Response of Planted Eastern White Pine *(Pinus strobus* **L.)** to Mechanical **Release, Competition,** and Drought in the Southern Appalachians

Barton D. Clinton, Katherine J. Elliott, ***and*** **Wayne T. Swank,**
USDA Forest Service, Southern Research Station, Coweeta Hydrologic Laboratory, 3160 Coweeta Lab Road, Otto, NC 28763.

ABSTRACT. *Conversion of low-quality, natural mixed pine/hardwood ecosystems, containing a mountain laurel (*Kalmia latifolia *L.) dominated understory, to more productive eastern white pine* (Pinus strobus *L.)/ mixed-hardwood systems is a common prescription on relatively xeric southern Appalachian forest sites. We examined the effects of mechanical release, interspecific competition, and annual precipitation on growth of planted white pine in four 14-yr-old stands in the southern Appalachians. Two stands were mechanically released at age 6. No significant differences in biomass, basal area, or diameter were found between treatments for all species combined. Radial increment was significantly less during a drought year for both treatments. Height increment was less sensitive to severe moisture limitation than radial increment. Height and radial increment were compared to distance-dependent and distance-independent measures of competition for the nonreleased stands. Indices based on height and height/distance explained the greatest amount of variation in both radial and height increment. The influence of post-release severe drought may have delayed or diminished the response to release. The competitive influence of understory dominant mountain laurel at stand age 14 appears to be slight compared to the influence of other competing hardwood vegetation. South. J. Appl. For. 21(1):19–23.*

An important component of southern Appalachian forest ecosystems is the mixed oak-pine forest type on xeric midslopes and ridges. In recent years, the pine component of this forest type has been substantially reduced by drought and associated southern pine beetle *(Dendroctonus frontalis* Zimmerman) infestations (Smith 1991). As a result, extensive areas are poorly stocked and have dense understories dominated by the evergreen mountain laurel (*Kalmia latifolia* L.) (Clinton et al. 1993, Swift et al. 1993, Vose and Swank 1993). Historically, these oak-pine stands depended on periodic fire for maintenance; however, in the absence of fire, these stands do not regenerate to commercially productive tree species (Barden and Woods 1973, Barden and Woods 1976, Van Lear and Waldrop 1988); therefore, silvicultural prescriptions are necessary to regain productivity.

Chainsaw felling, burning, and planting of eastern white pine *(Pinus strobus* L.) are currently prescribed to convert these shrub-dominated ecosystems to more productive stands of mixed-hardwood and white pine. A necessary objective is to reduce the competitive influence of mountain laurel sufficiently to allow the planted white pine to become established. The prescribed fire rarely eliminates the mountain laurel, so competition with the planted pines may intensify over time. A mechanical or other form of release is often prescribed during early stand development to reduce competition from mountain laurel and other vegetation. It is not known whether such release is necessary or effective. Pine growth during early stand development has been documented for the first year following outplanting, where diameter growth and seedling physiology were related to biomass of all competitors (Elliott and Vose 1993), but information on competitive effects later in stand development is lacking.

In addition to competition, severe drought can have long-term adverse effects on tree growth. Some species never fully

NOTE: This project was funded by the USDA Forest Service, Coweeta Hydrologic Laboratory, in cooperation with the Wayah Ranger District of the Nantahala National Forest. Additional funding was provided through the Southern Appalachian Forest Ecosystem Program. A special thanks to Bill Culpepper for providing historical information on past management in the Blazed Creek watershed and to Patsy Clinton for field assistance. Also, we would like to thank Timothy B. Harrington and Thomas A. Waldrop for providing critical reviews of the manuscript.

Manuscript received December 4, 1994, accepted January 22, 1996.

Reprinted from *The Southern Journal of Applied Forestry,* Vol. 21, No. 1, February 1997

recover, and subsequent droughts of lesser magnitude have been known to kill previously stressed individuals (Tainter et al. 1984). Vose and Swank (1994) observed significant declines in radial increment of mature planted white pines at the Coweeta Hydrologic Laboratory in response to a severe drought in the mid-1980s. This regionwide and particularly severe drought had an estimated return period of over 200 yr (Swift et al. 1989).

The objectives of our study were to evaluate white pine height and radial growth responses to: (1) mechanical release, (2) interspecific competition, and (3) drought. We used both distance-dependent and distance-independent measures of competition to evaluate the influence of competitors on growth increment and the contribution of competition to the growth-climate relationship. Simple size-distance indices of competition have proven useful to explain variation in individual tree height and diameter increment (Martin and Ek 1984, Daniels et al. 1986, Holmes and Reed 1991, Biging and Dobbertin 1992, Morris and Forslund 1992). Wagner and Radosevich (1991) suggests that if a neighborhood radius larger than the optimum (defined as the radius which includes all stems whose crowns intermingle with the subject or target tree) is used to measure competitive influence, the best competition index should be distance dependent.

Methods

Site Description

Four sites, all within 1 km of each other, were chosen for the study. They are located in the Blue Ridge physiographic province of the Southern Appalachians (lat. N35°, long. W83°) on the Wayah Ranger District of the Nantahala National Forest, approximately 10 km north of Franklin, NC. The annual precipitation of approximately 1700 mm is evenly distributed throughout the year. Mean annual temperature is approximately 14°C. The soils are primarily of the Evard-Cowee Complex, which consist of fine-loamy, mixed, mesic, Typic Hapludults. The sites ranged from 8 to 10 ha. Elevation (730 to 975 m) and aspect (approx. SE) are similar on all four sites.

Management History and Treatment

Much of the area in the watershed containing our study sites had been high-graded over the past 60 yr. Only areas that were too steep to log were left uncut. In addition, in the late 1960s, a southern pine beetle epidemic eliminated most of the pitch (*Pinus rigida* Mill.), shortleaf (*P. echinata* Mill.), and Virginia (*P. virginiana* Mill.) pines (USFS, unpublished information), leaving a scattered overstory of surviving yellow pine species (subgenus Diploxylon) and low-quality oaks, primarily scarlet (*Quercus coccinea* Muenchh.) and chestnut oak (*Q. prinus* L.)(Vose and Swank 1993).

In the summer of 1977, all woody vegetation (including shrubs) on all four sites was clear-felled and burned. A residual overstory component of pitch pine, shortleaf pine, and/or Virginia pine remained after the treatment to provide a pine seed source. Estimates of density and basal area for this component are 5 stems/ha and 0.46 m^2/ha, respectively. Eastern white pine was planted at a 6 x 6 m spacing the first winter after site-preparation. The wide spacing was prescribed to achieve a mixed species stand. At age 6, white pines on two of the four sites were released mechanically. All woody vegetation within 2 m of each planted white pine was cut to ground level with a chainsaw or by some other mechanical means.

Growth Measurements

In 1992, 16 to 20 individual white pine stems were randomly selected on each site for diameter and height growth measurements ($N = 72$ and $N = 74$, respectively). For diameter growth, two increment cores were extracted near the base of each tree and on opposite sides of the stem. Each core was analyzed with a computer-based growth increment measurement system. For height growth, internodal distance was measured to the nearest centimeter.

Competition Measurement and Index Calculation

Competition and drought effects were determined on an individual tree basis. To quantify the effect of interspecific competition on growth increment, competition indices were computed based on competitor size and distance to the target tree (Table 1). Comparisons were made between observed levels of competition and height, radial, basal area, and biomass increment for 16 randomly selected white pine trees on the nonrelease site only.

All stems which met the following size class restrictions were measured within a 6 m radius of each target tree. Size classes used in the index calculation were: (1) height of competitors to the nearest 0.5 m, (2) dbh of competitors to the nearest centimeter to a minimum of 0.5 cm, and (3) distance from target tree to each competitor to the nearest 0.5 m. Due to their large numbers, mountain laurel stems were simply tallied in two basal diameter classes: < 3 cm and > 3 cm, all stems were < 5 cm basal diameter. The growth habit of mountain laurel makes measurement of dbh impractical. All vegetation measurements were taken at stand age 14. All species nomenclature follows Little (1979) and Radford et al. (1968).

Statistical Analysis

Biomass (total aboveground dry weight of wood only) was estimated with allometric equations developed specifically for this and a related study (Elliott and Clinton 1993) and with allometric equations developed by others (Swank and Schreuder 1974, Phillips 1981, Boring and Swank 1986) for species in the Southern Appalachians.

Table 1. Type and computational form of competition indices used in the repeated measures ANOVA model.

Index type	Index form	Source
Distance dependent	$\sum((D_j / D_i)/L_{ji})/n_i$ $\sum((H_j / H_i)/L_{ji})/n_i$	Modified Hegyi (1974)
Distance independent	$\sum(D_j D_i)/n_i$ $\sum(H_j / H_i)/n_i$	Modified Lorimer (1983)

NOTE: D_j—Competitor dbh; D_i—Target dbh; L_{ji}—distance between competitor and target tree; n—number of competitors; H_j—competitor height; H_i—target height.

Both height (*N* = 74) and radial increment (*N* = 72) were examined with repeated measures ANOVA (PROC GLM, SAS 1987). Growth increment in the peak-drought year (1986) of a 5 yr period of below average precipitation was compared with that of nondrought years, and growth in the year of the release treatment was compared with that in all subsequent years. Mean growth responses to treatment were identified with the repeated measures model. Site differences in productivity were accounted for with a Least-Squares Means test (SAS 1987) in which target-tree total height at age 6 (release year) was used as a covariate.

Competition indices were compared to white pine growth increment for the nonreleased sites only. Pearson correlation coefficients were used to relate distance-dependent and distance-independent measures of competition to height and radial increment, basal area, and biomass growth of white pine trees (PROC CORR, SAS 1987). Competition indices were also used in a repeated measures ANOVA model (PROC GLM, SAS 1987) to evaluate the combined influence of competition and drought on white pine growth on nonreleased sites. The contrast transformation was used in all repeated measures tests. Significant differences were evaluated at a = 0.05.

Results and Discussion

By stand age 14, two distinct strata had developed in all stands: the overstory and a clearly defined shrub layer dominated by mountain laurel. This species accounted for 59% of the density and 67% of the basal area in the shrub strata on these sites (Clinton et al. 1993). In the overstory, 75% of the density was accounted for by red maple *(Acer rubrum* L.), scarlet oak, chestnut oak, sourwood (*Oxydendronarboreum* [L.] DC.), pitch pine, and planted eastern white pine. White pine alone accounted for 11% of the density and 41% of the basal area in the overstory. *Quercus* spp. accounted for 39% of the density and 21 % of the basal area (Clinton et al. 1993).

Response to Release

Although radial increment did not significantly respond to release through 1991, a trend toward divergence did occur in 1990 (*P* = 0.0970) and 1991 (*P* = 0.0881) (Figures la and 1b), suggesting that a treatment response may occur in subsequent years. Similarly, height increment did not show a significant response to release until 1988 (*P* = 0.0397) and 1989 (*P* = 0.0694). Height appeared to be following the same trend as radial growth; by 1991, height increment had returned to the pretreatment pattern where it was lower in the released than in the nonreleased trees. However, the release treatment did have an apparent effect on the canopy growing space of the white pine. Average height to live branches of the released trees (45.5 cm) was significantly lower ($t_{\alpha<0.05, df=69} = 3.41$; *P* = 0.001) than the average height to live branches of the nonreleased trees (81.6 cm) due to the retention of lower live branches as a consequence of the removal of adjacent competitors.

The results of our study suggest that in these Southern Appalachian hardwood systems, a single mechanical release may not be an effective treatment to eliminate hardwood and mountain laurel competition. Most hardwoods and mountain laurel sprout prolifically following cutting. Other studies have found similar results where cutting was used to reduce hardwood competition. For example, in a study of 6-yr-old planted loblolly pine *(Pinus taeda* L.), Fredericksen et al. (1991) found that pine stem volume was lower and the level of competition was more intense on sites that had been site-prepared by chopping only compared to other treatments.

Response to Drought

Trees on both released and nonreleased sites responded to a severe drought, which occurred over the period 1984–1988, with a substantial decrease in annual radial increment (Figure la). Not only was total annual precipitation well below average for these years, but growing season totals were low as well (Swift, unpubl. data). The observed decrease in growth began in 1985 and reached a minimum in 1986 when annual radial increment was as low as the annual increment

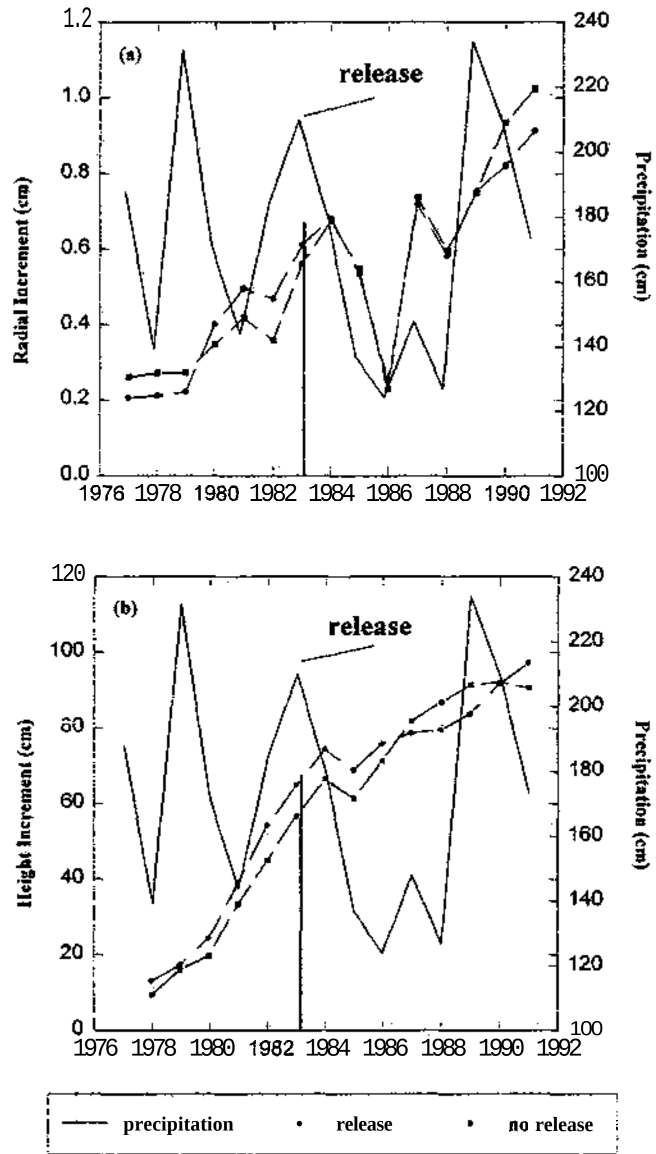

Figure 1(a and b). Height and radial increment in relation to precipitation. Included are responses for both released and nonreleased white pines.

during the first few years after outplanting (years prior to 1984). Although a similar precipitation deficit occurred in 1988, the corresponding decrease in radial increment was not as great as in 1986 (Figure la).

Height increment growth pattern for white pine approximated a sigmoid curve (Figure 1b), whereas radial increment growth pattern showed sharp declines in growth in years 1986 and 1988, suggesting that height increment was less sensitive than radial increment to variation in precipitation from year to year. There was a decline in height increment the first year of the drought then a recovery in the peak drought year of 1986 (Figure 1b). Furthermore, the relative magnitude of the decline in height increment was proportionately less than that for radial increment. Even extreme drought events may have only minor impacts on height growth depending on the timing of precipitation during the year. A rainfall deficit in late spring to midsummer can result in a large decline in annual height growth for growth determinant species such as eastern white pine (Kozlowski et al. 1991). In our study, late spring and early summer precipitation was adequate in years without drought. During the drought period, late spring to midsummer deficits did occur, but declines in height growth were not great. However, the form of the respective curves for radial and height annual increment are a function of a variety of phenomena, including climate and competition.

Response to Competition

The most negatively correlated competition indices with white pine growth were those based on competitor height (Table 2). In general, distance-independent measures of competition were more highly related to white pine growth than distance-dependent measures. Although competition indices, such as those used in our study, do provide measures of the outcome of biological processes and have been found useful in predicting tree growth, the extent to which competitor size and distance to target-tree are informative in predicting growth varies with forest type and age. For example, Martin and Ek (1984) found that no additional improvement was obtained by using distance-dependent measures compared to distance-independent measures of competition to predict red pine *(Pinus resinosa* Ait.) growth. Lorimer(1983) concluded that intertree distance was of no value for predicting growth of individual trees in natural even-aged hardwood stands. However, Daniels et al. (1986) found that distance-dependent indices were more highly correlated with loblolly pine *(Pinus taeda* L.) growth than were the distance-independent measures.

Significant positive correlations were found for total competitor biomass and mountain laurel density, suggesting that mountain laurel does not exert a competitive influence on white pine growth at this stage in stand development. Because of mountain laurel's low stature, this species had a minimal influence on light available to white pine; therefore distance to them is not important to competition for light. Clinton et al. (1993) found that stem density of hardwoods in the overstory was inversely related to mountain laurel basal area, which illustrates the inability of hardwoods to become established as mountain laurel abundance increases. However, those individual hardwood stems that do become established can compete for space and light with white pine. Thus, their spatial relationship with the target tree would determine the level of competition for this resource. Once white pine has overtopped mountain laurel, competition from mountain laurel would only be for belowground resources. Although we did not measure belowground competition directly, it can be assumed that the combined effect of above- and belowground competition (which is the case for hardwoods + mountain laurel) is likely stronger than that of belowground competition alone (only mountain laurel).

Even though high correlations existed between many of our distance-independent indices and white pine growth (Table 2), the only index to contribute to the repeated measures ANOVA model was the height-distance competition index. Over all years (1977–1991), the effect of competition was only marginally significant ($F = 3.94$, $P = 0.0673$). A significant decline in height growth occurred in 1985 compared to 1984 and 1986 (1984, $F = 5.18$, $P = 0.0391$; 1986, $F = 6.08$, $P = 0.0272$). No further differences were found for

Table 2. Pearson correlation coefficients relating mean incremental height, diameter, basal area, and biomass growth for the period 1984–1991 of 14-yr-old *Pinus strobus L.* to distance-dependent and distance-independent measures of competition (CI).

	Growth increment			
	Height	Diameter	Basal area	Biomass
Distance dependent				
$CI_{ht\text{-}dist}$	–0.781****	–0.565**	–0.545**	–0.693***
$CI_{dbh\text{-}dist}$	–0.617**	–0.763****	–0.740***	–0.828****
Distance independent				
CI_{ht}	–0.802****	–0.531**	–0.514*	–0.633***
CI_{dbh}	–0.667***	–0.783****	–0.764****	–0.847****
Total competitor biomass	0.367	0.458*	0.442*	0.342
Total competitor basal area	0.103	0.355	0.355	0.411
Mean competitor diameter	-0.322	-0.343	-0.334	-0.374
Mountain laurel density	0.342	0.482*	0.462*	0.473*

NOTE: *, **, ***, **** denotes significance at the 0.10, 0.05, 0.01, and 0.001 level, respectively ($n = 16$).

height increment in years beyond 1986 for any of the competition indices. Similarly, the height-distance index was the only index to show an effect of competition on radial growth, but the significance was only marginal ($F = 3.94, P = 0.0726$) and only occurred in 1990, several years following the drought. In general, competition was only slightly influential on growth during the drought years, likely due to inadequate moisture availability masking the potential effects of competition alone.

Conclusions

The effectiveness of the release treatment in this study was only slightly measurable. Even though pretreatment differences in stem size between treatment areas were accounted for in the analyses, drought masked possible treatment effects. The similar growth patterns between released and nonreleased trees during the drought (1984–1988) illustrate the overriding effects of severe moisture limitation on radial increment. Once precipitation returned to normal or average levels (1990), radial growth patterns suggest that light and possibly other resources became limiting.

Mountain laurel is thought to be a major competitor to successful establishment of planted white pine on these sites, and control of this species during site-preparation is a common practice. Even though mountain laurel is extremely abundant and dominates the lower strata on our study sites at age 14, based on our results it does not appear to be as important a competitor to white pine growth as other hardwood species. Hence, subsequent attempts to control mountain laurel and other competing vegetation may not be as effective or as critical as control of mountain laurel during site preparation for the purpose of white pine establishment. In addition, due to the dominating influence of moisture stress during early white pine growth, it is difficult to determine whether or not the increase in radial growth observed in 1990 is at all attributable to the release treatment. At best, there may be a marginal benefit to mechanical removal of competitors early in stand development, but its cost effectiveness is questionable. Repeated release treatments, especially the removal of stems competing for space in the overstory, may prove effective; however, if conducted precommercially, the practice is likely cost prohibitive.

Literature Cited

BARDEN, L.S., AND F.W. WOODS. 1973. Characteristics of lightning fires in southern Appalachian forests. Proc. of Tall Timbers Fire Ecol. Conf. 13:345-361.

BARDEN, L.S., AND F.W. WOODS. 1976. Effects of fire on pine and pine-hardwood forests in the southern Appalachians. For. Sci. 22:399–403.

BIGING, G.S., AND M. DOBBERTIN. 1992. A comparison of distance-dependent competition measures for height and basal area growth of individual conifer trees. For. Sci. 38(3):695-720.

BORING, L.R., AND W.T. SWANK. 1986. Hardwood biomass and net primary production following clearcutting in the Coweeta basin. P. 43-50 *in* Proc. 1986 South. For. Biomass Workshop.

CLINTON, B.D., J.M. VOSE, AND W.T. SWANK. 1993. Site preparation burning to improve southern Appalachian pine-hardwood stands: Vegetation composition and diversity of 13-year-old stands. Can. J. For. Res. 23:2271-2277.

DANIELS, R.F., H.E. BURKHART, AND T.R. CLASON. 1986. A comparison of competition measures for predicting growth of loblolly pine trees. Can J. For. Res. 16:1230–1237.

ELLIOTT, K.J., AND B.D. CLINTON. 1993. Equations for estimating biomass of herbaceous and woody vegetation in early-successional southern Appalachian pine-hardwood forests. USDA For. Serv. Res. Note SE-365. 7 p.

ELLIOTT, K.J., AND J.M. VOSE. 1993. Site preparation burning to improve southern Appalachian pine-hardwood stands: Photosynthesis, water relations, and growth of planted *Pinus strobus* L. during establishment. Can. J. For. Res. 23:2278-2285.

FREDERICKSEN, T.S., H.L. ALLEN, AND T.R. WENTWORTH. 1991. Competing vegetation and pine growth response to silvicultural treatments in a six-year-old piedmont loblolly pine plantation. South. J. Appl. For. 15:138–144.

HEGYI, F. 1974. A simulation model for managing jack pine stands. P. 74-90 *in* Growth models for tree and stand simulation, Fries, J. (ed.). Royal Coll. of For., Stockholm, Sweden.

HOLMES, M.J., AND D.D. REED. 1991. Competition indices for mixed species northern hardwoods. For. Sci. 37(5): 1338–1349.

KOZLOWSKI, T.T., P.J. KRAMER, AND S.G. PALLARDY. 1991. The physiological ecology of woody plants. Academic Press, New York. 657 p.

LITTLE, E.L. 1979. Checklist of United States trees. USDA For. Serv. Handbook No. 541.

LORIMER, C.G. 1983. Tests of age-dependent competition indices for individual trees in natural hardwood stands. For. Ecol. Manage. 6:343-360.

MARTIN, G.L., AND A.R. EK. 1984. A comparison of competition measures and growth models for predicting plantation red pine diameter and height growth. For. Sci. 30:731-743.

MORRIS, D.M., AND R.R. FORSLUND. 1992. The relative importance of competition, microsite, and climate in controlling the stem taper and profile shape in jack pine. Can. J. For. Res. 22:1999-2003.

PHILLIPS, D. 1981. Predicted total-tree biomass of understory hardwoods. USDA For. Serv. Res. Pap. SE-223. 22 p.

RADFORD, A.E., H.E. AHLES, AND C.R. BELL. 1968. Manual of the vascular flora of the Carolinas. Univ. North Carolina Press, Chapel Hill, NC. 1183 p.

SAS INSTITUTE INC. 1987. SAS User's Guide: Statistics, 1985 edition. SAS Institute Inc., Cary, NC.

SMITH, R.N. 1991. Species composition, stand structure, and woody detrital dynamics associated with pine mortality in the southern Appalachians. Masters Thesis, University of Georgia, Athens. 163 p.

SWANK, W.T., AND H.T. SCHREUDER. 1974. Comparison of three methods of estimating surface area and biomass for a forest of young white pine. For. Sci. 20(1):91-100.

SWIFT, L.W., K.J. ELLIOTT, R.D. OTTMAR, AND R.E. VIHANEK. 1993. Site preparation to improve southern appalachian pine-hardwood stands: Fire characteristics, and soil erosion, temperature and moisture. Can. J. For. Res. 23:2242-2254.

SWIFT, L.W., J.B. WAIDE, AND D.L. WHITE. 1989. Refinements in the Z-T method of extreme value analysis for small watersheds. P. 60-65 *in* Sixth Conf. on Appl. Climatol. Am. Meteorol. Soc., Boston, MA.

TAINTER, F.W., S.W. FRAEDRICH, AND D.M. BENSON. 1984. The effect of climate on growth, decline, and death of northern red oaks in the western North Carolina Nantahala mountains. Castanea 49(3): 127–137.

VAN LEAR, D.H., AND T.A. WALDROP. 1988. Effects of fire on natural regeneration in the Appalachian mountains. P. 56–70 *in* Guidelines for Regenerating Appalachian Hardwood Stands: Workshop proc.

VOSE, J.M., AND W.T. SWANK. 1993. Site preparation burning to improve southern Appalachian pine-hardwood stands: Aboveground biomass, forest floor mass, and nitrogen and carbon pools. Can. J. For. Res. 23:2255-2262.

VOSE, J.M., AND W.T. SWANK. 1994. Effects of long-term drought on the hydrology and growth of a white pine plantation in the southern Appalachians. For. Ecol. Manage. 64:25-39.

WAGNER, R.G., AND S.R. RADOSEVICH. 1991. Neighborhood predictors of interspecific competition in young Douglas-fir plantations. Can. J. For. Res. 21:821-828.