FORECASTING SHORTLEAF PINE SEED CROPS IN THE OUACHITA MOUNTAINS

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Abstract—We field tested a cone-rating system to forecast seed crops from 1993 to 1996 in 28 shortleaf pine (*Pinus echinata* Mill.) stands, which represented a wide range of stand conditions. Sample trees were visually assigned to one of three cone-density classes based on cone spacing, occurrence of cones in clusters, and distribution of cones within the crown. Classification took < 1 minute per tree, permitting a large number of trees to be evaluated rather than making precise counts on a few trees. The stand's mean cone rating and basal area explained 82 percent of the variation in sound seed production; however, the developed prediction equation had a large root mean square error (257,000 seeds per acre). Our cone-rating system did well in forecasting the poor and good seed crops. However, more precise determinations of both cone and seed density are probably warranted when seed crops are forecast to be marginal for stand regeneration.

INTRODUCTION

The largest concentration of shortleaf pine (*Pinus echinata* Mill.) is in the Ouachita Mountains of Arkansas and Oklahoma, where it can be successfully regenerated by both natural and artificial means (Lawson 1990). The greatest challenge to successful natural regeneration is providing an adequate seed supply on a receptive seedbed with low levels of competing vegetation (Cain 1991, Shelton and Cain 2000). This is especially true in the Ouachita Mountains, where shortleaf pine seed crops are erratic and successive years of low seed production often occur (Shelton and Wittwer 1996; Wittwer and Shelton, in press; Wittwer and others, in press). Seed production within a stand can be enhanced by selecting the appropriate reproduction cutting method, retaining productive trees as indicated by the presence of older cones, and promoting tree vigor. However, the greatest variation in seed crops is due to uncontrollable annual fluctuations that reflect differences in weather, insects and pathogens, and internal cycles within the trees. Because of this, shortleaf pine seed crops can vary from nil to over a million seeds per acre. Being able to forecast the size of upcoming seed crops in advance of seed dispersal would greatly aid land managers in scheduling silvicultural operations, such as stand harvesting and site preparation.

In this paper, we report a procedure for forecasting shortleaf pine seed crops in the Ouachita Mountains. The procedure visually assigned trees to three cone-density classes, which permits observers to rate a large number of trees rather than making detailed counts on a few trees. The procedure was tested in 28 shortleaf pine stands that were both evaluated for cone density and monitored for seed production from 1993 to 1996. Preliminary results of the forecasting system have been published earlier (Shelton and Wittwer 1995).

METHODS

Study Area

The study area extended from eastern Oklahoma through central Arkansas, and included 28 stands that were being monitored for seed production in conjunction with various studies of natural shortleaf pine regeneration (table 1). Eighteen stands were part of the Ecosystem Management Research in the Ouachita Mountains (Baker 1994) and included the following treatments: pine and pine-hardwood seed tree, pine and pine-hardwood shelterwood, and pine single-tree selection. There were three or four stands for each treatment. These 40-acre stands were located throughout the Ouachita Mountains, except for the extreme eastern part. There, the pine-only treatments of two research studies (shelterwood and single-tree selection) were used for our seed-forecasting study in addition to an operational-level seed-tree stand. Each research area was considered a single stand or replicate. Sampling was conducted in a total of 2 to 3 acres within each research area and the operational stand, but the sampled area was surrounded by a larger area with the same pine basal area. In the western part of the Ouachita Mountains, seven 22- to 40-acre operational-level stands were evaluated for cone density

Table 1—Characteristics of the 28 shortleaf pine stands in the Ouachita Mountains evaluated for cone rating and seed production

		Basal area[a]	
Stand type	Number	Mean	Range
		square feet per acre	
Seed tree	10	13.4	8.0-17.5
Shelterwood	8	36.1	26.7-48.0
Single-tree selection	9	52.1	40.4-65.0
Unmanaged sawtimber	1	98.3	—

[a] Trees ≥ 10 inches d.b.h.

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and seed production. There was one seed-tree stand, one shelterwood stand, four single-tree selection stands, and one unmanaged sawtimber stand.

In the research stands, basal area was determined on four to six plots per stand ranging from 0.1 to 0.7 acre in area. In the operational-level stands, basal area was determined with a 10 basal-area-factor prism at a point centered over each seed trap used for monitoring seed production.

Cone-Rating Procedures

We modified a cone-rating procedure that was developed for western conifers (McDonald 1992, Rietveld 1978, Schubert and Pitcher 1973) by employing several quantitative and qualitative features that permit rapid evaluation of the cone density in a tree's crown. Cone density was visually rated based on cone spacing, the occurrence of cones in clusters, and the distribution of cones within the crown (table 2). Development of guidelines for evaluating each element was described more fully in Shelton and Wittwer (1995). In our procedure, cone density was rated only for the side of the crown facing the evaluator (that is, the crown face). In application, the cone rating of trees was an integration of all features to choose the proper cone-density class. Similar visual-rating systems have also been developed for evaluating crown density as an expression of tree vigor (Belanger and Anderson 1989).

For good visibility, evaluators stood one to two tree heights away from the sample tree with the sun to their back and used high-quality 7-power binoculars. Most trees were classified when maturing cones were most visible—in the early morning or late afternoon and on days with low cloud cover and light winds. Stands were evaluated from late July through early September. A total of six evaluators rated stands; in some cases two evaluators rated different areas within the same stand. Maturing cones were distinguished from older cones of previous years based on the following criteria: (1) maturing cones were yellowish green to green compared with dark brown for older cones, (2) maturing cones were closed while older cones were open when dry, and (3) maturing cones were among the needles while older cones were farther back from the tip where needles had been cast. Evaluation was avoided on cloudy days following a rain because the older cones were closed and the low light intensity made the color differences subtle.

Table 2—Cone-density classes used to rate shortleaf pine sample trees

Property	Cone-density class Few	Average	Good
Spacing between cones (*feet*)	> 7	2.5 – 7	< 2.5
Multiple cones on branchlets	Rare	Occasional	Common
Distribution within crown	Erratic	Upper half	Uniform
Cones per crown face	< 10	10 – 80	> 80

Source: Shelton and Wittwer (1995).

Cone density was rated for two or three sample trees of seed-producing sizes—that is, ≥ 10 inches diameter at breast height (d.b.h.)—randomly selected within one to two tree heights from each seed trap used for monitoring seed production.

Numerical values were arbitrarily assigned to the three cone-density classes as follows: 0 for few, 1 for average, and 2 for good. However, the rating of sample trees was modified to accommodate borderline occurrences of classes by assigning pluses and minuses in the field tally. A plus indicated the tree was near the upper limits of the class, while a minus indicated the lower limits. Such variation would probably have averaged out, but it may have been critical in situations where a high percentage of the trees were near a class limit. Most important, assignment of pluses and minuses prevented evaluators from dwelling on the class of borderline sample trees. For calculating stand averages, a value of 0.3 was added to the class value for a plus or subtracted for a minus (for example, a "1+" had a value of 1.3, and a "1–" had a value of 0.7).

Seed Production

The number and type of seed traps used for monitoring seed production varied from study to study. Eighteen 0.86-square-foot seed traps were used in each of the Ecosystem Management Research stands (Wittwer and others, in press). For the research areas and seed-tree stand in the eastern Ouachita Mountains, seeds were collected in nine to sixteen 0.86-square-foot seed traps in each area or stand (Wittwer and Shelton, in press). Six to ten 4-square-foot seed traps were used in each of the operational-level stands in Oklahoma (Wittwer and Shelton, in press).

As a minimum, seeds were collected at the middle and end of the October-to-February monitoring period of each year. Seed viability was usually determined by splitting seeds and inspecting the contents (Bonner 1974). Seeds with full, firm, undamaged, and healthy tissue were judged to be potentially viable and were tallied as sound seeds. For large collections in the 4-square-foot seed traps, seeds were considered sound if they sank in ethanol (Krugman and Jenkinson 1974). A subsample of these seeds was split, and the flotation test yielded the same results as the split test.

Data Analysis

A common observation of studies making precise cone counts is that they tend to underestimate the actual number of cones on the tree because all the cones on the crown face are not visible from a single observation point. Such bias undoubtedly also occurred in our procedure, but it was corrected by using cone rating as a predicator of observed seed production in shortleaf pine stands that were evaluated for both cone rating and seed production from 1993 to 1996.

Cone rating and seed production were averaged for each stand and year, and basal area was averaged for each stand using the closest available inventory to midpoint of the monitoring period. The 18 stands from the Ecosystem Management Research were not sampled in 1993.

Regression was then used to evaluate the effects of basal area and cone rating as predictors of the stand's seed production as follows:

$$S = b_o + B^{b1} R^{b2} \, , \quad (1)$$

where

S = thousands of sound pine seeds per acre
B = basal area in square feet per acre in shortleaf pine trees $\geq$ 10 inches d.b.h.
R = mean cone rating
b = coefficients to be determined by nonlinear regression (SAS Institute 1988).

This approach allowed the regression coefficients to compensate for the effects of (1) the number of seeds per cone, (2) underestimation of the actual number of cones on trees by evaluators, (3) the arbitrary numerical values assigned to cone-rating classes, and (4) conversion of cone density for the crown face to values for the tree. An intercept coefficient was needed in the equation, because there may have been up to nine cones visible to the evaluator even though a tree received a zero cone rating. Examination of the residuals indicated an unequal error variance, which was reduced by square root transformation of the seed-production data. The final equation was retransformed for presentation and for calculation of fit statistics as described by Schlaegel (1982).

RESULTS AND DISCUSSION

The seed crops from 1993 through 1996 were highly variable, ranging from complete failures to bumper crops; yearly averages were 857, 70, 3, and 465 thousand sound seeds per acre, respectively. Geographically, the lowest production occurred in eastern Oklahoma.

Sound seeds (1,000 per acre) can be predicted from stand basal area (square feet per acre) in trees $\geq$ 10 inches d.b.h. and cone rating by the following equation:

$$S = \left(1.328 + B^{0.8004} R^{1.833}\right)^2 \quad (2)$$

Number of observations was 92, root mean square error was 257,000 seeds per acre, and fit index was 0.82.

Figure 1 compares predicted with observed seed production for equation 2. The wide variation in seed production that occurred over the 4-year period was apparent; observed values ranged from zero to over 3 million seeds per acre. The greatest deviations between predicted and observed values were for the larger seed crops; this pattern is common in biological relationships. Cain and Shelton (2001) state that from 40,000 to 90,000 sound seeds per acre are required to successfully regenerate mixed stands of loblolly (*P. taeda* L.) and shortleaf pines in the west Gulf Coastal Plain. Thus, we feel that a reasonable lower threshold for shortleaf pine in the Ouachita Mountains would be 50,000 sound seeds per acre, because shortleaf generally has a lower seedling-to-seed ratio than loblolly pine (Shelton and Cain 2000). Examination of the residuals indicated that a decision

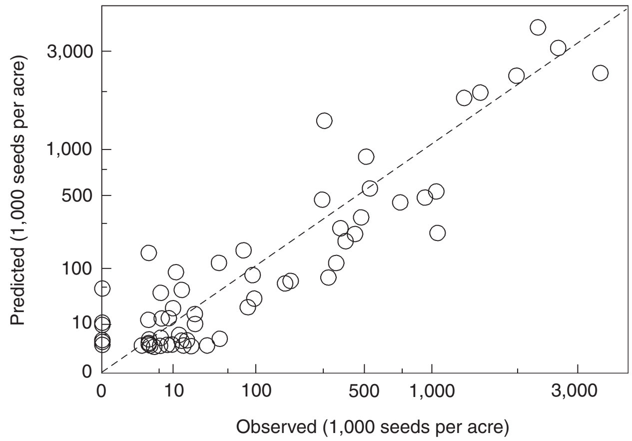

Figure 1—Predicted production of sound seeds plotted against observed values for shortleaf pine stands in the Ouachita Mountains. The dashed line represents equal values. Twenty-nine symbols are hidden along the lower part of the Y axis. The axes are in cubed-root scale.

based on predicted values and this threshold would have been correct for observed seed production in 94 percent of the stands and years. In 4 percent of the stands and years, seed production was predicted to be adequate but was not, while seed production was predicted to be inadequate in 2 percent of the stands and years but was actually adequate. There did not seem to be any pattern with evaluator, stand type, or geographic location in these decision errors.

Several obvious sources of error are associated with our forecasting procedure. Sampling error is associated with each variable in equation 2. For example, differences undoubtedly existed among the people rating cone density. After a 1-hour training session, the six evaluators in this study rated the same six trees in seven different shortleaf pine stands. The mean stand rating for evaluators had a coefficient of variation that averaged 14 percent in six of the stands. In the seventh stand, the coefficient of variation was 66 percent. This stand had a mean rating of only 0.11, so apparently a few trees near a class break can increase variation among the evaluators, especially when the rating is low.

Another source of variation is the number of sound seeds per cone. Our forecasting procedure does not include a sampling scheme to determine this value. Thus, the seed density in cones was intrinsically accounted for in the cone rating. Wakeley (1954) reported that shortleaf produces 25 to 35 sound seeds per cone during good years, and values are reduced by about one-half during poor years. Procedures for estimating the seed yields from cones exist (for example, Bramlett and Hutchinson 1964, McLemore 1962), but additional sampling is required. Such evaluations are most likely needed when seed production is predicted to be marginal.

Values generated from equation 2 are plotted in figure 2, which shows that a given level of seed production can be achieved by an array of basal areas and cone ratings. High basal areas coupled with low cone ratings can yield the same seed production as low basal areas and high cone

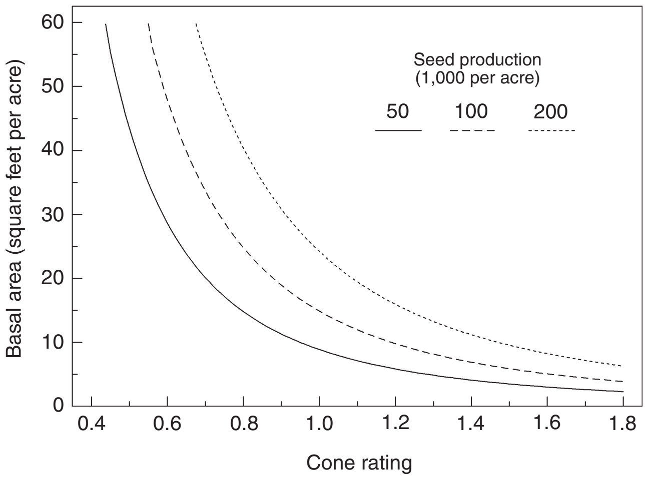

Figure 2—Combinations of cone rating and basal area that yield the specified sound seed production for shortleaf pine stands in the Ouachita Mountains. Data were calculated from equation 2.

ratings. Figure 2 can also be used to judge the acceptability of the upcoming seed crop based on a stand's cone rating and basal area. If trees are to be harvested before seed dispersal, the stand's residual basal area should be used, and the cone rating should reflect the retained trees.

Our forecasting procedure requires visual rating of the cone density on sample trees, determining stand basal area, and estimating seed production with equation 2 or figure 2. The number of seeds required for successful regeneration depends on a myriad of factors that include seed predators, seedbed conditions, competing vegetation, weather, and overstory vegetation. These factors must also be viewed within the context of landowner goals. Thus, proposing guidelines for making silvicultural decisions about the adequacy of a seed crop should include sufficient latitude for the skill and judgment of trained foresters. If 50,000 to 100,000 sound seeds per acre are assumed to provide acceptable shortleaf pine natural regeneration, figure 2 suggests that guidelines for the minimum value for mean cone ratings should be 1.0 to 1.2 for seed-tree stands, 0.6 to 0.8 for shelterwood stands, and 0.4 to 0.7 for uneven-aged stands. Some confirmation of the presence of a reasonable number of sound seeds in cones is recommended, especially when the cone rating is at the lower end of these ranges.

CONCLUSIONS

The visual cone-rating procedure evaluated in this study provides some insight into the adequacy of the upcoming seed crop. This procedure is rapid and appears to be sufficiently accurate to aid in making silvicultural decisions about the intensity and timing of site preparation and possibly the scheduling of reproduction cutting. Cone density can be rated in early July when developing cones are near their fully mature size. Consequently, this forecasting procedure provides a maximum lead time of about 4 months before the peak in seed dispersal. Longer lead times are possible with silvicultural treatments that do not require application before seed dispersal for optimum effectiveness. For example, hardwood control can extend from the time of cone rating through the early part of the growing season following seed dispersal. If a bumper seed crop was forecast, prescribed burning for site preparation might be extended later into the dormant season than is normal for optimizing seedling establishment (Cain 1986). The same logic could probably be extended to harvesting. In the Ouachita Mountains, where shortleaf pine seed crops are erratic, the greatest utility of this forecasting procedure would probably be in timing site preparation with the occurrence of an adequate seed crop and in matching the intensity of site preparation with the size of the anticipated seed crop.

An important goal of this study was to develop a keen appreciation for the entire pine reproductive cycle. For example, abundant numbers of both male and female flowers often indicate the potential for a good upcoming seed crop 18 months in advance of seed dispersal. Female flowers can be seen at the tip of the first flush in the spring using binoculars, and male flowers are easily visible when they fall to the ground in the late spring. This awareness can give longer lead times, especially when coupled with our forecasting procedure to provide confirmation during the summer before dispersal.

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