FORECASTING OF SHORTLEAF PINE SEED CROPS IN THE OUACHITA AND OZARK MOUNTAIN REGIONS

By

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CHAPTER I

INTRODUCTION

Background

There are four basic requirements for successful natural regeneration of any site: (1) an adequate supply of viable seed, (2) adequate dispersal of seed over the site, (3) successful germination which greatly depends on acceptable moisture and good seedbed conditions, and (4) early survival of new seedlings, which can be benefited by favorable environmental conditions, and protection from damaging agents (Smith 1986). All of these requirements are necessary for successful shortleaf pine (*Pinus echinata* Mill.) regeneration. However, the seed supply is the prerequisite for all succeeding steps, because without adequate seed the other requirements are not relevant. To increase the odds for successful natural regeneration, foresters need to be knowledgeable of the seed supply.

Shortleaf pine trees are typically sexually mature by age 20, but age to maturity can vary depending on stand competition levels (Lawson 1986) and the genetic make-up of individual shortleaf pine trees. There are several physical and biological factors that influence the production of seed. The factors influencing the production of seed can be more appropriately perceived by looking at the reproductive cycle of sexually mature shortleaf pine trees and the influences on the processes involved in the cycle (Figure 1). The cycle begins in the summer of year zero with strobili initiation which can be hindered greatly when preceded by a spring drought (Dewers and Moehring 1970; Schmidtling 1985).

Flowering and pollination occur in the spring of year zero when many losses and problems take place. Many flowers are lost due to frost from late freezes and consumption by large populations of insects (Campbell 1955; Huchinson and Bramlett 1964; McLemore 1977). Pollination, on the other hand, is affected largely by weather, such as extreme conditions of wind and precipitation (McLemore 1977). Conelet development during year one and cone and seed maturation during year two are affected primarily by large insect populations. Conelets, however, receive significantly more damage due to insects than maturing cones (Bramlett 1972).

Shelton and Wittwer (1995) proposed a method for forecasting seed production of loblolly (*Pinus taeda* L.) and shortleaf pine, using a cone abundance rating system similar to that used in ponderosa pine (*Pinus ponderosa* Laws.) (Rietveld 1978). In the study reported here refinements and adaptations of the rating system were evaluated to produce more reliable estimates of shortleaf pine seedfall. The procedure requires an ocular observation with binoculars of two to three trees per acre to determine a rating. This cone abundance rating is based on how many cones appear on crowns of the sample trees observed. Refinements and adaptations to the rating system were developed for shortleaf

Figure 1. The shortleaf pine reproductive cycle and influencing factors

Year	Season	Event	Influence
0	Summer	Strobili initiation	Early season moisture stress
	Fall		
	Winter		
	Spring	Flowering (Strobili)	Late freezes and insects
		Pollination	Wind and precip. extremes
1	Summer	Conelets develop	Insects
	Fall		
	Winter		
	Spring	Fertilization	
2	Summer	Cone & seed maturation	Insects (less than in first yr)
	Fall	Seedfall	
	Winter		
	Spring	Germination	Moisture
3	Summer	Establishment	Moisture, Competition

pine in the Ouachita and Ozark Mountains to aid management foresters in making informed decisions regarding natural stand regeneration.

Knowledge of the distribution of cones within the crown is important to the observer when determining the best location from which to evaluate a tree's fruitfulness. Developing a specific cone rating system for a region is important since fruitfulness varies throughout the range of shortleaf pine (Bramlett 1965). Some have speculated that the distribution of cones throughout the crown of slash pine changes with location relative to exposure to sunlight (Smith and Stanley 1969). It is also important to know how many seed are contained in cones and how many of the seed can be expected to germinate. In addition to cone abundance on individual trees, the density of potential seed-bearing trees within a stand is considered critical to predicting the number of seeds produced per acre (Shelton and Wittwer 1995). The previous statement is logical because more potential cone bearing sites are provided with each additional tree in the stand up to a point. Maximum seed production is attained at intermediate stand densities and would be expected to decrease at high stand densities. With knowledge of the distribution of cones throughout the crown of shortleaf pine and of the effects of stand densities on natural regeneration, average stand ratings can be used to estimate the number of seed produced within each stand.

Problem Statement

With the large expense of artificial regeneration and the public's desire for more natural stands, it has become increasingly important for the U.S.D.A. Forest Service, other public land managers, and nonindustrial private landowners to rely on natural regeneration. Today, approximately 4.2 million acres of pine are harvested annually in the southern United States. Of that 4.2 million acres, over two million acres of forest are artificially regenerated per year, while more than fifty percent of the harvested area is left to regenerate naturally or revert to other forest types (Duryea and Dougherty 1991). The use of artificial regeneration is limited in part due to the high cost of seed and seedlings, which are now produced from seed-orchard trees subjected to intense breeding and testing programs (Duryea and Dougherty 1991), as well as the cost and time of the actual planting process. Therefore, natural regeneration continues to be a significant means of reforestation in the South. As the reliance on natural regeneration continues for nonindustrial private landowners and increases for public lands, a need exists to capitalize on years of good seed production. In order to accomplish this goal, harvested stands must have suitable seedbed conditions during the time of seedfall to obtain successful regeneration. Forecasting good seed crops three to four months in advance of dispersal allows management foresters time to conduct seedbed preparation necessary for successful regeneration. In contrast, the forecast of a crop failure can be used to prevent unnecessary and expensive site preparation that will not be cost effective with few seed.

Objectives

The project included two complimentary studies. Study I involved evaluation of cone crops, stand density of potential seed producing trees, and monitoring of seed production in 28 shortleaf pine stands representing three reproduction harvesting methods and one uncut stand. The objective of Study I was to refine the seed forecasting system proposed by Shelton and Wittwer (1995) by developing a prediction equation using average stand cone abundance ratings and stand density as independent variables for specific application in shortleaf pine stands in the Ouachita and Ozark Mountains.

The objective of Study II was to determine the distribution of potential and actual cone bearing sites throughout the crown of shortleaf pine trees.

CHAPTER II

REVIEW OF LITERATURE

Time of Seedfall

To take advantage of good shortleaf pine seed years, it is necessary to know when the seed will fall from the tree to the forest floor. Seedfall for shortleaf pine begins in late October or early November, peaks during November and is usually 90 to 100 percent complete by December 31 (Wittwer and Shelton 1992). The seedling-to-seed ratio can be increased by completing seedbed preparation before seedfall begins. Studies show that most viable seed tends to fall during the peak of seedfall. For example, an eight year study of loblolly pine in North Carolina showed a strong relationship between viability of seed and the time when it falls (Jemison and Korstian 1944). An early rise in viability was exhibited in each year's records and lasted two to three weeks. Apparently small, unsound seeds became detached from the cones first, but during the peak of seed fall a large proportion of the seeds were sound. Thereafter there was a marked and steady decline in viability (Jemison and Korstian 1944). Hebb (1955) reported that, in shortleaf pine stands of east Texas, most viable seed fell in October and decreased as the season went on. Hebb recommended seedbed preparation prior to seedfall to take advantage of the larger numbers of viable seed that fall during the peak of seedfall, which occurs shortly after seedfall begins.

Using a seed forecasting system, foresters can predict satisfactory seed crops approximately four months in advance of seedfall initiation. When adequate seed crops are forecast, seedbed preparation can be implemented and completed before seedfall begins, providing a more optimum environment for seed germination and seedling establishment. On the other hand, if an unsatisfactory seedfall is expected expensive seedbed preparation can be delayed until an adequate seed crop is expected.

Seedbed Preparation

Shortleaf pine germinates best on mineral soil and survives and grows best with limited competition from other vegetation. Yocom and Lawson (1977) found that both summer burning and logging disturbance provide a favorable seedbed by exposing mineral soil in shortleaf pine stands in the Ouachita Mountains of Arkansas. If the area has logging disturbance about 1.0 percent of the seed produce established seedlings and burning does not significantly benefit establishment. However, if the area was not greatly disturbed by logging, burning increased seedling establishment and resulted in 0.5 percent of the seed producing established seedlings in a more uniform distribution than logging disturbance. Maple (1965) also showed that shortleaf pine regeneration was greater on areas with seedbed preparation when compared to areas with no seedbed preparation five years following a bumper seed crop.

Seed Forecasting Systems

Several methods of seed forecasting have been attempted over the years. Many were developed for southern pines in the 1950s and 1960s. The interest in developing effective methods was stimulated by the heavy reliance on natural regeneration and woods-run seed for forest-tree nurseries (Shelton and Wittwer 1995). Since the pine reproductive cycle takes two years from flowering until seedfall, there are many opportunities to observe seed crop development (Kozlowski 1971). Some researchers have attempted to forecast seed crops up to 18 months in advance by counting female flowers (strobili) and conelets (Read 1953; Rietveld 1978; Trousdell 1950a). Trousdell (1950a) concluded that cone crops can be reliably forecast six months in advance and that accurate forecasting 18 months before seedfall (next year's crop) is unreliable, because losses during the intervening period may be heavy. Bramlett (1965) found, in a six year study of shortleaf pine in Virginia, overall "survival" from emerged flowers in May to mature cones varied from four to 72 percent with the greatest reduction occurring between May and September of the first year. He also stated that for a four-year period with significant flowering, between 45 and 81 percent of the conelets observed in July "survived" until September of the following year as maturing cones.

Some seed forecasting systems for shortleaf and loblolly pine focused on making precise cone counts on sample trees (Wenger 1953; Grano 1957; Hoekstra 1960; VanHaverbeke and Barber 1962; Seidel 1970). This procedure proved to be very time consuming and did not allow for evaluation of an adequate number of trees to be representative of the stand (Shelton and Wittwer 1995).

Other seed forecasting systems observed the relative number of conelets, maturing cones, and older cones in the tops of trees felled in logging and correlated ratios with past seed crops (Trousdell 1950a; Read 1953). For this procedure to be effective, quantitative knowledge of the previous years seed production is required. Another limitation is that this method requires cutting in the stand of interest or in adjacent stands (Shelton and Wittwer 1995).

Another forecasting procedure was developed for ponderosa pine (*Pinus ponderosa* Laws.) (Schubert and Pitcher 1973; Rietveld 1978; McDonald 1992). This procedure does not use precise cone counts nor does it require correlating ratios with past seed crops, but it does require that a prediction equation must be developed based on past seed crops. The procedures for ponderosa pine is centered on a visual rating system for the cone abundance on seed-producing trees. A visual rating system is accomplished by placing trees in broad classes of fruitfulness, and assigning a rating to the overall cone crop from the percentage of trees occurring in these classes. Shelton and Wittwer (1995) applied this procedure to loblolly and shortleaf pine stands. The forecasting system developed by Shelton and Wittwer (1995) allows approximately four months of lead time before seedfall begins and gives management foresters the opportunity to make informed decisions regarding the need for seedbed preparation.

Number of Cones Present in the Crown

While researchers have studied the cone production of seed orchard trees, few studies have been conducted on natural stands. The number of cones produced by conifer trees is variable from location to location, from species to species, and from year to year. In northern Florida, 24 slash pine (*Pinus elliottii* Engelm.) trees averaged 125 cones per tree over a three-year period (Smith and Stanley 1969). Similarly, Yocom (1971) reported a five-year mean of 130 cones per tree in Arkansas shortleaf pine stands.

In Georgia, a one-year study of 21 shortleaf pine trees was found to average 352 cones with a range of 56 to 699 cones (Coulson and Franklin 1970). This range in tree-to-tree variation is typical. With such large tree-to-tree variation there is a need to sample numerous trees per stand to obtain a reliable cone abundance rating for the stand.

Distribution of Cones Throughout the Crown of Conifers

It has been well documented that the top two-thirds of most conifer crowns produce the majority of the cone crop. Winjum and Johnson (1964) found, in their study of Douglas-fir (*Pseudotsuga menziesii* Mirb.) trees in western Oregon and western Washington, the greatest number of cones in the middle third of the crown while the longest cones and the highest seed counts were located in the top third. Research on red pine (*Pinus resinosa* Ait.) in the Lake States showed cones to be concentrated in the middle third of the crown on younger trees and in the top third of the crown in older trees as the lower branches became less vigorous (Hard 1964). Mattson (1979), however, observed the bulk of cones in red pine to be distributed in the upper third of the crown, especially in higher density stands. The greatest number of cones were also reported in the upper third of the crown of shortleaf pine in two separate studies by Coulson and Franklin (1968, 1970). Similarly, Yates and Ebel (1972) observed five open-grown shortleaf pine trees over a two year period for conelet and cone production and found greater numbers of conelets in the top half of the trees during both years. It has also been documented in Michigan that stand basal area levels between 60 and 160 square feet per acre had little affect on the occurrence of cones in the lower one-third of the crown in red pine (Godman 1962).

Bilan (1960) suggested that cones in the upper part of the crown have more viable seed. In a five-year study of released loblolly pine trees located near Durham, North Carolina, cones borne on branches in the third whorl from the top and above had more viable seeds per cone than did cones borne on the branches in and below the fourth whorl from the top.

Evidence shows that strobili are generally not distributed at random in the crowns of pines, but that the majority are produced in the upper crown levels on the south and east aspects of the tree (Fatzinger et al. 1976). In the three studies discussed below, where the crowns were divided into quadrants relative to magnetic north, the southern exposure contained the most cones (Mattson 1979; Smith and Stanley 1969; and Winjum and Johnson 1964). Smith and Stanley (1969) stated in their study of slash pine that most variation was east versus west rather than the north versus south, which was not significant. They further stated that the cones predominated in the NE and SE portions of the crown and the NW quadrant contained the least. Smith and Stanley (1969) reasoned that the southern exposure receives more quantity and quality of light in the northern latitudes and that light is probably the greatest contributing factor in pine cone production. Winjum and Johnson (1964) found that the cone bearing twigs appearing to be most vigorous coincided with the portion of the crown receiving the most sunlight in Douglas-fir. Mattson (1979) thought it interesting that the yield patterns for red pine were similar to those observed for slash pine (Smith and Stanley 1969; DeBarr et al. 1975), and Douglas-fir (Winjum and Johnson 1964).

Correlation of Sound Seed with Seed Production

The percentage of sound seed has been shown to be correlated with the size of the crop. Three studies of loblolly pine in Virginia and North Carolina all showed that seed quality was usually higher in years of greater seed production (Allen and Trousdell 1961; Jemison and Korstian 1944; Pomeroy and Korstian 1949). Throughout South Carolina, North Carolina, and Georgia, the percentage of sound seed for shortleaf pine was reported highest in years of high seed production averageing 57% in the three best years (Bramlett 1965).

In a study of shortleaf pine in east Texas, seedfall was recorded in uncut stands, strip clearcuttings, and plots being regenerated by the selection, shelterwood, and seed-tree systems (Stephenson 1963). Seed quality, which averaged 61%, was usually highest in stands with the heaviest production. Thus, factors that favor increased production also enhance quality.

Correlation of Stand Density with Seed Production

Another factor in seed production of southern pines is stand density of potential seed producers. Most literature points to shelterwoods or medium density stands as the best producers of seed. Grano (1970), Croker (1973), and Mattson (1979) suggest that maximum seed yield occur at densities of less than 100 stems per acre for various sexually mature southern pines. Mattson (1979) indicated a more precise number of 88 stems per acre for maximum seed yield in mature red pine stands.

The trend of higher seed yields occuring in medium density stands was demonstrated in three studies for shortleaf pine. In east Texas two studies were implemented to study the effects of various types of reproductive cutting methods on the production of seed in shortleaf pine. Hebb (1955) used three reproduction cutting methods to compare seed production: single-tree selection, shelterwood, and strip clearcutting. The two shelterwood stands averaged twice as many seed (approximately 2 million seed per acre) as the two single-tree selection stands (1.12 million seed per acre), and the two clearcut strips averaged 540,000 seed per acre. Stephenson (1963) recorded seedfall in uncut stands, in strip clearcuttings, and on plots being regenerated by the selection, shelterwood, and seed-tree systems. He found the shelterwood stands consistently had the highest production of sound seed.

In southeastern Missouri mature shortleaf pine stands were cut to basal areas of 50, 70, 90, and 110 square feet per acre to compare seed production among various stand densities (Phares and Rogers 1962). The basal area of the unthinned stand was 138 square feet per acre. Stands thinned to 50 square feet per acre had consistently higher seed yields over a five-year period than any of the other treatments. These data lead us to believe that management foresters can maximize the seed production by using shelterwood or medium density regeneration cuts.

CHAPTER III

METHODOLOGY

Study I. Seed Prediction Model

Field Sampling

Twenty-six of the 28 stands evaluated for this study were located in southeast Oklahoma or southwest Arkansas on the Ouachita National Forest (ONF), while the other two stands were located in southeast Oklahoma on the Choctaw Nation Forest a few miles west of the ONF boundary. Eighteen of these stands were included in the Phase II Ecosystem Management Research program on the Ouachita and Ozark National Forests (Guldin et al. 1993). The remaining ten stands were being used for ongoing research as follows: four Phase I Ecosystem Management stands (J. Baker), three Southern Research Station stands (M. Shelton), and three Oklahoma State University stands (R. Wittwer). Also included were evaluations in 1993 from nine of the ten previous shortleaf pine stands not included in the Phase II Ecosystem Management Research program. This study applied the cone abundance rating system developed by Shelton and Wittwer (1995) to existing stands that were being monitored for seed production in conjunction with other ongoing research. Thus, sampling design to monitor seed production varied.

Determination of Actual Seed Yield

Eighteen of the stands located on the ONF were part of the Phase II Ecosystem Management Research program on the Ouachita and the Ozark National Forests (Guldin et al. 1993). Each stand was approximately 40 acres in size and was divided into three elevation or slope positions: upper, mid, and lower. In each slope position, four plots were established to evaluate stand characteristics (Guldin et al. 1993). Two of the four plots in each third were randomly selected for seed sampling. Located on each of the six plots per stand were three 0.9 square foot seed traps (Cain and Shelton 1993) with a total of 18 traps per stand. The traps were used to collect seed during seedfall to determine the amount of seed produced by the stand in a given year. Each trap was placed one-half chain from the plot center and the three traps were equally distributed about the plot center. The first trap was located at an azimuth of 0°, the second at 120°, and the third at 240°. The traps were placed at the beginning of October 1994 and seed samples were collected in March 1995. The stand characteristics were previously determined by the U.S.D.A. Forest Service for the Phase II Ecosystem Management program.

On the four Phase I Ecosystem Management stands and the three Oklahoma State University Research stands, different traps and trap spacing were utilized. On these stands six to 10, four square feet (2 ft x 2 ft) traps, were placed. The number of traps depended on the number that could be located according to the following placement criteria. The traps were located no closer than two chains from the edge of the stand and on a two chain by two chain grid throughout the stand. At each selected point, a half chain radius about the point existed where the trap could be positioned to avoid understory hardwood cover.

The remaining three Southern Research Station stands also used six 0.9 square foot seedtraps (Cain and Shelton 1993). The shelterwood stand consisted of four 1.7 acre plots. Each plot had six seedtraps systematically located a minimum of 100 feet from the plot boundary. The uneven-aged stand consisted of four 1.6 acre plots, each containing four seedtraps located a minimum of 100 feet from the plot boundary. The seed-tree stand had nine seedtraps located along a line transect with about 50 feet separating the traps.

The shortleaf pine seed found in the seed traps were counted and x-rayed to determine viability. The number of total seed and sound seed per acre were then calculated for each stand.

Cone Abundance Rating System

The cone abundance rating system established three ratings or classes for evaluating the relative density of cones on shortleaf pine sample trees. The factors considered when determining a rating were the spacing between cones, the occurrence of multiple cones or clusters on branchlets, the vertical distribution of cones throughout the crown, and the number of cones per face. Figure 2 describes in greater detail how these factors were applied to each rating. The predominant factor for determining a rating was the approximate number of cones per face. A zero rating had approximately ten cones or less per face, a one rating had approximately ten to 80 cones, and a two rating had approximately 80 cones or greater. It was not meant for the observer to arduously count cones, but for the observer to be familiar with how the cone densities appeared. Thus, the rating was very rapid which allowed a greater number of trees to be sampled within the stand. To further enhance the ease of using the system pluses or minuses could be used for marginal trees. For example, if a tree appeared to be at the upper end of the "zero" rating then it could be given a rating of "zero plus (0+)". Or if a tree appeared to be at the lower end of the "one" rating then the tree could be given a rating of "one minus (1-)". A plus could be added to a "two" rating if the tree appeared to be exceptionally productive. However, a minus would not be attached to a rating of "zero", with the reasoning that there cannot be less than zero cones. To quantify the plus or minus, 0.3 was added or subtracted from the major rating. For example a "one plus (1+)" would be equal to 1.3 or a "two minus (2-)" would be equal to 1.7. Thus, the range of ratings that could have been applied to a tree were 0, 0.3, 0.7, 1, 1.3, 1.7, 2, or 2.3.

To evaluate a tree, the observers stood approximately one and one-half times the tree's height away from the tree with the sun at their back. Standing with the sun at their back and viewing the face receiving the most sun allowed better visibility. The aspect of the tree viewed changed from the east aspect early in the day around the south aspect of the tree to the west aspect late in the day. Binoculars with a magnification of 7x or 8x and a minimum aperture of 35 millimeters were an essential aid to observe the cones and apply a rating.

Figure 2. Classes for rating the cone density of shortleaf pine trees

FEW		AVERAGE			GOOD		
0	0+	1-	1	1+	2-	2	2+
Cones widely spaced (> 7 feet on average)[1] Multiple cones rarely occur on branchlets Cones erratically distributed Cones per face: < 10		Cones moderately spaced (2.5 - 7 feet on average) Multiple cones occur on some branchlets Cones mostly in upper half of crown Cones per face: 10 - 80			Cones closely spaced (< 2.5 feet on average) Multiple cones commonly occur on branchlets Cones occur throughout the crown Cones per face: > 80		

[1] The average cone spacing includes cones occurring in multiple clusters.

The desired total number of trees to be rated was 30 to 40 per stand. The number of plots being evaluated for seed production on each stand determined approximately how many trees were rated from each plot. Therefore, an equal number of trees were rated on each plot to attain the 30 to 40 trees desired per stand.

Each rating was performed by one of five individuals consisting of two Oklahoma State University employees and three U.S.D.A. Forest Service/Southern Research Station employees. The ability for more than one person to consistently apply the ratings would make the system more useful. A pilot study was conducted in southwest Arkansas during the summer of 1994 to test for uniformity of ratings by different observers. The same five individuals used to do the ratings and one additional OSU employee rated six or seven trees in seven stands for the 1994 pilot study. The stands were selected to exhibit a range in cone crops. The data were analyzed as a nested factorial in which sample trees (6 or 7) were nested in stands (7) and observers were tested as factors. The GLM (SAS 1985) procedure was used since the number of sample trees varied slightly between stands.

Data Analyses

The data analysis for Study I was accomplished with Statistical Analysis Software (SAS 1985) using the "stepwise" procedure to find the best model with average stand ratings and basal areas used as predictors of total seed and sound seed. Stand densities used in the analysis were acquired from data collected the previous year. Linear regression techniques were used. Some models were linearized using a logarithmic transformation.

Study II. Distribution of Conelets

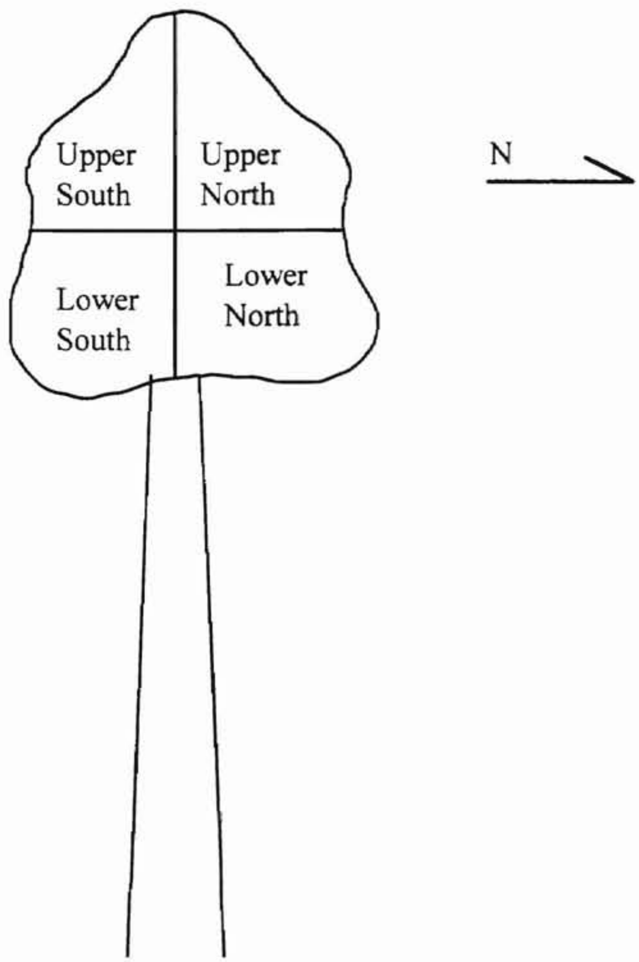
Field Sampling

Harvesting schedules in the Ouachita and Ozark Mountain regions governed the selection of one shortleaf pine stand from these regions for sampling. The stand was located north of Mena, Arkansas in the southern part of Scott county on the Ouachita National Forest. The basal area of the stand was 88 square feet per acre and the site index was approximately 50 feet at 50 years. Although low, it is representative of much of the Ouachita Mountain region. From this stand a total of 10 dominant or codominant trees, falling within two inch dbh classes 10, 12, 14, 16, and 18, were selected for sampling. After a tree had been selected the dbh was measured and the main stem was marked to identify the north and south aspects of the tree. The tree was then felled, after which the total height, the live crown length, and the live crown width were measured. The live crown was then divided into top and bottom halves. Although most of the studies in the past divided the crown into thirds, this study used halves in accordance with the directions given in the rating system and for simplicity. The resulting four quadrants were: upper-north, upper-south, lower-north, and lower-south (Figure 3). The branches were placed into the quadrants based on their origin at the main stem. All the branches in each quadrant were counted. From each quadrant two representative branches were selected for sampling and further analysis in the laboratory.

Laboratory Procedures

The original objective was to evaluate mature, two-year-old cones for this study; however there were few mature cones present on the sample trees. Only one mature cone was found on the ten sample trees. Therefore, conelets were evaluated to study the potential distribution of cones within the crown of the sample shortleaf pine trees. Branches were placed in a refrigerator at approximately 35° F to prevent moisture loss until they were processed. The following data were collected from each sample branch. All first flush sites bearing conelets and those sites greater than two inches in length, but lacking conelets were counted. Sites without conelets and at least two inches in length were considered sterile or where conelets had the potential to form but failed to. The sums of these were considered the total potential conelet bearing sites. All conelets from each sample branch were also counted.

Figure 3. Crown divisions



Data Analysis

Data were analyzed as a split plot in a randomized block design. Trees were treated as blocks with the crown half as the main unit factor and the crown aspect as the sub unit factor. The variables tested were the number of total sites, sterile sites, conelet bearing sites, and total conelets present. Differences were tested between the top and bottom halves, the north and south aspects, and the resulting four quadrants within the live crown of shortleaf pine. All significance tests were done using an alpha level of significance of 0.05.

CHAPTER IV

RESULTS & DISCUSSION

Study I. Seed Prediction Model

Pilot Study. Differences Between Observers

The F-test from the analysis of variance was significant at the 0.01 significance level. The overall mean of the ratings for Observer 5 was significantly less than for all other Observers, which were not significantly different from each other (Table 1) (Appendix A). A more conservative test which reduces the degrees of freedom for the test and is applicable to this experimental design did not detect significant differences (Anderson and McLean 1974). The lack of a significant difference between 5 of 6 observers suggests the rating system has the flexibility to be applied consistently by different personnel after limited training. Observer 5 did not participate in rating the cone crops for the stands used in developing the seed forecasting model.

Description of Stands and Their Seed Production

There were 28 total stands rated and evaluated for seed production in this study, including stands harvested by the seed-tree, shelterwood, and single-tree-selection

Table 1. Mean cone abundance ratings for each observer in the pilot study

Stand	Observer						Mean	Min	Max
	1	2	3	4	5	6			
1	0.83	0.83	0.83	0.88	0.72	0.78	0.81	0.72	0.88
2	0.22	0.17	0.22	0.17	0.17	0.28	0.20	0.17	0.28
3	0.67	0.60	0.50	0.57	0.45	0.50	0.55	0.45	0.67
4	0.12	0.05	0.05	0.17	0.05	0.22	0.11	0.05	0.22
5	0.83	0.72	0.78	0.55	0.60	0.72	0.70	0.55	0.83
6	1.43	1.53	1.38	1.57	1.08	1.43	1.40	1.08	1.57
7	0.96	0.94	1.16	1.13	0.88	1.28	1.06	0.88	1.16
Overall Means[1]	0.74a	0.72a	0.73a	0.75a	0.58b	0.77a	--	--	--

[1] Overall mean is different than mean of stand means for each observer because seven trees were observed in stands six and seven. Six trees were observed in stands 1-5.

Overall means with the same letter are not significantly different.

methods and one uncut stand (Table 2). Of the 28 stands, nine were rated and evaluated for seed production in 1993 and 1994. The data collected in 1993 was used in the analysis as well. The addition of the 1993 cone abundance ratings and seed production data provided a more complete range of data to develop a model.

Average total seed production between stands ranged from zero to over five million seed and sound seed ranged from zero to approximately 3.5 million seed per acre (Appendix B). Twenty-five of the stands had less than 100,000 total seed per acre.

Correlation of Percent Sound Seed with Total Seed Production

The percentage of sound seed tended to increase in the stands as the total production of seed increased (Figure 4). When fitting a linear relationship to sound seed and total seed, the two lines converge as seed production and corresponding cone abundance ratings increase. Stephenson (1963) proposed that factors favoring seed production in shortleaf pine also enhance seed quality. He based his reasoning on the findings of his study where stands with the highest percentage of sound seed usually exhibited the heaviest seed production.

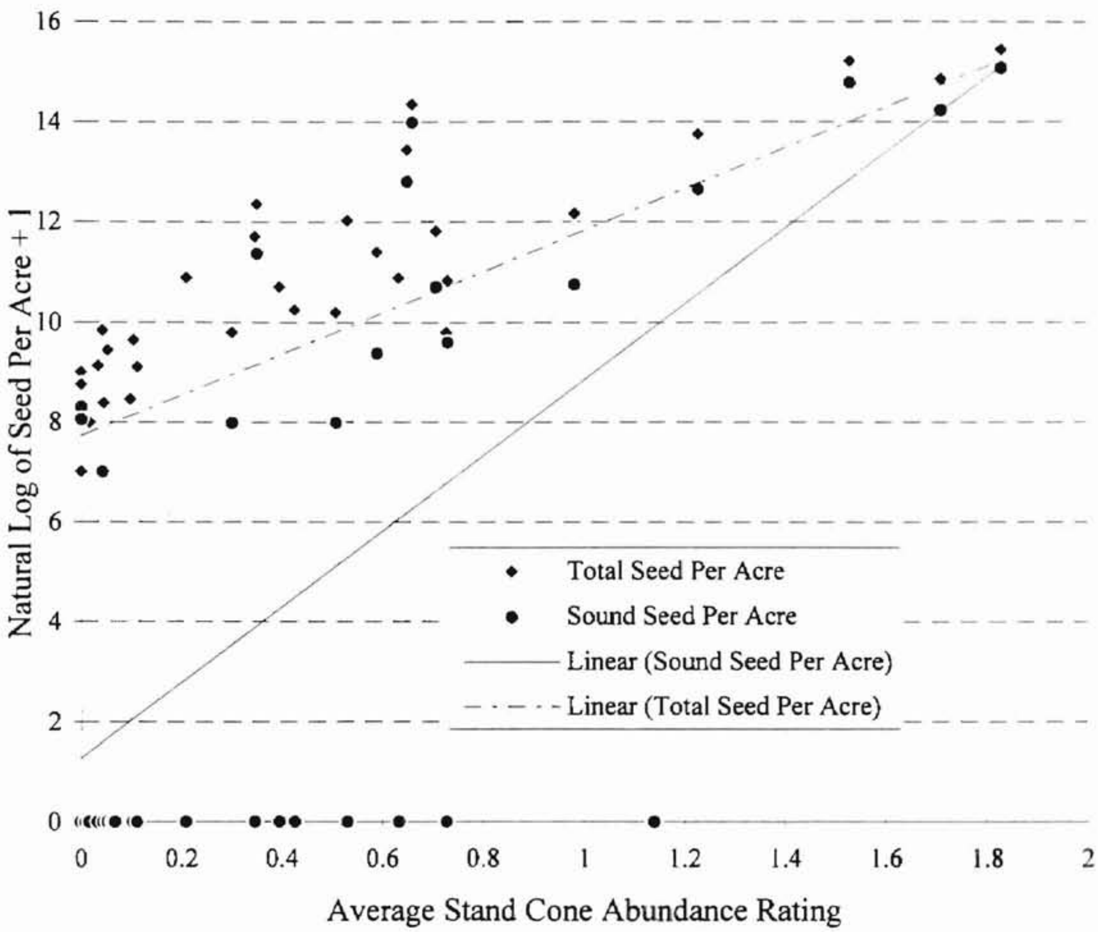
Seed Prediction Model

It was determined from the "stepwise" procedure (SAS 1985) that basal area was not significant in predicting sound seed or total seed. This might be explained by the poor seed production displayed during the years of evaluation throughout most of the study's

Table 2. Description of stands in the seed forecasting study

Regeneration Method	Sample Stands	Basal Area (ft^2/ac)	
		Range	Average
Seed-tree	10	8-18	13
Shelterwood	8	27 - 45	36
Single-tree-selection	9	40 - 65	52
Uncut	1	98	98

Figure 4. The relation between total seed and sound seed per acre



range. When few or no seed are produced, basal area appears unimportant. For example, a stand with a large number of trees with no seed produces the same amount of seed as a stand with a small number of trees with no seed. It could be speculated that basal area would be significant in seed prediction during years of greater seed production where differences could be observed. Due to the lack of significance of basal area, only the average stand cone ratings were used in the model. Prediction models for sound seed and total seed were developed. The cone ratings predicted total seed better than sound seed. The model with the best fit was:

$$\mathbf{LN(Total\ Seed + 1) = 7.596416 + 7.925546 \times LN(Cone\ Rating + 1)} \qquad (1)$$

or

$$\mathbf{Total\ Seed\ per\ Acre = e^{7.596416 + 7.925546 \times LN(Cone\ Rating + 1)} - 1} \qquad (2)$$

where LN is the natural logarithm (Figure 5). The logarithmic form of the model (1) had an R^2 of 0.56 and a standard error of 2.21 with 36 degrees of freedom. When transformed to equation 2, the fit index for total seed per acre was 0.63. The fit index is the proportion of variation in total seed per acre explained by equation 2. Because of the large range in total seed production the lower end of the curve is difficult to read considering that readings of 100,000 total seed per acre are hardly distinguishable from zero. The lower end of the graph, which is more important for practical use, was enlarged in Figure 6. In Figure 6 it is shown that an average stand cone rating of approximately 0.65 is equal to about 100,000 total seed per acre and a cone rating of 0.5 is equal to about 50,000 total seed per acre.

Figure 5. Observed and predicted total seed per acre vs rating

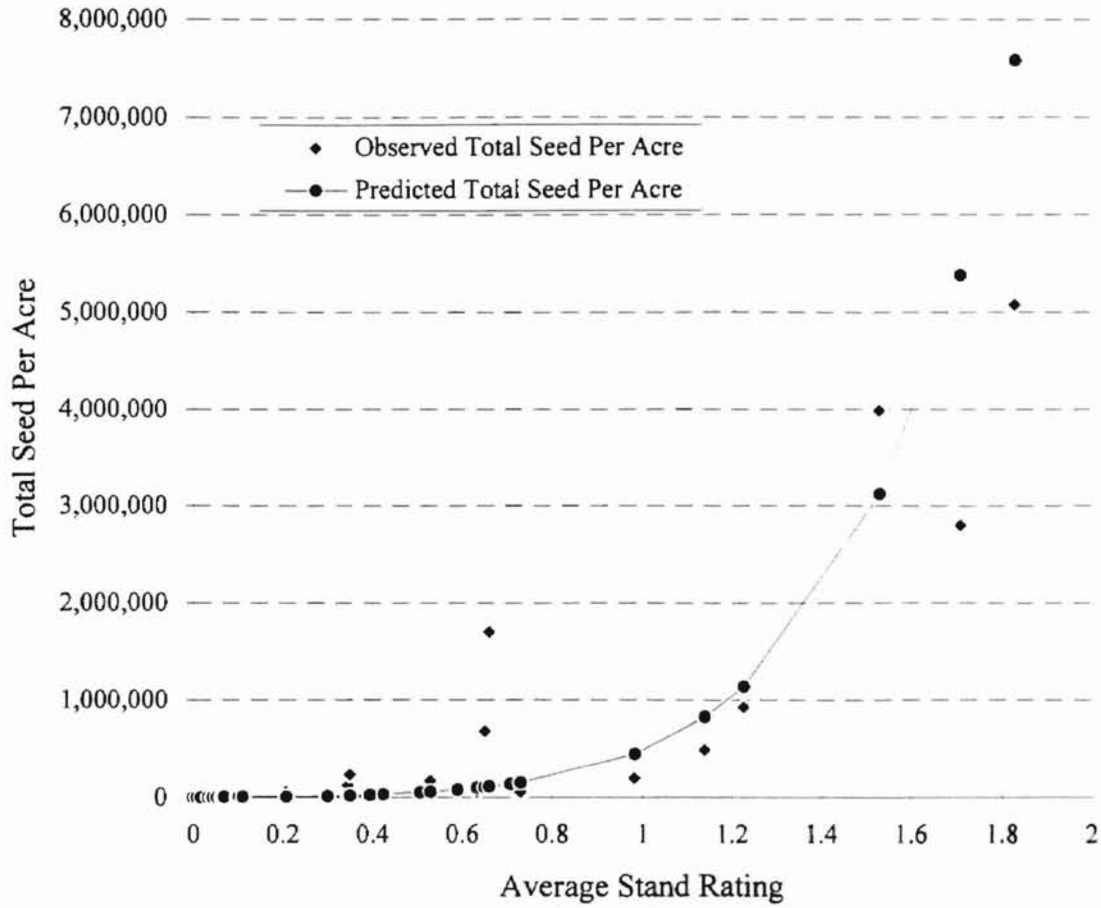
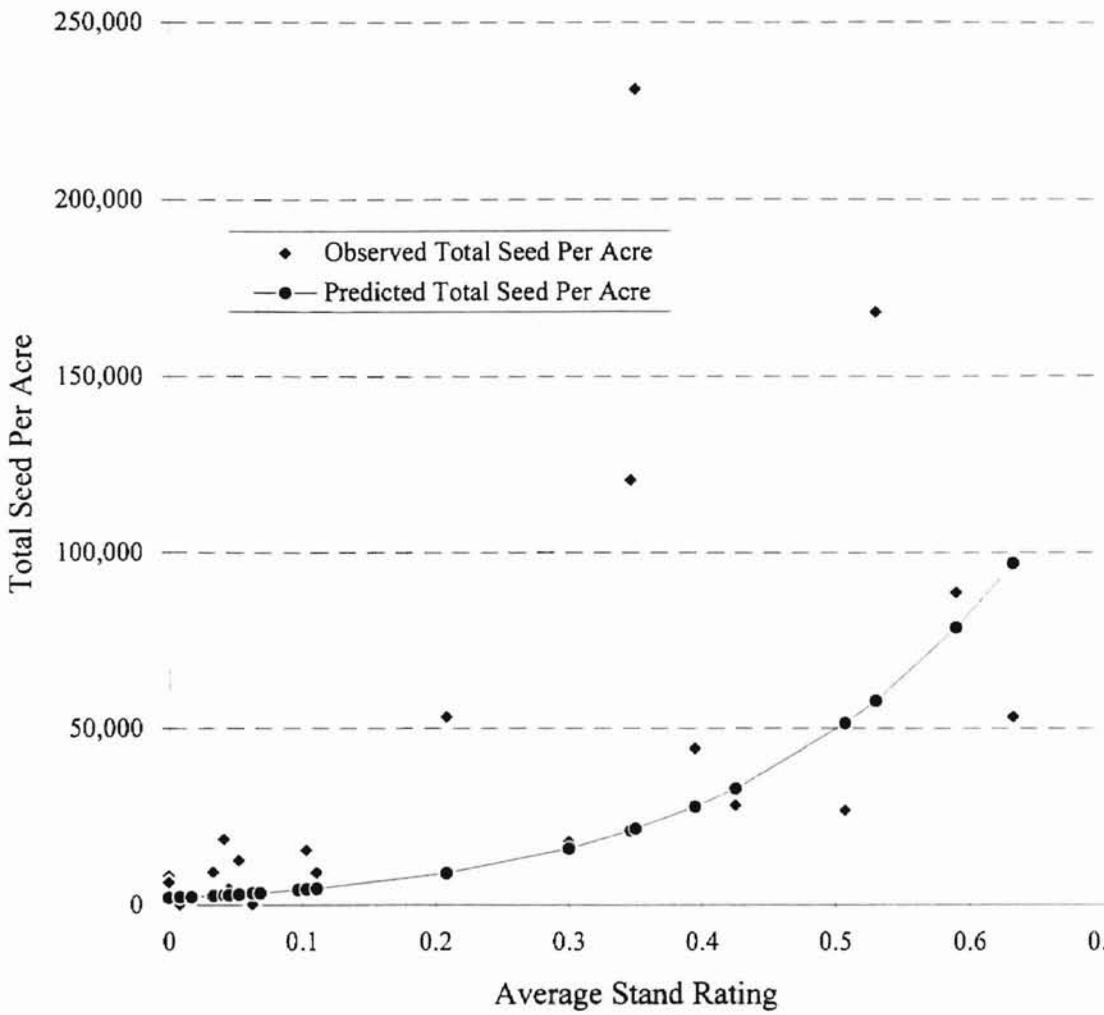


Figure 6. Observed and predicted total seed per acre vs ratings 0-0.65



In order to estimate the number of sound seed per acre a model was developed to determine the percent sound seed from the average stand cone ratings. The best model developed was:

$$\textbf{Percent Sound Seed} = 0.115995 + 0.295063 \ \textbf{(Cone Rating)}. \qquad (3)$$

with an R^2 of 0.29 and 36 degrees of freedom. Although the R^2 appears low the cone rating is highly significant with a p-value of 0.0006. Model (3) can be used in conjunction with the model for total seed production to estimate the number of sound seed. A conversion table for field use has been developed (Table 3).

Study II. Distribution of Conelets

Sample Tree Descriptions

For Study II, the ten sample trees had an average age of 89 years, average dbh of 13.4 inches, average total height of 67 feet, and average live crown ratio of 41% (Table 4) Also see Appendix C.

Crown Description

The average number of branches, one inch in diameter or larger, for all ten trees was 30 (Table 5). When considering the average number of branches found in each quadrant for all ten trees the upper-north had the fewest branches and the lower-south had the most. However, there was no significant difference in number of branches among quadrants.

Table 3. Estimated production of total seed, percent sound seed and sound seed for shortleaf pine stands exhibiting cone abundance ratings between 0.1 and 1.8 in the Ouachita Mountains

Cone Rating	Total Seed per Acre	Percent Sound Seed	Sound Seed per Acre
0.1	4,200	15	600
0.2	8,400	18	1,500
0.3	15,900	21	3,300
0.4	28,700	23	6,700
0.5	49,500	26	13,100
0.6	82,600	29	24,200
0.7	133,500	32	43,100
0.8	210,000	35	73,900
0.9	322,400	38	123,200
1	484,100	41	199,000
1.1	712,600	44	314,300
1.2	1,030,300	47	484,200
1.3	1,465,500	50	732,800
1.4	2,053,400	53	1,086,200
1.5	2,837,700	56	1,586,300
1.6	3,872,300	59	2,276,900
1.7	5,222,500	62	3,227,500
1.8	6,967,100	65	4,507,700

Table 4. Sample tree descriptions for the conelet distribution study

DBH Class (inches)	Sample Trees	Mean Age (years)	Mean DBH (inches)	Mean Total Height (feet)	Mean Live Crown Ratio
10	2	76	10.7	67	34%
12	3	86	12.2	60	43%
14	2	85	13.4	72	44%
16	2	105	16.2	72	38%
18	1	107	17.2	71	47%
Average[1]		89	13.4	67	--
Range		61-107	10.6-17.2	58-81	--

[1]Weighted averages by the number of trees per class

Table 5. Number of sample branches and average number of branches per tree by crown position for the conelet distribution study

DBH Class (inches)	Number of Sample Branches	Average Crown Width (feet)	Average Number of Branches				
			Lower North	Lower South	Upper North	Upper South	Whole Tree
10	16	13	6	6	7	6	25
12	23	16	9	10	5	6	30
14	16	15	6	6	3	8	23
16	16	23	7	8	9	8	32
18	8	25	14	15	4	10	43
Average[1]			8	8	6	7	30

[1]Averages weighted by the number of trees per class

There was also no significant difference between aspects (north and south) or halves (top and bottom). Average branch diameter was 2.31 inches and average length was 10 feet (Table 6).

Conelet Distribution

Eight sample branches were collected from each tree (Appendix D). Two branches were obtained from each quadrant, with the exception of tree Two. In the lower-north quadrant of tree Two only one branch was present. Analysis of the total first flush sites greater than two inches in length (includes sites with conelets and without conelets) revealed no significant difference between the north and south aspects or the top and bottom halves (Table 7 and Table 8) (Appendix E). This was also the case in "sterile" sites, i.e. first flush sites greater than two inches in length and barren of conelets. There was a significant difference, however, between top and bottom halves at the 95% significance level when the total number of conelets were analyzed for all ten trees. The top half had significantly more conelets than the bottom. This was expected with the most vigorous branches being located in the top half of the crown. Although, the total number of conelets between north and south aspects were not significant at the 95% significance level they would be significant at the 77% significance level. Though not significant, it should not be overlooked that there were on average more conelets located in the southern aspects of the trees than the northern aspects. When looking at differences between quadrants the upper-south had significantly more conelets than the lower-north

Table 6. Average basal diameter and length of sample branches by dbh class and crown position for the conelet distribution study

DBH Class (inches)	Sample Branch Averages							
	Lower/North		Lower/South		Upper/North		Upper/South	
	diameter (inches)	length (feet)	diameter (inches)	length (feet)	diameter (inches)	length (feet)	diameter (inches)	length (feet)
10	1.95	11.1	2.40	10.8	1.60	7.6	1.50	5.4
12	2.10	10.4	2.30	10.2	1.43	5.6	2.00	7.2
14	2.65	14.5	3.25	17.0	1.70	7.1	2.00	8.3
16	3.07	12.7	2.75	7.9	1.93	7.0	2.03	7.7
18	3.25	14.0	3.25	13.5	2.40	8.3	2.65	8.5
Average	2.60	12.5	2.79	11.9	1.81	7.1	2.04	7.4

[1] Averages weighted by the number of trees per class

Table 7. Distribution of total sites and conelets throughout the crowns of the sample trees by crown position for the conelet distribution study

DBH Class (inches)	Per Branch Averages											
	Lower/North			Lower/South			Upper/North			Upper/South		
	Total[1] Sites	Sites w/ Conelets	Total Conelets	Total[1] Sites	Sites w/ Conelets	Total Conelets	Total[1] Sites	Sites w/ Conelets	Total Conelets	Total[1] Sites	Sites w/ Conelets	Total Conelets
10	24	0%	0.0	45	1%	0.5	19	4%	1.3	15	7%	1.3
12	19	0%	0.0	23	0%	0.0	33	5%	2.0	54	2%	1.7
14	27	0%	0.0	33	0%	0.0	17	1%	0.3	30	1%	0.3
16	75	2%	1.8	39	6%	3.3	56	2%	1.8	52	13%	12.0
18	67	9%	6.5	59	8%	6.0	81	16%	16.0	81	27%	30.0
Average[2]	39	--	1.1	36	--	1.4	36	--	2.9	44	--	6.2

[1] Includes all first flush sites two inches in length or greater without conelets and all sites with conelets
[2] Averages weighted by the number of trees per class

Table 8. Estimated total conelets by dbh class and crown position

dbh	Crown Postion*				Total
Class	L/N	L/S	U/N	U/S	Conelets
10	0	3	9	8	20
12	0	0	10	10	20
14	0	0	1	24	25
16	13	26	16	96	151
18	91	90	64	300	545

* The crown positions are abbreviated as such: lower half of crown and north facing aspect, L/N; lower half of crown and south facing aspect, L/S; upper half of crown and north facing aspect, U/N; upper half of crown and south facing aspect, U/S.

and lower-south at the 95% significance level and would be significantly greater than the upper-north at the 85% significance level.

With nearly the same number of "potential" conelet bearing sites throughout the crown, and if it could be assumed that there are on average more cones on the southern aspect of the crown than the northern aspect, then it would be logical to consider the effects of outside forces on cone production. It has been speculated in the literature that sunlight is a driving force in cone production (Smith and Stanley, 1969). Other speculation might be that southerly winds in the spring blow the pollen onto the southern aspects of adjacent trees. A more pronounced development of conelets on the south aspect compared to the north aspect would be expected in a year of better conelet production.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

Study I. Objective

The objective of Study I was to refine the seed forecasting system proposed by Shelton and Wittwer (1995) by developing a prediction equation using average stand cone abundance ratings and stand density as independent variables. Specific application was for shortleaf pine stands in the Ouachita and Ozark Mountain regions. This objective was accomplished with the development of the prediction equation. However, further evaluations are recommended to continue to refine the seed forecasting system. The seed forecasting system would most likely be able to incorporate stand density into the prediction equation if seed crop evaluations were done during years of good seed production. Because good seed years occur about three to five years in ten, a ten year data set correlating stand cone abundance ratings with seed production should provide reliable predictions from year to year. Similar studies are also recommended for loblolly pine (*Pinus taeda* L.) stands in the Coastal Plain to aid management foresters in natural regeneration.

Study II. Objective

The objective of Study II, to determine the distribution of potential cone bearing sites and actual cone bearing sites throughout the crown of shortleaf pine trees, was also accomplished by studying the crowns of ten shortleaf pine trees. It is recommended that additional studies be done during years of greater cone production so that two-year-old cones could be evaluated in addition to conelets. Using two-year-old cones would allow evaluation of seed from the cones for differences in viablity and germination.

Summary

Information obtained from this research will be useful to management foresters when trying to naturally regenerate stands in regions where low seed production frequently limits success. It will let management foresters more efficiently determine when acceptable seed crops will occur by allowing them to evaluate more trees in stand in less time. Knowing that cone abundance is significantly higher in the top half of the tree crown than in the lower half adds validation to the guidelines given by Shelton and Wittwer (1995) for assigning a cone abundance rating to a tree. In addition, knowing cones do tend to occur more frequently on the south sides of shortleaf pine trees than on the north sides, though not significantly higher, shows the need for observers to be consistent when assigning cone abundance ratings. Rating trees without regard to the north or south aspect could result in bias. Reliable estimates of the upcoming seed production would aid foresters in the decision making process by indicating fruitful stands where seedbed preparation should be applied for optimum regeneration.

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APPENDICES

APPENDIX A

OBSERVER DATA FOR PILOT STUDY

STAND	OBSERVER*	RATING						
		TREE 1	TREE 2	TREE 3	TREE 4	TREE 5	TREE 6	TREE 7
1	1	1.0	2.3	0.0	0.7	0.0	1.0	--
1	2	1.0	2.3	0.0	0.7	0.0	1.0	--
1	3	1.0	2.3	0.0	0.7	0.0	1.0	--
1	4	1.0	2.0	0.0	0.7	0.0	1.0	--
1	5	1.3	2.3	0.0	0.7	0.0	1.0	--
1	6	0.7	2.0	0.0	0.3	0.0	1.3	--
2	1	0.3	0.0	0.0	1.0	0.0	0.0	--
2	2	0.3	0.0	0.0	0.7	0.0	0.0	--
2	3	0.3	0.0	0.0	1.0	0.0	0.0	--
2	4	0.3	0.0	0.0	0.7	0.0	0.0	--
2	5	0.3	0.0	0.0	0.7	0.0	0.0	--
2	6	0.7	0.0	0.0	1.0	0.0	0.0	--
3	1	1.3	0.0	0.0	0.0	1.0	1.3	--
3	2	1.3	0.0	0.0	0.0	0.7	1.0	--
3	3	1.0	0.0	0.3	0.0	1.0	1.7	--
3	4	1.0	0.0	0.0	0.0	1.0	1.0	--
3	5	1.7	0.0	0.0	0.0	0.7	1.0	--
3	6	1.0	0.0	0.0	0.0	0.7	1.0	--
4	1	0.3	0.0	0.0	0.0	0.0	0.0	--
4	2	0.3	0.0	0.0	0.0	0.0	0.0	--
4	3	0.7	0.0	0.0	0.0	0.0	0.0	--
4	4	1.3	0.0	0.0	0.0	0.0	0.0	--
4	5	1.0	0.0	0.0	0.0	0.0	0.0	--
4	6	0.3	0.0	0.0	0.0	0.0	0.0	--
5	1	0.0	0.0	0.3	2.0	0.0	2.0	--
5	2	0.7	0.0	0.3	2.0	0.0	1.7	--
5	3	0.7	0.0	0.3	2.0	0.0	2.0	--
5	4	0.7	0.0	0.0	2.3	0.0	1.3	--
5	5	0.0	0.0	0.0	2.0	0.0	1.3	--
5	6	0.3	0.0	0.0	1.3	0.0	2.0	--
6	1	2.0	2.0	1.0	0.7	1.7	2.0	1.3
6	2	2.0	2.0	1.0	0.7	1.3	1.0	1.7
6	3	1.7	2.0	1.0	0.7	1.3	1.3	2.0
6	4	2.0	2.0	1.3	0.0	1.3	1.7	1.7
6	5	2.0	1.3	1.0	0.7	2.0	2.0	2.0
6	6	1.3	1.7	0.3	0.3	0.7	2.0	1.3
7	1	1.0	1.3	1.0	1.3	0.0	0.7	1.3
7	2	1.7	1.0	2.0	1.7	0.0	0.7	1.0
7	3	1.0	1.3	1.0	1.0	0.7	0.7	1.0
7	4	2.3	1.0	2.0	1.3	0.0	0.7	1.7
7	5	1.3	1.3	2.0	1.3	0.0	0.7	1.3
7	6	1.0	1.0	1.3	1.3	0.0	0.3	1.3

* Six observers gave a cone abundance rating to the same six or seven trees in each stand.

APPENDIX B

INDIVIDUAL STAND DATA FOR STUDY I

Year	Compartment[1]	Stand	Treatment[2]	Basal Area (ft^2/acre)	Stand Rating	Total Seed Per Acre
1994	35	41	sw	35.0	0.05	12,499
1993	208	2	sts	45.0	0.53	168,000
1994	208	2	sts	58.0	0.10	15,246
1993	208	3	sts	51.0	0.35	231,000
1994	208	3	sts	51.7	0.03	9,075
1994	218	11	sw	32.1	0.01	0
1993	237	4	sts	43.0	0.65	682,000
1994	237	4	sts	45.7	0.10	4,667
1994	248	6	st	10.8	0.00	2,951
1993	254	1	st	17.0	0.00	8,000
1994	254	1	st	10.0	0.00	1,089
1993	261	16	sw	48.0	0.66	1,696,000
1994	261	16	sw	48.0	0.05	4,356
1994	458	10	st	16.7	0.98	190,614
1994	845	6	st	17.5	0.02	2,951
1994	895	1	sw	37.9	0.00	6,250
1994	1036	17	st	16.3	0.43	28,123
1994	1044	3	sts	40.4	0.51	26,561
1994	1084	7	st	17.1	0.73	50,171
1994	1094	4	sw	26.7	0.63	53,122
1994	1097	6	sw	45.0	0.73	17,707
1994	1119	22	st	8.3	0.30	17,707
1994	1125	5	sts	55.8	0.07	2,951
1994	1284	1	sts	44.2	0.59	88,537
1994	1646	8	st	15.0	0.21	53,122
1994	1651	6	st	14.6	0.11	8,854
1994	1658	16	sts	55.8	0.35	120,410
1994	1660	6	sw	33.3	0.39	44,268
1994	CNF	103	uncut	98.3	0.06	0
1993	CNF	106	sts	62.0	0.00	6,000
1994	CNF	106	sts	65.0	0.04	18,513
1993	LS	st	st	8.0	1.14	488,000
1994	LS	st	st	8.0	0.71	133,500
1993	LS	sts	sts	51.0	1.53	3,980,000
1994	LS	sts	sts	54.2	1.23	923,000
1993	LS	sw	sw	29.0	1.83	5,069,000
1994	LS	sw	sw	31.1	1.71	2,800,000

[1] The numbered compartments are the numbers assigned by the U.S.D.A., Forest Service on the Ouachita National Forest. Forest land owned by the Choctaw Nation is designated by CNF. Research stands located near Lake Sylvia, AR. that did not have an official compartment or stand number was abbreviated as LS and the stand was denoted by the treatment.
[2] Treatments are abbreviated as such: shelterwoods, sw; single-tree-selections, sts; and seed-trees, st.

APPENDIX C

SAMPLE TREE DATA FOR STUDY II

Tree No.	DBH	Stem Dia. at Crown Base	Tree Height	Height to Crown Base	Crown Width	Crown Length	Age	# OF BRANCHES				
								LN[1]	LS[2]	UN[3]	US[4]	Total
	(in)	(in)	(ft)	(ft)	(ft)	(ft)	(yrs)					
1	16.0	9.65	81.3	52.9	16.6	28.4	102	7	6	10	8	31
2	12.9	7.95	59.3	37.1	17.5	22.2	92	8	3	6	1	18
3	10.8	7.00	67.5	42.7	14.0	24.8	75	5	5	7	7	24
4	13.0	9.90	67.0	33.7	13.5	33.3	82	7	4	3	9	23
5	13.7	9.15	75.8	46.1	17.1	29.7	87	4	8	3	6	21
6	11.2	7.50	57.7	34.6	18.0	23.1	61	7	10	6	9	32
7	12.5	8.50	62.2	30.6	13.9	31.6	104	11	17	3	8	39
8	17.2	12.90	70.8	37.5	25.0	33.3	107	14	15	4	10	43
9	10.6	6.40	65.8	45.6	12.1	20.2	77	7	6	6	4	23
10	16.3	11.10	61.8	36.2	28.4	25.6	107	6	9	8	8	31

[1] The quadrant in the lower half and north facing aspect of the crown.

[2] The quadrant in the lower half and south facing aspect of the crown.

[3] The quadrant in the upper half and north facing aspect of the crown.

[4] The quadrant in the upper half and south facing aspect of the crown.

APPENDIX D

SAMPLE BRANCH DATA FOR STUDY II

Tree No.	Branch Location*	Basal Diameter (in)	Length (ft)
1	L/S	2.8	11.7
1	L/S	1.8	5.6
1	L/N	2.7	14.5
1	L/N	3.2	14.6
1	U/S	2.2	10.9
1	U/S	2.2	7.5
1	U/N	2.1	8.4
1	U/N	2.2	9.2
2	L/S	3.2	13.6
2	L/S	2.8	11.9
2	L/N	2.2	9.8
2	U/S	1.9	9.9
2	U/S	2.7	8.5
2	U/N	2.4	7.9
2	U/N	1.3	4.2
3	L/S	2.7	14.1
3	L/S	2.7	12.5
3	L/N	2.0	12.9
3	L/N	1.9	12.0
3	U/S	1.9	6.6
3	U/S	1.2	4.7
3	U/N	2.0	11.7
3	U/N	1.8	7.7
4	L/S	3.2	19.7
4	L/S	2.6	14.5
4	L/N	3.1	16.0
4	L/N	2.1	14.4
4	U/S	1.7	8.4
4	U/S	2.2	8.8
4	U/N	2.1	8.5
4	U/N	1.9	7.0
5	L/S	3.7	19.2
5	L/S	3.5	13.9
5	L/N	3.0	17.1
5	L/N	2.4	10.7
5	U/S	2.5	9.9
5	U/S	1.6	6.1
5	U/N	1.7	8.3
5	U/N	1.1	4.6

Tree No.	Branch Location*	Basal Diameter (in)	Length (ft)
6	L/S	1.9	8.5
6	L/S	2.2	9.5
6	L/N	2.4	11.4
6	L/N	2.3	10.2
6	U/S	2.6	6.8
6	U/S	1.5	4.7
6	U/N	1.5	6.4
6	U/N	1.1	4.4
7	L/S	2.1	9.1
7	L/S	1.6	8.2
7	L/N	2.0	11.3
7	L/N	1.6	10.1
7	U/S	1.9	7.5
7	U/S	1.4	6.0
7	U/N	1.1	5.0
7	U/N	1.2	5.5
8	L/S	3.7	14.0
8	L/S	2.8	12.6
8	L/N	3.2	13.3
8	L/N	3.3	15.4
8	U/S	3.4	10.7
8	U/S	1.9	5.9
8	U/N	3.0	10.6
8	U/N	1.8	5.5
9	L/S	1.9	7.8
9	L/S	2.3	8.4
9	L/N	2.0	9.4
9	L/N	1.9	9.9
9	U/S	1.8	6.3
9	U/S	1.1	3.9
9	U/N	1.4	6.2
9	U/N	1.2	4.4
10	L/S	3.4	6.2
10	L/S	3.0	7.6
10	L/N	3.2	10.7
10	L/N	3.2	9.6
10	U/S	2.5	7.7
10	U/S	1.2	4.4
10	U/N	1.8	5.0
10	U/N	1.6	5.3

* Abbreviations for branch locations within the crown are such: lower half and south facing aspect, L/S; lower half andnorth facing aspect, L/N; upper half and south facing aspect, U/S; upper half and north facing aspect, U/N.

APPENDIX E

CONELET DISTRIBUTION DATA FOR STUDY II

Tree No.	Branch No.	Half[1]	Aspect[2]	Sterile Sites	Conelet Clusters 1's	2's	3's	6's	Total Conelets
1	1	L	S	12	0	0	0	0	0
1	2	L	S	66	1	1	0	0	3
1	3	L	N	74	0	0	0	0	0
1	4	L	N	120	1	0	0	0	1
1	5	U	S	47	1	0	0	0	1
1	6	U	S	36	0	0	0	0	0
1	7	U	N	84	0	0	0	0	0
1	8	U	N	53	2	0	0	0	2
2	1	L	S	48	0	0	0	0	0
2	2	L	S	20	0	0	0	0	0
2	3	L	N	42	0	0	0	0	0
2	4	L	N	No Branch					
2	5	U	S	33	0	0	0	0	0
2	6	U	S	88	4	3	0	0	10
2	7	U	N	95	5	2	0	0	9
2	8	U	N	29	3	0	0	0	3
3	1	L	S	77	1	0	0	0	1
3	2	L	S	65	1	0	0	0	1
3	3	L	N	22	0	0	0	0	0
3	4	L	N	28	0	0	0	0	0
3	5	U	S	28	1	1	0	0	3
3	6	U	S	6	0	0	0	0	0
3	7	U	N	17	0	0	0	0	0
3	8	U	N	23	0	2	0	0	4
4	1	L	S	13	0	0	0	0	0
4	2	L	S	5	0	0	0	0	0
4	3	L	N	20	0	0	0	0	0
4	4	L	N	12	0	0	0	0	0
4	5	U	S	8	0	0	0	0	0
4	6	U	S	27	1	0	0	0	1
4	7	U	N	20	0	0	0	0	0
4	8	U	N	12	0	0	0	0	0
5	1	L	S	60	0	0	0	0	0
5	2	L	S	54	0	0	0	0	0
5	3	L	N	30	0	0	0	0	0
5	4	L	N	45	0	0	0	0	0
5	5	U	S	59	0	0	0	0	0
5	6	U	S	24	0	0	0	0	0
5	7	U	N	22	1	0	0	0	1
5	8	U	N	13	0	0	0	0	0

[1] The crown halves are abbreviated as such: upper half, U; lower half, L.
[2] The crown aspects are abbreviated as such: north facing aspect, N; south facing aspect, S.

Tree No.	Branch No.	Half[1]	Aspect[2]	Sterile Sites	Conelet Clusters 1's	2's	3's	6's	Total Conelets
6	1	L	S	7	0	0	0	0	0
6	2	L	S	32	0	0	0	0	0
6	3	L	N	14	0	0	0	0	0
6	4	L	N	27	0	0	0	0	0
6	5	U	S	96	0	0	0	0	0
6	6	U	S	49	0	0	0	0	0
6	7	U	N	21	0	0	0	0	0
6	8	U	N	12	0	0	0	0	0
7	1	L	S	14	0	0	0	0	0
7	2	L	S	17	0	0	0	0	0
7	3	L	N	3	0	0	0	0	0
7	4	L	N	10	0	0	0	0	0
7	5	U	S	34	0	0	0	0	0
7	6	U	S	18	0	0	0	0	0
7	7	U	N	12	0	0	0	0	0
7	8	U	N	20	0	0	0	0	0
8	1	L	S	49	0	1	0	0	2
8	2	L	S	60	6	2	0	0	10
8	3	L	N	47	1	0	0	0	1
8	4	L	N	74	10	1	0	0	12
8	5	U	S	68	21	10	2	0	47
8	6	U	S	50	9	2	0	0	13
8	7	U	N	96	15	4	0	0	23
8	8	U	N	40	5	2	0	0	9
9	1	L	S	10	0	0	0	0	0
9	2	L	S	26	0	0	0	0	0
9	3	L	N	30	0	0	0	0	0
9	4	L	N	17	0	0	0	0	0
9	5	U	S	9	1	0	0	0	1
9	6	U	S	13	1	0	0	0	1
9	7	U	N	16	0	0	0	0	0
9	8	U	N	15	1	0	0	0	1
10	1	L	S	30	0	0	0	0	0
10	2	L	S	40	4	3	0	0	10
10	3	L	N	43	1	2	0	0	5
10	4	L	N	57	1	0	0	0	1
10	5	U	S	80	11	10	3	1	46
10	6	U	S	16	1	0	0	0	1
10	7	U	N	47	0	2	0	0	4
10	8	U	N	33	1	0	0	0	1

[1] The crown halves are abbreviated as such: upper half, U; lower half, L.
[2] The crown aspects are abbreviated as such: north facing aspect, N; south facing aspect,

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