Shortleaf Pine Seed Production in Natural Stands in the Ouachita and Ozark Mountains

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ABSTRACT. *Seed production of shortleaf pine (*Pinus echinata *Mill.) was monitored from 1965 to 1974 to determine the periodicity of seed crops in both woods-run stands and seed-production areas. One bumper and two good seed crops occurred during the 9-yr period. The two largest crops occurred in successive years, then seed production was low for 4 yr before another good crop occurred. Mean annual seed production ranged from 84,000/ac in the western Ouachitas to 167,000/ac in seed-production areas in the southern Ozarks. Certain stand-level variables significantly influenced seed production. Seed production was positively related to stand age and negatively related to pine and hardwood basal areas; although frequently significant, no consistent relationship occurred with stand elevation. Results indicate that shortleaf pine seed production will usually be adequate for natural regeneration within most of the study area. South. J. Appl. For. 20(2):74-80.*

Shortleaf pine is distributed more widely than any other southern pine and is the principal softwood species in the Ouachita and Ozark Mountains of Arkansas, Missouri, and Oklahoma (McWilliams et al. 1986). Within this region natural regeneration can be used to establish even-aged stands of shortleaf pine and to sustain uneven-aged stands (Baker 1992). Natural regeneration may be the best alternative for establishing stands on the large acreage of nonindustrial private lands, because it has lower establishment and capitalization costs than artificial regeneration (Vesikallic 1981, Baker 1982). In addition, natural regeneration will be used increasingly on public lands because reliance on clearcutting and planting is being reduced.

An adequate seed supply, a suitable seedbed, and low levels of competing vegetation are the principal requirements to establish natural shortleaf pine regeneration (Lawson 1986). Although each of these requirements is critical, the seed supply drives the regeneration process, and it is influenced the least by silvicultural control. The periodicity of seed crops is critical for natural regeneration—reliable seed production is a blessing, while irregular seed production is a curse. Planning for natural regeneration can be cavalier when adequate seed crops are produced reliably, but managers must pay greater attention to the timing of harvesting and site preparation when this is not the case. Because seed supply is critical to the success of natural regeneration, a study of seed production in shortleaf pine stands in the Ouachita and Ozark Mountains was established during the mid-1960s (Yocom 1965) and maintained for almost a decade. The study was conducted to determine the amount and variability of shortleaf pine seed production within this region; such information would aid forest managers in planning for natural regeneration.

Methods

Study Area and Stand Selection

The study was conducted in the Ouachita and Ozark Mountains, which extend from southeastern Oklahoma through western and northern Arkansas to southern Missouri

NOTE: The contribution of Herbert A. Yocom (deceased) is gratefully acknowledged. He initiated and maintained this study while a research forester with the Southern Forest Experiment Station's Research Work Unit at Fayetteville/Harrison, AR. The completion of the data-collection phase of the study was unfortunately timed with Yocom's retirement, and the shift in interest from natural to artificial regeneration. Thus, the data have remained unpublished for 2 decades. The Forest Service's Ecosystem Management research initiative in the Ouachita and Ozark National Forests has renewed interest in natural shortleaf pine regeneration and was the stimulus for this publication. The authors also thank the reviewers of this article for their constructive comments.

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(Figure 1). These mountains occupy an area about 100 miles wide and 350 miles long. The study area is situated along the northwestern edge of shortleaf pine's natural range. Topography within the area ranges from rolling to steep, and elevations range from 500 to 2,800 ft above sea level. Upland soils are shallow to medium in depth and are derived from sandstone, shale, and limestone (Graney 1992). Climate is subtropical humid in the southern portion of the study area and temperate continental in the northern portion (Trewartha 1968). Normal daily temperatures average 80°F during July and 40°F during January (U.S. Department of Commerce 1968). The freeze-free period ranges from about 200 to 240 days. Annual precipitation ranges from 40 to 51 in.; it is lowest in the north and west and highest in the south-central part of the study area.

All stands were located in the Ouachita, Ozark, and Mark Twain National Forests. Initial reconnaissance for suitable sampling locations was made by randomly selecting two townships in each range in each National Forest. The search for suitable sampling locations began in the central portion of each township that was readily accessible by road and extended outward. If no suitable stand was found in a particular township, then an adjacent township was substituted. Suitable sampling locations were natural shortleaf pine stands that contained trees of cone producing sizes (≥10 in. dbh) and in which at least 70% of the dominant trees were in the same 20 yr age class. Conditions within a stand also had to be fairly uniform. A total of 65 stands were sampled beginning in 1965, and 9 additional stands (all in the Mark Twain National Forest) were sampled beginning in 1966. The 74 stands chosen for sampling in the randomly selected townships are referred to as woods-run stands. Two stands were dropped from the study because substantial damage occurred after sampling began. Thirteen seed-production areas in the Ozark Mountains were sampled starting in 1966. These stands were managed with the objective of increasing seed production by

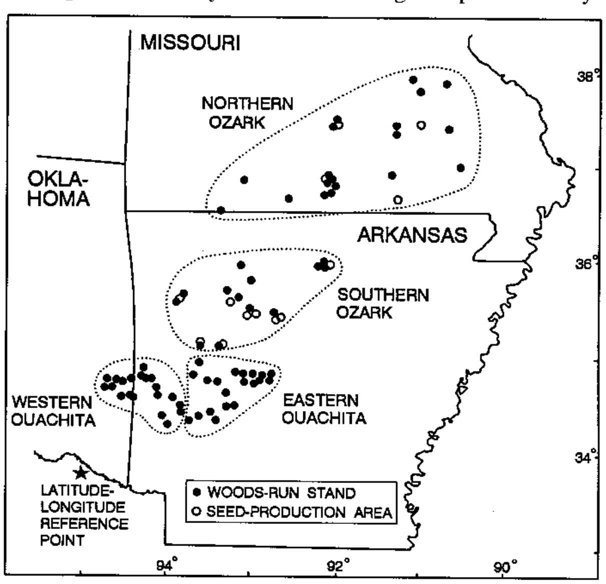

Figure 1. Locations of the woods-run stands and seed-production areas.

thinning to favor the best trees and by controlling hardwood competition (Rudolf et al. 1974). The criteria for selection of the seed-production areas are not known.

The average characteristics of the 72 woods-run stands and 13 seed-production areas are shown in Table 1. No significant differences occurred among the regional means for stand age (62 yr, coefficient of variation = 30%), hardwood basal area (16 ft^2/ac, CV = 121%), and shortleaf pine site index (55 ft at 50 yr, CV = 13%). The site indices measured in this study were comparable to those described for the Ouachita and Ozark Mountains by Graney (1992). Mean shortleaf pine basal area for the woods-run stands (89 ft^2/ac, CV = 39%) was nearly three times as great as that for the seed-production areas (32 ft^2/ac, CV = 58%). Mean elevations ranged from 760 ft (CV = 19%) in the western Ouachitas to 1,400 ft (CV = 37%) in the southern Ozarks.

Data collection

Within each stand, three seed traps (each 6.25 ft^2 in area) were spaced 33 ft apart in a triangular pattern. This sampling intensity provided a within-stand CV for seed production that averaged 51% over all stands and years. Traps were located at least 132 ft from the stand's edge or any other stand irregularity. Sampling in the seed-production areas was restricted to the center of a 400 ft buffer strip where no cone collection occurred. Sampling began by October of each year and a single collection was made in early February of the following year. Collected seeds were counted and evaluated for soundness by cutting and examining their contents. Seeds with full, firm, undamaged, and healthy tissue were judged to be sound (i.e., potentially viable). The study was terminated after 9 annual seed crops were sampled from October 1965 through February 1974. Data from approximately 5% of the 255 seed traps were lost annually due to various mishaps, principally vandalism and adverse weather.

During the first year of seed collection, pine and hardwood basal areas were determined using a BAF 10 prism at the midpoint between seed traps. The dbh of all tallied trees (1 in. and larger) was measured so that number of stems per acre could be calculated. The age and height of the three dominant shortleaf pines that were closest to the midpoint were determined; site indices were determined from these data and site index curves (USDA Forest Service 1929). Latitude, longitude, and elevation of each stand were determined from topographic maps.

Classes for the potential adequacy of seed crops for establishing natural regeneration were adapted from Haney (1962) and Baker (1982) as follows: failure, <10; poor, 10 to <30; fair 30 to <80; good, 80 to <250; and bumper, ≥250 thousand sound seeds/ac. Obviously, this scheme is approximate because the amount of regeneration developing from a seed crop depends on many additional factors. It is, however, intended to show the seed crop's general potential for regeneration if the other factors are favorable. It also assumes that the management objective is to establish a pure pine stand.

Data Analysis

Analysis of variance was used to test for differences among regions in annual seed production. The recognized

Table 1. Mean values of stand and site variables for the regions evaluated for shortleaf pine seed production.

	Region[1]								
Variable	Western Ouachita	Eastern Ouachita	Southern Ozark	Southern Ozark-SPA	Northern Ozark	Northern Ozark-SPA	Overall mean or (total)	Mean square error	$P > F$
Number of stands	20	20	13	9	19	4	(85)	—	—
Age (yr)	62	68	64	59	58	56	62	3.5E2	0.57
Pine basal area[2] (ft^2/ac)	96a	86a	88a	24b	86a	40b	80	1.1E3	0.0001
Hardwood basal area[2] (ft^2/ac)	14	18	18	13	15	12	16	3.7E2	0.94
Site index (ft at 50 yr)	54	55	56	57	54	52	55	5.6E1	0.89
Elevation (ft)	1,080ab	760b	1,350a	1,090ab	1,120a	1,050ab	1,050	8.2E4	0.0001
Latitude[3] (minutes)	54c	58c	120b	100b	200a	200a	110	3.1E2	0.0001
Longitude[3] (minutes)	40c	100b	110b	110b	190a	200a	120	1.1E3	0.0001

[1] Regional means are for woods-run stands unless designated as seed-production areas (SPA). Regional means followed by different letters differ significantly at the 0.05 probability level.
[2] Basal areas of trees 1 in. and larger in dbh. Trees 4 in. and larger in dbh accounted for 99 and 64% of the pine and hardwood basal areas, respectively.
[3] From a point to the southwest of the study area (33°47'N lat., 95°00'E long.).

regions were the eastern and western Ouachitas and the northern and southern Ozarks (Figure 1). For the southern and northern Ozarks, seed-production areas and woods-run stands were considered separate groupings. Means were separated by the Ryan-Einot-Gabriel-Welsch multiple range test at the 0.05–probability level using the SAS procedure GLM (SAS Institute Inc. 1985).

Our initial effort was to develop an overall stand-level prediction equation for seed production that would apply to all regions and years. Site variables were site index, elevation, and stand location (expressed in minutes of latitude and longitude from a common reference point located to the southwest of the study area). Stand variables were basal area, mean dbh, and number of shortleaf pine and hardwoods, pine basal areas in trees of several size classes (e.g., ≥10 in. in dbh, ≥14 in.), and mean age of the dominant pines. A number of equations were tested using both linear and nonlinear regression with little overall success. We tested several different transformations of dependent and independent variables, periodic totals for stand seed production, and standardized annual seed production using regional means and standard deviations to determine a standard deviate for each stand and year. However, no approach was found to give good results for all regions and years. We thus abandoned the goal of developing a general stand-level prediction equation and simply described the annual trends by regions.

Regional trends in annual seed production were determined in the following manner. Stand variables were reduced to pine and hardwood basal areas, which showed the best potential as predictors of the full set of stand-level variables. Site variables used were site index, elevation, latitude, and longitude. All independent variables and annual seed production were transformed logarithmically. For seed production, which had some zero values, a constant value of 1 was added to all values to prevent invalid arguments in the transformations. Seed production, stand, and site data were combined for seed-production areas and woods-run stands for regions in which both occurred. The SAS regression procedure RSQUARE was used to find subsets of independent variables with the greatest coefficients of determination (SAS Institute Inc. 1985). The equation selected was the one in which the coefficient of each variable was significantly different from zero at a probability level of <0.10.

Factors affecting seed quality were investigated by expressing the number of sound seeds as a percentage of the total (i.e., sound and defective). After testing several functions and stand-level variables, the following was selected:

$$P = b_0 T^{b_1}$$

where P is the percentage of total seeds that are sound, T is total seed production (thousands/ac), and the b's are coefficients determined using the nonlinear regression procedure MODEL (SAS Institute Inc. 1988). The fit index reported for this equation is analogous to the coefficient of determination.

Results and Discussion

Annual and Regional Variation

Seed crops within the study area were characterized by wide annual and regional fluctuations. Annual production in individual stands ranged from 0 to more than 2,000,000 sound seeds/ac. One bumper and two good seed crops occurred during the 9 yr monitoring period (Table 2). One of the good crops (1966) and the bumper crop (1967) occurred in successive years, and the second good seed crop occurred 5 yr later (1972). The four intervening seed crops (1968 to 1971) were classified as poor or failures. This trend suggests the lack of any regular periodicity in shortleaf pine seed production within the study area. Apparently, random environmental factors, such as fluctuations in weather or pest populations, have a controlling influence. This has been the general result of other long-term studies of shortleaf pine seed production (Wittwer and Shelton 1992). In contrast, Wenger (1957) found that seed crops in loblolly pine stands in North Carolina were negatively correlated with the crops produced 2 yr earlier.

No significant differences in seed production were observed among regions in 6 of the 9 yr that were monitored or in the 9 yr means (Table 2). In the 3 yr with significant differences, seed production was greatest in the seed-production areas during 2 yr (1969 and 1970) and in woods-runs-stands during 1 yr (1972). Over the 9 yr period, annual seed production averaged 103,000 sound seeds/ac and ranged from a low of 84,000 sound seeds/ac in the western Ouachitas to 167,000 sound seeds/ac in the seed-production areas in the

Table 2. Annual, regional, and overall means for shortleaf pine seed production.

	Region[1]								
Year	Western Ouachita	Eastern Ouachita	Southern Ozark	Southern Ozark-SPA	Northern Ozark	Northern Ozark-SPA	Overall mean	Mean square error	$P > F$
	(thousands of sound seeds/ac)								
1965	3.3	0.8	1.7	—	0.5	—	1.7	1.0E1	0.07
1966	330	230	100	330	70	160	200	8.2E4	0.05
1967	350	300	520	730	580	520	470	2.6E5	0.27
1968	5.4	6.7	3.2	5.9	2.8	0.0	4.6	9.5E1	0.69
1969	22b	71ab	59ab	110a	1b	1b	43	4.1E3	0.0004
1970	1a	10a	14a	55a	54a	120b	29	2.9E3	0.0003
1971	1.4	3.9	0.3	0.3	15.4	2.0	4.9	3.5E2	0.19
1972	31b	210ab	350a	240ab	100ab	3b	160	5.3E4	0.006
1973	11	13	9	28	17	35	15	9.2E2	0.55
Mean[2]	84	94	117	167	93	94	103	7.5E3	0.23

[1] Regional means are for woods-run stands unless designated as seed-production areas SPA). Regional means followed by different letters differ significantly at the 0.05 probability level.
[2] Regional means for SPAs in 1965 were assumed to be equal to those of the woods-runs stands.

southern Ozarks. Stands in the southern Ozarks, in the central portion of the study area, produced about one-third more seed than stands in the western Ouachitas and about one-quarter greater than stands in the northern Ozarks. However, these differences were not significant. Regional differences among the 9 yr means were far less than those observed in individual years, suggesting that regional seed production generally averages out over time. The seed-production areas in the southern Ozarks produced an average of 30% more seeds than did woods-run stands in the same region, but this difference was not significant. In the northern Ozarks, seed-production areas and woods-run stands produced the same average number of seeds. The reason for low productivity in the northern Ozark seed-production areas is unknown.

The success of natural regeneration often depends on a consecutive series of annual seed crops rather than a single one. Thus, seed crops occurring both before (in-place seed and/or seedlings) and after (seeds from the residual stand) the regeneration cut must be considered when evaluating regeneration potential. The opportunity to secure natural shortleaf pine regeneration generally lasts for 3 yr after site preparation, perhaps less on good sites and longer on poor sites (Shelton and Wittwer 1992). Thus, 3 yr totals for seed production are more indicative of the potential for regeneration success than annual values. Three year values for the woods-run stands are presented in Figure 2. If a 3 yr total of 80,000 sound seeds/ac generally yields acceptable regeneration, seed production will usually be adequate for natural regeneration within the study area. The 3 yr total seed production is about 80,000 seeds/ac at the lowest points (1968–1970 and 1969–1971) in all regions except the western Ouachitas. However, there is stand-to-stand variation, so production exceeds 80,000 seeds/ac in some stands but is less than 80,000 seeds/ac in others. Seed production in the western Ouachitas, at the western fringe of the natural range, drops well below 80,000 seeds/ac for all 3 yr periods beyond 1968. Thus, many natural reproduction cuts made in that region from 1968 through at least 1971 would have had a very low seed supply, which would probably result in poor regeneration.

Low values for the western Ouachitas reflect the influence of the fair seed crop produced in 1972, which was generally a good year in the other regions.

When periodic seed crops are low, closer attention must be paid to scheduling treatments for natural regeneration, such as harvesting and site preparation. Techniques for forecasting seed crops (Trousdell 1950, Wenger 1953, Grano 1957) could be very helpful in scheduling treatments and adjusting their intensity. In most situations, site preparation is undoubtedly easier to schedule than reproduction cutting. Site preparation can be deferred until a good seed crop is forecast, or site preparation treatments can be reapplied periodically. Prescribed burning has considerable potential for keeping seedbeds receptive in even-aged reproduction methods and for remedial treatments in uneven-aged stands (Shelton and Wittwer 1992). Shortleaf pine is particularity well suited for prescribed burning because it can sprout when young (Little and Somes 1956). Thus, marginal stocking levels would not be reduced by judicious burning, but rather would be increased by additional regeneration bought about by creating a receptive seedbed. Obviously, burning must take place prior to seed dispersal, which begins in mid October and peaks in November.

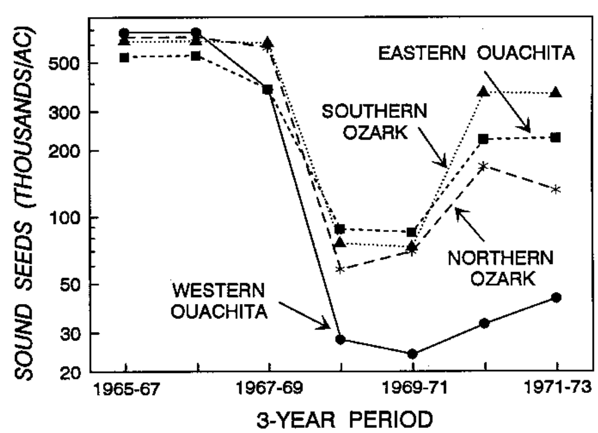

Figure 2. Three year seed production in woods-run stands by period and region.

A cautionary word is needed about interpreting regional seed production averages because stand-to-stand variation can be substantial. For example, an average seed production of 100,000/ac would seem adequate for regeneration, but if this average represented two stands with 10,000 and 190,000 seeds/ac, regeneration in the former would likely result in poorly stocked stands while the latter would be well stocked. To better express this variation, seed production in each of the 72 woods-run stands was classified as to its potential for regeneration success (Figure 3). During the bumper seed crop of 1967, 80% of the stands had good or better seed crops and 5% had poor crops or failures. By contrast, 50% of the stands had good or better seed crops during the generally good year of 1966 (an overall mean of 200,000 seeds/ac), but 40% had poor crops or failures. A few stands may have high yields even in a generally poor year. For example, 5% of the stands had fair and better crops in 1971, when the overall production averaged 4,900 seeds/ac. A similar classification of 3 yr seed production indicates that the seed supply was ample for natural regeneration throughout the entire study area during certain time periods (3 yr periods beginning in 1965, 1966, and 1967). However, seed production would probably limit regeneration success in many stands during other periods (3 yr periods beginning in 1968 and 1969), when only 25% of the stands had good or better seed crops. Such high stand-to-stand variability indicates that although regional trends may indicate the overall seed crop potential, individual stands should be evaluated in areas where the seed supply frequently limits regeneration success.

Stand-Level Influences

Stand-level variables also affected seed production, and examples of the trends occurring from 1966 through 1969 are shown in Table 3. Variables evaluated characterized the stand's vegetation (stand age, pine and hardwood basal areas) and site (site index, elevation, and location). Coefficients of determination ranged from 0.10 to 0.62, and values for the combined regions were generally lower than those for individual regions. Some fairly strong relationships were obtained within regions and years. For example, stand-level variables explained more than 50% of the variation in seed production in the western Ouachitas (1967 and the 4 yr total) and the southern Ozarks (1967 and 1969). However, effects of the variables were not consistently significant and some effects varied in sign. The low correlations found between seed production and stand and site variables are not unique to this study, and they point to the complex array of environmental factors and pest populations that occur over the 2 yr pine reproductive cycle.

Stand age and elevation appeared most frequently in the relationships, being significant in about one-third of the possible cases. Age effects were consistently positive, while elevation effects varied in sign. Hardwood basal area was significant in about one-quarter of the cases and was always negative. Pine basal area was significant in one-fifth of the cases and was usually negative. Site index was significant only twice. Latitude was significant in about one-quarter of the relationships and was usually negative (i.e., a northerly progression was associated with

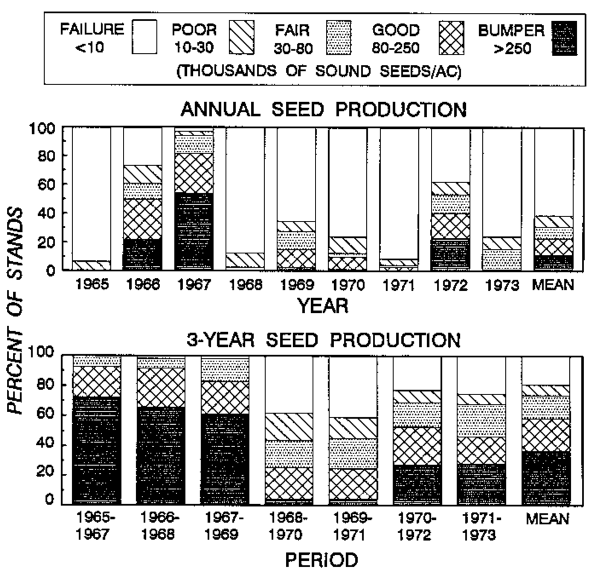

Figure 3. Percentage of woods-run stands by seed production class and year or 3 yr period.

Table 3. Effects of stand-level variables on seed production of selected years.

Region	Variables[1]	Coefficient of determination
	Bumper year (1967)	
Western Ouachita	+AGE +ELEV −PBA	0.55
Eastern Ouachita	+AGE	0.38
Southern Ozark	+LONG −HBA −LAT	0.52
Northern Ozark	—	—
All regions	−HBA +AGE	0.10
	Good year (1966)	
Western Ouachita	+AGE −LONG	0.30
Eastern Ouachita	—	—
Southern Ozark	−LAT −ELEV	0.39
Northern Ozark	−HBA	0.19
All regions	−LAT −ELEV −HBA	0.27
	Fair year (1969)	
Western Ouachita	−ELEV −SI	0.34
Eastern Ouachita	+LAT	0.24
Southern Ozark	+AGE −PBA	0.52
Northern Ozark	—	—
All regions	−ELEV −LAT −PBA	0.29
	Poor year (1968)	
Western Ouachita	−PBA +LONG	0.33
Eastern Ouachita	+ELEV	0.16
Southern Ozark	+ELEV +AGE	0.42
Northern Ozark	+PBA	0.25
All regions	+AGE +ELEV +SI	0.15
	4 yr total production	
Western Ouachita	+AGE +LAT	0.62
Eastern Ouachita	—	—
Southern Ozark	−HBA +LONG −LAT	0.45
Northern Ozark	—	—
All Regions	−HBA +AGE	0.10

[1] AGE = age of dominant shortleaf pines; PBA = shortleaf pine basal area; HBA = hardwood basal area; ELEV = elevation; SI = site index; LAT = north departure in latitude; LONG = east departure in longitude. The sign of the regression coefficient is indicated, although values are not shown. Variables are presented in order of their importance in the regression.

a decline in seed production). When data for all regions were combined, 4 yr total seed production was negatively related to hardwood basal area and positively related to stand age, but the regression explained only 10% of the variation in seed production.

The stand-level variables that were observed to affect seed production are expressions of the stand's developmental stage and general vigor. The effects of these variables were consistent with those observed in other studies of seed production. For example, Yocom (1971) found that hardwood control doubled cone production in shortleaf pine. Phares and Rogers (1962) showed that reducing stand basal area by thinning increased seed production. The variable effect of stand elevation observed in this study may reflect the interaction between elevation and weather events that may have occurred during flowering and cone development. In mountainous terrain, the occurrence of weather events, such as frosts, hail and ice storms, and droughts, is often affected by elevation. Hail storms (McLemore 1977), frosts (Campbell 1955, Hutchinson and Bramlett 1964, Bramlett 1972), and droughts (Schmidtling 1985) have been shown to limit shortleaf pine seed crops.

Seed Quality

The reproduction process in shortleaf pine, as in all plants, is hardly perfect, and many fully developed seeds have some defect that prevents their germination. Void and defective pine seeds result from lethal gene combinations, lack of pollen, self-pollination, insect damage, and environmental factors (Fatzinger et al. 1980). The percentage of sound seeds was positively related to total seed production in this study, with values ranging from 30% in years with poor seed crops to about 70% in bumper years (Figure 4). None of the regional, stand, or site variables were found to affect this relationship significantly. Seed quality has been commonly observed to increase with the better seed crops in other studies of southern pine seed production (e.g., Pomeroy and Korstian 1949, Allen and Trousdell 1961, and Campbell 1967). It probably occurs because good seed crops generally reflect a favorable environment for flower and cone development and that pest populations have a limited potential to damage the better seed crops.

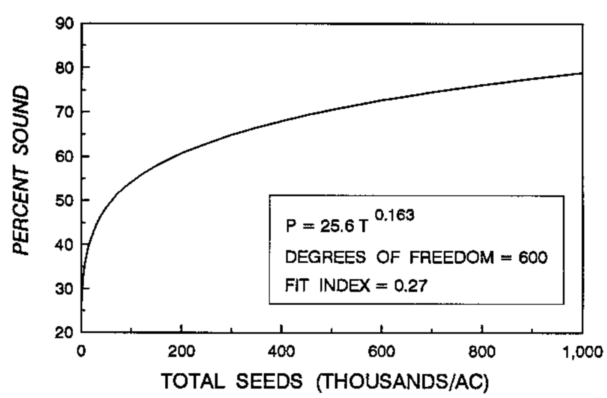

Figure 4. Percentage of sound seeds (P) in the total seed crop (T).

Comparisons with Other Studies

Long-term seed production in the Ouachita and Ozark Mountains (i.e., about 100,000 sound seeds/ac/yr and one-third of the crops good or better) is similar to that elsewhere within shortleaf pine's natural range. Bramlett (1965) found that annual seed production over a 10 yr period increased along a north-to-south gradient; stands in Virginia averaged 23,000 sound seeds/ac, while those in Georgia averaged 181,000 sound seeds/ac. Good crops were not observed in Virginia but occurred in one-half the years in Georgia. In a 5 yr Missouri study, Phares and Rogers (1962) reported that annual means ranged from 250,000 sound seeds/ac at a basal area of 50 ft^2/ac to 50,000 sound seeds/ac in the unharvested control (140 ft^2/ac). Stephenson (1963) found that seed production in seedtree, shelterwood, and selection stands in Texas were similar. Ten year means ranged from 71,000 to 101,000 sound seeds/ac, and four good seed crops occurred in 10 yr. All of these studies indicate that the long-term annual production for shortleaf pine is in the vicinity of 100,000 sound seeds/ac and that three to five good crops occur per decade within the core of its range. However, these good seed crops are not equally distributed through time, and fairly long periods of low seed production may occur.

Conclusions and Management Implications

Shortleaf pine seed crops in the Ouachita and Ozark Mountains were highly variable from 1965 to 1974, ranging from failures to bumper crops. Three good or better seed crops occurred during the 9 yr period, but these crops were not equally distributed through time. There were fairly long periods with low seed production in some areas. This observed feast-or-famine pattern of seed production would have a pronounced influence on the success of natural regeneration within the region. Seed supply for natural regeneration would have been adequate in about two-thirds of the monitored stands and regeneration periods. However, seed production could limit regeneration success in the other one-third of the stands and periods, especially in the western Ouachitas. Bumper seed crops occurred in about one-tenth of the stands and years, and their occurrence could lead to problems with overstocking if coupled with a favorable environment for regeneration. Results of this study also indicate that shortleaf pine significantly contributes to the food source available to many wildlife species, with production of about 2 lb/ac during average years and 10 to 20 lb/ac during bumper years.

This episodic pattern of seed production will likely have greater impacts where even-aged reproduction cutting methods are employed, because uneven-aged silviculture provides multiple opportunities for regeneration and retains higher stocking levels in residual stands. Results of this study indicate that seed production can potentially be increased by silvicultural treatments that promote stand vigor, such as thinning and hardwood control. However, a lag period will occur before the increased seed production is realized because of the 2 yr reproductive cycle. Moreover, this response will take place toward the end of the period of seedbed receptivity, and this will likely reduce its efficacy. Thus, overstocked stands should be thinned to increase tree vigor in preparation of even-aged reproduction cuts. Seed production can also be increased by selecting high-quality dominants and codominants with histories of good cone production as seed trees. Of the even-aged options, the additional seed trees retained by the shelterwood method seem to be justified when seed crops are episodic. The shelterwood method provides higher seed production, sawtimber growth, and litter production, which adds to fuel loads and improves the potential for using prescribed fire as a remedial site preparation treatment. Two strategies can be employed to increase the chances of regeneration success when seed production is a limiting factor: managers can forecast potential seed crops and then schedule and adjust the intensity of harvesting and site preparation accordingly, or they can periodically reapply low-intensity site preparation treatments to keep seedbeds receptive until acceptable seed crops occur.

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