# Residual Overstory Density Affects Survival and Growth of Sheltered Oak Seedlings on the Allegheny Plateau

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## Abstract

As many as two decades may be required to achieve natural regeneration of northern red oak (Quercus rubra L.) on mesic sites. However, when unplanned major disturbances affect desirable mixed-oak forests, both the amount of time and viable options available for influencing the composition of post-disturbance regeneration are reduced greatly. Salvage logging of dead or dying oaks and other valuable species followed by artificial regeneration of oak has been attempted following gypsy moth-induced mortality on the Allegheny Plateau in western Pennsylvania. We evaluated the use of tree shelters to protect planted northern red oak seedlings following salvage logging that resulted in a range of residual stand densities. This practice was common on the Allegheny National Forest in the early 1990's following widespread gypsy moth defoliation and subsequent mortality. A better understanding of this practice will enhance efforts to implement artificial regeneration of oak after unplanned major disturbance due to insects, disease, or factors such as storm damage. Artificial regeneration of oak using tree shelters can be effective when regeneration harvests are planned but natural oak regeneration is inadequate or lacking. This situation is common in mixed-oak forests of the Eastern United States.

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**Cover photo:** Tree shelter and emergent northern red oak located within the Allegheny National Forest following salvage logging.

## Introduction

Natural regeneration of northern red oak (*Quercus rubra* L.) requires adequate numbers of advanced seedlings of sufficient size before overstory removal (Sander and others 1984; Loftis 1990a). In eastern mixed-oak forests, shelterwood regeneration methods are recommended so that understory oak can grow large enough to compete with faster growing species following final overstory removal (Loftis 1990b; Brose and others 1999). If herbivory by white-tailed deer is moderate to high, oak seedlings developing in the understory of a shelterwood must be protected from deer with fencing (Miller and others 2004). To reduce understory competition to oak seedling development, herbicides and/or prescribed fire often are needed as an additional step (Loftis 1990b; Brose and Van Lear 1998; Miller and others 2004). Oak shelterwood regeneration methods may require 10 years or longer for oak seedlings to reach sufficient size and density before final overstory removal. However, unplanned events such as storm damage or gypsy moth defoliation that cause significant stand-level mortality necessitate the establishment of competitive reproduction in a shorter period. Such disturbances, possibly in conjunction with salvage logging, often remove all or part of the overstory before the understory oak component—if present—can respond vigorously to the sudden increase in available growing space. To establish competitive seedlings and saplings in a shorter time than that provided by shelterwood methods, plastic tree shelters are being used to protect planted seedlings.

Tree shelters are translucent plastic tubes that protect seedlings from animal damage and possibly create a greenhouse effect. Over the past 15 years, research has shown that planting and sheltering oaks in new clearcuts can establish competitive oak seedlings that can persist and respond to some types of crop-tree release in young, even-aged stands (Lantagne and others 1990; Smith 1993; Lantagne 1995; Schuler and Miller 1999). Tree shelters are particularly effective where new seedlings or seedling-sprouts of desirable species such as northern red oak are browsed heavily by deer (Gillespie and others 1996). The recommended use of tree shelters in the Central Appalachians includes clearcutting during the dormant season followed by spring planting and sheltering of high-quality, root-pruned northern red oak seedlings at least 0.5 inch in diameter at the root collar (Schuler and Miller 1996).

The effects of residual overstory trees on oak seedling development in tree shelters are not fully understood. In several cases following shelterwood harvests, residual trees reduced the height growth and survival of planted northern red oak seedlings protected with tree shelters (Teclaw and Isebrands 1991; Walters 1993; Lantagne and Miller 1997; Bardon and others 1999), though residual overstory stocking improved the development of oak seedlings protected with tree shelters in northern Wisconsin (Teclaw and Zasada 1996). In the latter case, the authors speculated that residual trees provided additional protection from growing-season frosts. While it seems clear that in most studies, residual overstory stocking typical of most shelterwood regeneration methods (e.g., 50 to 75 percent residual stocking) reduced the growth and survival of seedlings protected with tree shelters, the effect of lower levels of stocking on northern red oak seedlings in tree shelters has not been evaluated in other studies.

In this study, we discuss the use of tree shelters to protect northern red oak seedlings when planted under different levels of residual overstory stocking. Study sites incorporate existing operational efforts by the Allegheny National Forest (ANF) and include a range of residual overstory stocking levels. Levels of overstory stocking available for examination resulted from repeated gypsy moth defoliation, drought, and secondary pathogens that resulted in overstory densities reduced by mortality and subsequent salvage logging in the late 1980's (Walters 1993). Study sites were selected to limit variability associated with factors other than residual stocking, e.g., shelter design, regeneration source (seed vs. seedling), time since planting, and use of fencing. The primary objective was to prevent a significant reduction of oak from the affected sites by replacing overstory oak with understory oak rather than red maple (*Acer rubrum* L.), black cherry (*Prunus serotina* Ehrh.), black birch (*Betula lenta* L.), or American beech (*Fagus grandifolia* Ehrh.) (Walters 1993). We also wanted to identify an upper range of overstory density that is compatible with the use of tree shelters and planted oak seedlings in the heavily deer-impacted Allegheny Plateau of western Pennsylvania.

## Methods

In May 1995, study sites were established at four locations several miles south of Warren, Pennsylvania, adjacent to State Road 337 on the ANF (Fig. 1). Each location was the site of an ongoing regeneration effort using planted 2-0 northern red oak seedlings protected by 5-foot-tall, white Tubex® tree shelters but not by fencing (Table 1). Study sites are hereafter referred to as 411-1, 411-2, 424-3, and 424-4. The history of each site was obtained from ANF records. A sample of 100 sheltered trees at each site were selected by randomly choosing the first tree and then using the next 99 trees in sequence, both live and dead trees were included in the original sample. Trees were identified with brass tags for a total of 400 identified trees in shelters. Data from each tree included status (live or dead), tree height, crown class, general remarks, species of competing vegetation, and height of competing vegetation. Annual measurements were conducted from 1995 through 1999 and in 2001 and 2003. In April 1997, site 424-4 was dropped from annual measurements due to the theft of brass tags identifying the seedlings. However, following the 2003 growing season, a random sample of 100 sheltered seedlings (live and dead) was obtained in the same location as the originally tagged shelters to assess both understory and overstory conditions. Overstory measurements were taken in May 1995 and October 2003 (Table 1). Overstory characteristics
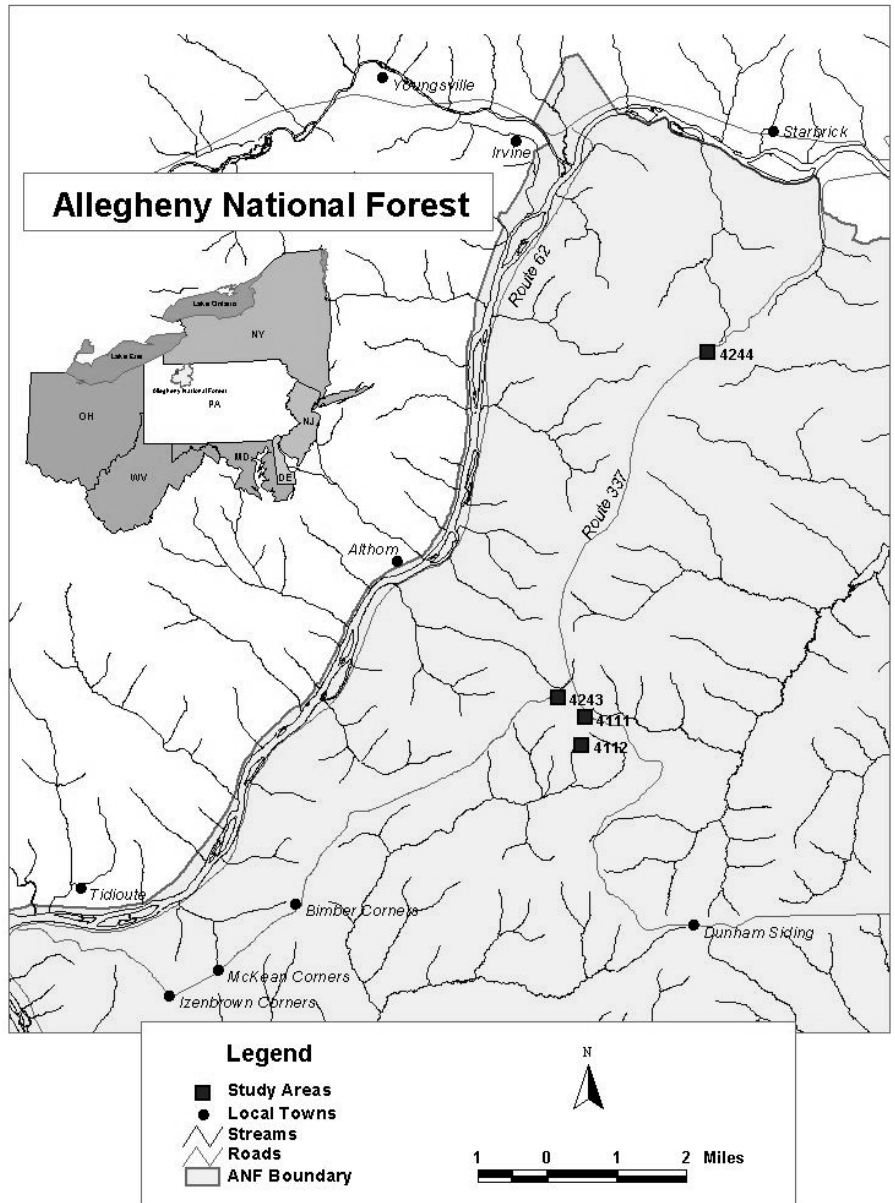


Figure 1.—Study sites on the Allegheny National Forest.

**Table 1.—Overstory residual mean basal area (SE in parentheses) of tree shelter study sites on the Allegheny National Forest as determined from 10 0.1-acre sample plots at each location**

| Study site | Date of origin[a] | Basal area | |
| --- | --- | --- | --- |
| | | May 1995 | October 2003 |
| | | - - - - - - - - - - ft²/acre - - - - - - -- - - - | |
| 411-2 | 1992 | 14.5 (4.8) | 17.3 (4.6) |
| 424-3 | 1991 | 31.8 (7.8) | 50.3 (11.1) |
| 424-4 | 1993 | 59.4 (5.2) | 87.3 (9.7) |
| 411-1 | 1991 | 62.8 (11.7) | 85.7 (9.0) |

[a]Planted before the onset of the growing season in the year specified.

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**Table 2.—Parameter estimates and measures of significance for predicting survival of sheltered northern red oak seedlings for a range of overstory densities as determined by binary logistic regression (BA1 and BA01 calculated from field inventories in 2003)**

| Variable | df | Parameter estimate | Wald chi-square | P > chi-square |
|----------|-----|--------------------|-----------------|----------------|
| BA01 | 1 | -0.0318 | 6.7060 | 0.0096 |
| Intercept | 1 | 1.1268 | 3.7906 | 0.0515 |
| BA1 | 1 | -0.0308 | 8.1500 | 0.0043 |
| Intercept | 1 | 1.2989 | 3.8567 | 0.0495 |

were sampled by randomly selecting 10 sheltered tree locations from each study site as center points of 0.1-acre circular plots (n = 40). Overstory sample locations differed in 1995 and 2003. In 1995, we recorded species and diameter at breast height (d.b.h.) for all trees ≥ 5 inches. In 2003, we added 0.01-acre overstory plots and included all trees with a d.b.h. ≥ 1 inch. Our intent was to determine whether smaller plot sizes can be used to predict the survival of sheltered seedlings.

In 1996, we began releasing overtopped seedlings when the competing vegetation was from the same stratum. This entailed removing stems that overtopped the desired crop tree, resulting in a codominant crown of the desired tree after release. This procedure has helped maintain height growth and crown class of northern red oak in West Virginia (Schuler and Miller 1999). All years in which individual trees received a crown release were documented. It was not our intention to evaluate the utility of crown release so no trees were selected as controls. However, our records provide some insight into the percentage, frequency, and need for crown release.

We used binary logistic regression to determine the probability of survival of sheltered northern red oak seedlings as a function of the basal area of the surrounding overstory. To provide a relative measure of model fit, we generated Hosmer-Lemeshow statistics and examined the percent concordant and discordant between predicted and observed responses (Allison 1999) for both 0.1-(BA1) and 0.01-(BA01) acre overstory plots. In 2003, BA1 ranged from zero to 132.8 ft2/acre (mean: 80.1 ft$^2$/acre; SE: 17.4 ft$^2$/acre), while BA01 ranged from zero to 582.8 ft$^2$/acre (mean: 60.1 ft$^2$/acre; SE: 6.3 ft$^2$/acre). Of course, high basal areas of smaller plot sizes do not mean such levels of stocking exist over larger areas.

## Results

On the basis of the 2003 sample data, both BA1 and BA01were significant predictors of the survival of sheltered northern red oak when evaluated independently (Table 2), but BA01 provided the best goodness of fit (rescaled R$^2$ = 0.43, Hosmer and Lemeshow Goodness-of-Fit chi-square = 6.98, df = 8, P = 0.5387). In binary stepwise regression, only BA01 (P = 0.01) and an intercept term were included in the final model. The overall correct model classification was 82.5 and 77.5 percent for BA01 and BA1, respectively. BA01 correctly classified 86.9 percent of the dead and 76.5 percent of the live seedlings; BA1 correctly classified 82.6 percent of the dead and 70.5 percent of the live seedlings. Survival probability of 10 to 12 years after outplanting was about 70 percent when BA01 was below 10 ft$^2$/acre and nearly 50 percent when BA01 was about 35 ft$^2$/acre (Fig. 2).

Survival of individual trees related to residual basal area were consistent with our stand-level assessments (Fig. 3). In 2003, site 411-2, which had a stand-level residual basal area of less than 20 ft$^2$/acre (Table 1), had the highest survival of sheltered trees (78 percent). Survival in units 411-1 and 424-4, both of which were about 90 ft2/acre of basal area at the most recent census, was 23 and 16 percent survival, respectively. These sites were characterized mostly by closed canopy conditions, though 411-1 had infrequent canopy gaps. These gaps were correlated with the survival of sheltered seedlings as more than 60 percent of the surviving seedlings in 411-1 were beneath breaks in the canopy. In these instances, survival of sheltered seedlings was predicted correctly more often using BA01 as the explanatory variable in the logistic regression equation (Table 2). For example, at 411-1, two surviving seedlings in gaps had BA1 values of 70 and 76 ft$^2$/acre, and BA01 values of 10 and 0 ft$^2$/acre, respectively.
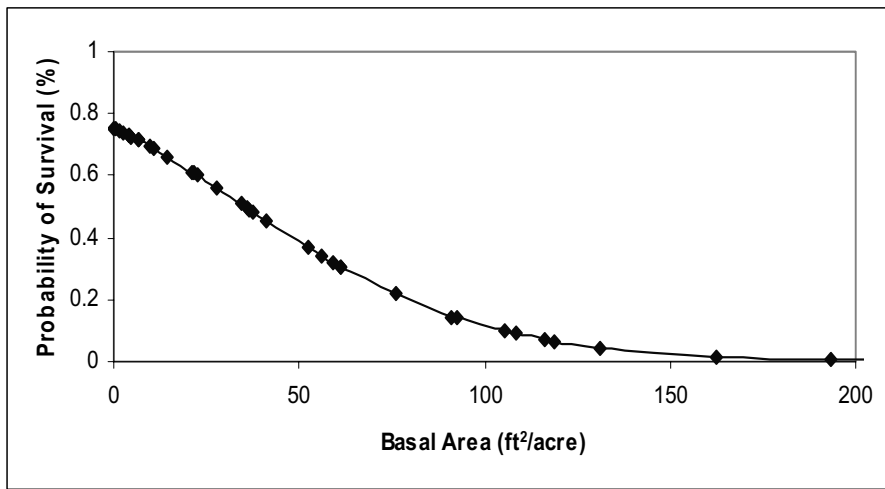
Figure 2.—Predicted probability of survival of northern red oak sheltered seedlings planted in northwest Pennsylvania under different levels of residual overstory density. Basal area was determined from all trees growing within 0.01-acre around the sheltered seedling (four observations with high levels of residual overstory basal area are not shown).
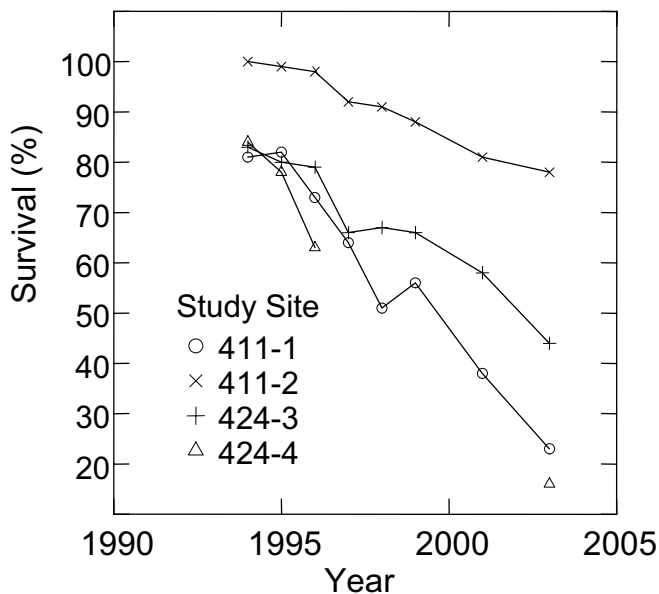


Figure 3.—Survival of planted and sheltered northern red oak seedlings (n = 100) at four study sites south of Warren, Pennsylvania. Observations at site 424-4 were suspended after 1997 due to the loss of sample-tree identification tags; data from 2003 are based on a random sample at the same location. Survival increased in some years because trees classified as dead, subsequently sprouted from the root collar the following year and were added to the live-tree category.
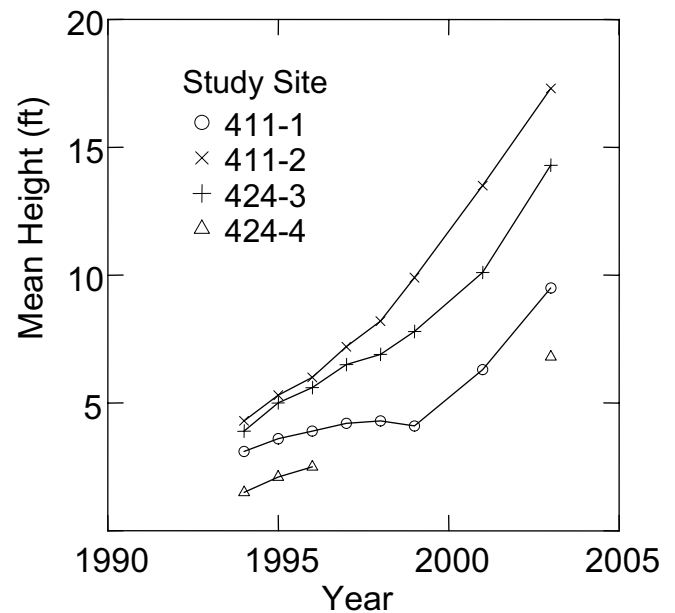


Figure 4.—Mean height of surviving northern red oak seedlings planted and sheltered at four locations south of Warren, Pennsylvania. Observations at site 424-4 were suspended after 1997 due to the loss of sample-tree identification tags; data from 2003 are based on a random sample at the same location.

Only BA01 values and parameter estimates predict correctly that these seedlings survive.

As expected, higher levels of survival were correlated with greater growth. Height growth of surviving trees was inversely proportional to stand-level basal area (Tables 1 and 3). In 411-2, maximum height growth occurred from 1994 to 2003 (22.4 feet). Current height growth of surviving sheltered seedlings is similar among the three

intact study sites (Fig. 4). Mean annual height growth for the last 2 years was 1.7, 1.9, and 2.1 feet for sites 411-1, 411-2, and 424-3, respectively. These rates are similar to that expected of free-to-grow northern red oak saplings (northern red oak site index$_{50}$ = 70) during early stand development (Schnur 1937). Although sapling height growth reflected historical norms, crown release often was necessary due to the greater height growth of competing vegetation.

**Table 3.—Stand level height and height-growth characteristics of sheltered northern red oak (NRO) and competing woody vegetation in western Pennsylvania, 1995-2003**

| Study site | Basal area (1995) | Mean height growth | Mean height of NRO saplings (2003) | Mean height of competing woody vegetation (2003)[a] | Mean crown class of NRO[b] |
|---|---|---|---|---|---|
| | - -ft²/acre - - | - - - - - - - - - - - - - - - - - - ft - - - - - - - - - - - - - - - - - | | | |
| 411-2 | 14.5 | 12.8 | 17.3 | 18.7 | 2.5 |
| 424-3 | 31.8 | 9.9 | 14.3 | 18.7 | 3.1 |
| 411-1 | 62.8 | 5.4 | 9.3 | 6.7 | 3.8 |

[a]Competing vegetation of the same cohort as the sheltered oak seedlings; does not include residual overstory competition, if present.
[b]Dominant = 1, codominant = 2, intermediate = 3, overtopped = 4.

**Table 4.—Competing vegetation of planted and sheltered northern red oak by study site, in percent**

| Competing vegetation | 411-2 | 424-3 | 424-4 | 411-1 |
|---|---|---|---|---|
| Black birch | 0 | 0 | 6.3 | 4.4 |
| Black cherry | 20.7 | 40.9 | 0 | 21.7 |
| Red maple | 74.1 | 27.3 | 68.8 | 13.0 |
| Mountain-laurel | 0 | 0 | 0 | 17.4 |
| Fern | 0 | 27.3 | 6.3 | 39.1 |
| Grass | 1.7 | 0 | 0 | 0 |
| Other | 3.5 | 4.5 | 18.6 | 4.4 |

Crown release was most common at 411-2, which had the lowest level of residual overstory basal area and the most aggressive encroachment by competing stems. At this location, we released 38 trees at least once; of these, 34 were alive in 2003. About half (n = 40) of the surviving trees at 411-2 have not required release thinnings as of the most recent remeasurment. This unit also had the best average crown class of any of the study sites (Table 3). Only three trees received a crown release at the more heavily stocked 411-1 and none survived. At 424-3, 12 trees were released at least once. All survived and five were thinned in 2003. The most common competing vegetation of the planted and sheltered northern red oak was red maple and black cherry (Table 4). In the absence of the planting and sheltering effort, the new cohort established following the gypsy moth/salvage logging disturbance would contain virtually no oak species. Even with management efforts to maintain oak in these stands, the new cohort will remain predominantly red maple and/or black cherry. Regeneration failures where fern or grass dominated the competing vegetation varied considerably among study sites (Table 4), but were in all cases less common than developing young stands of woody regeneration.

## Discussion

The results of this study show that enrichment planting using tree shelters under a residual overstory, such as in salvage logging operations, should be used only at low levels of residual overstory stocking. Our predictions of survival of sheltered northern red oak using binary logistic regression (Table 2) indicate that overstory basal area should be no more than about 22 ft²/acre if survival probabilities of about 60 percent are expected 10 years after planting and sheltering (Fig. 2). It should be noted that this level of residual overstory equates to only about 10 trees per acre with a d.b.h. of 20 inches. If the residual stand meets or exceeds criteria for full stocking following

salvage logging or other disturbances (Gingrich 1967; Stout and Nyland 1986), the stand need not be treated as a regeneration unit, and enrichment planting and sheltering is unnecessary and unlikely to succeed.

If salvage logging of dead trees will result in a residual stand well below fully stocked, we recommend marking to further reduce basal area to no more than about 20 ft²/acre during the salvage logging operation if underplanting of oaks with tree shelters is desired. If possible, the spatial arrangement of residual trees should be in patches and enrichment planting and sheltering should be done between the patches of residual trees to minimize the effect of residual stocking. All pole-size trees of undesirable species (e.g., red maple) between the patches should be felled so that they do not compete with planted seedlings. Grouping residual overstory trees also may reduce windthrow and the development of epicormic branches. We suspect that even with an herbicide treatment of small undesirable regeneration at the time of salvage logging (e.g., basal spraying of undesirable stems less than 1 inch d.b.h. within 5 feet of planted stock), crown release of developing planted stock still will be required. Herbicide applied to individual stems at the time of logging does not prevent new seedlings from developing that eventually will compete with and overtop desirable oak regeneration (Schuler and Miller 1995).

On the Allegheny Plateau, mixed-oak forests are less common than the Allegheny hardwood forest type. To maintain regional forest-type diversity, it is important to manage mixed-oak forests in a sustainable manner, regenerating oak when natural or planned disturbances create new waves of recruitment. The species composition of all the stands examined in this study was classified as mixed-oak by ANF personnel, but the regeneration following salvage logging was dominated by black cherry and/or red maple, major constituents of the Allegheny hardwood type, a subset of the northern hardwood type



Figure 5.—Deformed northern red oak stem that resulted from the emergent seedling contacting netting placed over the top of the shelter to exclude birds.

(Braun 1950; Stout and Nyland 1986). Thus it is likely that in the absence of enrichment planting, sheltering, and subsequent crown release, these mixed-oak stands affected by gypsy moth induced mortality would become more like the Allegheny hardwood type that dominates the region, reducing regional forest-type diversity.

Guidelines for successful use of tree shelters summarized by Schuler and Miller (1996) include issues related to shelter design, seedling age, planting location, and maintenance requirements. When doing enrichment planting, crown release of planted northern red oak also is necessary as seen in this study and in Schuler and Miller (1999). Crown release was necessary even though the planted oaks were growing according to expected rates of free-to-grow oaks in young even-aged stands.

In addition, we stress the importance of the following: 1) Removing netting from the top of the shelter before the seedling comes in contact with the netting. On the ANF, netting used to prevent birds from entering the shelters (Crothers 1991) often caused significant stem deformities when the shoot did not pass easily through it (Fig. 5). Nets should be removed in the spring before stem elongation. Since stems often grow more than 2 feet

annually inside the shelters, most nets should be removed during the second year of growth when beginning with 2-0 planting stock; 2) Checking that the tree shelters themselves do not restrict growth. In our study and elsewhere where tree shelters have been used for a decade or more, many trees were constricted by the shelter, especially near the groundline (Fig. 6). Shelters were stretched tightly by the growing stems and trapped rainwater. None of the shelters we observed had begun to disintegrate or become brittle and it is not clear whether a shelter could damage or kill a tree when this occurs. Newer designs by some manufacturers may prevent this but checks of older tree shelter installations should be conducted. We recommend cutting the shelters with a knife and leaving them in place once the trees become rigid and self supporting. Retaining the cut shelter protects the stem from deer rubs and makes the tree easier to find for secondary treatments; 3) Ensuring that tree shelters are not adjacent to or within patches of tall logging debris. At sites 411-2 and 424-3, we observed fast-growing natural regeneration in small clumps that were protected from deer browsing by the residual tops of harvested trees from salvage logging operations. These clumps often were dominated by pin cherry (*Prunus pensylvanica* L. f.), a preferred browse species on the Allegheny Plateau, and greatly exceeded the growth rates of the sheltered oak seedlings. As such, browsing probably had a positive effect on the survival of sheltered seedlings by slowing the development of competing vegetation when sheltered seedlings were not located near thick logging debris that deterred browsing. We also do not recommend using tree shelters inside deer exclosure regeneration fences for the same reason. Fencing is becoming a standard regeneration technique when the impact of deer is moderate or higher (Miller and others 2004), but sheltered oak seedlings inside an exclosure will have much greater competition from competing stems and probably will require much greater competition control than unfenced sheltered seedlings.



Figure 6.—Example of a tree becoming too large for the shelter before the shelter began to disintegrate.

On the basis of the results of this study and the performance of sheltered seedlings, we do not recommend using tree shelters in small gaps (e.g., 0.1 acre) in otherwise unbroken canopies. It is not clear whether sheltered seedlings can be used in conjunction with group selection or patch clearcutting if gaps are 0.5 acre or larger. The location within the gap, site characteristics, and height of the surrounding competition are potentially critical factors related to the survival and growth of sheltered seedlings within gap environments. Additional research on the effect of these factors is needed.

Our results need not be applied solely to unplanned disturbances and salvage logging operations. Private landowners who are adverse to delaying a harvest until natural oak regeneration is established sufficiently, can use these results to plan artificial regeneration efforts. The alternative to preparing for natural regeneration of oak over a 10-year period is to conduct the harvest now and use artificial regeneration methods. Harvest revenues could pay for planting and sheltering operations, and artificial regeneration gives landowners much greater flexibility in timing the harvest.

Finally, we add a cautionary note about using the results of this study. Our research developed following a series of unplanned events and as such does not conform to standards for designing ecological field experiments with respect to randomization and replication. As a result, we cannot estimate our precision or ensure an absence of bias in our stand-level comparisons. However, given that the patterns we documented are consistent with past research and robust patterns of stand dynamics, it is reasonable to assume that our conclusions can be used to further refine the use of tree shelters in forest-management activities. Managers who adopt our recommendations should plan on periodic assessments to monitor performance and make adjustments in the field if necessary.

## Literature Cited

Allison, P.D. 1999. **Logistic regression using the SAS system: theory and application.** Cary, NC: SAS Institute. 163 p.

Bardon, R.E.; Countryman, D.W.; Hall, R.B. 1999. **Tree shelters reduced height growth of underplanted red oak seedlings in southern Iowa.** Northern Journal of Applied Forestry. 16: 103-107.

Braun, E.L. 1950. **Deciduous forests of eastern North America.** Philadelphia, PA: Blakiston Co. 596 p.

Brose, P.H.; Van Lear, D.H. 1998. **Responses of hardwood advance regeneration to seasonal prescribed fires in oak-dominated shelterwood stands.** Canadian Journal of Forest Research. 28(3): 331-339.

Brose, P.; Van Lear, D.; Cooper, R. 1999. **Using shelterwood harvests and prescribed fire to regenerate oak stands on productive upland sites.** Forest Ecology and Management. 113(2/3): 125-141.

Crothers, C. 1991. **Tree shelters help ANF protect oak stand.** Pennsylvania Forests. Winter: 22-24.

Gillespie, A.R.; Rathfon, R.; Myers, R.K. 1996. **Rehabilitating a young northern red oak planting with tree shelters.** Northern Journal of Applied Forestry. 13(1): 24-29.

Gingrich, S.F. 1967. **Measuring and evaluating stocking and stand density in upland hardwood forests in the central states.** Forest Science. 13: 38-53.

Lantagne, D.O. 1995. **Effects of tree shelters on planted red oaks after six growing seasons.** In: Gottschalk, Kurt W.; Fosbroke, Sandra L.C., eds. Proceedings, 10th central hardwood forest conference; 1995 March 5-8; Morgantown, WV. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 215-221.

Lantagne, D.O.; Miller, R. 1997. **Tree shelters fail to enhance height growth of northern red oak in the Upper Peninsula.** In: Pallardy, Stephen G.; Cecich, Robert A.; Garrett, H. Eugene; Johnson, Paul S.; eds. Proceedings, 11th central hardwood forest conference; 1997 March 23-26; Columbia, MO. Gen. Tech. Rep. NC-188. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 351.

Lantagne, D.O.; Ramm, C.W.; Diskman, D.I. 1990. **Tree shelters increase heights of planted oaks in a Michigan clearcut.** Northern Journal of Applied Forestry. 7(1): 24-26.

Loftis, D.L. 1990a. **Predicting post-harvest performance of advance red oak reproduction in the southern Appalachians.** Forest Science. 36: 908-916.

Loftis, D.L. 1990b. **A shelterwood method for regenerating red oak in the southern Appalachians.** Forest Science. 36: 917-929.

Miller, G.W.; Kochenderfer, J.N.; Gottschalk, K.W. 2004. **Effect of pre-harvest shade control and fencing on northern red oak seedling development in the central Appalachians.** In: Spetich, Martin

A., ed. Proceedings, upland oak ecology symposium: history, current conditions, and sustainability. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 182-189.

Sander, I.L.; Johnson, P.S.; Rogers, R. 1984. **Evaluating oak advance reproduction in the Missouri Ozarks.** Res. Pap. NC-251. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 11p.

Schnur, G.L. 1937. **Yield, stand, and volume tables for even-aged upland oak forests.** Tech. Bull. 560. Washington, D.C.: U.S. Department of Agriculture. 85 p.

Schuler, T. M.; Miller, G.W. 1995. **Shelterwood treatments fail to establish oak reproduction on mesic forest sites in West Virginia.** In, Gottschalk, Kurt W.; Fosbroke, Sandra L.C. , eds. Proceedings, 10th central hardwood forest conference; 1995 March 5-8; Morgantown, WV. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 375-388.

Schuler, T.M.; Miller, G.W. 1996. **Guidelines for using tree shelters to regenerate northern red oak.** In Brisette, John, ed. Proceedings of the tree shelter conference, 1995 June 20-22; Harrisburg, PA. Gen. Tech. Rep. NE-221. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 37-45.

Schuler, T.M.; Miller, G.W. 1999. **Releasing sheltered northern red oak during the early stem exclusion stage.** In: Stringer, J.W.; Loftis, D.L., eds. Proceedings, 12th central hardwood forest conference; 1999 February 28-March 2; Lexington, KY. Gen. Tech. Rep. SRS-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 195-201.

Smith, H.C. 1993. **Development of red oak seedlings using plastic shelters on hardwood sites in West Virginia.** Res. Pap. NE-672. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.

Stout, S.L.; Nyland, R.D. 1986. **Role of species composition in relative density measurment in Allegheny hardwoods.** Canadian Journal Forest Research. 16: 574-579.

Teclaw, R.M.; Isebrands, J.G. 1991. **Artificial regeneration of northern red oak in the Lake States.** In: Proceedings, The oak resource in the Upper Midwest conference. St. Paul, MN: University of Minnesota: 187-197.

Teclaw, R.M.; Zasada, J. 1996. **Effects of two types of tree shelters on artificial regeneration of northern red oak in northern Wisconsin.** In Brisette, John, ed. Proceedings of the tree shelter conference, 1995 June 20-22; Harrisburg, PA. Gen. Tech. Rep. NE-221. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 68.

Walters, R.S. 1993. **Protecting red oak seedlings with tree shelters in northwestern Pennsylvania.** Res. Pap. NE-679. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 5 p.

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**Keywords:** tree shelters, northern red oak, artificial regeneration, Allegheny National Forest
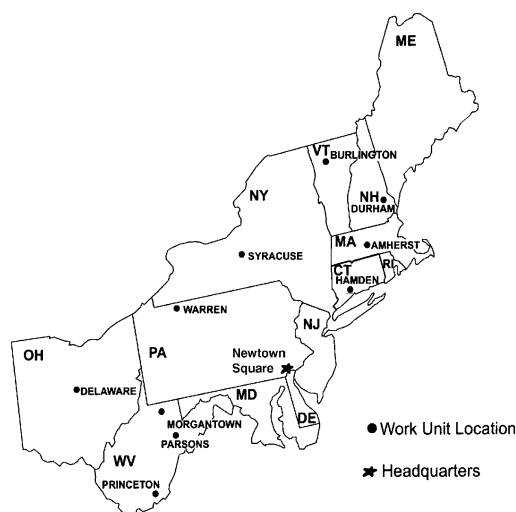
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