DISTRIBUTION & CHARACTERISTICS OF SHORTLEAF PINE CONES AFTER 10 YEARS OF UNEVENAGED SILVICULTURE IN THE OUACHITA MOUNTAINS

By

KENNETH JEREMY GRAYSON

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1997

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 2000

DISTRIBUTION & CHARACTERISTICS OF SHORTLEAF PINE CONES AFTER 10 YEARS OF UNEVENAGED SILVICULTURE IN THE OUACHITA MOUNTAINS

Thesis Approved:

____
Thesis Adviser

____

____

____
Dean of the Graduate College

ACKNOWLEDGMENTS

Much thanks and appreciation goes to my major advisor, Dr. Bob Wittwer, who possesses great insight, intellect, and a willingness to help and guide students. I am also grateful for the guidance that Dr. Mike Shelton Research forester, Southern Research Station has provided, but especially for his quick thinking in the field. Appreciation and thanks goes to Dr. Steve Hallgren and Dave Ferris for the equipment and technical assistance provided during seed germination testing. Thanks also goes to Dr. Mark Payton and Dr. Tom Lynch for their excellent statistical expertise.

I am especially appreciative of the Kiamichi Forestry Research Station staff, for there tireless sun-up to sun-down effort in field data collection. Sincere gratitude goes to the Oklahoma State University Department of Forestry for the research assistantship and research personnel made available during field and lab data collection. Thanks also goes to the Southern Research Station, USDA Forest Service, for their funding and support of the project.

TABLE OF CONTENTS

LIST OF TABLES

Table | Page

Chapter II

Chapter III

LIST OF FIGURES

Figure Page

Chapter II

Chapter III

CHAPTER I

INTRODUCTION

Two separate and complete manuscripts have been prepared from this study. The first, "Distribution of cones, conelets, older cones, cone clusters and male strobili in shortleaf pine-oak stands after an uneven-aged regeneration cut", was prepared in the format of Southern Journal of Applied Forestry. The second, "Cone characteristics and seed quality following an uneven-aged regeneration cut in shortleaf pine", was prepared in the format of the journal New Forests. Both manuscripts will be submitted in final form for publication as original research.

CHAPTER II

DISTRIBUTION OF CONES, CONELETS, OLDER CONES, CONE CLUSTERS & MALE STROBILI IN SHORTLEAF PINE-OAK STANDS AFTER AN UNEVEN-AGED REGENERATION CUT

ABSTRACT: This study examines the effects of an uneven-aged (UEA) regeneration cut on the distribution of cones, conelets, clusters of cones, older cones, and male strobili within the crowns of released and unreleased shortleaf pine. Sixteen released trees were felled in a stand ten years after an UEA regeneration cut reduced the overstory pine basal area to 60 ft^2/ac followed by complete hardwood control. Sixteen unreleased trees in an adjacent pine-hardwood mixed forest (120^2/ac) were felled for comparison. Released and unreleased trees were randomly selected by four predetermined 2-inch diameter classes (11,13, 15, 17 inches). Each tree crown was divided into four positions (upper south, upper north, lower south, and lower north). All branches were counted within each crown position, and two branches were sampled for counts of cones, conelets, older cones, cone clusters, and male strobili. All mature cones were collected and counted from all branches. The average released tree produced approximately triple the cone production compared to unreleased trees (1179>422). The 15 and 17 inch diameter class released trees produced significantly more mature cones than all other diameter classes. Cone production for trees that were not released did not differ significantly by tree diameter class. The cone production trend by crown position ranked as follows: lower north < lower south < upper north < upper south. The average released tree upper crown positions differed significantly from the lower crown positions. The average unreleased

tree upper crown positions differed significantly only from the lower north crown position. Cones found in clusters of twos and threes were highly correlated with total cone production and followed the same general trend as the mature cone distribution. Cone cluster counts should be good indicators of seed productivity with special attention given to the upper crown where the majority of cone clusters occur. Conelets differed significantly only by crown position with the lower north position producing significantly fewer conelets than all other crown positions for both released and unreleased trees. Released trees retained significantly more older cones than unreleased trees by an average of 1,766 cones. Older cones were correlated with mature cones and followed the same distribution trend. The average released tree produced significantly more male strobili than the average unreleased tree by approximately 3,741 male flowers. Male strobili by crown position ranked as follows: lower north and upper north < upper south < lower south. Results of this study suggest that under similar stand conditions seed-trees should be selected that are at least 14 inches or greater at dbh and show past evidence of good cone production through the presence of older cones for maximizing seed production.

INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.) is the most widely distributed of the southern yellow pines, and ranks second behind loblolly pine (*Pinus taeda* L.) for it's contribution to total softwood volume in the South (McWilliams et al. 1986). Nearly half of the country's entire shortleaf pine resource is located west of the Mississippi River, with the Highland Regions of Arkansas and Oklahoma having the largest concentrations (Baker 1992).

This species has been managed by uneven-aged and even-aged silvicultural systems in pure stands and as an associated species with loblolly pine (Murphy et al. 1991). According to Barnett and Haugen (1995) the emphasis on clearcutting and artificial regeneration of southern pines has shifted in recent years to even-aged and uneven-aged natural regeneration methods. The Deltic Farm and Timber Company practices uneven-aged management in the Interior Highlands, harvesting about every 10 years, due to slower growth rates of shortleaf pine in this region (Baker and others 1996).

Successful natural regeneration of shortleaf pine depends upon obtaining satisfactory levels of seeds and resources that are limited such as water, light, and nutrients along with appropriate seedbed conditions (Shelton 1995). Natural stands of shortleaf pine have highly variable seed crops due to many biotic and environmental factors, which lowers the reliability of natural regeneration methods in these stands (Wittwer and Shelton 1992). Many studies have indicated that good shortleaf pine seed crops are sporadic in nature throughout the South, and this has contributed to inadequate regeneration. According to Haney (1962) and Baker (1982), a good seed crop produces 80 to 250 thousand sound seed/ac. A study on shortleaf pine seed crops in woods-run and seed production areas in the Ouachita and Ozark mountains reported one bumper and two good seed crops occurring during a 9-year period (Shelton and Wittwer 1996). Another study in the southeastern Piedmont indicated only 3 good seed years out of 10 for annual shortleaf pine seedfall (Bramlett 1965). This unpredictability is of great economic concern when using natural regeneration, which is increasing on public lands (Shelton and Wittwer 1996).

A shortleaf pine seedbed condition study revealed that 2 lb. (92,000) of sound seed/ac would be required for an unburned seedbed if the goal was to establish 1000 seedlings/ac at the end of the first year of regeneration (Krugman and Jenkins 1974). A hot-burned, well prepared seedbed, would only require 0.55 lb/ac to achieve the same goal (Boggs and Wittwer 1993). The awareness of the large amounts of seed required to naturally regenerate forests and use in tree nurseries has sparked interest in the cone producing ability of stands and individual trees (Thorbjornsen 1960).

According to Barnett and Haugen (1995), five factors contribute to flower bud initiation: induction hormones, soil moisture, light conditions, nutrient relationships, and temperature. Three of these variables, light, nutrients, and moisture can be manipulated to increase seed production through thinning (Barnett and Haugen 1995). Yocom (1971) reported that the removal of all trees within 30 ft of shortleaf pine seed trees, resulted in an increase that doubled the average cone production per tree and significantly increased the average number of sound seeds per cone. Fertilizer has also increased seed yield in pine seed production areas in Missouri, where shortleaf pine trees that received large amounts of phosphorus and potassium, produced roughly twice as many sound seed as the control trees. The study also indicated that large amounts of nitrogen resulted in smaller gains in seed production (Brinkman 1962). Mechanical treatments, such as strangulation, subsoiling, and girdling, have also been used to increase flowering by manipulating flower-inducing hormones, but this can be harmful over a period of years (Barnett 1993, Barnett and Haugen 1995, Bower and Smith 1961, Gregory and Davey 1977).

Variation in seed production is due to many factors functioning over a long period of time, such as biotic (competition, insects, mammals and birds), and abiotic (weather) factors that influence seed production (Wittwer and Shelton 1992). In a study on loss of developing cones, in a seed orchard near Pollock, Louisiana, the strobili and conelet mortality averaged 84 % for two successive shortleaf pine crops. Missing conelets and unidentified insects accounted for most losses in this study (McLemore 1977). McLemore also reported a 20 % loss of shortleaf pine strobili due to a hail storm in April 1974. A six-year study in Virginia on the Lee Experimental Forest indicated that insects were the major cause of mortality to shortleaf pine female strobili that emerged from bud scales (Bramlett 1972). The only exception was in 1963 and 1966 when spring frost was the major cause of female strobili mortality.

According to Mattson (1979), little is known about the distribution of cones within the crowns of conifers. Lyons (1956) suggests there is variability within cones of red pine trees, and there is a danger of characterizing trees incorrectly by sampling cones without careful regard to their location in the crown. Fatzinger et al. (1980) found that the majority of southern pine strobili are produced in the upper crown levels on the east and south sides of seed orchard trees. A cone-distribution study for slash pine (*Pinus elliottii* Engelm.) revealed that the majority of the cones occurred on the east side of the crown (Smith and Stanley 1969). This was attributed to morning sunshine and afternoon cloudiness during the summer strobili bud initiation period. Smith and Stanley also reported a south > north distribution of cones for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in the Pacific Northwest, which contrasted the east > west distribution of female strobili for slash pine in Florida. They concluded that the contrast existed because of the lack of a sunshine differential for the Pacific Northwest Douglas-fir.

The present study was conducted to determine the effects of an uneven-aged regeneration cut on the distribution of cones, conelets, clusters of cones, older cones and male strobili within the crowns of released and unreleased trees by dbh class. We hypothesized that: (1) larger diameter released and unreleased trees would have a greater quantity of cones compared to smaller diameter released and unreleased trees, (2) the released trees would have a greater quantity of cones than the unreleased trees, (3) the upper south crown position would have the greatest quantity of cones compared to all other crown positions, and (4) the upper crown positions would have more cones than the lower crown positions.

STUDY AREA

The study area was located in the Ouachita National Forest on the Winona Ranger District of Perry County, Arkansas. The soils are well drained, and moderately deep, Typic Hapludults mapped as the Carnasaw and Pirum series (Shelton and Murphy 1997). Before implementing uneven-aged management, the study area was irregularly-aged with a uniform canopy dominated by shortleaf pine with mixed hardwoods in the mid to lower canopy. Pine regeneration was very scarce due to the poor seedbed and light conditions.

This study was implemented in research plots established to evaluate uneven-aged reproduction methods in a typical Ouachita Mountain shortleaf pine-hardwood stand. Sixteen 0.5 ac plots were established between December 1988 and March 1989. Plot overstory basal area was reduced to 60 ft^2/ac following single-tree selection guidelines. Only trees ≥ 3.6 inches at dbh were considered pine overstory. Four treatments were established with different hardwood retention levels (0, 15, 30 ft^2/ac) and spatial arrangements (grouped, scattered) (Shelton and Murphy 1997). The four complete hardwood control plots were selected for use in this study. These plots were selected because the overstory pine within these plots received maximum release. The four selected plots were positioned along an east-west ridge with three plots facing north and one facing south. The four plots span a distance of about ¾ of a mile and range in elevation from 650 to 800 ft. For a more detailed description of the study area see Shelton and Murphy's (1997) study area description.

METHODS

Each 0.5 ac plot was surrounded by a 58.7 ft buffer zone (1.1 ac) giving a total area of 1.6 ac for the gross plot. Trees were removed to create the reverse-J diameter distribution having an 18 in. maximum diameter limit. Several future harvest cuttings will be needed to achieve multiple distinct age classes. In April 1989 the four gross plots were treated with a stem-injected herbicide for hardwood control to improve establishment of natural pine regeneration.

As of October 1998, the four buffer zones used in this study had approximately 60 ft^2/ac of residual overstory pine basal area. After 10 years of growth the overstory pine basal area should have been greater than the established plot basal area of 60 ft^2/ac. The estimated basal area is probably less than expected due to a flaw in our point sampling techniques, or perhaps the buffer zones received more logging damage during the preparatory cut. The present basal area was based on 4 point samples (Factor 10 prism) per plot buffer zone with a point sample taken at the stump of each selected released tree The selected trees were included in the point sample tally as "in" trees. The fact that each prism point sample was taken at the stump of each selected released tree, induces some bias in the reliability of the estimated present basal area. This is the most likely explanation for the low present basal area estimate.

Four released trees were selected from the buffer zone of four uneven-aged management plots, and four unreleased or control trees were selected outside the buffer zone of each plot, in the untreated mixed pine-hardwood stand. The untreated stand had approximately 120 ft^2/ac total basal area with 80 ft^2/ac in shortleaf pine. This formed the first main treatment of released (60 BA), and unreleased (120 BA) trees. The order in which the released and unreleased trees were selected was determined by a random drawing of four predetermined 2-inch diameter classes selected for study (11, 13, 15, 17 inches). Starting along one of the buffer strip sides, released trees were selected according to the drawing of 2-inch diameter classes. If the first released tree diameter could not be found, the second pre-determined diameter would be searched for. After finding the second pre-determined diameter, we would continue to search for the first released tree diameter. This would continue until all trees were selected within the buffer zone.

Each released tree selected in the regeneration plot buffer zone was paired by diameter class to an unreleased tree outside the treated plot. There was little difficulty finding unreleased trees that had the same diameter class. The unreleased trees were selected as close to the released trees as possible, but far enough away from the buffer treatment as to ensure that the unreleased trees were not affected by the plot and buffer treatment. No sample tree pairs were ever more than three chains apart.

Released trees with hardwood competitors 4.6 inches at dbh or greater falling within a factor-10 prism plot were excluded from selection. Each prism plot was centered to the side of each potential sample tree. A released tree crown could not be in direct contact with other tree crowns, be malformed, or have excessive competition from surrounding trees. Great care was taken not to exclude sample trees based on current or past cone production because we desired an unbiased comparison between the released and unreleased trees.

On average two to three trees were felled per day during a two week-period in the middle of October when cones were mature. Selected trees were marked with yellow and white paint on the magnetic north and south sides of the bole (4° degrees east declination) so the proper crown positions could be established after felling. Once a tree had been properly marked and felled, the four crown positions were established: lower north, lower south, upper north, and upper south. 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. Branches were assigned to a particular crown position based on their origin at the main stem. The four crown positions with four, tree diameter classes were considered treatments split between the released and unreleased treatments with four replications (four blocks) of each treatment. This is a 2X4X4 factorial split-split plot randomized, complete block design.

Measurements

Each sample tree was measured for dbh, height, crown length, crown width, and 5-year radial growth increment at stump height. Tree age was determined at the stump, and branches greater than one inch in diameter were counted for each tree crown. A cone rating procedure described by Shelton and Wittwer (1995) was used to give each tree a cone density class based on cone spacing, occurrence of cones in clusters, and distribution of cones within the crown. The observer would stand one to two tree heights distance from the tree with the sun to their back using a 7-power binocular. The observer would give a cone rating of 0 for few (<10 cones), 1 for average (10-80 cones), and 2 for good (>80).

Two branches from each crown position for each tree, were randomly selected and measured for basal diameter and length. Sampled branches were evaluated for cones, conelets, older cones, cone clusters, and male strobili. Conelets are described as being immature cones one year from maturity. We defined older cones as having 50 % or more of their scales and attached to branches. The older cone counts were indicators of past productivity representing at least 4 cone crops.

Data Analysis

Mean values were calculated for all reproductive structures on a per crown position basis. The 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. This gave an estimated value for all reproductive structures within the crown position. No estimation was necessary for the number of mature cones per crown position due to the complete count, but an estimated value was calculated for comparison.

The MIXED procedure from the SAS Institute (1997) was used to make statistical inferences about the data. According to the SAS Institute (1997), the "mixed linear model is a generalization of the standard linear model used in the GLM procedure, the generalization being, that the data are permitted to exhibit correlation and non-constant variability". An analysis of variance for the split-split plot arranged in a randomized complete block design was used to make inferences about cone reproductive structure distribution by crown positions (split unit treatment), diameter class (split unit treatment), and stand density (main unit treatment). All variables were considered fixed for the mixed model except for the blocks. Multiple mean comparisons (Fishers Least Significant Difference) were attained by using the LSMEANS statement and DIFF and SLICE options (SAS Institute 1997). The Fisher's LSD test is the least conservative multiple means comparison test, and is well excepted within the field of forestry. Means presented in tables are arithmetic means, while means presented in figures are least squares means (LSMEANS) or estimated means. The arithmetic means and the least squares means will sometimes differ due to an unbalanced design (missing observations).

RESULTS AND DISCUSSION

Released and Unreleased Tree Descriptions

Age of released trees ranged from 54 to 88 years, averaging 76 years (Table 1), while unreleased trees ranged from 60 to 110 years and averaged 78 years. The height of unreleased trees averaged 66 feet compared to 67 feet for released trees. Using several selected dominant and codominant trees, the site index was determined to be 55 feet at base age 50 using Graney and Burkhart's (1973) polymorphic site index curves for shortleaf pine in the Ouachita Mountains. Trees averaged 14.1 inches in dbh and varied

Table 1. Shortleaf pine sample tree descriptions for unreleased and released trees by diameter class.

DBH Class (inches)	Sample Trees	Age (years)	DBH (inches)	Total Height (feet)	Crown Length (feet)	Crown Width (feet)	5-Year Radial Growth (inches)	Number Branches	Cone Rating
Unreleased Trees									
11	4	71	10.9	67	27	18	0.28	25	1.1
		(60-82)	(10.1-11.6)	(54-74)	(20-34)	(15-22)	(0.10-0.45)	(18-30)	(0.7-1.7)
13	4	80	12.9	64	24	21	0.36	28	0.8
		(68-92)	(12.5-13.2)	(59-70)	(18-29)	(21-22)	(0.21-0.56)	(19-39)	(0.0-1.3)
15	4	82	15.0	67	28	23	0.37	36	1.2
		(68-110)	(14.4-15.5)	(60-79)	(23-32)	(21-25)	(0.15-0.52)	(26-39)	(1.0-1.3)
17	4	83	17.8	68	40	34	0.39	38	0.8
		(75-91)	(16.8-18.7)	(59-74)	(35-50)	(31-36)	(0.30-0.43)	(31-41)	(0.0-1.3)
Average		78	14.0	66	30	24	0.34	31	1.0
Range		(60-110)	(10.1-18.7)	(54-79)	(18-50)	(15-36)	(0.10-0.56)	(18-41)	(0.0-1.7)
Released Trees									
11	4	68	11.1	61	31	24	.46	29	1.0
		(54-82)	(10.6-11.5)	(57-67)	(28-35)	(21-26)	(.31-.75)	(23-40)	(0.7-1.3)
13	4	74	13.2	68	28	25	.51	27	0.9
		(69-81)	(12.7-13.8)	(67-71)	(25-32)	(21-28)	(.41-.59)	(23-32)	(0.7-1.0)
15	4	82	14.9	67	35	27	.38	36	1.8
		(77-88)	(14.1-15.7)	(64-70)	(27-41)	(22-32)	(.35-.39)	(28-40)	(1.7-2.0)
17	4	78	17.7	73	38	32	.79	46	1.4
		(69-84)	(16.9-19.1)	(67-87)	(29-46)	(26-38)	(.44-1.43)	(39-66)	(0.7-2.0)
Average		76	14.2	67	33	27	.54	35	1.2
Range		(54-88)	(10.6-19.1)	(57-87)	(25-46)	(21-38)	(.31-1.43)	(23-66)	(0.7-2.0)

between released and unreleased trees by only two tenths of an inch. Crown length and width for the released trees averaged 33 and 27 ft respectfully, which was about 3 ft more than the unreleased trees (Table 1). Generally, the released trees produced longer branches with greater basal diameters per crown position, and this was most noticeable between the lower diameter classes (Table 2). The released trees also averaged 35 branches per tree compared to 31 branches for the unreleased trees. As one might expect, the last five years of radial growth for the released trees equaled two tenths of an inch more than the unreleased trees.

Table 2. Average basal diameter and length of sample branches by dbh class and crown position for unreleased and released shortleaf pine trees.

DBH	Sample Branch Averages							
Class	Lower/North		Lower/South		Upper/North		Upper/South	
(inches)	diameter (inches)	length (feet)	diameter (inches)	length (feet)	diameter (inches)	length (feet)	diameter (inches)	length (feet)
Unreleased Trees								
11	3.2	7.9	2.0	9.3	1.6	6.4	1.5	6.4
13	2.0	9.7	2.4	9.7	1.5	6.2	2.0	6.9
15	2.6	11.8	2.4	11.0	2.0	8.0	1.8	7.1
17	3.3	16.6	4.8	16.6	2.4	8.8	2.7	9.5
Average	2.9	11.4	2.7	11.3	1.9	7.4	2.0	7.4
Released Trees								
11	2.3	10.6	2.5	10.5	2.0	8.5	2.0	8.4
13	2.6	12.4	2.6	12.7	2.0	7.2	2.1	7.8
15	2.8	13.3	3.7	13.5	1.9	7.2	2.3	9.1
17	3.3	15.3	3.4	14.8	2.4	9.3	2.0	7.8
Average	2.8	12.9	3.1	12.9	2.1	8.1	2.1	8.3

All averages are based on eight branches.

Released & Unreleased Cone Production

Released trees produced an average of 1,179 mature cones compared to 422 mature cones for unreleased trees (Table 3). Out of all 32 sample trees, mature cone production per tree ranged from 17 to 3,175 cones. The average released tree produced almost triple the number of mature cones compared to the average unreleased tree. Bower and Smith (1961) compared mature cone production between five pairs of partially girdled and non-girdled trees that showed evidence of past cone production and found a significant difference between treatment means. 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) evaluating 21 shortleaf pine trees for cone damage by populations of *Dioryctria* species in Green and Clarke Co., 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 on estimating seed quantity and quality of shortleaf pine cones revealed that the average number of sound seed per cone was 14.5 for the seed-tree method and 17.5 for the single-tree-selection method (Wittwer et al. 1997). They also indicated from their results and previous work that at least 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 seed per tree would have been produced. The average unreleased tree would have producing approximately 8,400 sound seed. Four of the average released trees per acre would have produced a good seed crop at 94,400 sound seed per acre. Eleven average unreleased trees per acre would be

Table 3 Mean values of released and unreleased tree cone production variables by diameter class evaluated for shortleaf pine.

	Tree Diameter Class (in.) Means❶				
	11	**13**	**15**	**17**	**Means**
Released Trees					
Mature Cones	352	585	2269	1509	1179
Est. Mature Cones	532	404	2336	1662	1233
Two Cone Cluster	100	96	493	387	269
Three Cone Cluster	26	21	180	112	85
Four Cone Cluster	4	3	33	8	12
Five Cone Cluster	2	1	7	0	2
Conelets	44	19	364	508	233
Older Cones	1282	898	3624	3872	2419
Male Strobili	7652	7722	8520	13308	9301
Unreleased Trees					
Mature Cones	458	298	478	413	422
Est. Mature Cones	289	223	436	505	367
Two Cone Cluster	72	34	90	88	73
Three Cone Cluster	18	9	28	25	21
Four Cone Cluster	0	0	1	2	1
Five Cone Cluster	0	0	0	0	0
Conelets	40	121	124	175	110
Older Cones	124	476	440	1573	631
Male Strobili	2935	3479	5437	10523	5560

❶Mean values obtained from 4 sample trees for each diameter class by released and unreleased trees.

needed to produce a comparable 92,840 sound seed.

Distribution of Mature Cones by Tree Diameter Class

An analysis variance of mature cones indicated a significant interaction between stand density (released vs. unreleased) and tree diameter class (Table 4). When comparing cone production by diameter class for released trees, we saw a significant increase in total cones produced per tree between the 13 and 15 inch diameter classes (Fig. 1). This significant difference suggests that diameter is an important factor for maximizing cone production for released trees. No significant difference occurred for mature cone production by tree diameter class for the unreleased trees (Fig. 1). Cone production between released and unreleased trees differed significantly only at the 15 and 17 inch diameter class level (Fig. 1). These results demonstrate the importance of using larger diameter seed-trees within the 15-inch dbh class level or higher for maximizing seed production under similar stand conditions. The use of larger diameter seed-trees should also minimize the need for as many seed-trees given adequate seed dispersal. For example, the 15 inch diameter class released trees produced an average of 2,269 cones per tree (Table 3) or potentially 45,380 sound seed, based on an expectation of 20 sound seed per cone (Wittwer et al. 1997). Just four 15 inch diameter class released trees per acre would have produced 181,520 sound seed.

Table 4. The results of the analysis of variance to test for the effects of stand density, tree dbh class, and crown position on mature cones, 2-cone clusters, 3-cone clusters, conelets, and older cones.

Source of Variation	Mature Cones			2-Cone Cluster			3-Cone Cluster			Conelets			Older Cones		
	DF	F	P>F	DF	F	P>F	DF	F	P>F	DF	F	P>F	DF	F	P>F
1998 cone crop															
Tree dbh Class (F)	3	3.25	<0.075	3	2.50	0.124	3	4.02	<0.045	3	1.61	0.237	3	7.18	<0.009
Stand Density (C)	1	20.22	<0.001	1	18.85	<0.001	1	16.09	<0.002	1	2.91	0.115	1	22.04	<0.001
F x C	3	6.90	<0.007	3	4.23	<0.031	3	4.72	<0.022	3	2.12	0.154	3	2.55	0.106
Crown Position (D)	3	16.70	<0.001	3	5.46	<0.002	3	7.57	<0.001	3	2.71	<0.050	3	4.67	<0.005
F x D	9	1.52	0.156	9	1.18	0.318	9	1.44	0.188	9	1.10	0.373	9	0.68	0.727
C x D	3	3.59	<0.018	3	1.06	0.373	3	1.31	0.278	3	0.64	0.589	3	1.08	0.362
F x D x C	9	1.81	0.082	9	1.03	0.427	9	1.08	0.385	9	0.85	0.570	9	0.68	0.725
Error	72.9	❶RE = 21038.423		72.7	RE = 1992.701		72.4	RE = 351.907		72.5	RE = 6392.365		72.3	RE = 194732.055	

❶RE = Sum of Squares Residual Error

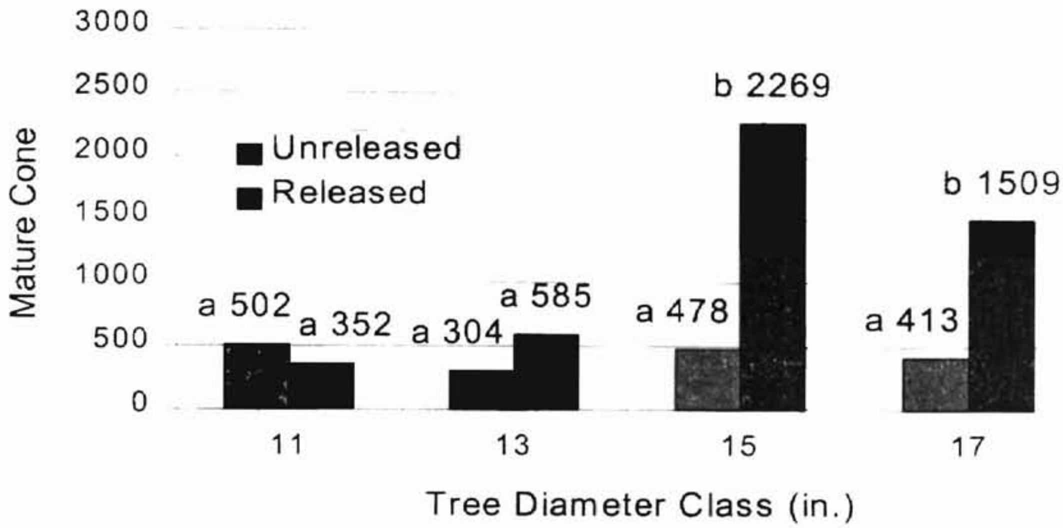

Figure 1. Total mature shortleaf pine cones per tree for released and unreleased trees by diameter class. Treatment least squares means preceded by the same letter are not significantly different at the 0.05 level. Sample size is 4 trees per bar.

Distribution of Mature Cones by Crown Position

An analysis of variance for mature cones revealed a significant interaction between stand density and crown position (Table 4). Cone production by crown position ranked as follows: lower north < lower south < upper north < upper south (Fig. 2). The released tree upper crown positions produced significantly more cones compared to the lower crown positions (Fig. 2). The increasing trend was not as strong for the unreleased trees, with only the lower north crown position being significantly different from the upper crown positions. Similar results were reported in a study on the differences in cone numbers in crowns of young open-grown Douglas-fir trees (Winjum and Johnson 1964). They reported that the outer extremities of the branches on the upper and middle south side of the crown appear to produce the greatest number of cones. They also note

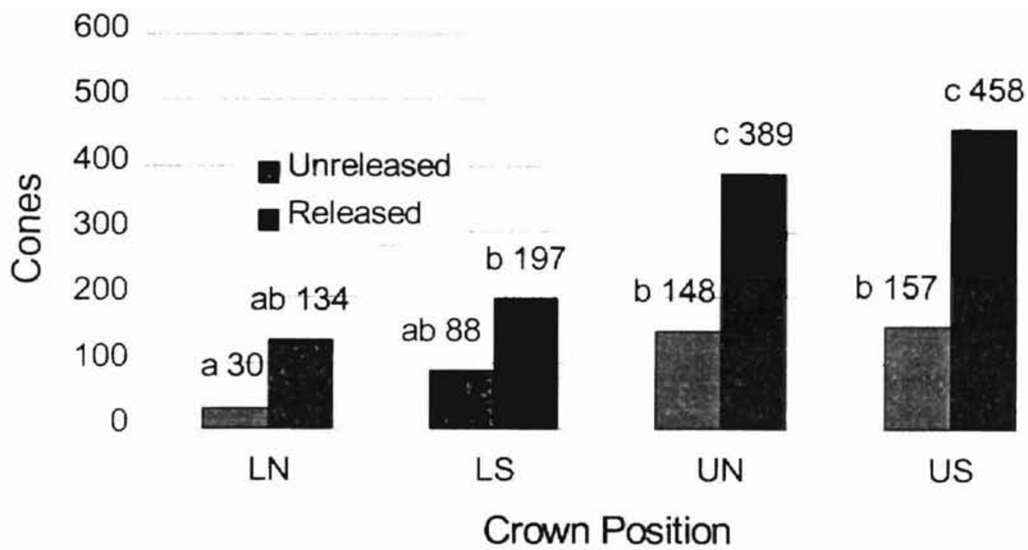

Figure 2. Mature shortleaf pine cones by crown position for released and unreleased trees. Treatment least squares means preceded by the same letter are not significantly different at the 0.05 level. Bars represent data pooled from all tree diameter classes. Sample size is 16 trees per bar. (LN = Lower North, LS = Lower South, UN = Upper North, & US = Upper South)

that the greatest seed yield occurs where cone-bearing twigs are more vigorous and where the greatest amount of sunlight strikes the crown.

Hard (1964) reported a relationship between branch age and fertility for red pine (*Pinus resinosa* Ait.), where older branches produced more male flowers and younger branches produced more cones. A shortleaf pine seed production study in Missouri revealed a 4 % increase in average crown length from 1951 to 1956 at the lowest density (50 ft^2/acre), and a 6 % loss in unthinned stands (Phares and Rogers 1962). Branch vigor should explain the increase in cone production in the upper crowns of the released and unreleased trees, but increases in overall crown length (Table 1) and branch vigor explain the significant increases in cone production for the upper crown positions of release trees (Fig. 2).

Cone Cluster Distribution

An analysis of variance indicated a significant interaction between stand density and tree diameter class for both two and three cone cluster distribution (Table 4). The two-cone cluster formation for released trees averaged 269 clusters per tree compared to 73 two-cone clusters per average unreleased tree (Table 3). On average, approximately 46 % of the total mature cones produced on released trees occurred in two-cone clusters. The average unreleased trees produced 35 % of the total mature cones in two-cone clusters. These results suggest a slight increase in two-cone cluster formation for released trees. The number of two-cone clusters by tree diameter class did not differ significantly for the unreleased trees but this was not the case for the released trees (Fig. 3). The 15 and 17 inch diameter class released trees produced significantly more two-cone clusters when compared to the lower diameter classes (Fig. 3). An analysis of variance for two-cone clusters also indicated a significant main effect by crown position. The upper crown positions produced significantly more two-cone clusters than the lower crown positions for both released and unreleased trees (Fig. 4). These results suggest that as cone production increases so do the number of cone clusters per tree, with much of the increase occurring in the upper crown. A ponderosa pine study on cone production in Colorado also found that the probability of cones being produced in clusters or groups rather than individually increased with larger cone crops (Roeser 1936).

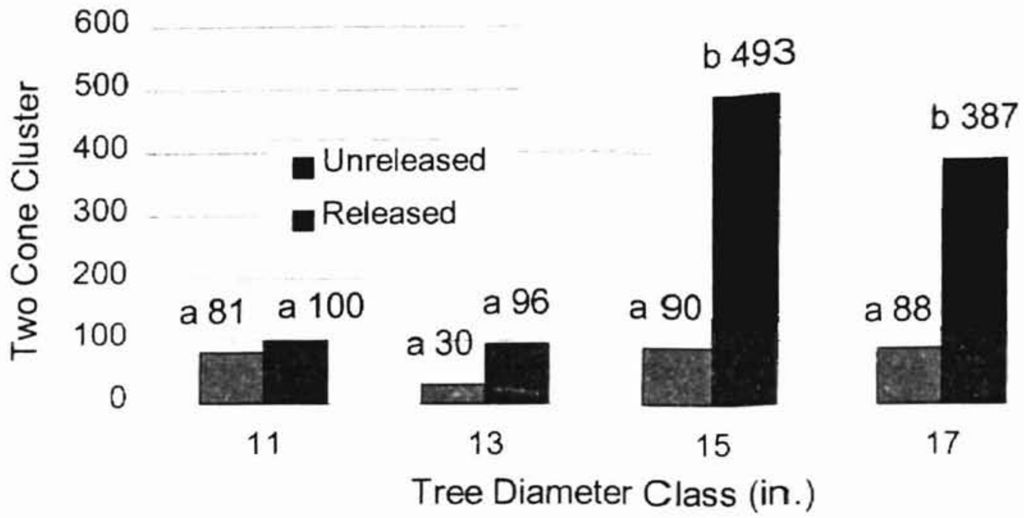

Figure 3. Total mature two cone clusters per tree for released and unreleased trees by diameter class. Treatment least squares means preceded by the same letter are not significantly different at the 0.05 level. Sample size is 4 trees per bar.

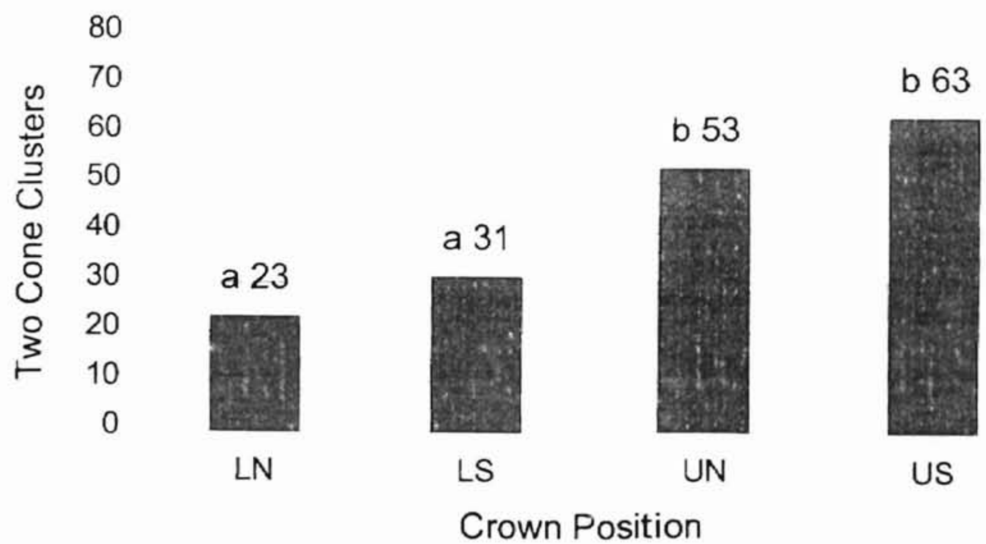

Figure 4. Mature two cone clusters by crown position for released and unreleased shortleaf pine trees. Treatment least squares means preceded by the same letter are not significantly different at the 0.05 level. Bars represent data pooled from both released and unreleased trees. Sample size is 32 trees per bar. (LN = Lower North, LS = Lower South, UN = Upper North, & US = Upper South)

The three-cone cluster distribution by diameter class has the same trend as the two-cone cluster diameter distribution (Fig. 5). On average, approximately 22 % of the total mature cones produced in the crowns of released trees were in clusters of threes, compared to 15 % for unreleased trees. The 15 and 17 inch diameter class released trees produced significantly more three-cone clusters than the lower diameter released trees, and significantly more clusters than unreleased trees (Fig. 5). The upper crown positions for both released and unreleased trees, produced significantly more three-cone clusters than the lower north crown position, but the upper south produced significantly more clusters than all other crown positions (Fig. 6). An analysis of variance was not conducted on the four and five-cone clusters due to the low occurrence of these cone clusters in released and unreleased trees (Table 3).

Conelet Production and Distribution

An analysis of variance conducted on conelets revealed a significant main effect by crown position only (Table 4). We found that the general trend for conelet production by crown position was the same as for mature cone production, but only the lower north crown position differed significantly from all other crown positions (Fig. 7). Howell (1996) found similar results in a previous study of shortleaf pine cone crops in the Ouachita and Ozark mountains. In Howell's study the number of conelets differed significantly between the upper and lower crown positions with the upper half having more conelets for the 10 trees sampled.

The average released tree produced 233 conelets compared to 110 conelets for the average unreleased trees (Table 3). A lack of significant difference between these

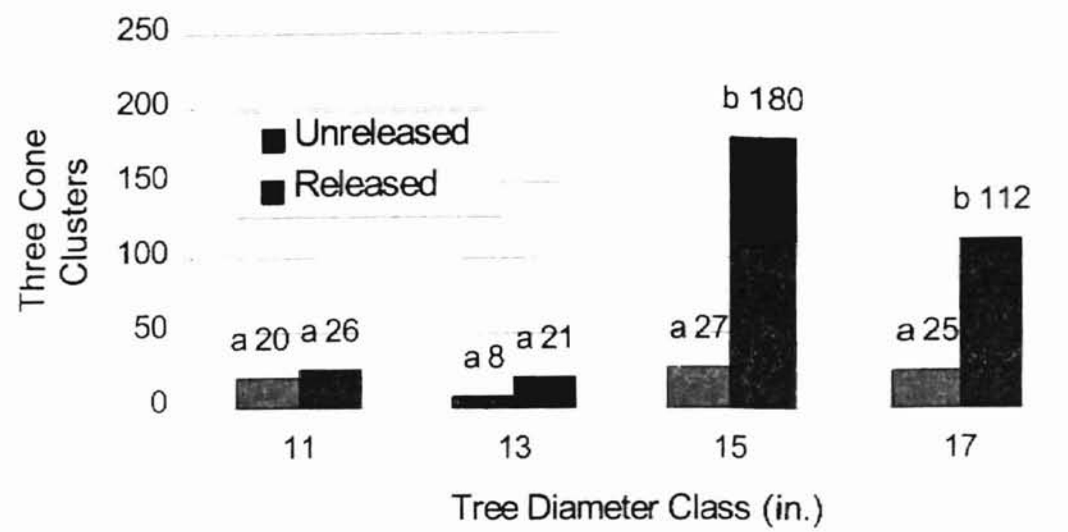

Figure 5. Total three cone clusters for released and unreleased trees by diameter class. Treatment least squares means preceded by the same letter are not significantly different at the 0.05 level. Sample size is 4 trees per bar.

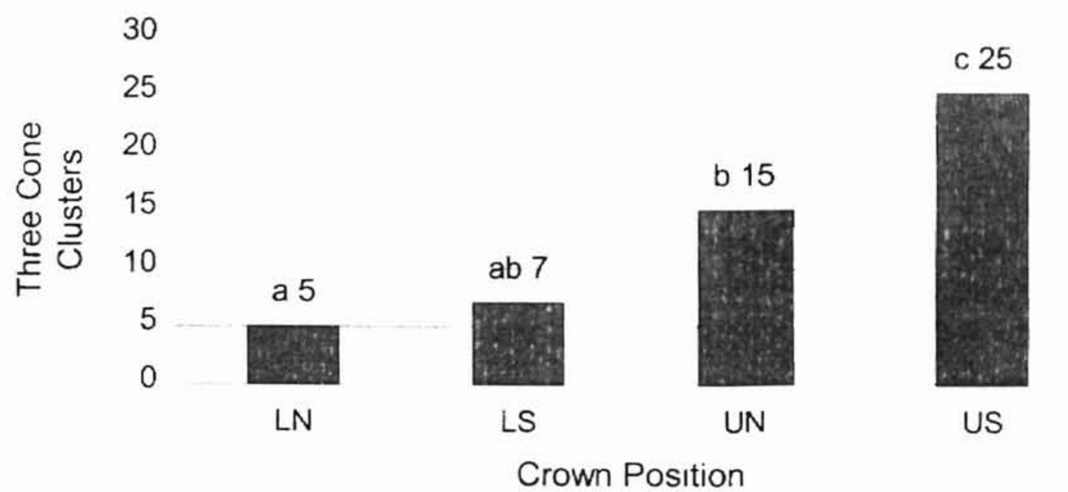

Figure 6. Three cone clusters by crown position for shortleaf pine. Treatment least squares means preceded by the same letter are not significantly different at the 0.05 level. . Bars represent data pooled from both released and unreleased trees. Sample size is 32 trees per bar. (LN = Lower North, LS = Lower South, UN = Upper North, & US = Upper South)

two means suggests that during poor cone crops the differences becomes less pronounced. If we compare the average number of cones produced by released trees in 1998 to the average number of conelets per released tree in the same year, there is an 80 % decrease in cone production. If the 233 conelets per released tree reached maturity and produced an average of 20 sound seed per cone, 18 average released trees per acre would be required to achieve at least 80,000 sound seed per acre.

Older Cone Distribution

An analysis of variance conducted on older cones, revealed significant main effects for stand density, crown position, and tree diameter class (Table 4). Older cones on released trees differed significantly from unreleased trees averaging 2,419 cones compared to 653 cones (Fig. 8). Wenger (1953) reported that the most reliable way to choose the fruitful trees is to choose the larger trees that show evidence of fruitfulness by the presence of older cones. If the dbh is the same between two trees, then the tree with the most old cones should be selected. This study also supports the selection of larger trees with evidence of older cones. The 15 and 17 inch diameter class released and unreleased trees both retained significantly more older cones than the lower diameter classes (Fig. 9).

Older cones also differed by crown position with the upper crown positions differing significantly from the lower north crown position, but not the lower south position (Fig. 10). The mature cone production trend by crown position appears to remain the same for older cones as well as conelets.

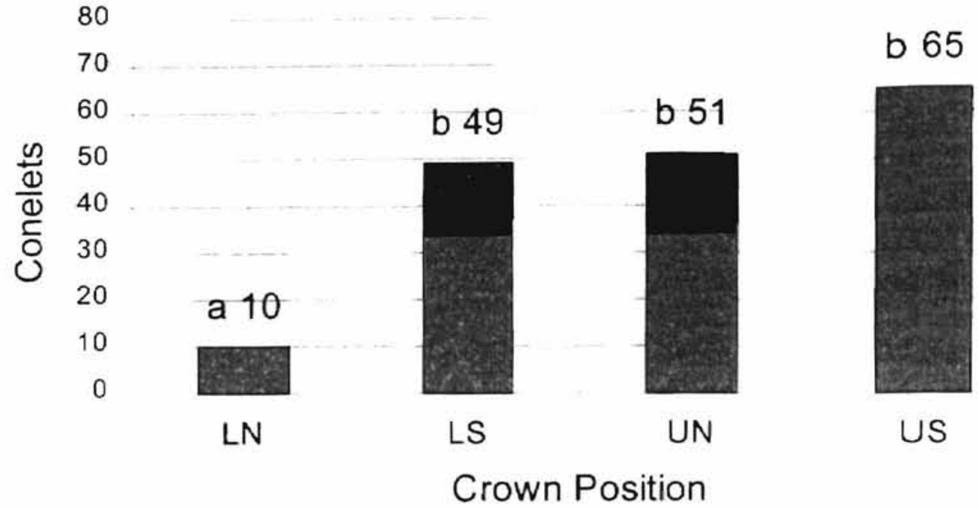

Figure 7. Conelets by crown position for released and unreleased trees. Treatment means preceded by the same letter are not significantly different at the 0.05 level. Bars represent data pooled from both released and unreleased trees. Sample size is 32 trees per bar. (LN = Lower North, LS = Lower South, UN = Upper North, & US = Upper South)

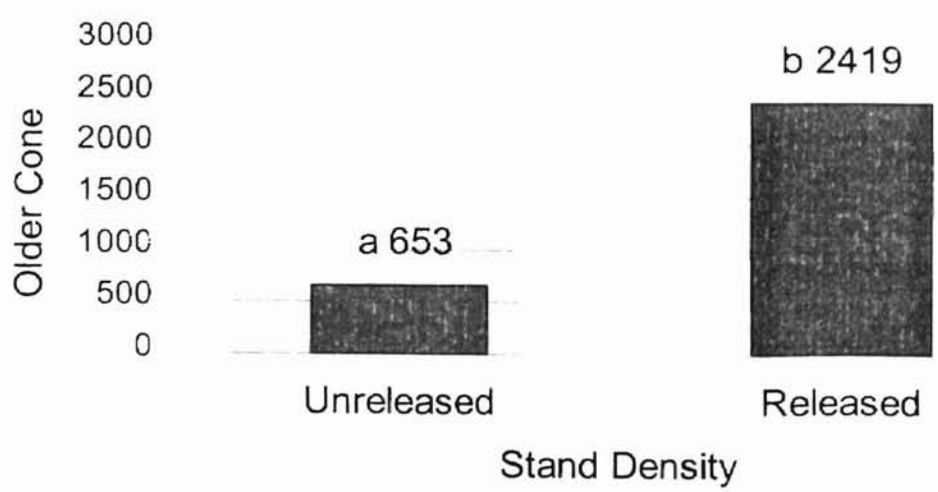

Figure 8. Older cones per tree for released and unreleased trees. Treatment least squares means preceded by the same letter are not significantly different at the 0.05 level. Sample size is 16 trees per bar.

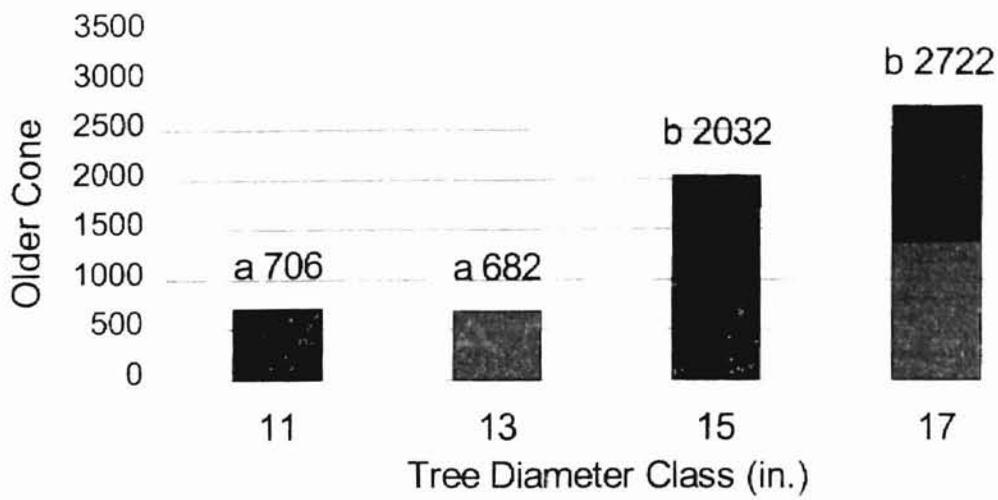

Figure 9. Older cones by tree diameter for released and unreleased trees. Treatment means preceded by the same letter are not significantly different at the 0.05 level. Bars represent data pooled from both released and unreleased trees. Sample size is 8 trees per bar.

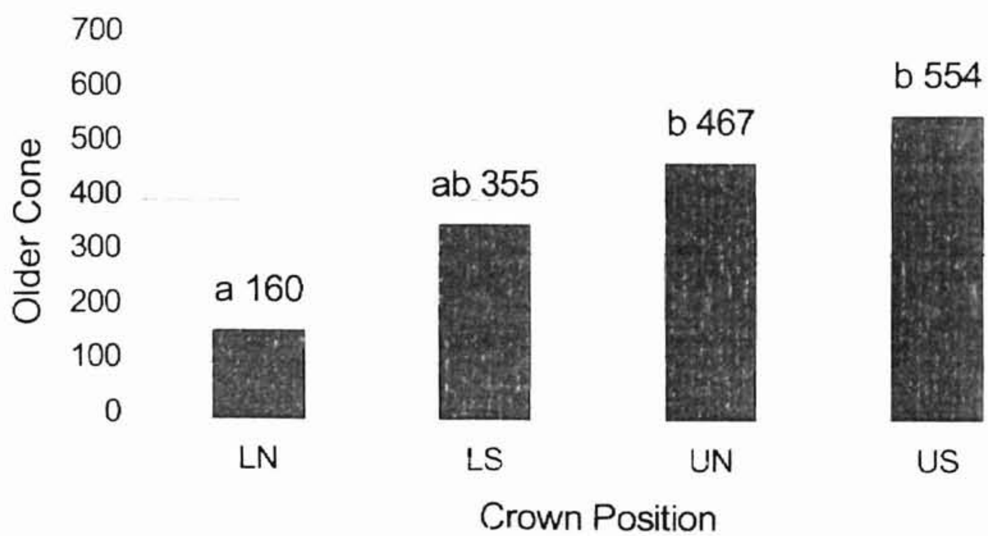

Figure 10. Older cones by crown position for released and unreleased trees. Treatment least squares means preceded by the same letter are not significantly different at the 0.05 level. Bars represent data pooled from both released and unreleased trees. Sample size is 32 trees per bar. (LN = Lower North, LS = Lower South, UN = Upper North, & US = Upper South)

Male Strobili Distribution

An analysis of variance conducted on male strobili revealed two significant main effects by stand density ($P = 0.009$) and crown position ($P = 0.031$). The average released tree produced significantly more male strobili than the average unreleased trees by approximately 3,741 male flowers (Table 3). The large increases in male strobili should increase the chances for successful pollination of adjacent released trees given adequate humidity, acceptable wind speeds, and receptive female flowers. Male strobili production also differed significantly by crown position with the lower south crown position producing significantly greater quantities of male strobili buds than the lower and upper north crown positions (Fig. 11). Male strobili by crown position ranked as follows: lower north and upper north < upper south < lower south. This trend was observed for both released and unreleased trees. Hard (1964) reported similar findings in a study on vertical distribution of red pine cones where the male strobili were concentrated in the bottom half of the crown on older branches. We found slightly different results with most male strobili produced in the upper and lower south side of the crown.

Correlation Analysis for Cone Production Variables

Possible relationships between cone variables were determined by conducting a correlation analysis (Table 5). The estimate of mature cones per tree was highly correlated with the actual total count of mature cones per tree with a correlation coefficient of +0.85 (Table 5). This strong correlation suggests that the cone counts on the 8 sample branches per tree were adequate in predicting total cones per tree. This represents a 24 % sample, given the average selected tree produced 33 branches one inch

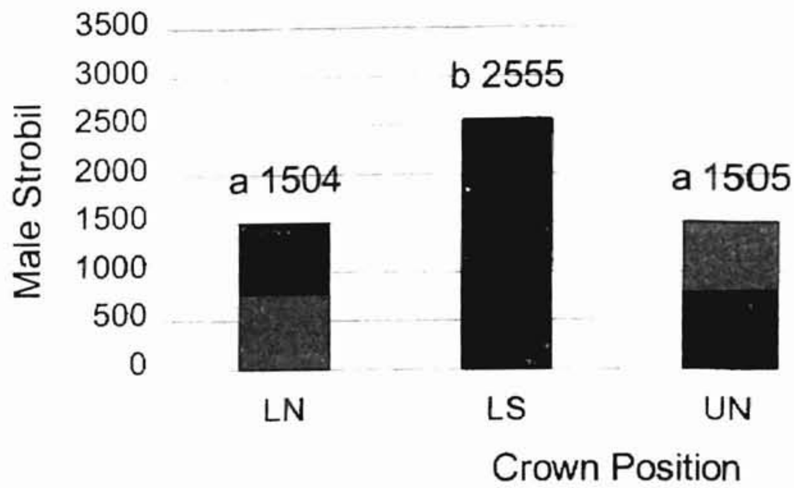

Figure 11. Male strobili by crown position. Treatment least sq preceded by the same letter are not significantly different at th represent data pooled from both released and unreleased trees. trees per bar. (LN = Lower North, LS = Lower South, UN = U Upper South)

Table 5. Pearsons correlation coefficients for cone variables from 32 natural sh unreleased trees.

		Variable			
Variable		X2	X3	X4	X5
Mature Cones	X1	.8487**	.4823**	.7130**	.6104**
Est. Mature Cones	X2		.5493**	.8318**	.7243**
Conelets	X3			.7520**	.3395
Older Cones	X4				.6115**
Damaged Cones	X5				
Two Cone Clusters	X6				
Three Cone Clusters	X7				
Four Cone Clusters	X8				

** Correlation Coefficients are significant at .01 level.

in basal diameter or greater (Table 1). Cone production was also significantly correlated with 2-4 cone clusters, and older cones (Table 5). The older cone correlation with mature cones and conelets in this study supports choosing trees that show evidence of fruitfulness by the presence of old cones as reported by Wenger (1953).

Model Development for Predicting Mature Cones

Based on the correlation analysis (Table 6) of several possible regression variables, cone rating was the most promising variable for estimation of mature cones per tree. The cone rating correlation coefficient was +0.80 and was significant at the 0.01 level (Table 6). No other variables proved to be even moderately correlated with mature cone production.

The stepwise regression procedure was used to determine the best no-intercept model for predicting mature cone production per tree. The SAS default significance level at 0.15 was used as a criterion for adding or deleting independent variables. The stepwise procedure selected the cone rating and basal area independent variables for the best regression model. Both of the variables were significant at the 0.01 level. The multicollinearity was acceptable as indicated by the correlation coefficient between the two independent variables (–0.81). The calculated variance inflation factor was also acceptable at 2.91. The residuals were plotted with the independent variables and a slight non-linear trend was detected for the cone rating variable. The cone rating variable was transformed by raising to the second power. This gave the final model better statistics of fit. After further evaluation of the residual plots no violations of the regression assumptions were detected. The coefficient of multiple determination (R-squared) for the stepwise model was 0.906. The Mallows Cp statistic was 3.13 and the Fit Index was

Table 6. Pearsons correlation coefficients for multiple regression variables related to mature cone production of natural shortleaf pine.

		Variables							
Variable		X2	X3	X4	X5	X6	X7	X8	X9
Tree dbh	X1	.7325**	.6055**	.4374**	-.1722	.4239**	.2996*	.0631	.2403
Crown Width	X2		.7254**	.1618	-.3416**	.1274	.3225*	.0860	.3345*
Crown Length	X3			.0278	-.3013*	.2311	.3446**	.3377*	.3643**
Tree Age	X4				.2252	.0728	-.3053*	-.1274	.0021
Basal Area at Tree	X5					-.0952	-.6189**	-.3080*	-.4370**
Tree Height	X6						.1710	-.0158	-.0354
5-year Radial Growth	X7							.2142	.3816**
Cone Rating	X8								.8007**
Mature Cones	X9								

* Correlation Coefficients are significant at .05 level.
** Correlation Coefficients are significant at .01 level.

0.825. Regression through the origin creates a problem because the line does not necessarily pass through point average X, average Y (Zar 1996). The coefficient of multiple determination (R-squared) calculated by SAS was not comparable to the R-squared from the model with an intercept. To gain a better representation of fit, the Fit Index was calculated. The model of best fit predicted negative cones for 3 of the 32 trees used to form this model (Fig. 12). This model may overestimate cone production during fair to poor cone crop years due to model formation from trees during a good cone crop year. The model with the best fit was:

Total Cones Per Tree = -2.68 (BA at Tree F-10) + 716 (Cone Rating)^2

R-Squared = 0.906 Fit Index = 0.825 Mallows Cp = 3.127

BA at Tree F-10 = The number of "in" trees with a F-10 prism at subject tree

Assessing trees with the cone rating method described by Shelton and Wittwer (1995) appears to be a very promising method because many of the uncontrollable factors that prevent maximum cone yield have been excluded by the time maturing cones are observed. Another advantage to the cone rating procedure is the efficiency in which many trees can be observed in a stand in a short amount of time. There is a problem with the cone density rating in relation to seed yield. According to Yocom (1971), there is not a consistent relationship observed between the production of sound seed and the number of cones on individual trees in the Ouachita mountains of Arkansas. Due to this inconsistency it is recommended that future studies address the quality of seeds within shortleaf pine crowns as well as cone distribution.

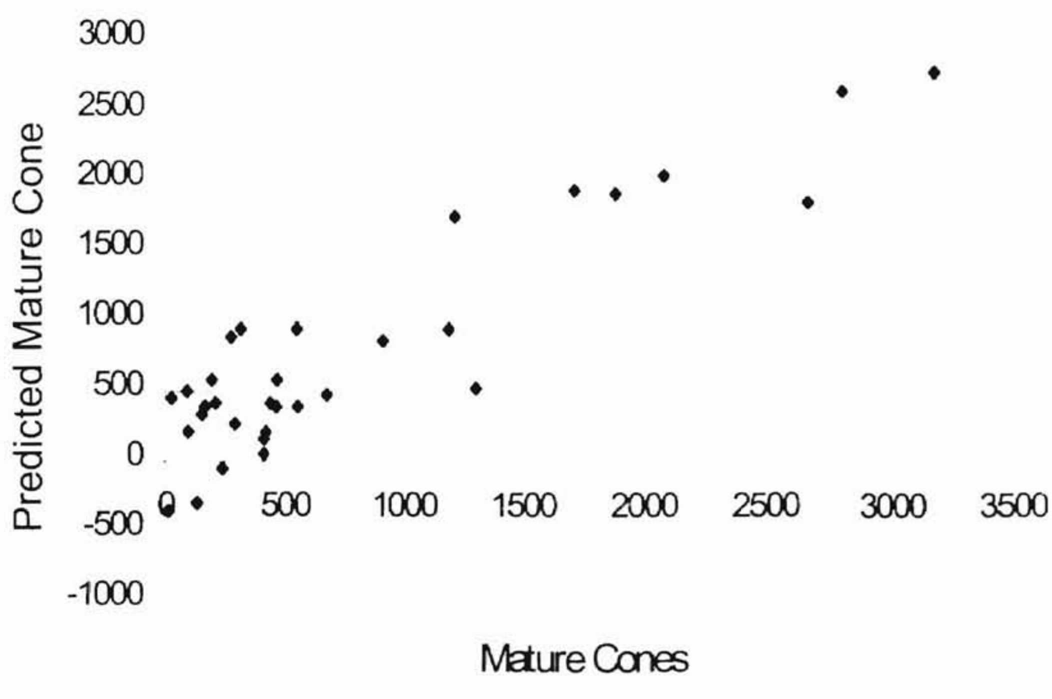

Figure 12. Predicted mature cones per tree crown plotted by the actual mature cone values.

Based on the distribution of cones and clusters of cones found in this study, the cone rating would be applied most successfully to the south facing tree crown with special attention given to the upper south crown position (Fig. 1, 4 & 6). This is even more important for lower density stands where the difference in cone production between the north and south crown face is even more evident (Fig. 2).

CONCLUSIONS

The average released tree produced almost triple the number of cones compared to the average unreleased tree. The uneven-aged regeneration cut had its greatest impact on released trees 14 inches at dbh 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 diameter class. The only real significant difference for unreleased trees occurred by crown position with the upper crown positions producing significantly more cones than the lower north crown position. The results in this study suggest that under similar stand conditions, release trees should be selected that are at least 14 in. at dbh for maximizing seed production.

The two and three-cone clusters distribution was highly correlated with total cone production. Cone clusters were also significantly more prominent in the upper crown positions. Clusters of cones should be a good indicator of seed productivity but special attention should be given to the upper crown where the majority of cone clusters, and cones occurred.

Conelet production differed significantly only by crown position with the lower north position producing significantly fewer conelets than all other positions. Conelet production was poorly correlated with mature cone production. This agrees with the reported sporadic nature of shortleaf pine cone crops in the southern United States. The conelet distribution results in this study suggest that during poor cone crops the differences become less noticeable at all levels of observation.

Older cones per tree differed significantly between released and unreleased trees with average released trees producing almost quadruple (3.7) the number of cones compared to the average unreleased trees. Older cones also differed significant by tree diameter with the 15 and 17 inch diameter class trees having significantly greater quantities of older cones than the lower diameter classes. As for older cones by crown position, the lower north position produced significantly fewer older cones than all other crown positions. A correlation analysis revealed that older cones were significantly correlated with mature cone production. These results suggest that the presence of older cones is a good indicator of future cone production and should be used to select potential seed-trees. This method of seed-tree selection does have its limitations due to poor cone crops, and lack of retention of older cones. Most older cones will not stay attached to branches for more than 4-years.

The average released tree produced significantly more male strobili than the average unreleased trees by approximately 3,741 male flowers. The increase in male strobili production improves the chances for successful pollination of adjacent released trees given adequate humidity, acceptable wind speeds, and receptive female flowers. Male strobili production also differed significantly by crown position with the lower south crown position producing significantly greater quantities of male strobili than the lower and upper north crown positions.

The cone density rating squared and basal area variables have proven to be most successful in predicting mature cones per tree. 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. This should benefit forest managers who are trying to establish shortleaf pine regeneration. Regeneration cuts or seedbed treatments could coincide with good cone crops to maximize regeneration success. The cone density rating is an efficient way to observe many trees in a stand in a short amount of time, with many uncontrollable factors that prevent maximum cone yield excluded by the time trees are observed.

LITERATURE CITED

Baker, J.B. 1982. Guidelines for natural regeneration. P. 35-40 in How to help landowners with forest regeneration. Miss. For. Com., Jackson, MS.

Baker, J.B. 1992. Natural regeneration of shortleaf pine. P. 102-112 in Proc. Shortleaf Pine Regeneration Workshop. USDA For. Serv. Gen. Tech. Rep. SO-90.

Baker, J.B. and others. 1996. Uneven-aged silviculture for the loblolly and shortleaf pine forest cover types. Gen. Tech. Rep. SO-118. Asheville, NC: USDA, For. Serv. Southern Research Station. 65 p.

Barnett, J.P. 1993. Merits of using mechanical treatments to stimulate cone production of slash and longleaf pines. In: Proceedings of the 22nd southern forest tree improvement conference; 1993 June 14-17; Atlanta, GA. Atlanta, GA: Southern Forest Tree improvement Committee: 59-64.

Barnett, J.P., and R.O. Haugen. 1995. Producing seed crops to naturally regenerate Southern pines. USDA For. Serv. Res. Note SO-286.

Boggs, J.A., and R.F. Wittwer. 1993. Emergence and establishment of shortleaf pine seeds under various seedbed conditions. South. J. Appl. For. 17(1) 44-48.

Bower, D.R., and J.L. Smith. 1961. Partial girdling multiples shortleaf cones. USDA For. Serv. South. For. Notes 132: 3-4.

Bramlett, D.L. 1965. Shortleaf pine seed production in the Piedmont. USDA For. Serv. Res. Note SE-38. 4 p.

Bramlett, D.L. 1972. Cone crop development records for six years in shortleaf pine. For Sci. 18: 31-33.

Brinkman, K.A. 1962. Fertilizers increase seed production of shortleaf pine in Missouri Tree Planters Notes. 53: 18-19.

Coulson, R.N., and R.T. Franklin. 1970. *Populations of Dioryctria* sp. (Lepidoptera: phycitidae) in relation to cone destruction. J. Georgia Entomol. Soc. 5 (4): 197-202.

Fatzinger, C.W., G.D. Hertel. E.P. Merkel, W.D. Pepper and R. S. Cameron. 1980. Identification and sequential occurrence of mortality factors affecting seed yields of southern pine seed orchards. USDA For. Serv. Res. Pap. SE-216. 30 p.

Graney, D.L., and H.E. Burkhart. 1973. Polymorphic site index curves for shortleaf pine in the Ouachita Mountains. South. For. Exp. Stn., New Orleans, La. 12 p. USDA For. Serv. Res. Pap. SO-85.

Gregory, J.D., and C.B. Davey. 1977. Subsoiling to stimulate flowering and cone production in a loblolly pine seed orchard. South. J. Appl. For. 1 (2): 20-23.

Haney, G.P. 1962. Seedbed scarification aids regeneration of shortleaf pine. J. For. 60:400-402.

Hard, J.S. 1964. Vertical distribution of cones in red pine. U.S. Forest Serv. Res. Note LS-51.

Howell, R.K. 1996. Forecasting of shortleaf pine seed crops in the Ouachita and Ozark Mountain Regions. Unpubl. M.S. Thesis. Oklahoma State University, Stillwater, OK. 62 pp.

Krugman, S.L., and J.L Jenkins. 1974. *Pinus* L. pine. P. 598-638 in Seeds of woody plants in the United States. Agric. Handb. No. 450. USDA For. Serv., Washington, DC.

Lyons, L.A. 1956. The seed production capacity and efficiency of red pine cones (*Pinus resinosa* Ait.). Can. J. Bot., 34: 27-36.

Mattson, W.J., Jr. 1979. Red pine cones: distribution within trees and methods for sampling. Can. J. For. Res. Vol. 9: 257-262.

McLemore, B.F. 1977. Strobili and conelet losses in four species of southern pines. USDA For. Serv. Res. Note SO-226.

McWilliams, W.H., R.M. Sheffield, M.H. Hansen, and T.W. Birch. 1986. The shortleaf resource. P. 9-24 in Proc. Symp. Shortleaf Pine Ecosystem. Univ. Arkansas Coop. Ext. Serv., Monticello, AR.

Murphy, P.A., J.B. Baker, and E.R. Lawson. 1991. Selection management of shortleaf pine in the Ouachita Mountains. South. J. Appl. For. 15: 61-67.

Phares, R.E., and N.F. Rogers. 1962. Improving shortleaf pine seed production in Missouri. J. For. 60: 322-324.

Roeser, J., Jr. 1936. Some aspects of flower and cone production in ponderosa pine. J. For. 39: 534-536.

SAS Institute Inc. 1997. SAS/STAT User's Guide, Release 6.12 Edition. Cary, NC. 1028 p.

Shelton, M.G. 1995. Effects of seed production, seedbed condition, and overstory basal area on the establishment of shortleaf pine seedlings in the Ouachita Mountains. South. Res. Sta. USDA For. Serv. Res. Pap. SO-293

Shelton, M.G., and P.A. Murphy. 1997. Understory vegetation 3 years after implementing uneven-aged silviculture in a shortleaf pine-oak stand. South. Res. Sta. USDA For. Serv. Res. Pap. SO-296

Shelton, M.G., and R.F. Wittwer. 1995. Forecasting loblolly and shortleaf pine seed crops. pp. 605-612. In: Proc. Eight Bienn. South. Silvi. Res. Conf. USDA For Serv. Gen. Tech. Rep. SRS-1.

Shelton, M.G., and R.F. Wittwer. 1996. Shortleaf pine seed production in natural stands in the Ouachita and Ozark Mountains. South. J. Appl. For. 20 (2): 74-80.

Smith, W.H., and R.G. Stanley. 1969. Cone distribution in crowns of slash pine (*Pinus elliotii* Engelm.) in relation to stem, crown, and wood increment. Silvae Genet. 18:86-91.

Thorbjornsen, E. 1960. A cone production study in loblolly pine on the coastal plain of North Carolina. J. For. 58: 543-547.

Wenger, K.F. 1953. How to estimate the number of cones in standing loblolly pine trees U.S.A., For. Serv. Res. Note SE-44.

Winjum, J.K., and N.E. Johnson. 1964. Differences in cone numbers, lengths, and cut-counts in the crowns of young open-grown Douglas-fir J. For. 62: 389-391.

Wittwer, R.F., and M.G. Shelton. 1992. Seed production in natural shortleaf pine stands. P. 113-123 in Proc. Shortleaf Pine Regeneration Workshop. USDA For. Serv. Gen. Tech. Rep. SO-90.

Wittwer, R.F., C.G. Tauer, M.M. Huebschmann and Y. Huang. 1997. Estimating seed quantity and quality in shortleaf pine (*Pinus echinata* Mill.) cones from natural stands. New Forests 14: 45-53.

Yocom, H.A. 1971. Releasing shortleaf pines increases cone and seed production. USDA For. Serv. Res. Note SO-125. 2 p.

Zar, H.J. 1996. Biostatistical Analysis. Prentice-Hall. Inc., New Jersey. P 334-335, 433-434.

CHAPTER III

CONE CHARACTERISTICS & SEED QUALITY FOLLOWING AN UNEVEN-AGED REGENERATION CUT IN SHORTLEAF PINE

Abstract: This study characterizes seed quality and cone characteristics for 16 released (stand density 14 m^2/ha) and 16 unreleased (stand density 28 m^2/ha) shortleaf pine trees by tree diameter class and crown position. Trees were randomly selected from four predetermined 5.0 cm diameter classes (28, 33, 38, 43 cm), and each tree crown was divided in to four crown positions (upper south, upper north, lower south, and lower north). Twenty mature cones were sampled from each crown position for evaluation of cone characteristics and seed quality. Cone green weight was significantly less in the lower north crown position compared to other crown positions for both released and unreleased trees. The 38-cm diameter class released and unreleased trees produced significantly heavier cones at 7.9 grams compared to all other diameter classes. The average cone dry weight for released trees did not differ significantly by crown position but this was not the case for unreleased trees. The lower north crown for the unreleased trees produced significantly lighter cones compared to all other crown positions including the released tree crowns. The average number of potentially productive scales per cone differed significantly only by crown position, with the lower north crown producing significantly fewer scales per cone than all other crown positions. The upper north position produced significantly more scales compared to the lower crown positions. Total seed per cone did not differ significantly between released (48) and unreleased (45) trees, but released trees did produce significantly more sound seed per cone than

unreleased trees (31 vs. 22). Both released and unreleased trees produced significantly more sound seed per cone in the upper south crown position (31) compared to the other crown positions (23, 26, & 26). The upper crown positions produced significantly greater percent sound seed per cone (59, 63) than the lower crown positions (48, 51) for both released and unreleased trees. Percent sound seed also differed significantly between released and unreleased trees with the 38 and 43 cm diameter class released trees producing a higher percentage of sound seed per cone. Overall released trees averaged 88 % germination compared to 84 % for unreleased trees. The smaller diameter class trees (28, 33) had significantly higher percent germination compared to the 38 cm diameter class trees but not the 43 cm diameter class trees. Based on the results of this study, released trees at least 36 cm in diameter or greater should be selected to increase sound seed per cone production under similar stand conditions, and regardless of stand density the upper south crown position will yield more sound seed per cone.

INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.) is an important species throughout much of its range occupying millions of acres of commercial forest land in the southern US (Bramlett 1965). Nearly half of the shortleaf pine resource is located west of the Mississippi River, with Oklahoma and Arkansas having the greatest concentrations (Baker 1992).

The requirement for large amounts of seed to naturally regenerate forests or for use in tree nurseries has sparked interest in the cone producing ability of stands and individual trees (Thorbjornsen 1960). Flower induction is believed to be influenced by at least five factors: (1) nutrient relationships, (2) induction hormones, (3) light conditions, (4) soil moisture, and (5) temperature (Barnett and Haugen 1995). A thinning or regeneration cut should positively affect three of the above variables: moisture, light, and nutrients. Beginning in late July and August, it takes nearly 31 months between the time of strobili initiation and seed maturity (Eggler 1961, Barnett and Haugen 1995). This is a fairly long period of time before increased seed yield can be realized.

Yocom (1971), reported that the removal of all trees within 9.1 m of shortleaf pine seed trees significantly increased the average number of sound seed per cone and doubled the average cone production per tree. A ten-year study of shortleaf pine seed crops in Texas recorded seedfall in uncut stands, in strip clearcuts, and on plots being regenerated by the selection, shelterwood, and seed tree systems (Stephenson 1963). The results indicated that all regeneration systems produced more sound seed than in the strip clearcuts and uncut stands and the shelterwood system produced more sound seed than the selection and seed tree systems. Several studies have also found that pine seed quality is higher when seedfall is greatest (Stephenson 1963 Bramlett 1965, Shelton and Wittwer 1996).

According to Wittwer et al. (1997) knowledge is lacking about cone quality and variation in seed content in natural stands of shortleaf pine. They conducted a study that estimated seed quantity and quality in shortleaf pine cones from two 15 ha natural stands. They reported 36 total seed per cone with sound seeds per cone averaging 17.5 and 14.5 for single-tree selection, and seed-tree stands, respectively. They also found that percent sound seed averaged 41.1 and 45.4 percent for the seed-tree and single-tree selection stands (Wittwer et al. 1997). According to Yocom's (1971) shortleaf pine cone and seed production study, released trees produced an average of 38 sound seed per cone compared to 35 sound seed per cone for unreleased trees. Sound seed was 81 % of total for the unreleased trees and 85 % for the released trees. Based on these two studies, sound seed and percent sound seed can vary greatly from year to year, with cultural operations having some affect on sound seed per cone.

Perry and Coover (1933) reported that shortleaf cone shape, size, and weight, differ greatly from tree to tree as well as seed color, wings, and percent germination. According to Lyons (1956) little attention has been given to the relationship between cone size and seed yield. Lyons (1956) reported that red pine (*Pinus resinosa* Ait.) cone "seed capacity" and ovule abortion both vary according to their position in the tree and the size of cone. Seed capacity was defined as the number of ovules in the productive region of the cones (45 % for red pine). Dickmann and Kozlowski (1971) reported that the number of seed per cone for red pine depends on the number of productive ovules, degree of pollination, and ovule abortion. They concluded that the number of productive ovules per cone was not highly dependent on the number of scales. They also found a linear relationship between cone volume and the number of seeds per cone with a correlation coefficient of + 0.76. According to Lyons (1956), the young ovule's ability to form a seed depends on whether the ovule is normally developed at the time of pollen dispersal and pollination. Lyons suggests that nutritional factors may be involved because of the distribution of abortion within the tree and cone. Lyons contends that his view is supported by published evidence on the adverse effect of resin extraction on seed production in pines.

A South Florida slash pine (*Pinus elliottii* Engelm.) study revealed that cone weight and length did not affect the amount of viable seed produced (McIntyre 1929). Also, no relationship was reported between tree age, seed viability or cone size. Eliason and Heit (1940) reported that on a volume basis, small Scotch pine (*Pinus sylvestris* L.) cones produced the same amount of viable seed as the large cones, but larger seedlings were produced from larger cones and smaller seedlings were produced from smaller cones. They also reported that small cones produce the smallest seed, the fewest seedlings per gram of seed sown, and the percentage of empty seed in the small cones was almost twice as much for the large cones.

Squillace (1957) reported that heavier western white pine seeds were produced on shoots from the upper and outer south and west sides of the crown compared to the upper north and east sides of the crown. A study on young open-grown Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) revealed that the outer extremities of the branches on the upper and middle south side of the crown have the greatest cone numbers, the highest cut-counts (sound seed per one half longitudinally sliced cone) and longest cones except for the west quarter of the crown (Winjum and Johnson 1964). A study on ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) cone production in Colorado revealed that the average green weight of cones and weight of the seed decreases as the number of cones per cluster increase (Roeser 1933).

According to Righter (1945), seed weight is positively correlated with seedling size but not with inherent vigor. Bilan and Fisher (1970) reported that small sonderegger pine (*Pinus sondereggeri* H. H. Chapm.) seed in east Texas produced taller seedlings compared to large seed, but large seed produced seedlings with the longest needles and cotyledons. They also reported that seedling survival after 8-weeks did not appear to follow any pattern regarding seed size. According to a study on the influence of seed size on germination and early development of loblolly pine, larger seeds germinated more quickly and produced larger germinants after 28 days of growth under laboratory conditions (Dunlap and Barnett 1983). Based on the above studies, larger seed appears to have a short-term advantage due to quicker germination rates and larger seedlings. Both of these factors should lead to better seedling establishment under natural conditions.

This study was conducted to determine if cone characteristics and seed quality vary by crown position, tree diameter, and release treatment. We hypothesized that: (1) larger diameter released and unreleased trees would produce more sound seed per cone than smaller diameter released and unreleased trees, (2) the upper crown positions would produce more sound seed per cone than lower crown positions, (3) the average released tree would produce more sound seed per cone than the average unreleased tree, (4) and percent germination would be greater for average released trees compared to unreleased trees.

STUDY AREA

The study area was located within the Ouachita National Forest on the Winona Ranger District in Perry County, Arkansas. 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. Pine regeneration was very scarce due to a thick duff layer and lack of light filtering through to the forest floor Sixteen uneven-aged management plots were established between December 1988 and March 1989 (Shelton and Murphy 1997). Plots were established to further the knowledge base concerning uneven-aged silviculture in a typical Ouachita Mountain forest. The uneven-aged regeneration cut reduced the overstory pine basal area for each plot from approximately 27.6 m^2/ha to 13.8 m^2/ha. Also, each plot received one of three possible residual hardwood basal area treatments (0, 3.4, and 6.9 m^2/ha). Only trees ≥9.1 cm diameter at 1.37 m in height (dbh) were considered in the overstory. These stands will need several decades to develop the balanced reverse-J size class distribution. The stands are presently irregularly aged resembling a shelterwood stand but have too much variation to be described as even-aged.

Four 0-hardwood control plots were selected for this study. Reducing the pine basal area to 13.8 m^2/ha and controlling all hardwoods within each plot should have provided significant release of the residual pine stand. Each of the 0.20-ha plots were surrounded by a 0.45 ha buffer zone measuring 17.7 m in width. During plot establishment the buffer zones received the same treatments as the 0.20 ha plot area. Plots were positioned along an east-west ridge top with three plots facing north and one plot facing south. Shortleaf pine site index averaged 17.4 m at 50 years and ranged from

16.2 to 19.5 m (Shelton and Murphy 1997). The selected plots presently have 13.8 m^2/ha pine basal area, with well established pine and hardwood regeneration. After 10 years of growth we would expect to see an increase in overstory pine basal area. The present basal area is probably less than expected due to a flaw in our point sampling techniques or, more logging damage to trees in the buffer zone during the regeneration cut. The present basal area was based on 4 point samples (Factor 10 prism) per plot buffer zone. Each point sample was taken at the stump of each selected released tree. Selected released trees were included in the point sample tally as "in" trees. The fact that each prism point sample was taken at the stump of each selected released tree, induces some bias in the reliability of the estimated present basal area. This is the most likely explanation for the low present basal area estimate. For more details concerning the study area see Shelton and Murphy's (1997) study area description.

METHODS

Tree Selection

Sixteen released trees were selected from the buffer zones of four treated plots, and sixteen unreleased trees were selected from the adjacent pine-hardwood mixed forest. The released and unreleased trees were randomly selected from predetermined 5-cm dbh classes (28, 33, 38, and 43 cm). Potential sample trees with malformed crowns or significant hardwood competition were excluded from selection. Each released tree was paired by tree diameter class to an unreleased tree in the adjacent untreated mixed pine-hardwood stand. The unreleased stand contained approximately 27.6 m^2/ha total basal area with 18.4 m^2/ha attributed to shortleaf pine. Paired sample trees were never more than 60 m apart. The unreleased sample trees were selected far enough away from the buffer zone to avoid the effects of the regeneration cut and hardwood control treatments.

Sample trees were measured for height, dbh, crown length, crown width, and 5-year radial growth increment at stump height.

Cone Sampling

Thirty two trees were felled during the middle of October 1998 when cones were mature but before seed fall. Wakeley (1954) reported that shortleaf pine cones were usually mature by October 1-20 and collections occurred between October 11 - 30. This provided a narrow window of opportunity for felling of sample trees and collection of cones. Once a tree was felled, the crown was measured for total length and divided into two equal upper and lower halves. The crown was further divided into a magnetic north and south face, (4° east declination) creating four unique crown positions: lower north, lower south, upper north, and upper south. Branches were removed and separated by crown position. Cones were picked from all branches from each crown position. This provided a complete population of cones from which to sample. The four crown positions and four tree diameter classes were considered treatments split between the released and unreleased treatments with four replicates of each treatment. This represented a 2X4X4 factorial split-split plot randomized complete block design.

Twenty cones with no visible defects were randomly sampled from the pool of available cones from each crown position and placed in paper bags for drying and seed extraction. Very few crown positions failed to produce at least 20 healthy looking cones, but when a shortage occurred all cones were used. Out of 128 possible crown positions only 27 positions produced less than 20 cones. The 20 sample cones per crown position for the 32 sample trees, represented a potential sample of 2,560 cones. An additional 10 cones per crown position were sampled specifically for cone dry weight determination.

Cone Attributes & Measurements

Cone measurements included length, diameter, green weight, dry weight, and volume. Cone green weight was obtained daily for each tree felled to ensure measurements would not be affected by cone moisture loss. The volume by water displacement method was used to measure cone volume. The cone volume and weight measurements were used to calculate cone specific gravity by dividing the cone weight by volume. Wakeley (1954) reported that southern pine cones may mature and eventually open if cones were collected when specific gravity was between 1.00 and 0.89; results were best if specific gravity had dropped to 0.88. Daily cone measurements also included length and diameter. Other cone attributes evaluated were potentially productive scales per cone, seed per cone, sound seed per pound, percent sound seed and percent germination of sound seed.

Seed Processing

Sacks of sampled cones were spread out to air dry in a well ventilated room. Cones were allowed to air dry and expand freely with no obstruction for 6 weeks. Sampled cones were then tumbled for 25 minutes in a machine designed to remove seed from small numbers of cones without loosing seed. Cones were then placed in a convection oven at 35° Centigrade for 48 hours and then machine tumbled for an additional 15 minutes. The majority of seed were extracted prior to the oven drying process, so this was simply a secondary measure to further remove seed. The efficiency of the seed extraction process was tested by dissecting 80 randomly selected processed cones from 8 released and 8 unreleased crown positions. Based on the 80 cone destructive sample, only 2.3 seeds per cone were not removed with a coefficient of variation of 63 %. This level of seed extraction was considered acceptable and no further attempts were made to extract additional seed.

Potentially productive cone scales were counted after all seed had been removed by the tumbling and drying process. Ten of the original 20 cones per crown position were used for cone scale counts. The main reason for counting cone scales was to determine the average potential seed capacity of cones by crown position. Determining which cone scales were potentially productive was a subjective process based on the experience gained through dissecting sample cones previously mentioned. Potentially productive scales were defined as being large enough for two enlarged sound or empty ovules that did not abort during the first growing season. Most of these potentially productive scales were found in the upper two thirds of the cone.

Before determining total seeds per cone, the wings and other inert matter had to be removed. Wings were removed by first wetting for about one-half hour; then, the seeds, wings, and impurities were placed on a large 2-mm nylon screen and rubbed gently to further remove wings. Seeds and wings were allowed to air dry for about 2 to 4 hours. Seeds and wings were then placed within a 4-mm sieve and shaken over a large plastic container. The 4-mm sieve filtered out all seed that had separated from the wings and left behind wings and seed still attached to wings. Seeds that were still attached to wings were placed back on the screen and rubbed gently to further remove wings. A fan was then used to remove wings and impurities that were lighter than the remaining seed. Seeds separated by the sieve and the fan were then combined together for the removal of any remaining attached wings and inert matter. Identification and removal of inert matter was accomplished using the guidelines set forth by the Association of Official Seed

Analysts (1978). Total seed per cone was calculated by counting the remaining dewinged seed and then dividing by the number of sample cones per crown position.

A series of float tests were used to separate the empty seed from the sound seed. First seeds were soaked in water for about 7 hours. The sinking seeds were removed and dried on a 2-mm nylon screen, while floating seeds were soaked for an additional 17 hours. Seed that sank during the second interval (17 hours) were re-dried for 4 hours and subjected to another float test for 20 minutes. The twenty minute float test determined if these particular seeds were truly sound seed or just empty seed that took on water after 24 hours of soaking. Sinking and floating seeds for the two tests were combined with their respective groups for counting. To test the efficiency of this process, 20 discarded floating seeds were sampled from each crown position and cut to verify that the seeds were indeed empty. After cutting 2,460 floating seeds only 1 % appeared to be sound. We considered this to be an acceptable level of error. The sound seeds were allowed to air dry for about three days before storing in a refrigerator. Seed moisture content should be between 5 and 10 % before placing in storage (U.S. Forest Service 1974). The number of sound seed per cone was determined by counting the sound seed, and then dividing by the number of sample cones per crown position.

Germination

A germination test was conducted using a sample of 200 sound seeds per crown position with four replicates of 50 sound seed each. This is a potential subsample of 25,600 sound seed total or 800 sound seed per tree. The Association of Official Seed Analysts (1978) recommend using 400 sound seed per germination test with four replicates of 100 seed each. We used 200 sound seed per tree crown position with four reps of 50 seed due to the occasional low numbers of sound seed produced from some crown positions. Approximately 22 % of the total crown positions did not have adequate amounts of sound seed to meet the 200 seed maximum. A system was devised that allowed all sound seed to be tested, with a maximum number of replicates and seeds per replicate per crown position. Crown positions with only 50 sound seed or less, would have one replicate, two replicates for crown positions having 51 to 100 sound seed, three replicates for crown positions with 101-150 sound seed, and finally four replicates for crown positions having 151-200 sound seed.

To improve germination all seeds were stratified in accordance with the Association of Official Seed Analysts (1978) rules for testing seeds. Replicates of 50 sound seed or less were soaked for 24 hours at 21.1° Centigrade. The excess water was drained and the seeds were placed in polyethylene bags and pre-chilled for 28 days at 4.4 Centigrade. After 28 days of pre-chill, all replicates were placed into small 4.5 cm dishes with three layers of filter paper as the substrate. Seeds were equally spaced to prevent the spread of fungi from infected seed. Two ml of de-ionized water was added to each dish at the start of the germination test, and 0.20 ml were added every 7 days until the test was terminated. A very low concentration of fungicide (captan) was applied to every dish on the fifth day of the germination test to contain its potential spread. Two cabinet germinators with eight trays per germinator were used to conduct the germination test. Water was placed in the bottom of the germinator chamber to keep the relative humidity at a constant of around 95 percent. The eight trays per germinator were rotated every three days to reduce the effects of micro-environmental variation. Replicates one and two were placed in germinator one, and replicates three and four were placed in germinator two. An analysis of variance indicated no significant difference in percent germination between trays or germinators. During the 28 day germination test light was applied eight hours per 24 hour period at a temperature of 30° Centigrade. The remaining 16 hours without light coincided with a temperature of 20° Centigrade. Testing temperatures, light intervals, and germination duration were recommended by the Association of Official Seed Analysts (1978).

According to the Association of Official Seed Analysts (1978), seed germination in the laboratory is defined as the emergence and development from the seed embryo of those essential structures which, for the kind of seed in question, are indicative of the ability to produce a normal plant under favorable conditions. Germination counts began on the fourth day and continued daily thereafter. Seedlings with radicles half the size of the seed or longer were evaluated as normal or abnormal. If a seedling could not be classified as normal or abnormal with a radicle length at half the size of the seed, the seedling was allowed to grow until an accurate decision could be made. Only those seedlings considered normal were counted and removed daily. The descriptions of abnormalities applied in this study were described by the Association of Official Seed Analysts (1978). At the end of the germination test all seeds that had failed to germinate were cut to determine if the seeds were full or empty.

The percent germination was calculated for each replicate by taking the number of seed germinated and dividing by the total seed per replicate. If the percent germination for a replicate deviated by 25 % or more below the average of all replicates it was omitted from the data analysis. Replicates were also omitted when 20 % or more of the sound seeds were fungi filled. Only 12 replicates had to be excluded due to fungi or deviation from the mean percent germination. A similar way of excluding replicates is described by the Association of Official Seed Analysts (1978). Percent germination by crown position was determined by averaging the percent germination for all remaining replicates.

Data Analysis

Mean values for cone characteristics were calculated on a per crown position basis. Calculated means for cone length, diameter, volume, green weight, dry weight, specific gravity, and scale counts were based on ten cone samples. When crown positions lacked numbers of cones for dry weight measurements, cones already processed for their seeds were used, and weight of the missing seeds were estimated based on actual seed weight from the crown position in question. Out of 128 crown positions, only 35 lacked sufficient numbers of cones for actual cone dry weight measurements. Mean calculations for total seed per cone, sound seed per cone, seed per gram, and percent germination were based on seed from twenty cone samples. Percent germination was the only variable that needed to be transformed. The angular, or inverse sine transformation was used to equalize the variance.

The MIXED procedure from the SAS Institute (1997) was used to analyze the data. An analysis of variance for the split-split plot arranged in a randomized complete block design was used to make inferences about cone characteristics by crown positions, diameter class, (split unit treatments) and stand density (main unit treatment). All variables were considered fixed for the mixed model except for blocks. Multiple means comparisons were attained by using the LSMEANS statement and DIFF (Fishers Least Significant Difference) and Slice options (SAS Institute 1997). The Fisher's LSD test is the least conservative multiple means comparison test, and is well accepted within the field of forestry. Means presented in tables are arithmetic means, while means presented in figures are least squares means (LSMEANS) or estimated means. The only exception is the percent germination figure which uses arithmetic means because of the transformation. The arithmetic means and the least squares means will sometimes differ due to an unbalanced design (missing observations). The percent germination figure indicates significant differences between means that contradict one another due to several potential factors. These factors include the use of transformed data, multiple standard errors, and missing observations. Multiple standard errors are due to calculations used in the means comparison tests (LSMEANS / DIFF). This apparent contradiction also occurs in the figure comparing means for cone dry weight.

RESULTS AND DISCUSSION

Released & Unreleased Tree Description

Tree age, dbh, and total height of released and unreleased trees were very comparable (Table 1). Crown width and length of released trees averaged 0.9 m greater than the unreleased trees. On average the released trees contained four more branches 2.54 cm in basal diameter or greater in their crowns compared to unreleased trees. The released trees also put on approximately 0.51cm more radial stem wood over the last 5 years of release. As of October 1998 the average released tree stand density was 14 m^2/ha compared to 27 m^2/ha for the unreleased trees .

Table 1. Sample tree descriptions for unreleased and released trees by diameter class.

DBH Class (cm)	Sample Trees	Age (years)	DBH (cm)	Total Height (m)	Crown Length (m)	Crown Width (m)	5-Year Radial Growth (cm)	Number Branches	Basal Area (m^3/ha)
Unreleased Trees									
28	4	71	27.7	20.4	8.2	5.5	0.71	25	29
		(60-82)	(25.7-29.5)	(16.5-22.6)	(6.1-10.4)	(4.6-6.7)	(0.25-1.14)	(18-30)	(25-34)
33	4	80	32.8	19.5	7.3	6.4	0.91	28	25
		(68-92)	(31.8-33.5)	(18.0-21.3)	(5.5-8.8)	(6.4-6.7)	(0.53-1.42)	(19-39)	(23-25)
38	4	82	38.1	20.4	8.5	7.0	0.94	36	28
		(68-110)	(36.6-39.4)	(18.3-24.1)	(7.0-9.8)	(6.4-7.6)	(0.38-1.32)	(26-39)	(28-30)
43	4	83	45.2	20.7	12.2	10.4	0.99	38	25
		(75-91)	(42.7-47.5)	(18.0-22.6)	(10.7-15.2)	(9.4-11.0)	(0.76-1.09)	(31-41)	(23-30)
Average		78	35.6	20.1	9.1	7.3	0.86	31	27
Range		(60-110)	(25.7-47.5)	(16.5-24.1)	(5.5-15.2)	(4.6-11.0)	(0.25-1.42)	(18-41)	(23-34)
Released Trees									
28	4	68	28.2	18.6	9.4	7.3	1.17	29	15
		(54-82)	(26.9-29.2)	(17.4-20.4)	(8.5-10.7)	(6.4-7.9)	(0.79-1.91)	(23-40)	(7-23)
33	4	74	33.5	20.7	8.5	7.6	1.29	27	14
		(69-81)	(32.3-35.1)	(20.4-21.6)	(7.6-9.8)	(6.4-8.5)	(1.04-1.50)	(23-32)	(11-16)
38	4	82	37.8	20.4	10.7	8.2	0.97	36	16
		(77-88)	(35.8-39.9)	(19.5-21.3)	(8.2-12.5)	(6.7-9.8)	(0.89-0.99)	(28-40)	(11-18)
43	4	78	44.9	22.3	11.6	9.8	2.01	46	10
		(69-84)	(42.9-48.5)	(20.4-26.5)	(8.8-14.0)	(7.9-11.6)	(1.12-3.63)	(39-66)	(2-21)
Average		76	36.1	20.4	10.1	8.2	1.37	35	14
Range		(54-88)	(26.9-48.5)	(17.4-26.5)	(7.6-14.0)	(6.4-11.6)	(0.79-3.63)	(23-66)	(2-23)

Cone Size Characteristics

Cone length, diameter, green weight, and volume, varied little between released and unreleased trees (Table 2, 3). Analysis of variances indicated no significant main effects or interactions at the 0.05 level of significance for cone diameter, volume, or length (Table 4). The cone size characteristic differing the most between released and unreleased trees was cone dry weight, by 1.0 g. Cone dry weight also appeared to vary considerably by tree diameter class for both released and unreleased trees (Table 2). On average the lower north crown position produced cones that weighted the least, were smaller in volume and contained fewer potentially productive scales (Table 3).

An analysis of variance revealed a significant difference by crown position for cone green weight (Table 4). Cone green weight in the lower north crown position produced significantly lighter cones compared to all other crown positions (Fig. 1). This indicates that cone size can vary within the crowns of released and unreleased shortleaf pine. This was probably due to less carbohydrate production in the lower north crown where sunlight was less available.

An analysis of variance for cone specific gravity revealed a significant difference by stand density with the average released trees having greater specific gravity. This difference suggest that cones from released trees will dry out more slowly than unreleased trees. This seems counterintuitive because released trees are more exposed to the wind and radiant sunlight than unreleased trees and should dry out more quickly. If the cones and seed of the unreleased trees reached maturity earlier than the released tree, this would offer some explanation for the differences in cone specific gravity.

Table 2. Mean values of released and unreleased tree cone size attributes by dbh class evaluated for shortleaf pine.

	Tree Diameter Class➊ (cm)				
Released Trees	**28**	**33**	**38**	**43**	**Means**
Cone Length (cm)	4.4	4.8	4.8	4.9	4.8
Cone Diameter (cm)	2.2	2.2	2.2	2.2	2.2
Cone Green Weight (g)	10.6	10.7	13.1	13.1	11.8
Cone Dry Weight (g)	6.6	6.8	8.3	8.1	7.5
Cone Volume (cm^3)	10.5	11.2	12.9	13.0	11.9
Cone Specific Gravity	1.00	0.95	1.00	1.00	0.99
Potentially Productive Scales	53	56	61	54	56
Unreleased Trees					
Cone Length (cm)	4.8	5.3	5.3	4.9	5.0
Cone Diameter (cm)	2.2	2.1	2.3	2.2	2.2
Cone Green Weight (g)	10.6	11.3	12.5	10.5	11.2
Cone Dry Weight (g)	6.5	6.3	7.7	5.5	6.5
Cone Volume (cm^3)	11.0	12.2	13.1	11.3	11.8
Cone Specific Gravity	0.97	0.92	0.96	0.92	0.95
Potentially Productive Scales	56	52	55	52	54

➊ Mean values obtained from 4 sample trees for each diameter class by release and non-release trees.

Table 3. Mean values of released and unreleased tree cone size attributes by crown position evaluated for shortleaf pine.

	Crown Position ❶				
Released Trees	**Lower North**	**Lower South**	**Upper North**	**Upper South**	**Means**
Cone Length (cm)	4.7	4.8	4.8	4.7	4.8
Cone Diameter (cm)	2.2	2.2	2.2	2.2	2.2
Cone Green Weight (g)	11.5	12.3	11.8	11.7	11.8
Cone Dry Weight (g)	7.3	7.5	7.4	7.7	7.5
Cone Volume (cm^3)	11.6	12.3	11.9	11.7	11.9
Cone Specific Gravity	1.0	1.0	1.0	1.0	0.99
Potentially Productive Scales	54	56	57	57	56
Unreleased Trees					
Cone Length (cm)	4.9	5.1	5.0	5.1	5.0
Cone Diameter (cm)	2.1	2.2	2.2	2.2	2.2
Cone Green Weight (g)	10.3	11.5	11.1	11.6	11.2
Cone Dry Weight (g)	5.3	6.3	7.0	7.3	6.5
Cone Volume (cm^3)	11.0	12.2	11.8	12.2	11.8
Cone Specific Gravity	0.94	0.94	0.95	0.95	0.95
Potentially Productive Scales	52	54	55	54	54

❶ Mean values obtained from 16 sample trees for each crown position by released and unreleased trees.

*Table 4. The results of the analysis of variance to test for the effects of stand density, tree dbh class, and crown position on cone specific gravity, cone volume, cone green weight, cone dry weight, and productive scales per cone.

Source of Variation	Cone Specific Gravity			Cone Volume			Cone Green Weight			Cone Dry Weight			Productive Scales / Cone		
	DF	F	P>F	DF	F	P>F	DF	F	P>F	DF	F	P>F	DF	F	P>F
1998 cone crop															
Tree dbh Class (F)	3	1.98	0.145	3	1.60	0.216	3	1.87	0.163	3	3.56	<0.033	3	1.49	0.292
Stand Density (C)	1	10.16	<0.004	1	0.00	0.992	1	0.88	0.359	1	6.31	<0.021	1	2.04	0.187
F x C	3	0.36	0.782	3	0.40	0.753	3	0.69	0.569	3	2.19	0.122	3	0.52	0.678
Crown Position (D)	3	2.66	0.055	3	2.41	0.075	3	2.77	<0.048	3	6.28	<0.001	3	5.95	<0.001
F x D	9	1.51	0.164	9	0.83	0.594	9	1.21	0.306	9	1.21	0.303	9	1.87	0.070
C x D	3	0.37	0.775	3	1.44	0.239	3	0.90	0.447	3	2.85	<0.044	3	0.15	0.929
F x D x C	9	0.64	0.759	9	0.51	0.865	9	0.48	0.886	9	1.23	0.293	9	0.93	0.506
Error	68.1	❶RE = 0.0003		68.2	RE = 1.8702		68.0	RE = 1.7179		68.4	RE = 1.4019		68.6	RE = 9.2432	

❶RE = Sum of Squares Residual Error.

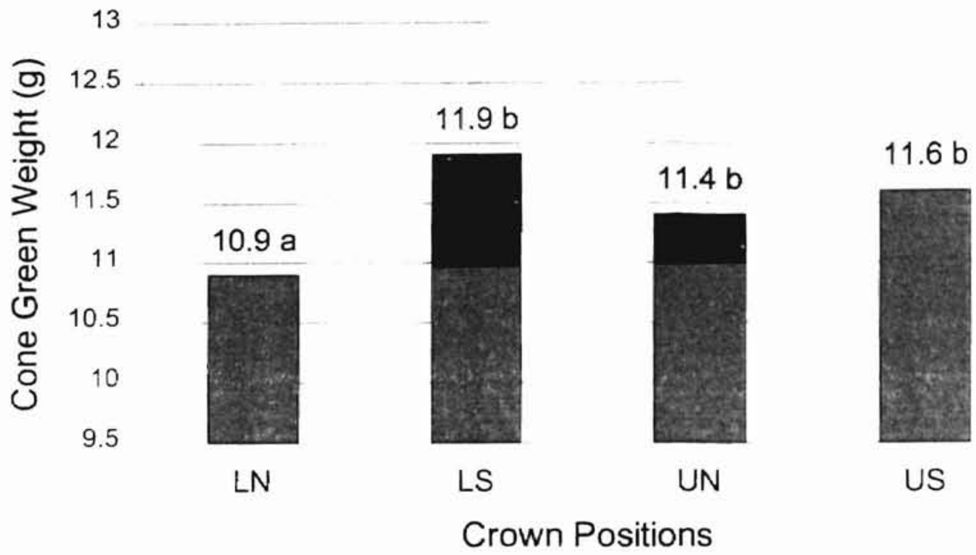

Figure 1. Shortleaf pine cone green weights by crown positions. Treatment least squares means followed by the same letter are not significantly different at the 0.05 level. Bars represent data pooled from both released and unreleased trees. Sample size is 32 trees per bar. (LN = Lower North, LS = Lower South, UN = Upper North, & US = Upper South)

An analysis of variance conducted for cone dry weight indicated a significant interaction between stand density and crown position with a significant main effect for tree diameter class. Cone dry weight averaged 7.5 g per cone for released trees and 6.5g for unreleased trees (Table 2, 3). The 38-cm diameter class released and unreleased trees produced significantly heavier cones at 8.0 g compared to all other diameter classes (Fig. 2). Average released tree cone dry weight did not differ significantly by crown position but this was not the case for unreleased trees (Fig. 3). The lower north crown position differed significantly from all other crown positions including the released tree crown positions.

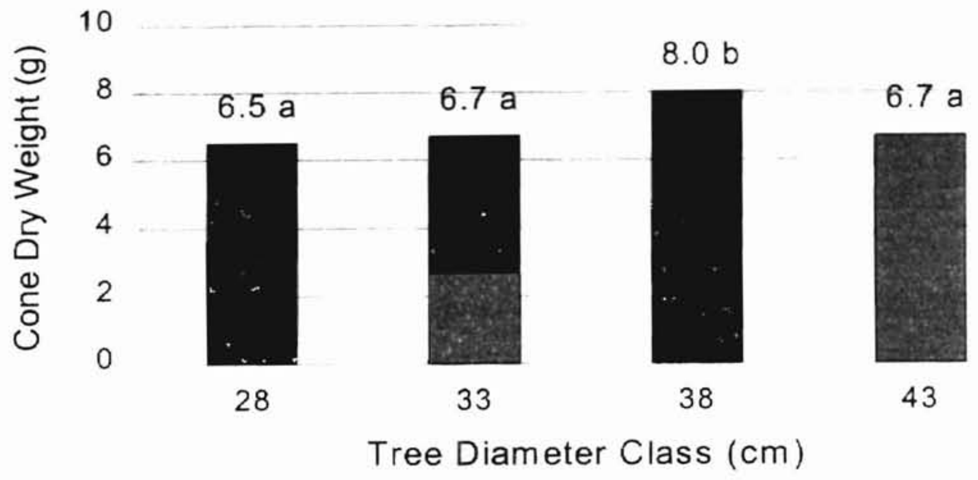

Figure 2. Shortleaf pine cone dry weight by tree diameter class. Treatment least squares means followed by the same letter are not significantly different at the 0.05 level. Bars represent data pooled from both released and unreleased trees. Sample size is 8 trees per bar.

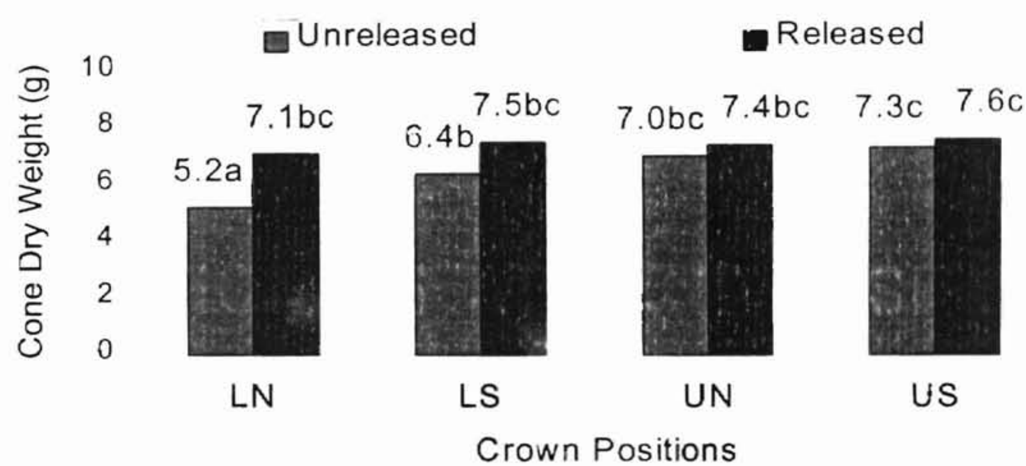

Figure 3. Shortleaf pine cone dry weight for released and unreleased trees by crown position. Treatment least squares means followed by the same letter are not significantly different at the 0.05 level. Bars represent data pooled from all tree diameter classes. Sample size is 16 trees per bar. (LN = Lower North, LS = Lower South, UN = Upper North, & US = Upper South)

The number of potentially productive scales per cone gives us an indication of how many total seed per cone could possibly be produced with each scale capable of containing two ovules. An analysis of variance for cone scales indicated a significant main effect by crown position (Table 4). The lower north crown position produced significantly fewer potentially productive scales than all other crown positions, while the upper north crown position produced significantly more scales than the lower crown positions (Fig. 4). With each scale capable of containing two ovules, cones from the upper north crown (56) could have produced on average 112 seeds per cone. The small cone scale differences were probably related to differences in average cone size by crown position. In realty the differences have little practical importance due to the small differences that occurred.

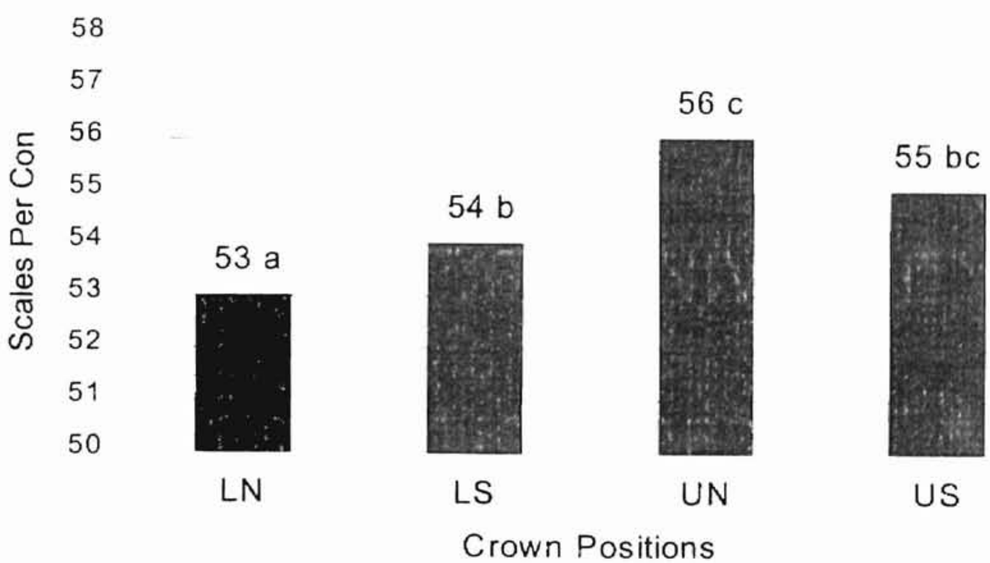

Figure 4. Number of potentially productive scales per cone by crown position. Treatment least squares means followed by the same letter are not significantly different at the 0.05 level. Bars represent data pooled from both released and unreleased trees. Sample size is 32 trees per bar. (LN = Lower North, LS = Lower South, UN = Upper North, & US = Upper South)

Seed Quality Attributes

All seed quality attributes for released trees tended to be slightly higher compared to the unreleased trees (Table 5,6). The most noticeable seed attribute difference between released and unreleased trees, occurred between percent sound seed and sound seed per cone. If we look at seed attributes by tree diameter class, percent sound seed and sound seed per gram varied the most for both released and unreleased trees (Table 5). Several of these seed attributes varied noticeably by crown position including percent sound seed, total seed, and sound seed per cone (Table 6). Total seed and sound seed per gram were the only seed quality variables without significant interactions or main effects (Table 7).

Released trees averaged 48 seed per cone compared to 45 for the unreleased trees (Table 5,6). Total seed per cone for the unreleased trees ranged from 9 to 92 seed compared to 12 to 90 seed for the released trees. Wittwer et al. (1997) reported that out of 886 shortleaf pine cones from 48 trees in two stands, the number of total seeds per cone ranged from 0 to 102, and averaged 38.0 and 34.6 for the two stands. Despite the cultural benefits applied to the released trees in this study, the average gain in seed production per cone appeared to be negligible. An analysis of variance for total seed per cone revealed no significant main effects (Table 7).

An analysis of variance for sound seed per cone reveled significant main effects for stand density and crown position (Table 7). Released trees produced significantly more sound seed per cone than unreleased trees by an average by 9 sound seed (Fig. 5). Sound seed per cone for the released trees ranged form 3 to 75 seed compared to 4 to 55 seed for the unreleased trees. Wakeley (1954) reported that during a good seed year

Table 5. Mean values of released and unreleased tree seed quality attributes by dbh class evaluated for shortleaf pine.

	Tree Diameter Class❶ (cm)				
Released Trees	**28**	**33**	**38**	**43**	**Means**
Sound Seed / g	108	96	98	92	99
Percent Sound Seed	48	54	75	67	61
Sound Seed / Cone	23	26	46	30	31
Total Seed / Cone	47	44	60	41	48
Percent Germination	89	88	83	93	88
Unreleased Trees					
Sound Seed / g	107	80	96	88	95
Percent Sound Seed	53	51	48	46	50
Sound Seed / Cone	21	22	23	24	22
Total Seed / Cone	42	43	45	49	45
Percent Germination	86	94	88	70	84

❶ Mean values obtained from 4 sample trees for each diameter class by released and unreleased trees.

Table 6. Mean values of released and unreleased tree seed quality attributes by crown position evaluated for shortleaf pine.

	Crown Position Means❶				
Released Trees	**Lower North**	**Lower South**	**Upper North**	**Upper South**	**Means**
Sound Seed /g	99	96	99	101	99
Percent Sound Seed	55	56	65	68	61
Sound Seed / Cone	27	29	32	36	31
Total Seed / Cone	47	49	47	51	48
Percent Germination	92	89	85	88	88
Unreleased Trees					
Sound Seed /g	97	92	94	95	95
Percent Sound Seed	42	54	53	57	50
Sound Seed / Cone	20	22	21	26	22
Total Seed / Cone	46	51	39	45	45
Percent Germination	84	83	82	86	84

❶ Mean values obtained from 16 sample trees for each crown position by released and unreleased trees.

Table 7. The results of the analysis of variance to test for the effects of stand density, tree dbh class, and crown position on total seed per cone, sound seed per cone, sound seed per gram, percent sound seed, and percent germination.

	Total Seed Per Cone			Sound Seed Per Cone			Sound Seed Per Gram			Percent Sound Seed			❶Percent Germination		
Source of Variation	DF	F	P>F	DF	F	P>F	DF	F	P>F	DF	F	P>F	DF	F	P>F
1998 cone crop															
Tree dbh Class (F)	3	0.74	0.540	3	1.67	0.206	3	2.54	0.107	3	0.81	0.521	3	3.79	<0.050
Stand Density (C)	1	0.60	0.446	1	4.18	<0.054	1	1.33	0.273	1	8.16	<0.015	1	2.97	0.131
F x C	3	1.00	0.412	3	1.24	0.323	3	0.47	0.709	3	3.89	<0.039	3	1.18	0.322
Crown Position (D)	3	2.34	0.080	3	4.13	<0.010	3	0.77	0.515	3	10.93	<0.001	3	0.62	0.607
F x D	9	0.84	0.586	9	1.41	0.201	9	0.62	0.780	9	0.98	0.463	9	0.93	0.503
C x D	3	1.00	0.400	3	0.51	0.677	3	0.13	0.944	3	0.14	0.934	3	2.06	0.113
F x D x C	9	0.28	0.977	9	0.32	0.964	9	0.61	0.781	9	0.37	0.945	9	1.33	0.237
Error	69.0	❷RE = 132.126		68.4	RE = 73.643		68.2	RE = 24833983.9		68.2	RE = 130.439		305.0	RE = 2.602	

❶Percent germination has been transformed using the angular or inverse sine transformation before analysis of variance.
❷RE = Sum of Squares Residual Error

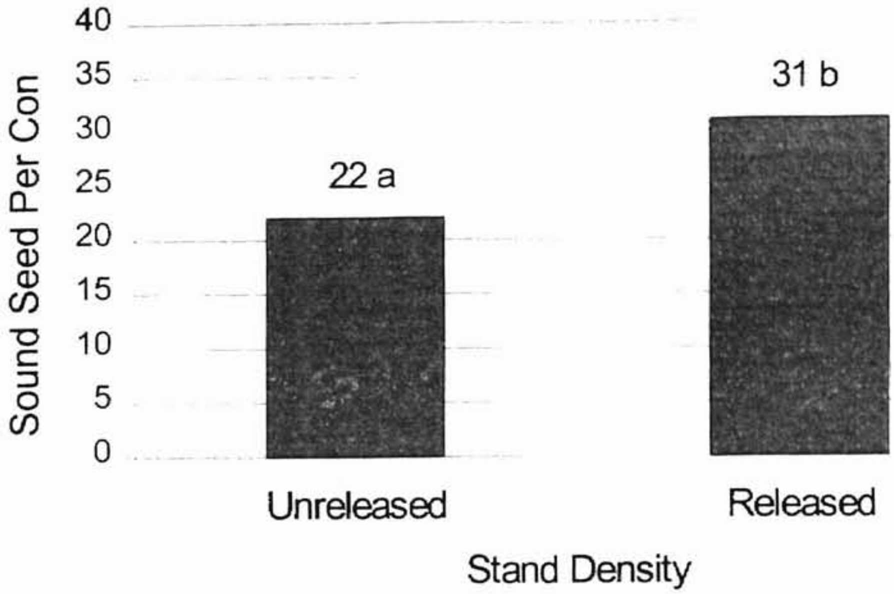

Figure 5. Shortleaf pine sound seed per cone by released and unreleased trees. Treatment least squares means followed by the same letter are not significantly different at the 0.05 level. Sample size is 16 trees per bar.

cones may average between 25 and 35 sound seed for shortleaf pine. In this study the cone crop produced very comparable results with an average of 27 sound seed per cone.

The reduction in sound seeds for unreleased trees could be due to carbohydrate deficiencies or inbreeding given both released and unreleased trees produced approximately the same average number of total seed per cone. If pollen cloud dispersal was hampered by reduced air movements in unthinned stands, this could have lead to increased self pollination and embryo abortion. Lyons (1956) reported that ovule abortion within the cones and trees of red pine suggests that nutritional factors may be involved. If this is the case, then released trees in this study should have received a short term increase in available nutrients which should have increased the overall tree fitness.

As indicated by the analysis of variance (Table 7), sound seed per cone also differed significantly by crown position with the upper south crown producing (31) more sound seed per cone than all other crown positions (Fig. 6). According to Perry and Coover's (1933) study shortleaf pine cones from the top of the crown produced the most viable seed per cone (24) followed by the middle crown (20), and finally the crown base (18). Perhaps greater sound seed yield in the upper south crown position is due to greater carbohydrate production where higher light levels are apparent and growth is more vigorous compared to other crown positions.

There are three main parts of a pine seed: the megagametophyte or the actual female gametophyte, the seed coat, and the embryo which contains hereditary factors from both parents (Righter 1945). The embryo, which contains the only genetic component from the male plant, makes up less than 15 % of the conifer seed weight

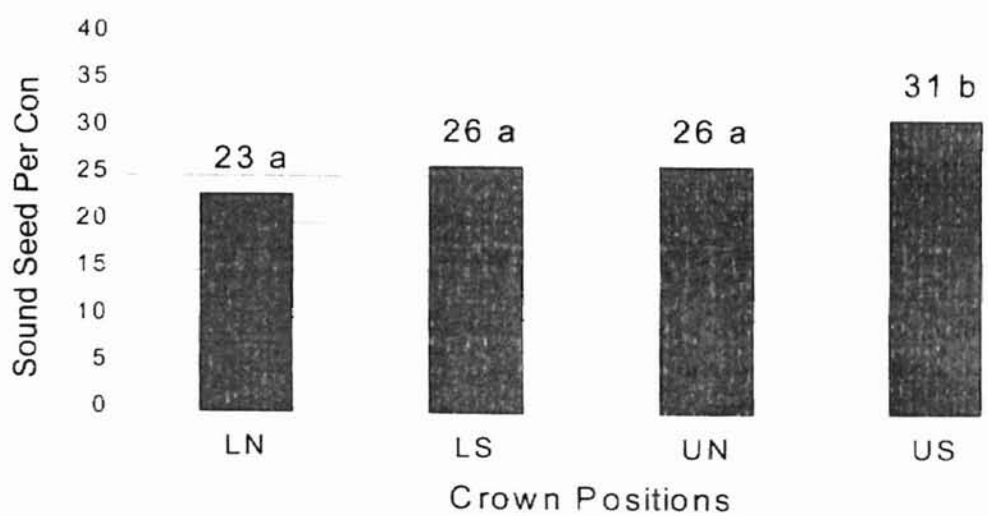

Figure 6. Shortleaf pine sound seed per cone by crown position. Treatment least squares means followed by the same letter are not significantly different at the 0.05 level. Bars represent data pooled from both released and unreleased trees. Sample size is 32 trees per bar. (LN = Lower North, LS = Lower South, UN = Upper North, & US = Upper South)

(Barnett 1996). According to Righter (1945), pine tree seed weights may vary so much that the heaviest sound seed is more than twice as heavy as the lightest sound seed. Wakeley (1954) reported cleaned and de-winged shortleaf pine seed to contain 106 seed per gram on average, ranging from 80 to 138 seed per gram. In this study, released trees averaged 99 sound seed per gram compared to 95 for the unreleased trees (Table 5.6). Sound seed per gram ranged from 68 to 132 for released trees and 66 to 147 for unreleased trees. Despite these differences no significant main effect or interactions were revealed by the analysis of variance for sound seed per gram (Table 7).

Based on the sound seed per cone and gram results in this study, it would take approximately 16 average released trees producing 200 cones per tree to produce a kilogram of seed compared to 21 unreleased trees producing the same number of cones. This example demonstrates that even though the unreleased trees produced on average larger seed per cone, the lack of sound seed produced per cone requires more unreleased trees to produce an equivalent kilogram of seed. In reality the number of unreleased trees would be much greater due to the poor cone production associated with unmanaged heavily stocked natural stands.

An analysis of variance for percent sound seed revealed a significant main effect for crown position (Table 7). The average upper crown positions produced significantly higher percentages of sound seed per cone compared to the lower crown positions for both released and unreleased trees (Fig. 7). This increase could be attributed to higher carbohydrate production in the upper crown where increased light levels are apparent.

An analysis of variance for percent sound seed also revealed a significant simple effect between stand density and tree diameter. The released and unreleased trees

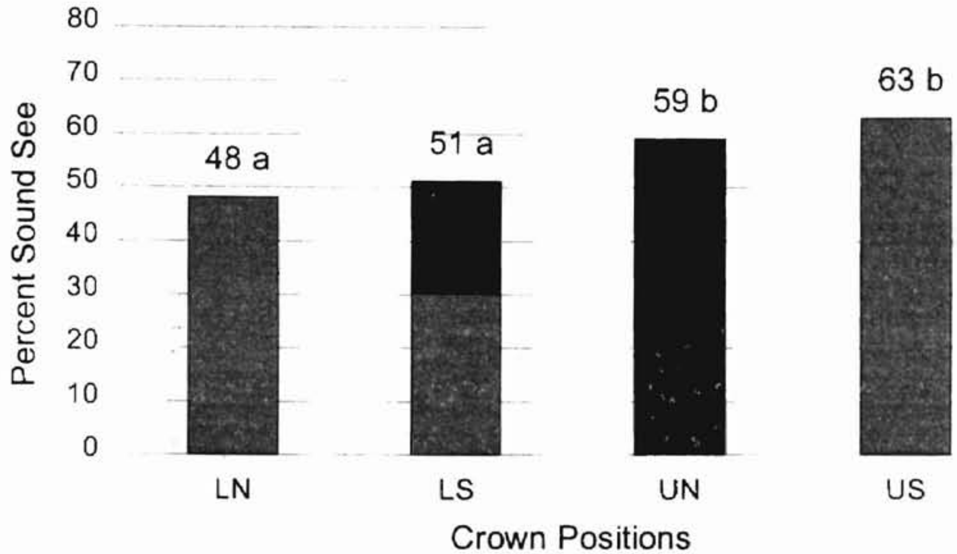

Figure 7. Shortleaf pine percent sound seed by crown position. Treatment least squares means followed by the same letter are not significantly different at the 0.05 level. Bars represent data pooled from both released and unreleased trees. Sample size is 32 trees per bar. (LN = Lower North, LS = Lower South, UN = Upper North, & US = Upper South)

differed significantly at the 38 and 43 cm diameter class levels with released trees having the higher percentages of sound seed (Fig. 8). A significant difference was not detected between unreleased tree diameter classes, but this was not the case for the released trees. The average 38 cm diameter class released tree differed significantly by approximately 23 % from the 28 and 33 cm diameter class trees (Fig. 8). These results suggest that under similar stand conditions, the percentage of sound seed per cone could be increased by selecting release trees 36 cm or greater in diameter.

Released trees averaged 88 % germination compared to 84 % for the unreleased trees at 28 days (Table 5,6). The U.S. Forest Service (1974) reported shortleaf pine germinative energy at 14 days to be 88 % and germinative capacity to average 90 % out of 139 samples. An analysis of variance for percent germination revealed only one main

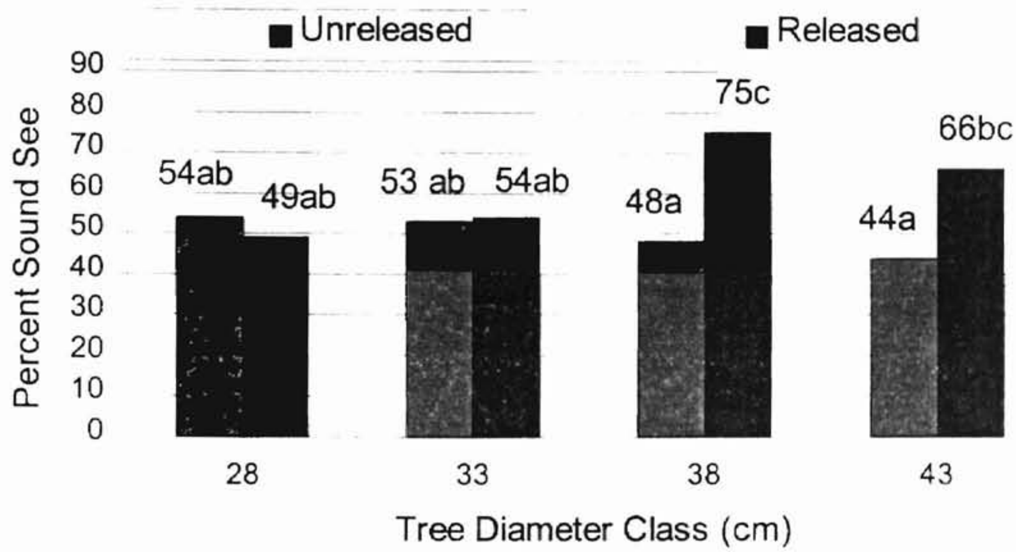

Figure 8. Shortleaf pine percent sound seed for released and unreleased trees by tree diameter class. Treatment least squares means followed by the same letter are not significantly different at the 0.05 level. Sample size is 4 trees per bar.

effect by tree diameter class (Table 7). Significant differences were detected between the 38 cm diameter class and the 28 and 33 cm diameter class trees (Fig. 9). Apparently the smaller diameter class trees had significantly higher percent germination compared to the 38 cm diameter class trees but not the 43 cm diameter class trees. There appears to be no explanation for the significant differences. The lack of trend by tree diameter suggests that percent germination varies considerably from tree to tree and has less to do with environment and more to do with genetics. Analysis of variance indicated no other significant interactions or main effects. The lack of a significant difference by crown position and stand density suggests that percent germination is fairly consistent within the crowns of shortleaf pine for both released and unreleased trees. The germination test

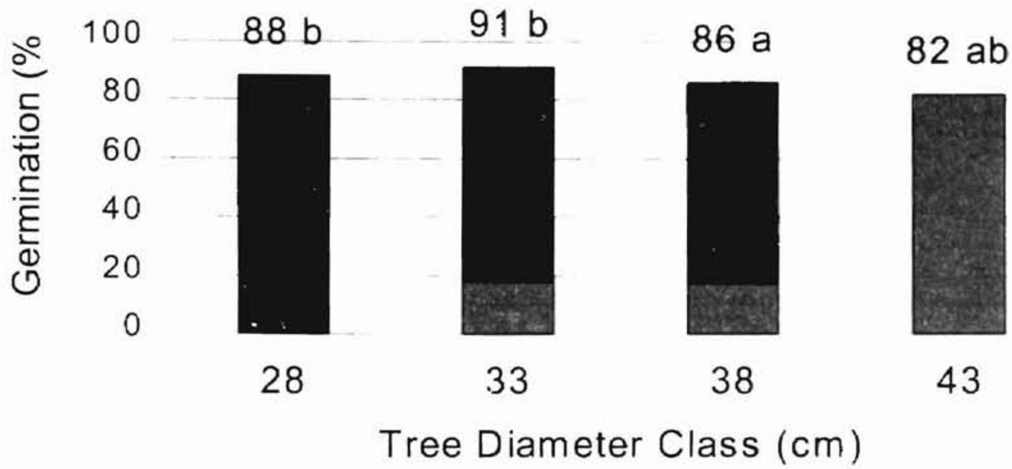

Figure 9. Percent germination by tree diameter. Treatment means followed by the same letter are not significantly different at the 0.05 level. Bars represent data pooled from both released and unreleased trees. Sample size is 8 trees per bar.

results appear to be too inconclusive for recommending a particular tree diameter, crown position or stand density.

Correlation Analysis

Cone volume was poorly correlated with total seed and sound seed per cone (Table 8). These results agree with a Table Mountain Pine (*Pinus pungens* Lamb.) cone and seed study that reported no relationship between size of the cone, viability of seed, or age of tree (McIntyre 1929). In contrast, Dickmann and Kozlowski (1971) reported a linear relationship between cone volume and sound seed per cone for red pine. The relationship was positive with a correlation coefficient of 0.76. They also reported that cone volume was well correlated with the number of scales per cone with a correlation coefficient of +0.81. We found that cone volume for shortleaf pine was poorly correlated with the number of scales per cone (+0.49), and moderately poor with total sound and

Table 8. Pearsons correlation coefficients for cone characteristics by crown position for 32 natural shortleaf pine released and unreleased trees.

		Variables									
Variable		X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
Total Seed Per Cone	X1	.3238*	1478	.3391*	.2783*	.3075*	.1955*	.5463*	.8025*	-.1213	.1310
Cone Length	X2		.3285*	.5766*	.3901*	.7092*	-.2661*	.4121*	.2965*	-.4333*	-.3809*
Cone Diameter	X3			.8396*	.5738*	.8308*	.2076*	.4217*	.2332*	-.5959*	-.5738*
Cone Green Weight	X4				.7122*	.9563*	.3599*	.5330*	.4580*	-.6767*	-.5602*
Cone Dry Weight	X5					.6461*	.3766*	.5035*	.5252*	-.4945*	-.2301*
Cone Volume	X6						.0794	.4907*	.3737*	-.6611*	-.6046*
Cone Specific Gravity	X7							.2252*	.3572*	-.1723	.0428
Scales Per Cone	X8								.5502*	-.2326*	-.0756
Sound Seed Per Cone	X9									-.4190*	.0535
Total Seed Per Gram	X10										.7573*
Sound Seed Per Gram	X 11										

* Correlation coefficients are significant at 0.05 level.

sound seed per gram having a correlation coefficient of –0.66 and –0.60 respectfully (Table 8). This indicates that as cone size increased, the number of seed per cone decreased, but larger seed were produced per cone.

Shortleaf pine cone length by crown position was found to be poorly correlated with total and sound seed per gram or total and sound seed per cone (Table 8). McIntyre (1929) reported that cone weight or length had no effect on the amount of viable seed produced for Table Mountain Pine. Perry and Coover (1933) reported in their seed source and quality study that shortleaf pine cone size was of little value as an index of seed quality. They found that medium-sized and small cones contained more seed and viable seed than large cones. Contrary to these studies, Squillace (1957), found that western white pine seed yield was often directly correlated with cone length. Langdon (1958), also reported a definite positive relationship between cone length and seed-size distribution for south Florida slash pine.

CONCLUSIONS

The lower north crown position produced significantly smaller cones by weight compared to all other crown positions. Cone dry weight differed significantly between released and unreleased trees in the lower north crown position with released trees producing heavier cones. On average the unreleased trees produced significantly lighter dry weight cones in the lower north crown position compared to other crown positions. Cone dry weight also differed significantly by tree diameter class with the 38 cm diameter class trees producing heavier cones compared to all other diameter classes.

Cone size by crown position for length, diameter, volume and weight, were all poorly correlated with total seed per cone. The number of potentially productive scales were only moderately correlated with total seed per cone with a correlation coefficient of +0.55. For this years 1998 cone crop, sound seed per cone by crown position was highly correlated with total seed per cone with a correlation coefficient of +0.80. Cone dry weight (+0.53) and potentially productive scales per cone (+0.55) were partially correlated to sound seed per cone. These two cone attributes appear to be the best indicators of sound seed production by crown position. Cone diameter, green weight and volume, were all moderately correlated with total seed and sound seed per gram. This correlation indicated that as cone size increased by crown position the numbers of seed per cone decreased, but the size of the seed increased. This relationship indicates that carbohydrate availability and allocation play a meaningful role in determining seed size within the crowns of individual shortleaf pine trees.

The average number of potentially productive scales per cone varied significantly by crown position. The upper north crown position produced significantly greater numbers of potential productive cone scales than the lower north and south crown positions. The lower north crown position produced significantly less potentially productive cone scales on average than all other crown positions. Overall the differences in cone scale numbers by crown position were very small and may have very little real application.

Sound seed per cone differed significantly between the released and unreleased trees with the released trees producing on average 9 more sound seed per cone. The upper south crown position produced significantly more sound seed per cone than all other crown positions by 5 to 8 seed per cone. These results suggest real differences in seed quality produced by released and unreleased shortleaf pine trees. Not only do released trees produce more cones per tree, they also produce seed of higher quality and especially in the upper south crown position.

Percent sound seed per cone differed significantly by stand density, tree diameter, and crown position. Released and unreleased trees differed significantly at the 38 and 43 cm diameter class level with released trees having a greater percentage of sound seed. The average 38 cm diameter released tree produced significantly greater percentages of sound seed compared to the lower diameter classes. No significant difference was detected between diameter classes for unreleased trees. Both upper crown positions for released and unreleased trees, produced greater percentages of sound seed per cone compared to the lower crown positions. For released trees the general trend was higher sound seed percentages in the upper crown, with increasing diameter. Percent sound seed tends to decrease with increasing diameter for unreleased trees. The percent sound seed data suggests using larger diameter released trees, at least 36 cm in diameter or greater, for increased seed quality.

Germination of seed from released trees averaged 88 % compared to 84 % for unreleased trees at 28 days. The 38 cm diameter class trees differed significantly from only the 28 and 33 cm diameter class trees. Apparently the smaller diameter class trees have significantly higher percent germination compared to the 38 cm diameter class trees but not the 43 cm diameter class trees. The lack of trend by tree diameter suggests that percent germination varies considerably from tree to tree and has little to do with environment and more to do with genetics. Analysis of variance revealed no significant differences by crown position or stand density, indicating that percent germination is fairly consistent within the crowns of released and unreleased shortleaf pine. The germination test results appear to be too inconclusive for recommending a particular tree diameter, crown position or stand density.

LITERATURE CITED

Association of Official Seed Analysts. 1978. Rules for testing seeds. J. Seed Technol. 3(3): 1-126.

Baker, J.B. 1992. Natural regeneration of shortleaf pine. P. 102-112 in Proc. Shortleaf Pine Regeneration Workshop. USDA For. Serv. Gen. Tech. Rep. SO-90.

Barnett, J.P. and Haugen, R.O. 1995. Producing seed crops to naturally regenerate Southern pines. USDA For. Serv. Res. Note SO-286.

Barnett, J.P. 1996. How seed orchard culture effects seed quality: experience with the southern pines. The For. Chronicle. 72 (5) p. 469-473.

Bilan, M.V. and Fisher, R.J. 1970. Seed and seedlings of sonderegger pine in East Texas. Michigan State University First North American forest biology workshop. August 5-7 1970 p. 262-266.

Bramlett, D.L. 1965. Shortleaf pine seed production in the Piedmont. USDA For. Serv Res. Note SE-38. 1 p.

Dickman, D.I. and Kozlowski, T.T. 1971. Cone size and seed yield in red pine. Amer Midland Naturalist. 85: 431-436.

Dunlap, J.R. and Barnett, J.P. 1983. Influence of seed size on germination and early development of loblolly pine (*Pinus taeda* L.) germinants. Can. J. For. Res. 13: 40-44.

Eggler, W.A. 1961. Stem elongation and time of cone initiation in southern pines. For. Science. 7: 149-159.

Eliason, E.J. and Heit, C.E. 1940. The size of Scotch pine cones as related to seed size and yield. J. For. 38: 65-66.

Langdon, O.G. 1958. Cone and seed size of south Florida slash pine and their effects on seedling size and survival. J. For. 56: 122-127.

Lyons, L.A. 1956. The seed production capacity and efficiency of red pine cones (*Pinus resinosa* Ait.). Can. J. Bot., 34: 27-36.

McIntyre, A.C. 1929. A cone and seed study of the Mountain pine (*Pinus pungens* Lamb.) Amer. J. Bot. 16: 402-406.

Perry, G.S. and Coover, C.A. 1933. Seed source and quality. J. For. 31: 19-25.

Righter, F.I. 1945. Pinus: The relationship of seed size and seedling size to inherent vigor. J. For. 43: 131-137.

Roeser, J., Jr. 1936. Some aspects of flower and cone production in ponderosa pine. J For. 39: 534-536.

SAS Institute Inc. 1997. SAS/STAT User's Guide, Release 6.12 Edition. Cary, NC. 1028 p.

Shelton, M.G. and Murphy, P.A. 1997. Understory vegetation 3 years after implementing uneven-aged silviculture in a shortleaf pine-oak stand. South. Res. Sta. USDA For. Serv. Res. Pap. SO-296

Shelton, M.G. and Wittwer, R.F. 1996. Shortleaf pine seed production in natural stands in the Ouachita and Ozark Mountains. South. J. Appl. For. 20 (2): 74-80.

Squillage, A.E. 1957. Variation in cone properties, seed yield and seed weight in western white pine when pollination is controlled. Mont. State Univ. School Forest. Bull. No. 5.

Stephenson, G.K. 1963. Ten years of shortleaf pine seed crops in Texas. J. For. 61 (4): 270-272.

Thorbjornsen, E. 1960. A cone production study in loblolly pine on the coastal plain of North Carolina. J. For. 58: 543-547.

U.S. Forest Service. 1974. Woody-plant seed manual. U.S. Dept. Agric. Misc. Publ. 654. Washington, DC: U.S. Dep. Of Agr. 416 p.

Wakeley, P.C. 1954. Planting the southern pines. U.S. Department of Agriculture Agric Monograph 18. Washington, DC. 233 p.

Winjum, J.K. and Johnson, N.E. 1964. Differences in cone numbers, lengths, and cut-counts in the crowns of young open-grown Douglas-fir. J. For. 62: 389-391.

Wittwer, R.F., Tauer, C.G., Huebschmann, M.M., and Huang, Y. 1997. Estimating seed quantity and quality in shortleaf pine (*Pinus echinata* Mill.) cones from natural stands. New Forests 14: 45-53.

Yocom, H.A. 1971. Releasing shortleaf pines increases cone and seed production. USDA For. Serv. Res. Note SO-125. 2 p.

VITA

Kenneth J. Grayson

Candidate for the Degree of

Master of Science

Thesis: THE DISTRIBUTION & CHARACTERISTICS OF SHORTLEAF PINE CONES 10 YEARS AFTER IMPLEMENTING UNEVENAGED SILVICULTURE IN THE OUACHITA MOUNTAINS

Major Field: Forest Resources

Biographical:

Personal Data: Born in Joplin, Missouri, April 13, 1974, the son of Kenneth L. and Pam K. Grayson.

Education: Graduated from Miami High School, Miami, Oklahoma in May 1992; received Bachelor of Science degree in Forestry from Oklahoma State University, in May, 1997; completed requirements for Master of Science degree at Oklahoma State University in May 2000.

Professional Experience: Forest Inventory Intern, Westvaco Corporation Timberlands Division, May 1996 to August 1996 and January 1995 to May 1995. Paraprofessional (crew member), Department of Forestry, Oklahoma Stated University, August 1997 to November 1997. Research Assistant, Department of Forestry, Oklahoma State University, January 1998 to December 1999.

Professional Organizations: Society of American Foresters, Xi Sigma Pi Honor Society, Forestry Club.