Effects of Reproduction Cutting Method and Hardwood Retention on Shortleaf Pine Seed Production in Natural Stands of the Ouachita Mountains

Robert F. Wittwer, *Department of Forestry, Oklahoma State University, Stillwater, OK 74078-6013;* **Michael G. Shelton** *and* **James M. Guldin,** *USDA Forest Service, Southern Research Station, Monticello, AR 71656-3516.*

ABSTRACT: *Shortleaf pine (*Pinus echinata *Mill.) seed production was monitored for 4 yr in stands harvested by a range of even- and uneven-aged reproduction cutting methods. The fifty-two 35–40 ac stands were distributed throughout the Ouachita Mountains from central Arkansas to eastern Oklahoma. Seed crops were characterized as good, poor, poor, and bumper, averaging 109,000, 18,000, 5,000, and 379,000 sound seeds/ac, respectively. Seed production the first year after harvest was generally correlated with residual density of shortleaf pines; unharvested control stands, single-tree selection, and shelterwood stands produced more seeds than seed tree stands. Differences in seed production among regeneration cutting methods were not significant for the crop dispersed 4 yr after harvest; this is attributed to release and response of residual seed-producing trees in the seed tree and shelterwood stands. Results also indicated that seed production was lowest for stands located in the western section of the Ouachita Mountains. South. J. Appl. For. 27(3):206–211.*

Key Words: Even-aged silviculture, natural regeneration, *Pinus echinata*, uneven-aged silviculture.

Although shortleaf pine (*Pinus echinata* Mill.) is the most widespread of the southern pines, the greatest concentration is in the Ouachita Mountains of central Arkansas and eastern Oklahoma (Lawson 1990). Within this region, shortleaf pine is an important commercial species and is the dominant naturally-occurring pine. Shortleaf pine can be successfully regenerated by both artificial and natural methods. One of the more critical determinants of successful natural regeneration of shortleaf pine is an adequate seed supply (Baker 1992, Lawson 1986). Silvicultural strategies, such as choice of reproduction cutting method, retention of especially fruitful trees based on past cone production, and promotion of tree vigor, can be used to enhance seed production within a stand.

Several studies have investigated shortleaf pine seed production in other regions and stand conditions. In a 10 yr study in east Texas, Stephenson (1963) reported abundant seed dispersal in only 4 yr while the other 6 yr were almost complete failures. Production exceeded 500,000 sound seeds/ac in the years with abundant seed production. For the 4 yr with abundant seeds, significant differences occurred among reproduction methods only during 1 yr when the shelterwood treatment produced more seeds than uncut stands or stands harvested by single-tree selection. During the other 3 yr with good crops, all regeneration methods produced more than adequate seeds to obtain successful regeneration. Shelton and Wittwer (1996) observed three good seed crops in a 9 yr study of unmanaged stands in Arkansas, Missouri, and Oklahoma. Production in this study was generally lower than found in the east Texas stands sampled by Stephenson (1963). In a study along the Atlantic coast, Bramlett (1965) found shortleaf pine seed production tended to increase from north (Virginia) to south (Georgia).

Providing an adequate seed supply in combination with a receptive seedbed and low levels of competing vegetation is the greatest challenge to managers relying on natural reproduction cutting methods (Shelton and Cain 2000). In this article, we present data on shortleaf pine seed production from stands located in the Ouachita Mountains of west central Arkansas and eastern Oklahoma. This information will provide land managers knowledge about the adequacy of seed crops within the region and the extent to which seed production is related to silvicultural manipulations.

NOTE: Robert F. Wittwer can be reached at Phone: (405) 744-5478; E-mail: rfw1124@okstate.edu. The cooperation and assistance of numerous USDA Forest Service personnel on several Ranger Districts of the Ouachita and Ozark National Forests are gratefully acknowledged. James Baker, USDA Forest Service (retired), deserves special thanks for the significant contribution he made to this study. Forest Service entomologists, Alex Mangini and James Hanula, provided assistance with evaluation of seed quality. This article was approved for publication by the Director of the Oklahoma Agricultural Experiment Station. Manuscript received June 6, 2002, accepted December 9, 2002.

Methods

Study Area and Treatments

A replicated stand-level study was installed in mature, shortleaf pine-hardwood stands on the Ouachita and Ozark National Forests during summer 1993 (Baker 1994). The Ouachita Mountains consist of a series of east-west ridges and structural valleys and are commonly divided into two ecoregions—the Arkansas River Valley to the north and the Ouachita Mountain Ecoregion to the south (Giese et al. 1987). The Ouachita Mountain Ecoregion has been further divided into two subregions—the Upper to the north and the Lower to the south (Clingenpeel and Cochran 1992). For this study the Upper Ouachita Mountain Subregion was further divided into eastern and western components, corresponding to mean annual temperature and precipitation gradients. Thus, stands within each of the four ecoregions and subregions were recognized as being similar in land forms, vegetation, and climate: the Arkansas Valley Ecoregion (North); the Lower Ouachita Mountain Ecoregion (South); the eastern Upper Ouachita Mountain Sub-Ecoregion (East); and the western Upper Ouachita Mountain Sub-Ecoregion (West) (Figure 1). A detailed description of the structure and composition of midstory and overstory trees was provided by Guldin et al. (1994).

The fifty-two 35–40 ac stands included in our study were randomly selected from the population of stands that were candidates for reproduction cutting with the following criteria: 70+ yr for stand age, south or west facing aspects, 60–110 ft^2/ac for pine basal area, and 20–50 ft^2/ac for hardwood basal area (Baker 1994). Treatments included five uneven-aged and four even-aged reproductive cutting methods. In addition, two control treatments were implemented to represent two extremes of a continuum ranging from minimal human intervention to the most intensive.

A detailed description of the reproduction cutting treatments was presented by Baker (1994). A brief description of the 11 treatments is provided here:

Controls

1. Unmanaged control (UM): No management activities. Pretreatment condition.

2. Clearcut control (CC): Harvest all pines and hardwoods except 2–5 ft^2/ac of hardwoods retained for mast production and den trees. Inject all other trees with herbicide, mechanically rip on 10 ft centers, and plant genetically improved shortleaf pine seedlings.

Uneven-Aged Methods

3. Low-impact, pine/hardwood single-tree selection (LI-STS): Harvest some pines and hardwoods using single-tree selection; residual basal areas range between 60–80 ft^2/ac.

4. Pine/hardwood single-tree selection (PH-STS): Harvest pines and hardwoods using single-tree selection leaving 45–65 ft^2/ac basal area, with 5–20 ft^2/ac being hardwoods.

5. Pine single-tree selection (P-STS): Harvest pines using single-tree selection leaving 45–65 ft^2/ac in pine. All hardwoods were harvested or removed except 2–5 ft^2/ac for den trees and mast production.

6. Pine/hardwood group selection (PH-GS): All pines and hardwoods were harvested in openings ranging from about 0.1 to 1.0 ac. Residual basal area of hardwoods in openings ranged from 5–10 ft^2/ac. Pine basal area outside of group openings was reduced to 70–80 ft^2/ac.

7. Pine group selection (P-GS): Same as pine/hardwood group selection, except no hardwoods were left in openings.

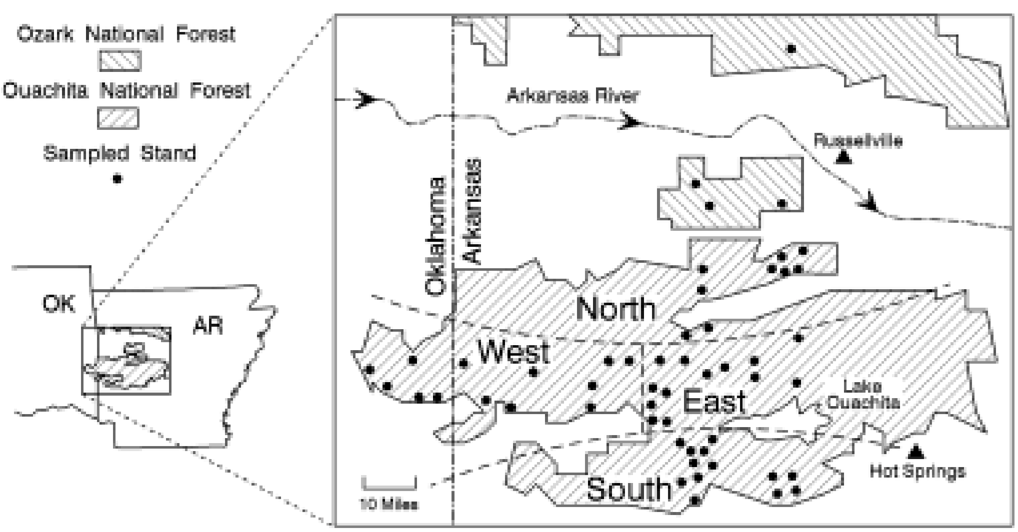

Figure 1. Location of stands sampled for shortleaf pine seed production in central Arkansas and eastern Oklahoma. Ouachita Mountains were subdivided into North, East, South, and West Ecoregions within the Ouachita and Ozark National Forests.

Even-Aged Methods

8. Pine/hardwood shelterwood (PH-SW): A total of 20 to 40 of the largest pines and hardwoods were retained for a total basal area of 30–40 ft^2/ac, of which 5–15 ft^2/ac was hardwood. All other trees were harvested or removed.

9. Pine shelterwood (P-SW): A total of 20 to 40 of the largest pines were retained with a basal area of 30–40 ft^2/ac. All other trees were harvested or removed except for 2–5 ft^2/ac of hardwood retained for den trees and mast production.

10. Pine/hardwood seed tree (PH-ST): A total of 10 to 15 of the largest pines and hardwoods with a basal area of 10–20 ft^2/ac were retained; 5–15 ft^2/ac was in hardwoods. All other pines and hardwoods were removed except those retained for den trees and mast production as in other treatments.

11. Pine seed tree (P-ST): A total of 10 to 15 of the largest pine trees with a basal area of 10–20 ft^2/ac were retained. All other pines and hardwoods were removed except those retained for den trees and mast production as in other treatments.

There was one stand per treatment in each of the four ecoregions except for the PH-SW and PH-STS treatments, which had two stands per ecoregion. This resulted in a total of 52 stands for the study. Duplicate stands for the PH-SW and PH-STS treatments were used to allow other monitoring activities associated with the overall ecosystem management study (Baker 1994). In the 24 stands representing six treatments (PH-STS, P-STS, PH-SW, P-SW, PH-ST, and P-ST), each stand was subdivided into quarters perpendicular to the slope to impose four site preparation treatments for removal of hardwoods (stems ≥ 2 in. dbh) that were not designated for retention: herbicides (triclopyr amine) applied as a cut-surface application; manual felling; no control but with future release; and no control at any time. In the LI-STS stands, the herbicide site preparation treatment was not implemented, and no site preparation at all was imposed in the UM control. The 20 remaining stands, including the duplicate PH-STS and PH-SW stands, were treated entirely with manual felling. Stands that were not split for site preparation were quartered for the purposes of seed collection so that the sampling procedure was the same in all stands. Site preparation treatments were imposed following collection of the 1993 seed crop.

Data Collection

Each stand quarter was stratified into upper, middle, and lower slope positions, and two stand quarters were randomly selected for locating seed traps in each slope position. A plot center was randomly located within each subdivision. At these six plot centers, two per slope position, three seed collection traps were positioned 22 ft from center on azimuths of 0, 120, and 240 degrees. There was a total of 18 seed traps per stand. Seed traps consisted of metal wastebaskets, modified to provide for drainage and measuring 0.86 ft^2 (Cain and Shelton 1993). Seeds and debris were collected during February and March each year from 1994 through 1997 to estimate seed production for the crops dispersed during Fall 1993 through 1996.

Seeds were separated from debris and counted to estimate total seed production. Seed quality for the 1993 through 1995 seed crops was evaluated by radiographic examination (Bramlett et al. 1977) at the Forest Service Seed Laboratory in Macon, GA. Seeds from the 1996 crop were evaluated by cut testing (Bonner 1974). In both tests, seeds that were fully filled and had fully developed embryos were considered sound. Radiographic examination and cut testing have been shown to provide virtually the same results (Mangini et al. 1994).

Data Analysis

The six treatments, which were split for site preparation treatments (PH-STS, P-STS, PH-SW, P-SW, PH-ST, and P-ST), were initially analyzed separately so that the effects of site preparation could be isolated. Seed data for 1993 were not used in the analysis because site preparation had not been applied until seed collection was completed. A split-plot design was used with the silvicultural system/hardwood retention treatment as whole plots, site preparation treatment as subplots, and ecoregions as the blocking factor. Site preparation treatment and its interaction with the silvicultural system/hardwood retention treatment were not significant ($P > 0.05$) for individual years. Thus, values for the site preparation treatments were combined, and means were calculated for the 18 traps representing each stand. Seed production data for each year for all 52 stands were then analyzed as a randomized complete block design with ecoregions being the blocking factor. When the analysis of variance indicated significant effects, means were separated using Tukey's studentized range test at $\alpha = 0.05$. A regression equation was developed using nonlinear least squares regression for predicting the percentage of total seeds that were sound. Only stands with three or more seeds collected for the seed year were used. All regression coefficients reported were significantly different from zero at a probability of less than 0.05. The reported fit index for regression equations is analogous to the coefficient of determination reported for linear regressions.

Results and Discussion

Seed Production Trends

Seed production for the study period was characterized by wide variation between years and stand condition, ranging from 0 to 600,000 sound seeds/ac (Table 1). Average annual production can be classified as good, poor, poor, and bumper for 1993, 1994, 1995, and 1996, respectively, using the classes for potential adequacy of seed crops for establishing natural regeneration suggested by Shelton and Wittwer (1996). This production generally falls in the range found in a 9 yr study (1965–1973) including over 70 stands throughout the Ouachita and Ozark Mountains. Mean annual production ranged from total failures to over 700,000 sound seeds/ac (Shelton and Wittwer 1996). Production in the range of 2–3 million seeds/ac has been found for individual stands in some years [Shelton and Wittwer 1996, Wittwer and Shelton (in press)].

Table 1. Mean production of sound seeds over a 4 yr period by treatments manipulating stand composition and imposing different silvicultural systems in mature shortleaf pine-hardwood stands of the Ouachita Mountains. Treatments are listed in order of decreasing basal area in retained trees.

Treatment*	Seed year 1993	1994	1995	1996
	(1,000 sound seeds/ac)			
UM	453a†	8	10	430
LI-STS	174ab	66	5	438
PH-STS	90b	27	9	333
P-STS	56b	7	2	593
PH-SW	85b	29	10	600
P-SW	196ab	13	6	585
PH-ST	38b	1	0	209
P-ST	13b	18	4	413
PH-GS††	76b	0	3	61
P-GS	53b	5	2	259
CC	5b	1	0	73
Mean	109	18	5	379
Statistics				
MSE	21,540	1,701	147	90,818
P	0.01	0.50	0.91	0.07

* Compositions are: P = pine, PH = pine-hardwood. Silvicultural systems are: UM = unmanaged, LI = low intensity, STS = single-tree selection, GS = group selection, SW = shelterwood, ST = seedtree, and CC = clearcut.
† Means of a column followed by different letters differ at α = 0.05.
†† Sampled near the center of openings.

Effects of stand treatments were significantly different only in the first year (1993) following harvest. In that year, extremes in the range of seed production were in the two control treatments representing the extremes in disturbance; the unmanaged stands exhibited the greatest seed production, and not surprisingly, the least seed production was observed in the clearcut opening. Seed production in the various even- and uneven-aged reproduction methods in 1993 was generally correlated with the basal area level of residual shortleaf pines. The UM (453,000 seeds/ac), LI-STS (174,000 seeds/ac), and P-SW (196,000 seeds/ac) treatments produced the most seeds, and ST stands (26,000 seeds/ac) produced the fewest.

Following two poor seed crops in 1994 and 1995, bumper production occurred in 1996. There were no significant differences among reproduction cutting methods, and most reproduction cutting methods produced over 100,000 sound seeds/ac. This result is likely due to the effects of release and response of residual pines in treatments with lower initial densities such as the seed tree and shelterwood treatments. Baker (1992) suggested that shortleaf pine stands to be reproduced by the seed tree method should be thinned 3–5 yr before harvest to 60–70 ft^2/ac to release potential seed trees and enhance seed production. The average pretreatment basal area of stands in this study was 130 ft^2/ac in trees >3.5 in. dbh with over 25% in hardwoods (Guldin et al. 1994), and seed production by residual pines was limited immediately following harvest by crown condition and vigor.

Significant differences in seed production were found among ecogregions (Table 2). There was a tendency for the North (Arkansas Valley) and East (eastern upper Ouachita Mountains) Ecoregions to produce more seeds, and the West Ecoregion fewer seeds, with the South Ecoregion ranking intermediate. In the bumper seed year (1996), production in the West Ecoregion was only 23 to 36% of that in other ecoregions. The trend for lower seed production along the western limit of the natural range of shortleaf pine has also been found in other studies [Shelton and Wittwer 1996, Wittwer and Shelton (in press)].

The shortleaf pine seed production observed in this study was characterized by large year-to-year variation. In shortleaf pine, more than 2 yr elapse between flower bud initiation and seed maturation. During that time at least five chemical and

Table 2. Regional variation in mean production of sound seeds over a 4 yr period in mature shortleaf pine-hardwood stands in the Ouachita Mountains.

Ecoregion	Seed year 1993	1994	1995	1996
	(1,000 sound seeds/ac)			
North	85b*	58a	1	583a
East	227a	5b	11	376ab
South	73b	6b	9	420ab
West	50b	2b	0	137b
Mean	109	18	5	379
Statistics				
MSE	21,540	1,701	147	90,818
P	0.02	<0.01	0.05	0.01

* Means of a column followed by different letters differ at α = 0.05.

physiological mechanisms contribute to the pine reproductive cycle: hormones, nutrients, soil moisture, light, and temperature (Barnett and Haugen 1995). Variation in weather conditions is one of the leading causes of fluctuations in these five mechanisms. Some adverse effects of weather on the pine reproductive cycle are very apparent. For example, Schoenike (1955) observed that heavy rains (8 in. in 4 days) coincided with peak pine pollen dispersal in southeast Arkansas and washed tremendous quantities of pollen onto the ground just when the flowers were at maximum receptivity; this resulted in a pine seed crop failure. Others have observed that late spring frosts have damaged shortleaf pine flowers (Campbell 1955, Bramlett 1972). In contrast, other effects of weather on the pine reproductive cycle are more subtle. In long-term studies of seed production in loblolly (*Pinus taeda* L.) and shortleaf pine, both Lamb et al. (1973) and Cain and Shelton (2000) observed that precipitation during the late growing season of the year during flower bud initiation was positively correlated with seed production 2 yr later when the seeds developing from those flowers matured. Although statistically significant, the observed relationships were too weak to be of much predictive value. Much of the wide variation observed in shortleaf pine seed crops in the Ouachita Mountains is probably due to variation in weather conditions. In addition, the lower seed production of the western portion of the Ouachita Mountains may reflect its lower precipitation during critical periods of the reproductive cycle.

Seed Quality

The percentage of sound seeds was positively related to total seed production (Figure 2). Values ranged from less than 20% in years with the lower seed production (<100,000 seeds/ac) to over 60% in good or better seed years. A 9 yr study conducted between 1965 and 1973 found sound seeds to be about 30% of total production in poor seed years and 70% of total production in years with good or better crops (Shelton and Wittwer 1996). Void and defective seeds result from several factors, which are not greatly influenced by management in natural stands. These factors include lack of pollen, lethal gene combinations, self-pollination, insect damage, and climatic factors (Fatzinger et al. 1980).

Management Implications

Of the factors influencing natural regeneration of shortleaf pines, seed production is perhaps least subject to management through silvicultural treatments. Competing vegetation and seedbed conditions can be manipulated with an array of site preparation techniques. However, most of the environmental and biotic factors influencing flowering, and cone and seed development are not subject to much control through silvicultural manipulation.

This study showed a relationship between residual stand density levels associated with various reproduction cutting methods and seed production. Seed production immediately following harvest in a moderately good seed year was generally related to density of residual shortleaf pines—greater numbers of pines in unharvested controls or selection stands produced more seeds. It should be remembered that flowering, pollination, fertilization, and development of 1-yr-old cones for the 1993 seed crop occurred before application of harvesting treatments in this study.

Stand densities in these mature stands were relatively high before treatment, often with a significant hardwood component. These conditions are not conducive to optimum seed production. The effects of releasing trees through reproduction cutting can be seen by comparing the good crop in 1993 with the bumper crop in 1996. While seed production for the unmanaged control treatment was very comparable for 1993 and 1996 (453 versus 430 thousand seeds/ac), production for seed tree and shelterwood treatments was 3 to 30 times greater in 1996. While environmental conditions and biotic factors influencing seed production were most likely more favorable for production of the 1996 crop, part of the increase can also be attributed to response of residual trees following the release provided by application of the reproduction cuttings.

The irregular pattern of annual seed crops has greater consequences for even-aged silvicultural systems since an

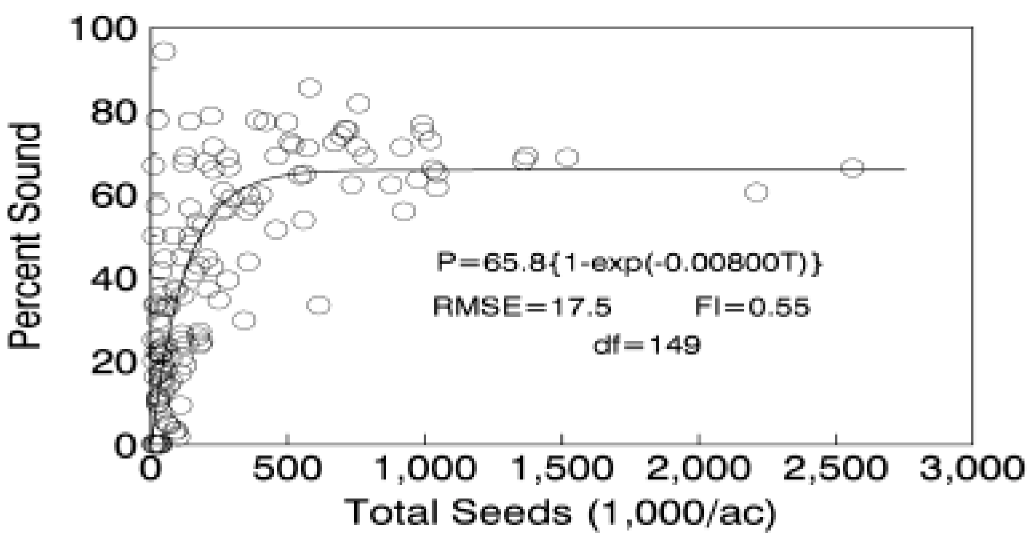

Figure 2. Percentage of sound seeds (P) in the total seed crop (T) of mature shortleaf pine-hardwood stands in the Ouachita Mountains from 1993–1996. RMSE = root mean square error.

investment in site preparation followed by prompt regeneration constitutes the idealized scenario—poor seed crops can result in wasted site preparation efforts and slow restocking of the harvested site. Uneven-aged systems maintain a relatively high level of stocking and provide for a longer window of opportunity to attain successful regeneration. Options for foresters using even-aged systems in areas with erratic seed production include: (1) giving close attention to stand density levels and release of potential seed producing trees, and (2) observing flowering and cone production trends in order to coordinate harvesting and site preparation when good seed crops are anticipated.

Literature Cited

Baker, J.B. 1992. Natural regeneration of shortleaf pine. P. 102–112 *in* Proc. of the shortleaf pine regeneration workshop, Brissette, J.C., and J.P. Barnett (comps.). USDA For. Serv. Gen. Tech. Rep. SO-90.

Baker, J.B. 1994. An overview of stand-level ecosystem management research in the Ouachita/Ozark National Forests. P. 18–28 *in* Proc. of symp. on ecosystem management research in the Ouachita Mountains: Pretreatment conditions and preliminary findings, Baker, J.B. (comp.). USDA For. Serv. Gen. Tech. Rep. SO-112.

Barnett, J.P., and R.O. Haugen. 1995. Producing seed crops to naturally regenerate southern pines. USDA For. Serv. Res. Pap. SO-286. 10 p.

Bonner, F.T. 1974. Seed testing. P. 136–152 *in* Seed of woody plants in the United States, Schopmeyer, C.S. (tech. coord.). USDA Agric. Handb. 450.

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(1):31–33.

Bramlett, D.L., III, et al. 1977. Cone analysis of southern pines, a guidebook. USDA For. Serv. Gen. Tech. Rep. SE-13. 28 p.

Cain, M.D., and M.G. Shelton. 1993. Modification of GSA metal wastebaskets for use as seed and litter traps. Eng. Field Notes 26(3):65–69.

Cain, M.D., and M.G. Shelton. 2000. Revisiting the relationship between common weather variables and loblolly shortleaf pine seed crops in natural stands. New For. 19(2):187–204.

Campbell, T.E. 1955. Freeze damages shortleaf pine flowers. J. For. 53(6):452.

Clingenpeel, J.A., and B.G. Cochran. 1992. Using physical, chemical, and biological indicators to assess water quality on the Ouachita National Forest utilizing basin area stream survey methods. Proc. Ark. Acad. Sci. 46:33–35.

Fatzinger, C.W., G.D. Hertel, E.P. Merkel, W.D. Pepper, and S.R. Cameron. 1980. Identification and sequential occurrence of mortality factors affecting seed yields of southern pine seed orchards. USDA For. Serv. Res. Pap. SE-216. 41 p.

Giese, J., B. Keith, M. Maner, R. McDaniel, R. Singleton, and C. Shackleford. 1987. Physical, chemical, and biological characteristics of least-disturbed reference streams in Arkansas' ecoregions: Data analysis. Vol. 2. Dep. Pollution Control and Ecol., State of Arkansas. Little Rock, AR. 148 p.

Guldin, J.M., J.B. Baker, and M.G. Shelton. 1994. Midstory and overstory plants in mature pine/hardwood stands of the Ouachita/Ozark National Forests. P. 29–49 *in* Proc. of symp. on ecosystem management research in the Ouachita Mountains: Pretreatment conditions and preliminary findings, Baker, J.B. (comp.). USDA For. Serv. Gen. Tech. Rep. SO-112.

Lamb, R.C., M.P. Waters, and E.V. Brender. 1973. Apparent influence of weather upon seed production of loblolly pine. USDA For. Serv. Res. Note SE-183. 7 p.

Lawson, E.R. 1986. Natural regeneration of shortleaf pine. P. 53–63 *in* Proc. of symp. on the shortleaf pine ecosystem, Murphy, P.A. (comp.). Univ. Arkansas Coop. Ext. Serv., Monticello, AR.

Lawson, E.R. 1990. *Pinus echinata* Mill. Shortleaf pine. P. 316–326 *in* Silvics of North America, Vol. 1, Conifers, Burns, R.M., and B.H. Honkala (tech. coords.). USDA Agric. Handb. 654.

Mangini, A., C. Carlton, R.W. Perry, and J. Hanula. 1994. Seed, cone, regeneration, and defoliating insects in forest ecosystem management. P. 154–162 *in* Proc. of symp, on ecosystem management research in the Ouachita Mountains: Pretreatment conditions and preliminary findings, Baker, J.B. (comp.). USDA For. Serv. Gen. Tech. Rep. SO-112.

Schoenike, R.E. 1955. Why pine seed crops fail. For. Farmer 14(10):10.

Shelton, M.G., and M.D. Cain. 2000. Regenerating uneven-aged stands of loblolly and shortleaf pines: The current state of knowledge. For. Ecol. Manage. 129(1–3):177–193.

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.

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

Wittwer, R.F., and M.G. Shelton. In press. Shortleaf pine seed production following partial cutting in the Ouachita Mountains. *In* Proc. of symp. on ecosystem management research in the Ouachita and Ozark Mountains, Guldin, J.M. (comp.). USDA For. Serv. Gen. Tech. Rep. South. Res. Sta.