Survival and Growth of Seed Trees 20 Years after a Natural Regeneration Cut in the Piedmont of Georgia

Stephen R. Logan, *The University of Georgia, Daniel B. Warnell School of Forest Resources, University of Georgia, Athens, GA 30602;* **M. Boyd Edwards,** *Southern Research Station, Macon, GA 31203; and* **Barry D. Shiver,** *The University of Georgia, Daniel B. Warnell School of Forest Resources, University of Georgia, Athens, GA 30602.*

ABSTRACT: *An experiment was installed in 1982 to compare six methods of natural regeneration in the Piedmont of Georgia. These methods include (1) clearcut with seed in place; (2) clearcut with seed in place and preharvest burn; (3) seed tree; (4) seed tree with preharvest burn; (5) shelterwood; and (6) shelterwood with preharvest burn. Because of endangered species regulations in the years after establishment of the study, no seed trees were cut and the seed tree and shelterwood plots have grown into two-story stands. Individual tree and stand characteristics were analyzed to determine the effects of burning and regeneration method on the remaining seed trees after 20 years. Diameter at breast height (dbh) growth was greater on seed tree plots than on shelterwood plots, but burned plots had increased dbh growth on shelterwood plots and decreased dbh growth on seed tree plots. Total height growth also exhibited an interaction between the burning and regeneration method but with an opposite effect. Total height growth decreased on burned shelterwood plots but increased on burned seed tree plots. Shelterwood plots had approximately double the basal area and merchantable green weight of the seed tree plots. The economic analysis indicates the seed tree method leads to greater financial returns and is less sensitive to discount rate variations than the shelterwood method. South. J. Appl. For. 29(4):173–178.*

Key Words: Loblolly pine, shelterwood, two-story stand, economic analysis.

Natural pine stands occupied 4.6 million ac in Georgia in 1997. Of those, approximately 2.7 million ac (59%) were predominately loblolly pine (FIA Mapmaker, www.ncrs2.fs.fed.us/4,801/FIADB/fim_tab/wc_fim_tab.asp. Feb. 4, 2004). Landowners not willing to spend the up-front out-of-pocket costs associated with artificial pine regeneration often are interested in natural regeneration as an economical way to start a new timber stand. Considerable work has been published on effective methods of natural regeneration of southern pine (Brender 1952, Langdon 1981, Edwards 1987, Cain and Shelton 2001). Situations may occur where the seed trees are never removed from a site because of unforeseen circumstances or the landowner may want to leave the overstory for aesthetic reasons. Although multistoried pine stands have been studied widely (Baker et al. 1996, Guldin and Baker 1998, Shelton and Cain 2000), these studies focused on methods for regenerating uneven-aged pine stands with more than two age classes. A two-story stand should be easier to establish and manage than the more complex uneven-aged stand alternative.

Little work has been published on the survival or growth of seed trees, especially over a long time period. Seed tree fate is interesting from both a biological and financial standpoint. How much of a penalty can a landowner expect from the loss of growth of the regeneration caused by the presence of seed trees? Will the seed trees respond to the release at the time of the regeneration cut, and will the growth of these seed trees offset the financial returns that could have been gained if they were cut 3–5 years after the regeneration cut?

Latham and Tappeiner (2002) investigated the response of the old-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws), and sugar pine (*Pinus lambertiana* Dougl.) to stand density reductions in western Oregon. Many of the stands were shelterwood treatments in which the overstory trees were not removed, similar to the situation in this study. They found that these trees, ranging in age from 158 to 650

NOTE: Stephen R. Logan can be reached at (706) 542-7578; Fax: (706) 542-8356; Slogan@forestry.uga.edu. Manuscript received November 8, 2004, accepted March 9, 2005.

years, significantly increased basal area growth after the shelterwood cut.

Baker and Shelton (1998) investigated the response of intermediate and suppressed loblolly pine trees with an average age of 26 years that were released from overtopping pines and hardwoods in an uneven-aged cut. They found that the trees responded impressively to the release over the next 15 years. The trees in this study differ in that they were in the dominant and codominant crown positions in the harvested stand and had not had their growth suppressed. Also, the seed trees in this study were considerably older, averaging 52 years.

The objectives of the current study were to determine the differences in growth of seed trees when cut to two different stocking levels, those that are commonly associated with loblolly pine seed tree and shelterwood cuts. A secondary objective was to determine if burning had any significant effect on the growth of the seed trees. A final objective was to rank the seed tree methods financially to determine if one of the cutting methods is preferable in the event that the seed trees cannot be removed. In addition, the regeneration methods with seed trees left were to be compared to leaving no seed trees to evaluate the tradeoff of leaving seed trees to grow in value versus accelerating growth of regeneration by removing seed trees.

Materials and Methods

The study began in spring 1982 on a 100-ac research and demonstration area within the Hitchiti Experimental Forest. The Hitchiti Forest Research Center was established in 1946 to investigate methods to produce more wood from the depleted forests of lower Piedmont Georgia, Alabama, and South Carolina (Brender 1952). The forest is located in the lower Piedmont in Jones County, Georgia, at longitude 83°42′30″ W, latitude 33°1′30″ N. The site received an average rainfall of 46.3 in. annually and had a mean temperature of 64° F between the start of the study and the end of 2002 (National Oceanic and Atmospheric Administration (NOAA), www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20004868. Feb. 5, 2004). Typical of much of the timberland in this area, the site contained a natural stand mixture of pine and hardwood that regenerated in the late 1930s on abandoned cotton fields.

Five replications of six treatments were laid out in a randomized block design. Permanent 2.0-ac square plots were installed for each treatment on each block. The six treatments were:

1. Clearcut with seed in place and no preharvest burn (CCN).
2. Clearcut with seed in place, with a preharvest burn (CCB).
3. Seed tree cut with 8–10 seed trees/ac after harvest and no preharvest burn (STN);
4. Seed tree as in treatment 3, with preharvest burn (STB).
5. Shelterwood cut that reduced the stand to 25 ft^2 of basal area/ac and no preharvest burn (SWN).
6. Shelterwood cut as in treatment 5, with preharvest burn (SWB).

A complete inventory of all merchantable trees on each 2-ac plot was made in 1982. Residual trees were selected on all seed tree and shelterwood plots. Trees selected were straight, had good form, were free from injury and disease, and were observed to have numerous cones present. Residual trees were selected so that they were evenly distributed across each plot to give good seed coverage. All seed trees were given a numbered aluminum tag. Table 1 gives summary statistics for the residual stand on seed tree and shelterwood treatments in fall 1983.

A late summer burn was conducted on the plots assigned to treatments 2, 4, and 6 before harvest. This was accomplished by strip headfires that consumed the understory vegetation but did not damage the overstory. The duff layer was reduced to less than 1 in. and the burn significantly improved the seedbed. The burning was timed so that it occurred before seed fall.

In the spring of 1983, a total of 823 thousand board feet (mbf) of pine logs and 355 mbf of pine roundwood was harvested from the 100-ac study area. Care was taken not to damage the selected seed trees. During the summer of 1983, all residual hardwood stems greater than 1 in. dbh were injected with picloram. A precommercial thinning (PCT) was conducted with chainsaws in the summer of 1995 to reduce pine stocking to approximately a 12 × 12 ft spacing and to remove hardwoods.

Initial planning included cutting the residual seed trees 3–5 years after the initiation of the study. However, in 1984, an endangered species, the red-cockaded woodpecker (*Picoides borealis*), was found nesting within the stand and federal law did not allow the seed trees to be removed. It was decided at that time to continue the study as a two-canopied stand because this could be of interest to many landowners facing similar situations in the future.

By the summer of 2003, 24 of the original 30 plots remained. All plots in block 1 were lost because of construction of a new road. Remeasurements of all remaining

Table 1. Summary statistics for seed trees in 1983 and 2003.

Regeneration method	Burn	TPA 1983	TPA 2003	dbh (in.) 1983	dbh (in.) 2003	Height (ft) 1983	Height (ft) 2003	BA (ft^2/ac) 1983	BA (ft^2/ac) 2003	Merchantable tons 1983	Merchantable tons 2003
Seedtree	Yes	8.9	8.1	14.9	19.1	80.4	98.0	9.8	16.3	10.9	22.5
	No	9.0	8.4	15.1	19.8	84.1	100.8	11.0	18.6	13.1	26.6
Shelterwood	Yes	20.7	20.5	14.2	17.9	80.4	93.3	22.5	35.6	26.0	47.7
	No	19.1	17.8	15.0	18.1	79.1	94.2	22.2	32.5	24.7	43.5

BA = basal area; TPA = trees per acre.

plots were made in the summer of 2003. If a seed tree had the original tag, the original tag number was recorded and the tree was retagged. Of the 469 seed trees originally tagged on the remaining plots, 127 trees still had the original tags. All other seed trees were given new tags. All seed trees on each plot were measured for dbh to the nearest 0.1 in., total height to the nearest foot, height to a 4- and 8-in. outside bark top to the nearest foot, height to live crown to the nearest foot, and number of 16-ft logs to the nearest 0.5 logs to either an 8-in. top or where the log would no longer be taken as sawtimber, whichever came first. Regeneration also was measured on five plots systematically placed over each 2-ac plot. Each stem was measured for dbh and total height and given a product code.

An analysis of variance (ANOVA) was conducted to test for significant differences in individual and stand characteristics caused by the regeneration method and burning. The skewness, kurtosis, and range of the seed trees' diameter distributions also were tested. Tukey's multiple range test was used to determine whether differences among means were significant at the $\alpha = 0.05$ level. All data analysis was performed using the SAS statistical package (SAS Institute, Inc. 1990).

An economic analysis was performed as an additional way to rank the treatments. Two methods of economic analysis were used, net present value (NPV) and internal rate of return (IRR). NPV is the present value of revenues minus the present value of costs. A general formula for NPV is

$$\mathrm{NPV} = \sum_{y=0}^{n} \left[\frac{R_y}{(1+i)^y} - \frac{C_y}{(1+i)^y} \right]$$

where

R_y = revenues in year y;
C_y = costs in year y;
n = number of years in investment;
i = discount rate.

Real discount rates of 4, 6, and 8% were chosen to investigate the effect of varying hurdle rates on treatment combination selections. An ANOVA was conducted on the NPVs to test for significant differences in discounted returns of the treatments.

IRR is simply the discount rate at which the present value of revenues minus the present value of costs equals zero. A general formula for IRR is

$$\sum_{y=0}^{n} \left[\frac{R_y}{(1+\mathrm{IRR})^y} \right] - \sum_{y=0}^{n} \left[\frac{C_y}{(1+\mathrm{IRR})^y} \right] = 0$$

where all variables are the same as defined previously. An ANOVA was conducted on the IRRs to test for significant differences between treatments.

Product green weights were calculated for pulpwood with a minimum dbh of 4.5 in. to a 3-in. top, chip-n-saw with a minimum dbh of 8.5 in. to a 6-in. top, and sawtimber with a minimum dbh of 12.5 in. to an 8-in. top. Any portion of a chip-n-saw or sawtimber tree over the merchantable top to a 3-in. top was included in the pulpwood weights.

Stumpage prices were based on north Georgia averages obtained from Timber Mart-South (2004). Product values used were \$5.36/ton for pine pulpwood, \$21.67/ton for pine chip-n-saw, and \$34.16/ton for pine sawtimber. Burning was estimated to cost \$25.00/ac, and the PCT had an associated cost of \$140.00/ac. Annual tax and administration costs were assumed to be \$4.00/ac/year.

Results and Discussion

Diameter at Breast Height

Although it is common knowledge that diameter growth decreases as density increases, we thought it would be interesting to look at the diameter growth on the seed tree and shelterwood plots after the regeneration cut to see if trees of this age would respond differently, both having relatively low residual densities. Diameter growth between 1982 and 2003 was analyzed to answer this question. Burning also was analyzed to see if it affected diameter growth.

The ANOVA indicated an unexpected significant interaction between regeneration method and burning. As expected, both the burned and the nonburned seed tree plots had significantly larger average dbh growth than the corresponding shelterwood plots because of their low residual density (Table 2). What was unexpected was that burned plots had increased diameter growth on shelterwood plots and decreased diameter growth on seed tree plots. The nonburned shelterwood plots averaged 3.1-in. diameter growth and the burned plots averaged 3.7 in. of growth. In comparison, the burned seed tree plots averaged 4.2 in. of diameter growth and the nonburned plots averaged 4.7 in. of growth. When examined on a block-by-block basis, all four shelterwood plots had significantly greater diameter growth on the burned plots than the on nonburned plots, whereas three of the four seed tree plots had decreased growth on the burned plots than the on nonburned plots. The other seed tree plot had approximately the same diameter growth on both the burned and nonburned plots. There is little evidence as to why the burned trees had greater growth on the shelterwood plots and less growth on the seed tree plots. The initial diameter of the nonburned shelterwood plots averaged 0.8 in. smaller than the burned shelterwood plots, but at this age it would not be expected that this would lead to increased growth. Also, the seed tree plots had 0.2 in. smaller average tree diameter on the burned plots, but these

Table 2. Summary statistics for seed tree growth from 1983 to 2003.*

Regeneration method	Burn	DBH (in.) growth	Height (ft) growth	BA (ft^2/ac) growth	Merchantable tons growth
Seed tree	Yes	4.2^{b}	17.6^{a}	6.5^{c}	11.6^{c}
	No	4.7^{a}	16.7^{ab}	7.6^{bc}	13.5^{bc}
Shelterwood	Yes	3.7^{c}	12.9^{c}	13.1^{a}	21.7^{a}
	Yes	31.1^{d}	15.1^{b}	10.3^{ab}	18.8^{ab}

* Treatments with the same letter are not significantly different at $\alpha = 0.05$ level.

trees had lower average growth than the nonburned seed tree plots. Further investigation is needed to determine if there is a plausible reason or if this was just an anomaly in this study.

Total Height

Total height growth was analyzed to see if significant differences existed between seed tree and shelterwood plots and between burned and nonburned plots. As with dbh, there was a significant interaction between the regeneration method and burning, although the interaction was different. Although seed tree plots had significantly greater dbh growth on nonburned plots than burned plots, total height growth was greater on burned plots than nonburned plots, but the difference was not significantly different. Nonburned seed tree plots averaged 16.7 ft of height growth and the burned plots averaged 17.6 ft of growth. Total height growth on nonburned shelterwood plots averaged significantly more than on burned shelterwood plots, again the opposite of what occurred with the dbh interaction. Nonburned shelterwood plots averaged 15.1 ft of height growth and burned plots averaged 12.9 ft of growth. Table 1 contains total height for each treatment at the 2003 measurement and Table 2 contains total height growth between 1982 and 2003.

Both the burned and nonburned seed tree treatments had greater height growth in the last 20 years than the shelterwood plots, averaging 3.2 ft more growth on seed tree plots than shelterwood plots. It is somewhat odd that at this low residual density there would be a significant difference in total height growth between the treatments.

Basal Area

In 1983 the shelterwood plots had an average basal area of 22.4 ft^2/ac and the seed tree plots had an average basal area of 10.4 ft^2/ac. The basal area difference between the burned and nonburned plots was negligible at 16.2 and 16.6 ft^2/ac, respectively. By 2003 the shelterwood plots had added an average of 11.7 ft^2/ac of basal area to an average of 34.0 ft^2/ac and the seed tree plots had grown an average of 7.0 ft^2/ac of basal area to an average of 17.4 ft^2/ac.

Again, there is a significant interaction between the regeneration method and burning when analyzing basal area growth. Table 2 indicates that there is no significant difference between burned and nonburned shelterwood treatments. Although the burned shelterwood treatment had significantly more average basal area growth than either of the seed tree treatments, the nonburned shelterwood treatments did not have significantly more basal area growth than the nonburned seed tree treatment.

Merchantable Green Weight

Merchantable tons per acre to a 3-in. top outside bark were calculated for each plot in 2003. As expected, the shelterwood had significantly more green weight than the seed tree plots (averaging 45.6 tons/ac versus 24.5 tons/ac). Growth for the shelterwood plots averaged 20.2 tons/ac and growth for the seed tree plots averaged 12.5 tons/ac. Burning had no significant effect on merchantable green weight growth, and there was no significant interaction between the regeneration method and burning. Table 2 shows merchantable growth between 1983 and 2003.

Diameter Distribution

The changes in range, skewness, and kurtosis of the diameter distribution between 1982 and 2003 were analyzed to see if the regeneration method or burning caused differences between treatments. Neither skewness nor kurtosis was significantly affected by either treatment, but there was a significant interaction between the regeneration method and burning on diameter range. The burned seed tree plots' dbh range increased an average of 2.6–9.8 in. In contrast, the nonburned seed tree plots' dbh range decreased by 0.1–9.9 in. The burned shelterwood plots' diameter range increased by 0.6–13.3 in. and the nonburned plots' range increased by 2.9–13.7 in.

Although the change in range was significantly different between 1982 and 2003, the average current range is approximately the same within a regeneration method (Figures 1 and 2). The range of the seed tree plots is less than the range of the shelterwood plots. This was expected because there are fewer trees on the seed tree plots and thus a more even stand was selected during the seed tree cut. It is interesting that the plots with lower initial diameter distribution ranges spread out and now are approximately the same as the plots with the wider initial diameter distribution.

Economic Analyses

Beyond the biological and aesthetic interest a landowner may have in a two-storied stand, most will be interested in how the regeneration methods compare economically. Recall that there were six treatments in this study. Four of them involved an overstory and were the basis for the majority of the study. The other two treatments were clearcut with seed in place. All six treatments had more than enough seedlings for regeneration and were precommercially thinned at the same time and in the same way. The size of the regeneration on the clearcut treatments as compared with the seed tree and shelterwood treatments is an indication of the effect of the seed trees on the growth of the regeneration. Table 3 presents the characteristics of the regeneration by treatment

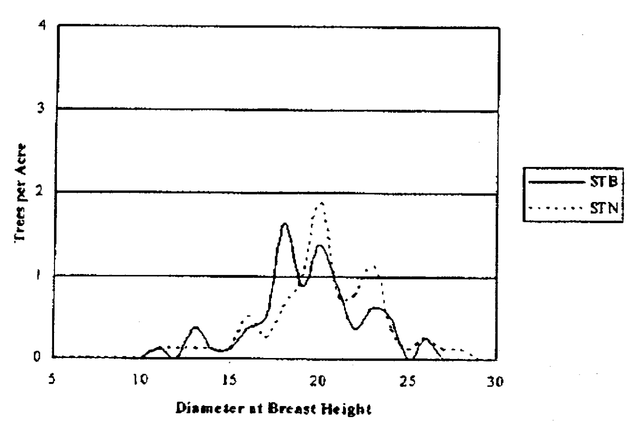

Figure 1. Diameter distribution for burned (STB) and nonburned (STN) seed tree plots in 2003 for a natural loblolly pine stand in the Georgia Piedmont.

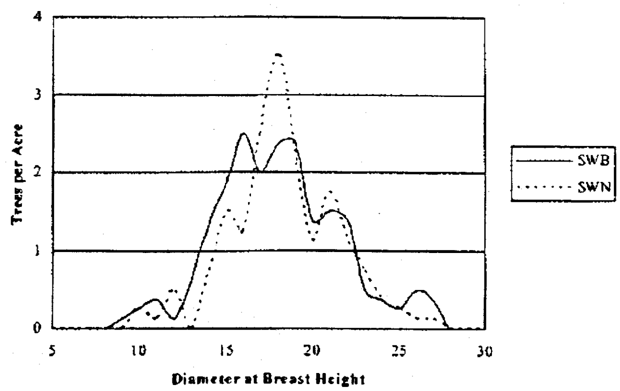

Figure 2. Diameter distribution for burned (SWB) and non-burned (SWN) shelterwood plots in 2003 for a natural loblolly pine stand in the Georgia Piedmont.

Table 3. Pine regeneration characteristics just after PCT and in 2003 by treatment.

	Summer 1996		Summer 2003	
Treatment	dbh (in.)	Total height (ft)	dbh (in.)	Total height (ft)
CCN	5.1	29	7.8	51.1
CCB	4.0	24	7.6	49.6
STN	4.7	28	7.1	50.8
STB	4.2	34	6.9	47.6
SWN	3.3	22	6.3	44.8
SWB	3.5	23	6.2	45.6

after the PCT and again in 2003. It is obvious that the seed trees had a negative impact on regeneration growth over time, but balancing this out somewhat was the growth and value of the seed trees. An economic analysis was performed to evaluate the performance of the six treatments.

For the economic analysis, the opportunity cost of the seed trees and shelterwood trees was considered at the time of the regeneration cut, but their growth over the 20-year period was considered as part of the returns. The size and product class of the regeneration at age 20 years also was considered for the economic returns. No claim is made that age 20 years is the optimum time to make economic comparisons between treatments. They are made at age 20 years here because we have the data to make the comparisons. We do not have the ability to confidently predict growth into the future, particularly for the regeneration.

The two clearcut treatments had the best NPVs of the six treatments (Figure 3). With an average IRR of 9.9%, the clearcut treatments had significantly better rates of return than the seed tree or shelterwood two-story stands that averaged 3.5 and 2.6%, respectively (Figure 4). This illustrates both the negative effect of the seed trees on the regeneration and the inability of the biological growth of the seed trees to overcome the economic compounding of the opportunity cost of not removing them at the regeneration cut at moderate interest rates. The clearcut without burning had the greatest NPVs at all discount rates. This is not surprising because the burning did not affect the growth and all treatments produced more than enough seedlings. The

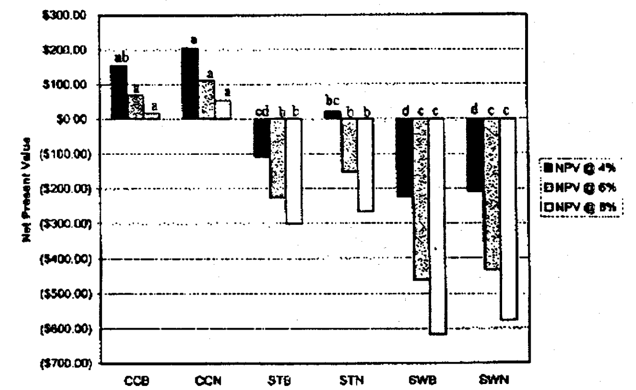

Figure 3. NPVs for six treatments at three discount rates in 2003 for a natural loblolly pine stand in the Georgia Piedmont. Treatments with the same letter are not significantly different as determined by Tukey's multiple range test.

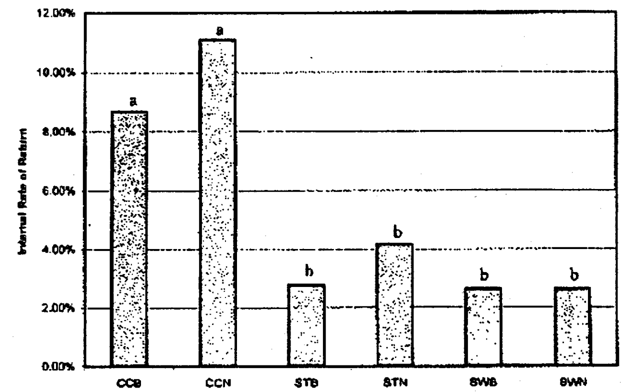

Figure 4. IRR for six treatments in 2003 for a natural loblolly pine stand in the Georgia Piedmont. Treatments with the same letter are not significantly different as determined by Tukey's multiple range test.

clearcut with burning had the second-best return but was not significantly better than the seed tree without burning at the 4% discount rate.

When comparing shelterwood and seed tree methods, there is no statistically significant difference between the treatments when examining IRR, although the NPV analysis indicates a significant difference between the two methods of regeneration at the 6 and 8% discount rates. This is due to primarily the larger amount of high-value timber that the shelterwood treatments carry throughout the rotation and the negative impact of that overstory on the growth of the regeneration.

The sensitivity analysis indicates that both the seed tree and shelterwood treatments for producing two-story stands are more sensitive to increases in discount rates than the clearcut treatments (that produces an even-aged stand), as can be seen in Figure 3. Again, this is due to the high value of the seed trees that are carried throughout the rotation. Between the seed tree and shelterwood method, the seed tree method is less affected by increases in discount rate than the shelterwood method.

It is important to realize that this economic analysis of the seed tree and shelterwood methods is specific to two-story stands. In a more traditional seed tree or shelterwood method where the overwood would have been removed at age 3–5 years, neither the long-term opportunity cost nor the negative affect on the regeneration would have reduced the rate of return as dramatically for these methods.

We also should point out that the timing of the treatments in this study should not necessarily be used as a model for producing two-aged stands. The PCT, in particular, could have been done at an earlier age at lower cost, and the growth of the regeneration would have benefited from the extra years of release on all treatments. Because it was done at the same age on all treatments, we feel that it is legitimate to compare the treatments, but it may well be that the timing was not optimal.

Conclusions

The comparison between seed tree and shelterwood treatments, both burned and nonburned, uncovered some interesting interactions on this study. The dbh growth over the 20-year study period was greater on seed tree plots than on shelterwood plots, but increased dbh growth was noted on shelterwood plots when the plots were burned and decreased growth was noted on seed tree plots when the plots were burned. An interaction also was present when examining total height growth, but with an opposite effect. Basal area of the shelterwood plots was approximately double the basal area of the seed tree plots in 2003. Basal area growth analysis indicated a statistically significant interaction between the regeneration method and burning, but this interaction was not present in the merchantable green weight analysis.

The burning treatment was added to this study to examine the differences between natural regeneration on burned and nonburned seedbeds. The interaction between burning and the regeneration method on the seed trees was unexpected and further investigation by other studies would be beneficial to indicate if other seed trees react in a similar manner.

The economic analysis indicates that between the seed tree and shelterwood regeneration methods with overstory remaining, the seed tree method leads to the greatest financial return. The greater initial cash flow generated from cutting more mature timber on the seed tree treatment is more valuable than the extra biological growth gained on the shelterwood treatments, when discounted. It also is evident that the seed tree treatment is less subject to variations in discount rates than the shelterwood treatment because the seed tree treatment captures a larger value early in the investment than the shelterwood treatment. For the landowner who is choosing between shelterwood and seed tree methods of natural regeneration, and there is a possibility that the mature trees may be left throughout the rotation, the seed tree method will produce more income during the initial seed tree cut and will allow more growth of the regeneration because of less overstory competition.

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