows of 10 seedlings each, for a total of 640 seedlings in the 16 plots. Each row contained two individuals of each species, planted in a random order. One individual of each species was randomly selected to have a tree shelter placed over it. Thus, two seedlings of each possible combination of species, planting method, and shelter application occurred in each plot. Seedling height was measured at planting. Both seedling height and survivorship were measured after one growing season on Apr. 28, 2002 and again after three growing seasons on Aug. 11, 2003.

All plots were plowed and disked before planting, making them initially weed free. However, weeds quickly took root and the areas between seedlings were vegetated within a few weeks, with the height of this vegetation more than 0.3 m after 6 weeks in control plots. The soil type for the site was primarily Lawrence silt loam with 0–3% slopes. The corners of each experimental plot were clearly marked by fence posts to facilitate proper location of seedlings and application of weed treatments. Eurasian cool season grasses and noxious weeds such as Canada thistle (*Cirsium arvense* L. [Scop.]), mile-a-minute weed (*Polygonum perfoliatum* L.), and oriental bittersweet (*Celastrus scandens* L.) were present at the site.

All seedlings were containerized and obtained from Octoraro Native Plant Nursery, Inc., in Chester County, Pennsylvania. Inclusion of bareroot stock in the design (i.e., a 2 × 2 factorial; bareroot/potted seedling and auger/dibble-bar) was not possible because the research site could not accommodate the additional plots needed to keep replication within a treatment sufficiently high. The seedlings were planted on Apr. 6, 2001, using either a hand auger or dibble-bar on a 3 × 3 m spacing grid. The species chosen are native to the region and were selected because they were either good for improving the stream, providing a crop (long-term marketable timber), or enhancing aesthetic value. Specifically, red maple is adapted to wet conditions, and its broad root system provides streambank stabilization. Green ash and sweet gum not only benefit the stream through the input of fruits, leaves, and shade, but also may provide a marketable timber crop for the landowner. The cropping aspect is important because most riparian areas are on private lands, and landowners, especially farmers, may be unable or unwilling to reforest these areas because of financial or other constraints. Thus, some riparian trees could provide landowners with a source of income, albeit not annually. Eastern redbud and sweetbay magnolia are highly desired species for aesthetic reasons.

Tubex (Aberaman Park, Aberaman, South Wales, United Kingdom) tree shelters (1.2 m tall and translucent) were placed over half the seedlings, except sweetbay magnolias, at planting (one individual of each species per row). Shelters used for sweetbay magnolias were 0.6 m tall because of the species' smaller stature and multistemmed nature. Shelters were installed immediately after planting the seedling. Each shelter was pushed into the soil approximately 3–4 cm and fastened with plastic ties to wooden stakes driven into the ground approximately 0.3 m. Coarse plastic netting was placed over the tops of the shelters to prevent birds from entering and becoming trapped inside. The Tubex shelters used in these experiments were translucent, which have been shown to have light transmission (measured as percent photosynthetic photon flux and ratio of red/far red light) within the ranges found in open canopy forest (Sharew and Hairston-Strang 2005).

To gauge the effect of weed competition on seedling survival and growth, one of four experimental treatments was applied to each

Table 1. Results from regression models analyzing seedling survivorship and seedling growth across all species.

Source	df	Survivorship				Growth			
		Year 1		Year 3		Year 1		Year 2	
		F	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Initial height	1	0.01	0.92	2.40	0.12	38.56	<0.01	107.99	<0.01
Auger	1	1.32	0.25	1.83	0.18	0.08	0.78	0.03	0.85
Species	4	13.80	0.01	12.05	0.02	28.45	<0.01	11.52	<0.01
Tree shelter	1	9.79	<0.01	11.80	<0.01	277.51	<0.01	234.67	<0.01
Weed treatment	3	1.66	0.65	2.48	0.48	0.17	0.91	0.19	0.90
Auger × tree shelter	1	0.15	0.70	0.07	0.79	0.01	0.92	0.04	0.85
Auger × weed treatment	3	1.97	0.58	3.11	0.38	1.20	0.31	0.86	0.46
Species × Auger	4	5.92	0.21	4.21	0.38	0.26	0.90	3.98	0.01
Species × tree shelter	4	5.11	0.28	7.47	0.11	7.94	<0.01	10.06	<0.01
Species × weed treatment	12	8.22	0.77	9.92	0.62	0.96	0.49	0.88	0.57
Tree shelter × weed treatment	3	3.08	0.38	7.24	0.07	2.10	0.10	1.38	0.25

plot (viz., tree mat, single herbicide, multiple herbicide, and control). Plot treatments were randomly assigned to a given block. Each treatment application involved an area between 0.8 and 1.0 m^2 around the seedling base. Black VisPore tree mats (Treessentials Co., St. Paul, MN) were installed at planting. For herbicide treatments, Roundup (glycophosate) was applied because the site was classified as a nonwetland. Herbicide treatments were applied on June 26, 2001 (plots 1, 4, 8, 9, 10, 13, and 15); June 4, 2002 (plots 1, 8, 13, and 15); and May 26, 2003 (plots 1, 8,13, and 15). Note that the unequal number of plots for one application ($n = 3$) versus multiple-year application ($n = 4$) of herbicide was accounted for in our analytical model and that seedlings were protected from windblown overspray (herbicide "drift") by choosing a calm day for application and holding a semicircular plastic cylinder between the seeding and the spray as it was applied in the 0.8- to 1.0-m^2 area around the base of each seedling.

Analysis

Trees were scored as alive or dead, with dead meaning that there was no indication that any visible part of the tree was still alive. Survival data were analyzed with repeated measures logistic regression models (Proc GENMOD; SAS Institute, Inc. [1989]). The models included all main effects and two-way interactions, with survival as the dependent variable and initial height, planting method, species, tree shelter use, and weed treatment as independent variables.

Seedling growth was estimated by subtracting the mean height at planting from the height at the end of the first and third growing seasons. Height was taken as the highest vertical extent of either the stem or leaves. Growth measures were analyzed with linear regression models (Proc MIXED; SAS Institute, Inc. [1989]). The models included all main effects and two-way interactions, with seedling growth as the dependent variable and initial height, planting method, species, tree shelter us, and weed treatment as independent variables. Results of seedling growth are presented as least-squares mean (LSM ± SE).

Results

First- and Third-Year Seedling Survivorship

No significant main effects for survivorship were observed for years 1 or 3 with regard to initial seedling height, auger versus dibble-bar planting method, or weed treatment (control versus tree mats versus herbiciding; Table 1).

Significant main effects after 1 year included species and tree shelter (Table 1). Green ash had significantly higher survivorship (averaged across treatments and planting method) than red maple, sweet magnolia, and sweet gum (Table 2; Figure 1); red maple had significantly higher survivorship than sweet gum; and survivorship for seedlings with shelters (averaged across species, treatments, and planting method) was significantly higher (by about 45.8%) than those without shelters (Table 2; e.g., 90.3% [confidence interval {CI}, 84.7, 94.0) versus 54.5% {CI}, 44.4, 64.2], respectively). There were no significant interactions among study variables after 1 year.

Significant main effects after 3 years were consistent with year 1 (i.e., included species and tree shelter [Table 1]). However, the relative differences among species were more sharply defined; e.g., green ash had significantly higher survivorship than all other species except eastern redbud, sweet gum had significantly lower survivorship than all other species except sweet magnolia, and the survivorship of red maple was intermediate and similar only to eastern redbud (Table 2; Figure 1). Consistent with year 1, 3-year survivorship for seedlings with shelters was still significantly higher (by about 41.3%) than those without shelters (e.g., 70.6% [CI, 63.1, 77.2] versus 29.3% [CI, 21.1, 39.1], respectively; Table 2). However, the decline in survivorship between years 1 and 3 was about 27.9% greater for unsheltered (54.5% versus 29.3%) than for sheltered seedlings (90.3% versus 70.6%; Table 2). There were no significant interactions after 3 years, although the tree shelter × weed treatment interaction bordered on significance ($P = 0.065$; Table 1; Figure 2) because of, mainly, a higher survivorship of seedlings when treated with both a shelter and a herbicide.

First- and Third-Year Seedling Growth

No significant main effects for growth were observed for years 1 or 3 with regard to auger versus dibble-bar planting method or weed treatment (control versus tree mats versus herbiciding; Table 1).

Significant main effects after both 1 and 3 years included initial seedling height, species, and tree shelter (Table 1). The significant effect of initial seedling height and species reflects the innate differences in growth rate among the test species. All were the same age at planting but, in general, the relative average size at planting for the species was eastern redbud > green ash > red maple > sweet gum > sweet magnolia. Similarly, the fastest growing seedlings as potted plants (eastern redbud and green ash) exhibited the greatest amount of growth after 3 years regardless of treatment. The significant tree shelter effect reflects a general response of significantly better growth

Table 2. Comparison of seedling survivorship (mean percent [confidence limits]) and growth (mean cm [± SE]).

	Survivorship		Growth	
	Year 1	Year 3	Year 1	Year 3
Planting method				
Dibble-bar	74.2 (69.4, 78.5)	46.6 (38.6, 54.8)	4.4 (±2.3)	14.8 (±4.3)
Auger	79.5 (71.7, 85.5)	53.3 (44.4, 62.0)	3.6 (±2.3)	14.1 (±4.1)
Shelter				
Unsheltered	54.5**A** (44.4, 64.2)	29.3**A** (21.1, 39.1)	−22.3**A** (±2.6)	−19.0**A** (±5.0)
Sheltered	90.3**B** (84.7, 94.0)	70.6**B** (63.1, 77.2)	30.2**B** (±2.0)	47.9**B** (±3.6)
Weed treatment				
Control	80.8 (71.0, 87.9)	52.9 (30.7, 74.0)	5.3 (±3.2)	10.8 (±7.1)
Tree mat	73.5 (65.0, 80.5)	55.1 (45.8, 64.1)	3.1 (±3.3)	15.3 (±6.8)
One herbicide	77.3 (72.9, 81.1)	51.3 (45.5, 57.1)	5.0 (±3.5)	18.2 (±7.1)
Multiple herbicide	75.8 (62.7, 85.4)	40.6 (28.7, 53.7)	2.5 (±3.4)	13.5 (±8.1)
Species				
Eastern redbud	80.0**A,B,C** (60.9, 91.1)	70.1**A,B** (54.9, 81.9)	−6.2**B** (±5.3)	34.3**A** (±6.4)
Green ash	95.6**A** (87.1, 98.6)	76.1**A** (65.1, 84.5)	28.7**A** (±3.1)	34.3**A** (±4.4)
Red maple	76.3**B** (70.2, 81.4)	47.7**B,C** (39.9, 55.7)	16.2**A** (±3.4)	19.2**A,B** (±5.7)
Sweet gum	50.6**C** (43.0, 58.2)	26.2**D** (16.5, 39.0)	−8.8**B** (±4.7)	2.9**B** (±7.2)
Sweet magnolia	59.0**B,C** (40.4, 75.3)	29.0**C,D** (16.8, 45.3)	−10.0**B** (±5.7)	−18.5**C** (±7.4)

Values in a given column followed by the same letter are not significantly different within the grouping variables shelter and species.

with shelters than without shelters, regardless of seedling species or weed treatment after both 1 and 3 years (Table 2; Figure 3).

The interaction between species and tree shelter was significant after both 1 and 3 years (Table 1; Figure 3). Thus, although all species grew significantly better with shelters during the experiment, the relative improvement over unsheltered seedlings varied substantially among species (e.g., being greatest for eastern redbud and least for sweet magnolia). The only other significant interaction was between species and type of planting method (auger versus dibble-bar) after 3 years (Table 1). Hence, although there was no overall effect of planting method when averaged across all species and treatments, there was a significant effect for two species: sweet gum (significantly less growth with auger) and eastern redbud (significantly more growth with auger; Figure 4).

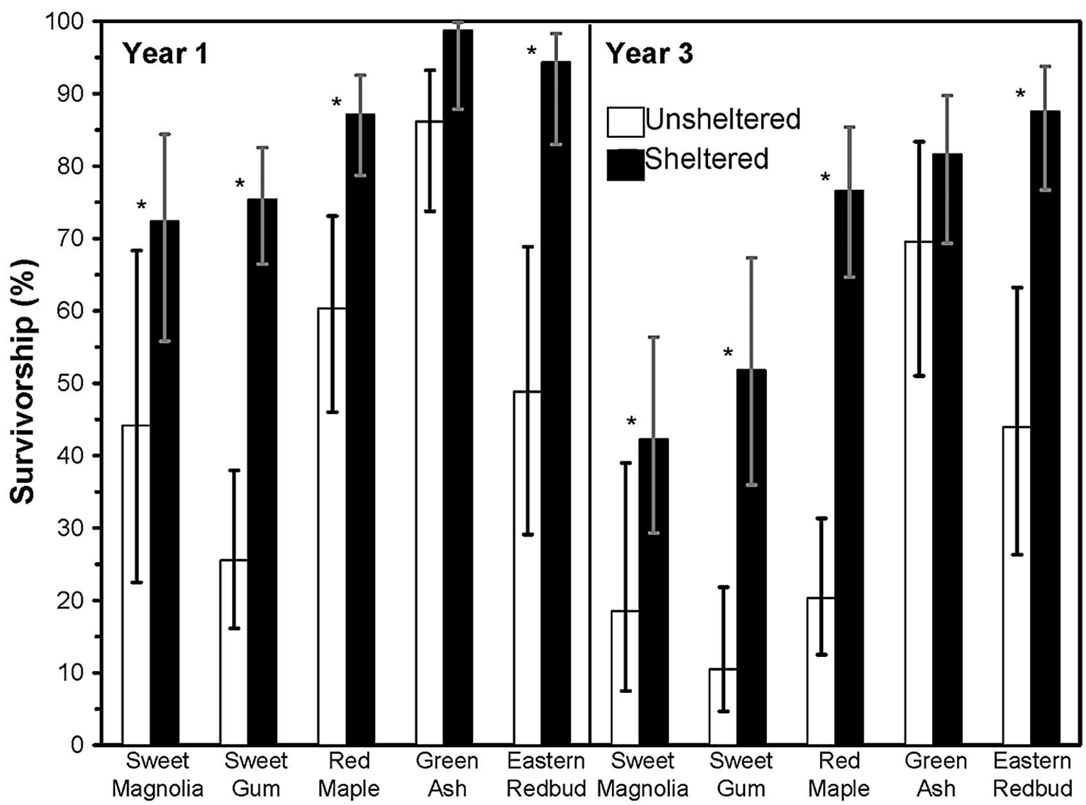

Figure 1. Effects of tree shelter presence or absence on mean seedling survivorship (percent ± confidence limits) for each species (averaged across weed treatment and planting method) through one and three growing seasons. Asterisks indicate significant differences between sheltered and unsheltered pairings.

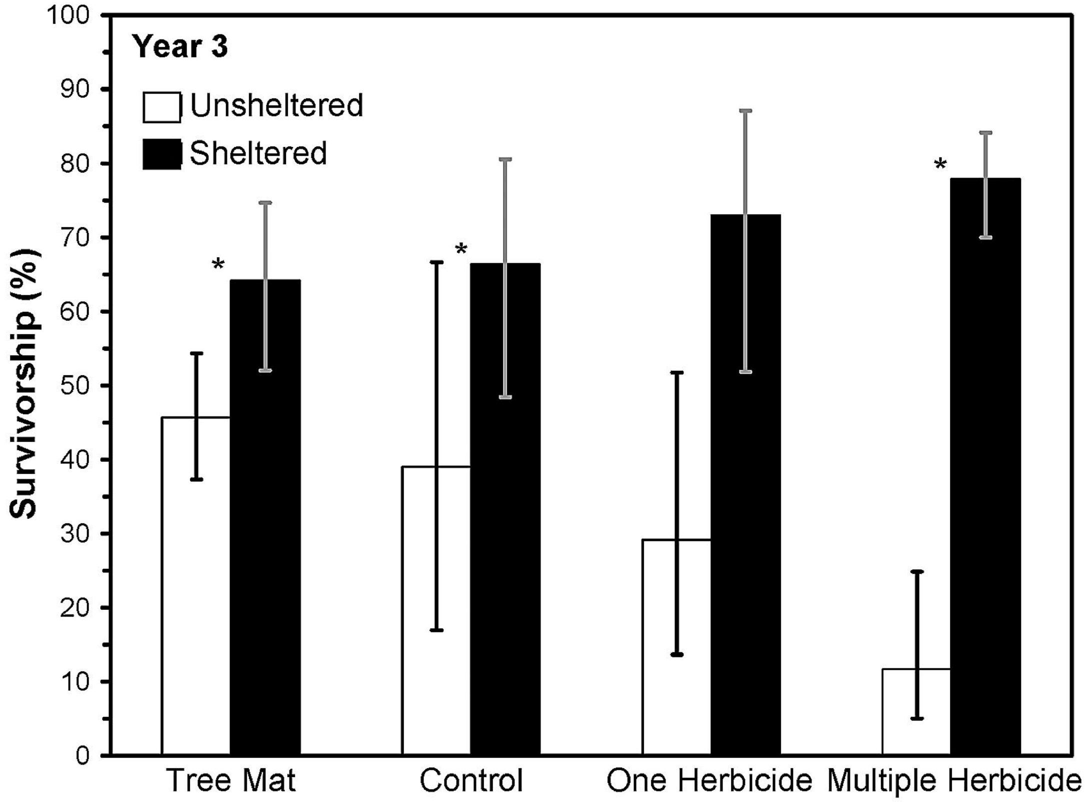

Figure 2. Effects of tree shelter presence or absence on mean seedling survivorship (percent ± confidence limits) for each weed treatment (averaged across species and planting method) through three growing seasons. Asterisks indicate significant differences between sheltered and unsheltered pairings.

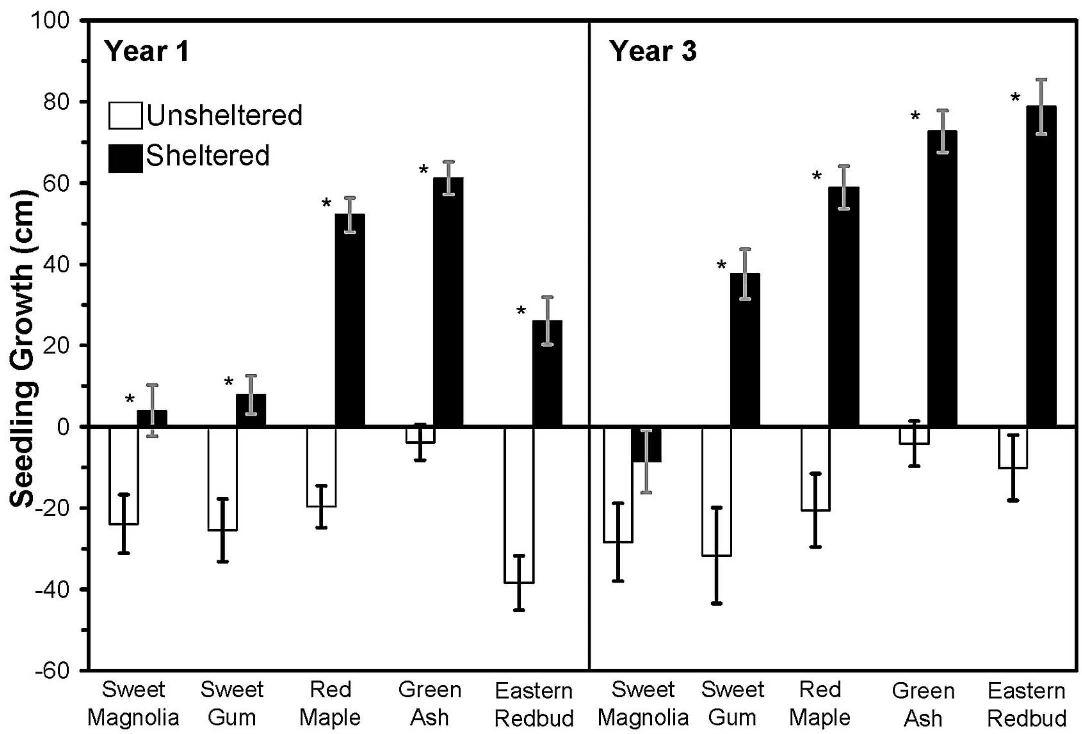

Figure 3. Effects of tree shelter presence or absence on mean change in overall seedling height (cm ± SE) for each species (averaged across weed treatment and planting method) through one and three growing seasons. Asterisks indicate significant differences between sheltered and unsheltered pairings.

Discussion

Landowners, whether private or public, who decide to restore forest to cultivated upland or riparian areas face a number of questions. One is whether they should let nature take its course. The answer is yes—if there is a good local source of seeds from nearby forests, competition from invasive plants is not extreme, herbivore

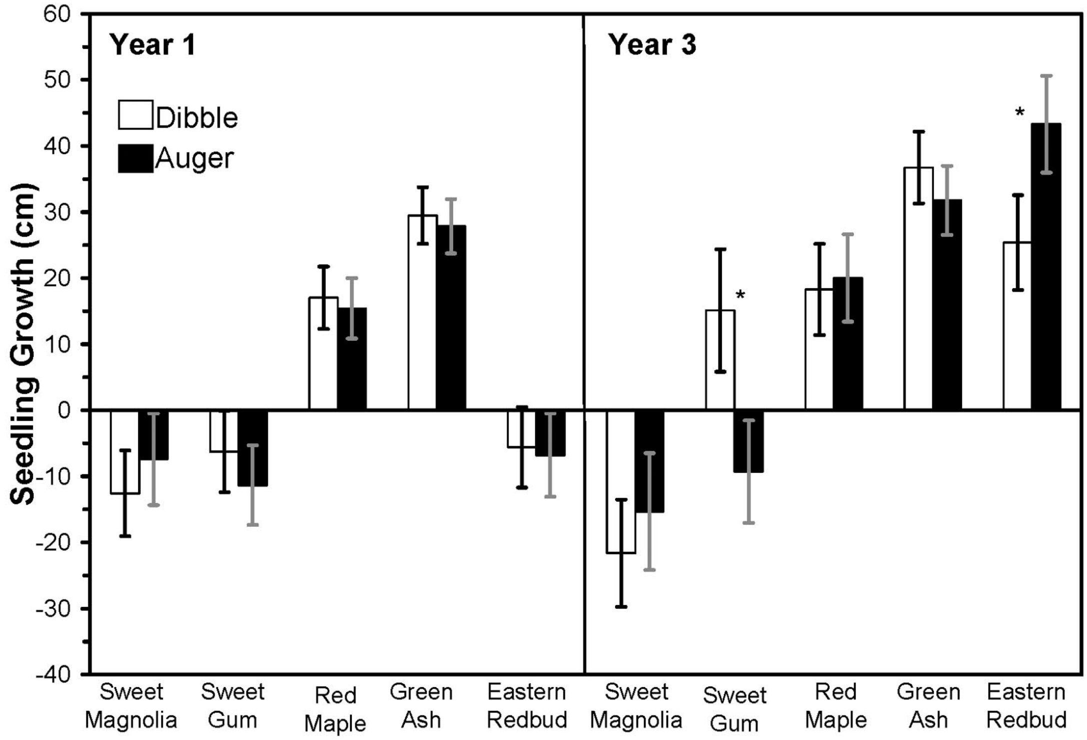

Figure 4. Effects of planting using a dibble-bar or auger on mean change in overall seedling height (cm ± SE) for each species (averaged across weed treatment and shelter use) through one and three growing seasons. Asterisks indicated significant differences between dibble-bar and auger within species.

populations are not abnormally high, and the rate of restoration is not important to the landowner. The absence of one or more of these factors, however, calls for some level of proactive restoration at a site. That, in turn, requires choices associated with (i) type of site preparation, (ii) species of trees, (iii) kind of seedling stock (potted versus bareroot), (iv) method of planting (dibble-bar, auger, shovel, or mechanical), and (v) protection against both herbivory (shelters, fencing, systemic chemical, wire mesh) and plant competition (tree mats, herbicides, and mulching). In this study, we kept some of these variables constant (viz., site preparation [disking and plowing] and seedling stock [potted]), while we experimentally manipulated others (viz., planting method, protection from competing plants and herbivores).

Our study shows that both the short-term (1 year) and longer-term (3 years) main effect of planting method (dibble-bar versus auger) on seedling survivorship and growth was insignificant when averaged across the five test species of deciduous trees. Although there was a significant interaction for growth between species and planting method after 3 years, we discount it because the two species involved (sweet gum and eastern redbud) exhibited opposite responses (Figure 4). These findings add perspective to an earlier study (Sweeney et al. 2002) that found no significant difference in survivorship or growth for bareroot and potted seedlings of five species on the coastal plain of Maryland. Although the two studies were conducted on separate sites, in different years, and with only one overlapping test species, both sites were in the mid-Atlantic region, on abandoned fields previously in corn production, and in areas of high deer density (more than 25 deer/km^2), and we used identical methods. The results reported here suggest that the dibble-bar planting method used by Sweeney et al. (2002) did not confound their findings or their conclusions (i.e., forcing the large root structure of a potted plant into the confined space of a dibble-bar hole does not appear to compromise subsequent growth and survivorship of the seedling). We know of no other controlled studies that bear on this important choice for landowners. Thus, our data suggest that any concerns about compromising the survivorship and growth of planted seedlings by choosing the wrong combination of root stock type (potted versus bareroot) or planting method (dibble-bar versus auger) may be unwarranted. Rather, landowner choices should be based on factors such as economics (available resources to purchase seedlings); timing (seedlings planted at times other than spring probably would have to be potted); and available time, labor, and equipment (augers are expensive, usually have to be rented, and can be as time- and labor-intensive as dibble-bar planting in rocky terrain).

Our study also shows that weed treatment did not significantly affect either the short-term or the longer-term pattern of survivorship and growth for the five species. It is unlikely that this was because the seedlings were relatively weed free at planting (caused by disking of the site). The weeds quickly and extensively colonized the planting site within a few weeks after planting, and no significant effect of a multiple-year application of herbicide (relative to a first-year-only application) was observed for either survivorship or growth when averaged across all treatments for the five species. These results differ from other studies in which weed treatment resulted in significantly higher survivorship or growth of seedlings (Sweeney et al. 2002, Ramsey et al. 2003, Sweeney and Czapka 2004). This discrepancy is likely caused by site-specific differences in factors such as soil moisture and nutrient content, type and levels of competing plants and herbivores, and more. Regardless, there is some evidence in our study that multiple weed treatment might increase mortality because of increased exposure of seedlings to herbivory, even though weed treatment was not significant as a main effect (as noted previously; $P = 0.48$) and there was no significant interaction between tree shelter and weed treatment ($P = 0.07$).

Thus, although longer weed control tended to increase survivorship of seedlings protected by shelters, survivorship for those without shelters actually decreased (Figure 2). In fact, the poorest survivorship in the experiment occurred for seedlings without shelters and with multiple herbicide application. These findings, combined with actual field observations of herbivory during the study, suggest that continuous herbiciding may increase the exposure of seedlings to deer browse. The significantly higher survivorship of seedlings with shelters in plots herbicided for three growing seasons suggests that seedlings herbicided beyond the 1st year (regardless of site conditions) need to be protected by tree shelters. Whereas these findings are suggestive rather than definitive, and more data are clearly needed, the issue is important because landowners currently can and do receive federal and state subsidies for herbicide applications in afforestation plots (e.g., a maximum of two herbicide applications for USDA CP22 funded projects in the Conservation Reserve Enhancement Program).

Our study strongly suggests that if afforestation projects need a site-specific ecological prescription to assure success (sensu Sweeney and Czapka [2004]), that prescription should include the use of tree shelters—especially for sites where the level of mammalian herbivory or foreign invasive plants is significant. In this study, we observed significant short-term (1 year) and longer-term (3 year) effects of tree shelters on the survivorship and growth of seedlings among five species known to differ substantially in their ecological requirements. Without exception, the levels of survivorship and growth of each species were substantially greater (and usually significant) with shelters, regardless of planting method or weed control regime (although the magnitude of response was species specific). In the case of sweet gum, shelters increased 3-year survivorship as much as fivefold. Moreover, for all five test species, seedlings unprotected by shelters actually lost height during the study (Figure 3). By contrast, four of the five test species with shelters exhibited significant positive growth after 1 year. The lone exception, sweet magnolia, can be explained by the shorter shelter used on it for the experiment. Overall, these data suggest that, without shelters at this study site, the afforestation process would be significantly delayed or fail altogether.

Although it may seem premature to reach conclusions on some of these issues after only 3 years of observations, the data argue otherwise. For example, the pattern of growth and survivorship of the various test species after year 1 is completely consistent with that after year 3 (see Figures 1 and 3). In addition, both year 1 and year 3 results showed that some choices (e.g., planting method) made by landowners in eastern North America may have little effect on the success of their afforestation efforts, while others may range from being important on some sites (e.g., weed control) to being critical on most, if not all, sites (e.g., shelters). The impact of those choices seems to manifest itself in the 1st year, and effects, whether negative or positive, persist over time. Moreover, good choices quickly result in more trees outstripping competitors and surviving predators. From an environmental perspective, having more trees in less time is a good thing because most afforestation projects are intended to restore ecological services to a given piece of a watershed. Hence, more and quicker is better. From a landowner perspective, more trees in less time also may have an economic component, especially if he or she has a limited budget and the afforestation project is being subsidized in part or whole by state or federal funds.

In summary, this study and other related studies (Sweeney et al. 2002, Sweeney and Czapka 2004) suggest that in eastern North America, the degree and type of herbivore protection may be among the most important choices made by landowners seeking to reforest their property. Unprecedented levels of herbivores such as white-tailed deer (Horsley et al. 2003) have now added herbivory to the list of key factors affecting the success of an afforestation project (i.e., in addition to good quality planting stock, good quality planting, site preparation, and weed control). We have shown that, at least for our study site, herbivore protection is significantly more important than either planting method or weed control. These results from a mid-Atlantic Piedmont watershed support an earlier study in the mid-Atlantic Coastal Plain (Sweeney and Czapka 2004), which concluded that where money and resources are limited, the first priority of the landowner should be to protect seedlings from herbivory with tree shelters.

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