DISTRIBUTION OF MATURE CONES, CONELETS, AND OLD CONES IN SHORTLEAF PINE-OAK STANDS AFTER AN UNEVEN-AGED REGENERATION CUT

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Abstract—Sixteen shortleaf pine trees were felled in a stand 10 years after an uneven-aged regeneration cut reduced pine basal area to 60 square feet per acre and hardwoods were controlled. Sixteen unreleased trees in an adjacent uncut pine-hardwood stand (120 square feet per acre) were felled for comparison. Sample trees were selected from four 2-inch d.b.h. classes (11, 13, 15, and 17 inch) and tree crowns were divided into four positions (upper south, upper north, lower south, and lower north). The 15- and 17-inch released trees produced significantly more mature cones than unreleased trees in the same classes (by four times) and released trees in smaller classes (by four times). Cone production for unreleased trees did not differ among diameter classes. Cone production by crown position ranked: lower north = lower south < upper north < upper south. The lower north position produced significantly fewer conelets than other positions. Released trees retained more older cones than unreleased trees, and older cones were significantly correlated with both mature cones and conelets.

INTRODUCTION

Successful natural regeneration of shortleaf pine depends upon production of adequate crops of viable seeds along with appropriate seedbed conditions (Shelton 1995). Natural stands of shortleaf pine have highly variable seed crops because of many biotic and abiotic factors which reduce the reliability of natural regeneration methods in these stands (Wittwer and Shelton 1992). An adequate seed crop consists of 80 to 250 thousand sound seeds per acre (Baker 1982, Haney 1962). Awareness of the amount of seeds required to naturally regenerate forests has stimulated interest in the cone producing ability of trees in natural stands (Thorbjornsen 1960). Five factors contribute to flower bud initiation: induction hormones, soil moisture, light conditions, nutrient relationships, and temperature. Light, nutrients, and moisture can be manipulated to increase seed production through thinning (Barnett and Haugen 1995). For example, removal of all trees within 30 feet of shortleaf pine seed trees doubled cone production per tree and significantly increased the number of sound seeds per cone (Yocom 1971).

Little is known about the distribution of cones within the crowns of conifers (Mattson 1979). Lyons (1956) found seed yields varied between cones of red pine (*Pinus resinosa* Ait.) trees, and there is a danger of not estimating seed production correctly if cones are sampled without regard to their location in the crown. Fatzinger and others (1980) found the majority of southern pine strobili were produced in the upper crown on the east and south sides of seed orchard trees. A study of slash pine (*Pinus elliottii* Engelm.) found the majority of cones occurred on the east side of the crown (Smith and Stanley 1969).

Our study was conducted to determine the effects of an uneven-aged regeneration cut on the distribution of mature cones, clusters of mature cones, conelets (immature cones), and older cones within the crowns of released and unreleased shortleaf pine trees by d.b.h. class. A better understanding of these relationships will be useful for selecting trees to retain for seed production and will provide indicators for forecasting future seed crops.

STUDY AREA

The study area was located in the Ouachita National Forest on the Winona Ranger District, Perry County, AR. Before implementation of uneven-aged management, the stand was irregularly aged with a uniform canopy dominated by shortleaf pine with mixed hardwoods in the mid to lower canopy. Sixteen 0.5-acre plots were established and were harvested from December 1988 to March 1989 to reduce the overstory pine basal area to 60 square feet per acre (Shelton and Murphy 1997). Plots received one of three residual hardwood basal area treatments (0, 15, and 30 square feet per acre). However, only the four plots with complete hardwood control were used for this study. Each of the 0.5-acre plots was surrounded by a 58 foot buffer zone receiving the same treatment. Shortleaf pine site index averaged 57 feet at 50 years. Shelton and Murphy (1997) have given a more detailed description of the study area.

METHODS

Sample Tree Selection

Sixteen released trees were selected from the buffer zones of the four treated plots (60 square feet per acre of pine basal area with no hardwoods). Sixteen unreleased trees were selected from the adjacent unharvested pine-hardwood mixed forest (120 square feet per acre of total basal area with two-thirds in pine and the remainder in hardwoods). Sample trees were randomly selected from 2-inch d.b.h. classes (11, 13, 15, and 17 inch). Sample trees with malformed crowns were excluded from selection. Sample trees were measured for height, d.b.h., crown length, crown width, and 5-year radial growth increment at stump height. A cone rating procedure described by Shelton and Wittwer (1995) was used to give each sample tree a cone density class based on cone spacing, occurrence of cones

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Citation for proceedings: Connor, Kristina F., ed. 2004. Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 594 p.

in clusters, and distribution of cones within the crown. The observer stood one to two tree heights away from the tree with the sun to their back and viewed the tree crown with 7-power binoculars. The same observer evaluated each sample tree before felling and gave a cone rating of 0 for few (< 10 cones), 1 for average (10-80 cones), and 2 for good (> 80 cones) as viewed from a single position. After felling sample trees, basal area was determined with a 10-factor prism at a point centered over the stump.

Trees were felled during a 2-week period in the middle of October 1998 when cones were mature. Selected trees were marked with paint on the magnetic north and south sides of the bole so the proper crown positions could be established. After felling, each crown was measured for total length and divided into two equal upper and lower halves. The crown was further divided by north and south facing branches to form four crown positions: lower north, lower south, upper north, and upper south. Branches (≥ 1.0 inch basal diameter) were assigned to a particular crown position based on their origin at the main stem.

The four crown positions and four d.b.h. classes were considered treatments split between the released and unreleased treatments with four replications (four blocks) of each treatment. This resulted in a two by four by four factorial, split-split plot randomized, complete block design. Two branches from each crown position for each tree were randomly selected for evaluation of mature cones, conelets, and older cones. Mature cones were counted by the number of cones present in a cluster (i.e., cones occurring at the same location on the branch). We defined older cones as having 50 percent or more of their scales intact and still attached to branches. The older cone counts were indicators of past production through at least 4 years. Mature cones were counted from the remaining branches from each crown position.

Data Analysis

Mean values were calculated for all reproductive structures on a per crown position basis. Reproductive structure counts for the two sample branches per crown position were averaged and then multiplied by the number of branches in each crown position to estimate reproductive structures within each crown position. The number of mature cones per crown position was determined by a complete count, but an estimated value was also calculated for comparison.

The MIXED procedure from SAS Institute (1997) was used for analysis of variance for the split-split plot arranged in a randomized complete block design to make inferences about cone distribution by crown position, d.b.h. class, and stand density (main unit treatment). All variables were considered fixed for the mixed model except blocks. Multiple mean comparisons (Fishers Least Significant Difference) were attained by using the LSMEANS statement and DIFF and SLICE options (SAS Institute 1997). The SLICE option tests for simple effects; if the interaction of factors A*B is significant, the effect of A for each level of B is tested. In addition, correlation analysis was used to determine possible relationships between cone variables. Significance for all statistical tests was accepted at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Sample Tree Characteristics

Age of unreleased trees ranged from 60 to 110 years, averaging 78 years, while released trees ranged from 54 to 88 years and averaged 76 years. Sample trees averaged 14.0 inches d.b.h. for unreleased trees and 14.2 inches for released trees. The height of unreleased trees averaged 66 feet compared to 67 feet for released trees. Crown length and width for the released trees averaged 33 and 27 feet, respectfully; this was about 3 feet more for each dimension than the unreleased trees. Released trees also averaged 35 branches per tree compared to 31 branches for the unreleased trees. As one might expect, the last 5 years of radial growth for the released trees was 0.2 inch greater than that for unreleased trees.

Mature Cone Production

Released trees produced an average of 1,179 mature cones compared to 422 mature cones for unreleased trees. For all 32 sample trees, mature cone production ranged from 17 to 3,175 cones per tree. Bower and Smith (1961) compared mature cone production between five pairs of partially girdled and non-girdled shortleaf pine trees showing evidence of past cone production and found the partially girdled trees produced an average of 750 cones per tree compared to 185 cones for the non-girdled trees. Coulson and Franklin (1970) evaluated 21 shortleaf pine trees for cone damage by populations of *Dioryctria* spp. in Georgia and reported cone production ranged from 56 to 699 cones per tree with an average of 352 cones. Cone production appears to vary greatly from year to year and between trees for any given year.

A study estimating seed quantity and quality of shortleaf pine cones in the Ouachita Mountains found the average number of sound seed per cone was 14.5 in a seed-tree stand and 17.5 in a single-tree-selection stand (Wittwer and others 1997). Their results indicated that approximately 20 sound seeds per cone could reasonably be expected for shortleaf pine. If the average released trees in the present study produced 20 sound seeds per cone, approximately 23,600 sound seeds per tree would have been produced. The average unreleased tree would have produced approximately 8,400 sound seeds.

Mature Cone Distribution

A significant interaction occurred between stand density (released versus unreleased) and tree d.b.h. class for mature cone production. Released trees in the 15- and 17-inch d.b.h. classes produced significantly more cones than smaller trees (fig. 1). However, significance was found only in these d.b.h. classes, and no significant difference occurred for mature cones by d.b.h. class for the unreleased trees. These results demonstrate the importance of retaining the larger trees within the stand to maximize seed production under similar conditions as in this study.

A significant interaction occurred between stand density and crown position for the distribution of mature cones within the crown. Cone production by crown position was ranked as follows: lower north = lower south < upper north < upper south (fig. 2). Upper crown positions produced significantly more cones than lower crown positions for

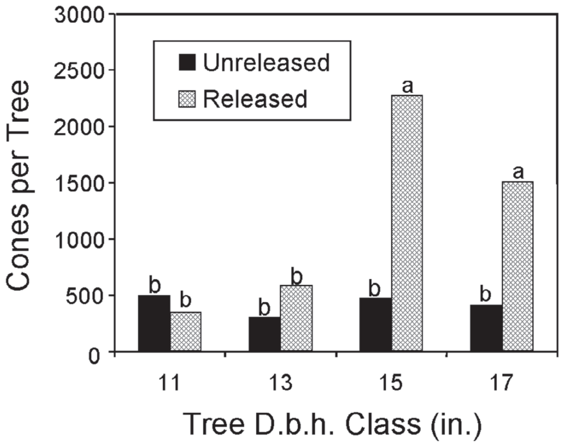

Figure 1—Effects of release and tree d.b.h. on the number of mature cones in shortleaf pine trees. Bars with the same letter are not significantly different at $\alpha = 0.05$.

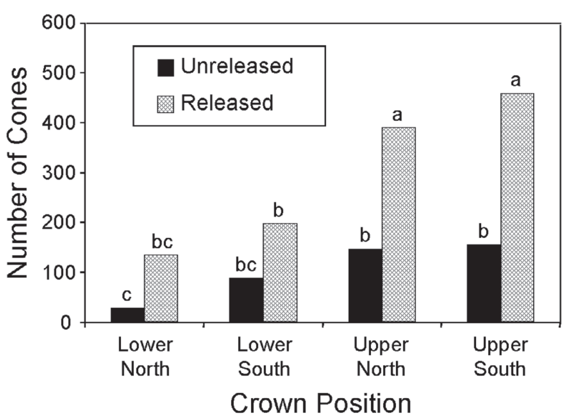

Figure 2—Effects of release and crown position on the number of mature cones in shortleaf pine trees. Bars with the same letter are not significantly different at $\alpha = 0.05$.

released trees. However, this trend was not as strong for the unreleased trees, and only the lower north crown position was significantly different from the upper crown positions. The distribution of cones within the crown is probably associated with the vigor and age of branches. A similar distribution pattern was reported for young, open-grown Douglas-fir trees; branches on the upper and middle south side of the crown produced the greatest number of cones (Winjum and Johnson 1964). Hard (1964) reported a relationship between branch age and fertility for red pine, where older branches produced more male flowers, and younger branches produced more mature cones. For species with wind-disseminated seeds, having most of the cones located in the upper portion of the crown would maximize seed dispersal and the opening of cones through drying.

Conelet Production and Distribution

Analysis of variance indicated no significant difference in conelet production between released and unreleased trees. The average released tree produced 233 conelets compared to 110 conelets for the average unreleased trees. A lack of significant difference between these two means suggests that during poor cone crops variability increases and differences becomes less pronounced. This level of conelet production suggests that next year's mature cone crop will only be 20 percent of the current year's crop. This shows the highly variable nature of shortleaf seed production in the Ouachita Mountains. Analysis of variance indicated a significant effect of crown position with only the lower north position varying significantly from the other crown positions (fig. 3).

Older Cone Distribution

Analysis of variance revealed significant effects for stand density, crown position, and tree d.b.h. class. Older cones on released trees differed significantly from unreleased trees, averaging 2,419 and 631 cones, respectively. The 15- and 17-inch d.b.h. classes for released and unreleased trees retained significantly more old cones than smaller trees (fig. 4). Older cones also differed by crown position; the upper crown positions were significantly greater than the lower north crown position, but not the lower south position. These findings were very similar to the mature

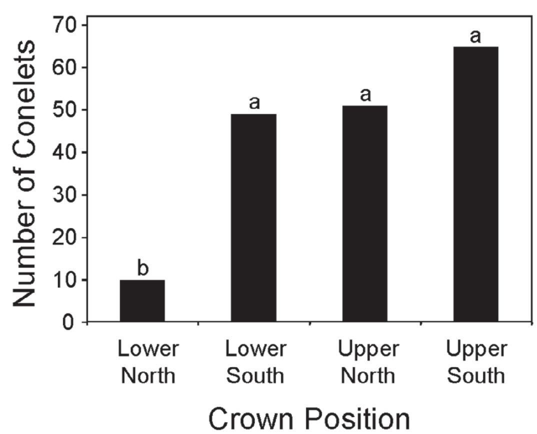

Figure 3—Effects of crown position on the number of conelets in shortleaf pine trees. Bars with the same letter are not significantly different at $\alpha = 0.05$.

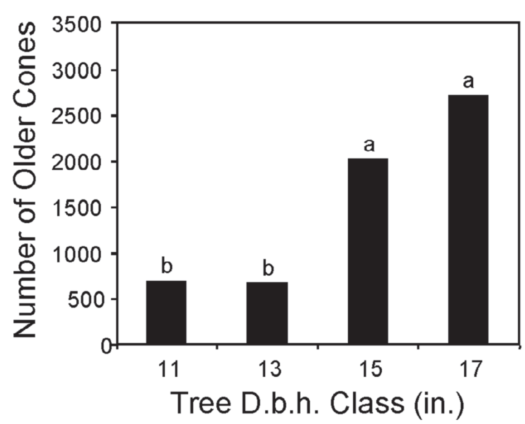

Figure 4—Effects of tree d.b.h. on the number of older cones in shortleaf pine trees. Bars with the same letter are not significantly different at $\alpha = 0.05$.

cone production trend with more cone production occurring in the upper crown positions. Wenger (1953) suggested that the most reliable way to select fruitful trees was to choose larger trees that show evidence of past production by the presence of older cones. If d.b.h. was the same for two trees, then the tree with the greatest number of older cones should be selected. Our study supported this conclusion.

Correlation Analysis

The estimate of mature cones per tree was highly correlated with the actual total count of mature cones per tree (r = +0.85, P = 0.0001), suggesting that the cone counts on the eight sample branches per tree were adequate to estimate total cones per tree. This represents a 24 percent sample since the average sample tree had 33 branches.

Mature cone production was significantly correlated with the number of two-, three- and four-cone clusters (r = +0.92, +0.87, and +0.65, respectively; P = 0.0001 in all cases). This suggests that the presence of multiple-cone clusters could be used as an indicator of the total production of mature cones. The correlation coefficient between older cones and mature cones was +0.71 (P = 0.0001), and the correlation between older cones and conelets was +0.77 (P= 0.0001). This suggests that the older cones are a good indicator of the tree's potential for future cone production.

For sample tree variables, mature cone production was significantly correlated with crown length (r = +0.36, P = 0.04), stand basal area at the sample tree's location (r = -0.44, P = 0.01), 5-year radial growth (r = +0.38, P = 0.03), and cone rating (r = +0.80, P = 0.0001). Thus, the cone rating method of Shelton and Wittwer (1995) was the most promising variable for estimating mature cones per tree.

CONCLUSIONS

The average released tree produced almost three times the number of mature cones of the average unreleased tree. The uneven-aged regeneration cut had its greatest impact on released trees 14 inches d.b.h. or greater, with most of the increase in cone production occurring in the upper crown positions. Cone production for unreleased trees did not differ significantly by tree d.b.h. class. The only significant difference for unreleased trees occurred among crown positions, with the upper crown positions producing significantly more cones than the lower north position. Results suggest that under similar stand conditions, released trees at least 14 inches d.b.h. should be selected to maximize seed production.

The presence of multiple-cone clusters was highly correlated with total cone production. Cone clusters were also significantly more abundant in the upper crown positions. Clusters of cones in upper crown positions should be a good indicator of potential seed production.

Conelet production differed significantly only by crown position, with the lower north position having significantly fewer conelets than other positions. Conelet production was poorly correlated with mature cone production. This demonstrates the sporadic pattern of shortleaf pine cone crops in the Ouachita Mountains. Results for conelet distribution found in this study suggest that during poor cone crops, the differences among tree d.b.h. classes are less noticeable.

Older cones differed significantly between released and unreleased trees, with released trees having nearly four times the number of older cones as unreleased trees. Older cones also differed significantly among tree d.b.h. classes, with the 15 and 17 inch trees having significantly more older cones than smaller trees. The lower north position had significantly fewer older cones than other crown positions. Older cones were significantly correlated with both mature cones and conelets, suggesting that the presence of older cones is a good indicator of future cone production and could be used to select fruitful trees for retention.

The cone density rating appeared to be a promising method for successfully predicting the seed production of individual trees. According to Shelton and Wittwer (1995), the cone density rating can be applied with a maximum lead time of about 5 months prior to seed fall. Although south crown positions produced more cones than north positions, the effects were minor and often not statistically significant. Thus, this factor can probably be ignored in making cone counts or ratings.

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