FATE OF THE 2001 ACORN CROP AT CLEAR CREEK STATE FOREST, PENNSYLVANIA

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Abstract.—One of the key steps in the oak regeneration process is the successful germination of acorns into new seedlings. Several factors can greatly reduce or entirely destroy a red oak acorn crop between seed fall in the autumn and germination the following spring. In 2001, a bumper acorn crop occurred on Clear Creek State Forest in Jefferson County, PA. This event coincided with the installation of a root development study and the establishment of an oak silviculture short course for SILVAH. This fortuitous coincidence allowed for a series of three simple experiments to evaluate factors affecting acorn overwintering success and subsequent seedling survival. The crop was estimated at approximately 210,000 acorns per acre for all oak species. Insect infestation of the acorns varied among stands, with infestation rates ranging from 5 to 20 percent. Overwintering success of unburied sound acorns was 20 percent, but burial increased survival to more than 80 percent. Unburied acorns succumbed to desiccation (48 percent), insect infestation (15 percent), disease (15 percent), and consumption by wildlife (2 percent). Seedlings that germinated from acorns outside of deer fences and in dense understory shade had the lowest survival rate (2 percent) during the next 8 years. Excluding the deer or reducing the dense understory shade increased survival rates to approximately 26 percent during the same period. Seedlings in fenced, partial-shade stands had an 8-year survival rate of 56 percent. These data indicate that: 1) oak management activities need to be flexible and opportunistic to take advantage of mast years; 2) there is a several-year window for management following such an event; and 3) dense understory shade and excessive deer browsing are two major obstacles to establishing new oak seedlings, an essential step in the oak regeneration process, at Clear Creek State Forest.

INTRODUCTION

Oak (*Quercus* spp.) forests throughout the eastern United States regenerate through a multi-step process that often takes 10 to 20 years to complete (Sander 1990, Johnson and others 2002). Generally, this process consists of acorn production, seedling establishment from acorns, development of the seedlings into competitive-sized reproduction, and a timely, adequate release of that reproduction (Loftis 2004). Various factors can retard or stop any step in the process, but establishing new oak seedlings from acorns seems especially prone to disruption. For example, acorns and new seedlings can be killed by insects, pathogens, weather, or wildlife. Consequently, the occurrence of mast years is often critical to overwhelm these potential obstacles and start the oak regeneration process in many stands.

Numerous studies, including several conducted in Pennsylvania, have quantified acorn production, documented production periodicity through time, and identified the causes of acorn losses. Sharp (1958) showed that while acorn production is positively correlated with crown size and exposure to sunlight, spring

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weather has a strong influence on annual acorn production, especially on the formation of bumper crops. Marquis and others (1976) documented that acorn production and consumption vary from stand to stand and some locations inherently have less production and/or more consumption than others. Galford and others (1991, 1992) and Auchmoody and others (1994) found that a suite of insects attacks fallen acorns, even during the winter and early spring months. Steiner (1995) and Steiner and Joyce (1999) reported substantial losses of red oak acorns to wildlife, primarily white-tail deer (*Odocoileus virginiana*).

In 2001, a bumper acorn crop occurred throughout northern Pennsylvania. At Clear Creek State Forest (CCSF), this acorn crop coincided with the start of an oak seedling root development study (Brose 2008) and the establishment of a network of regeneration sampling plots for a SILVAH short course emphasizing oak ecology and silviculture. This coincidence allowed for a series of small studies to document 1) the quantity and soundness of the acorns; 2) the proportional losses of acorns to insects, pathogens, weather, and wildlife during the 2001-2002 winter; and 3) survival of the new oak seedlings when subjected to dense shade, partial shade, deer browsing, and no deer browsing through the following 8 years.

STUDY AREA

Clear Creek State Forest (CCSF) is a 13,500-acre property owned and managed by the Pennsylvania Bureau of Forestry in northern Jefferson County, PA (41°18' N, 79°00' W). This location places CCSF in the Appalachian Plateau Province (Schultz 1999), a dissected plateau characterized by broad, flat-topped hills with steep side slopes. Elevations range from 1200 feet a.s.l. in the river valleys to 1800 feet a.s.l. on the summits. Climate is continental; the summers are warm and humid while the winters are cold and snowy. Average annual temperature is 46.4 °F with an average minimum mean of 14.0 °F in January and an average maximum mean of 78.1 °F in July (Zarichansky 1964). Annual precipitation averages 42 inches of rain and 72 inches of snow distributed evenly throughout the year. Growing seasons average 122 days. Generally, soils are loams derived in place from gneiss, schist, and shale parent material. Consequently, these soils are moderately fertile and strongly acidic. Oak site index ranges from 65 to 80 feet at age 50. CCSF contains three forest types: Allegheny hardwood, mixed oak, and northern hardwood. Of these, the mixed oak type is the most common and occupies approximately 85 percent of the land base, and northern red oak (*Q. rubra*) is the most abundant tree species within this forest type. Other common oaks and associated tree species include white oak (*Q. alba*), chestnut oak (*Q. montana*), black oak (*Q. velutina*), red maple (*Acer rubrum*), black birch (*Betula lenta*), black cherry (*Prunus serotina*), American beech (*Fagus grandifolia*), and eastern hemlock (*Tsuga grandifolia*). Nearly all forest stands are about 100 years old, originating after a catastrophic wildfire in 1903.

METHODS

Twelve mature mixed oak stands were selected for this study. Each stand was 10 to 20 acres with oak composing at least 50 percent of the overstory basal area. Six of the stands had been undisturbed for decades and had basal areas ranging from 120 to 145 ft^2/ac. The other six had received the first removal cut of a two-step shelterwood sequence 2 to 5 years earlier. This cut was primarily from below (75:25 ratio) and removed poor quality oaks as well as low value and undesirable trees. Residual basal areas ranged from 75 to 90 ft^2/ac. Half of the shelterwood and uncut stands had been previously fenced with 8-foot high woven wire fence to exclude white-tailed deer. This arrangement created four treatments—uncut/unfenced (control), uncut/fenced, cut/unfenced, and cut/fenced—with three replications of each. In all 12 stands, a systematic grid of 12-foot-diameter regeneration plots was installed at a density of one plot per acre for a total of 188 plots.

To estimate acorn production and determine seed viability (Study 1), the regeneration plots in the six uncut stands were sub-sampled using four 1-ft^2 quadrats per plot. These quadrats were placed systematically at the edge of each plot and the acorns in them were collected between mid-October and mid-November 2001. Because of time and work constraints, collections were done only once. Collected acorns were tallied by oak family (red or white) and immersed in water to separate sound from infested acorns (Olsen 1974). In this method, sound acorns sink while infested ones float. A random subsample of 100 sound acorns per oak family from each stand was dissected to determine the infestation rate because the flotation method will not detect all infested acorns (Olsen 1974).

To determine overwintering losses of red oak acorns (Study 2), three fenced and three unfenced stands were randomly chosen and in each, four 12-foot × 24-foot planting plots were established in early November 2001 (after the majority of acorns had fallen). In each stand, all acorns were removed by hand from each planting plot and the plot was then randomly assigned to one of four treatments: litter (control), hardware cloth, buried, and buried/hardware cloth. In each planting plot, 384 sound northern red oak (NRO) acorns from a single mother tree were uniformly placed at a density of 16 acorns per square yard. In the control treatment, the acorns were placed among the leaf litter to simulate naturally fallen acorns. The hardware cloth treatment was prepared the same as the control except ¼-inch wire screen was placed on top of each plot and fastened to the ground with sod staples to exclude predation by wildlife. In the buried treatment, the leaf litter was raked from each plot; then it was tilled with a front-tine rototiller to scarify the soil. The acorns were then placed approximately 1 inch into the soil. The buried/hardware cloth treatment was prepared the same as the buried treatment except ¼-inch wire screen was placed on top of each plot and fastened to the ground with sod staples to exclude predation by wildlife. Acorns that had not germinated by July 2002 were collected and dissected to determine whether they died from disease, insects, or weather. Acorns containing larvae or signs of prior insect infestation (exit holes, frass) were classified as having been killed by insects. Acorns that had begun to germinate, but stopped and had fungal mycelium inside the shell, were classified as having been killed by disease. Weather-killed acorns were those that failed to germinate, but had no evidence of insect infestation or fungal infection. Missing acorns were assumed eaten by wildlife.

To determine the impact of deer browsing and dense understory shade on the long-term survival of the new NRO seedlings (Study 3), they were tallied annually from 2002 to 2009 in late summer in each of the 188 regeneration plots.

For the acorn production and viability study, analysis of variance (ANOVA) with the Student-Keuls mean separation test (SAS Institute, Inc. Cary, NC, 2000) was used to detect differences among the six stands regarding the average number of acorns by family and by soundness. For the acorn overwintering study, the proportion of acorns germinating in each planting plot was calculated. These data were arcsine transformed and ANOVA was used to detect differences among the eight treatments (buried, buried/fenced, in litter, in litter/fenced, buried/protected, in litter/protected, buried/fenced/protected, and in litter/fenced/protected). In addition, the proportion of acorns that failed to germinate was calculated for all the planting plots in unburied treatments. These data were arcsine transformed and ANOVA was used to detect differences among the four mortality agents (disease, insect, weather, and wildlife). For the seedling survival study, the annual survival rate relative to the initial (2002) seedling counts was calculated for each of the 12 stands, and then repeated-measures ANOVA was used to test for differences among the control, no deer, reduced shade, and no deer/reduced shade treatments. For all tests, residuals were analyzed to ensure ANOVA assumptions were met and alpha was 0.05.

RESULTS

Stand-level acorn production in fall 2001 varied among stands (Table 1). Average acorn production ranged from 169,000 ± 36,000 acorns per acre at Spring Creek to 247,000 ± 41,000 acorns per acre at Pine Run. However, these differences were not significant ($p = 0.0641$). Acorn production differed between red and white oaks within stands and reflected the composition of the overstory trees. The Edeburn, Jimtown, and Lonestar stands were dominated by chestnut and white oaks and their acorns accounted for 61 to 94 percent of the acorns collected. Conversely, Pine Run and Spring Creek were red oak stands and those acorns accounted for 69 percent of the acorns collected. McNeil had an approximately even mix of red and white oaks and the ratio of their acorns was 51:49. There was no difference in the distribution of sound acorns among stands as acorn soundness ranged from 80 to 95 percent. Likewise, no differences were found in the soundness rate between red and white oak acorns in any of the stands. The flotation method did a good job separating sound from unviable acorns as the subsampling of sound acorns revealed an insect infestation rate between 1 and 3 percent.

Overwintering survival of red oak acorns was affected only by whether the acorn was buried or in the leaf litter on the forest floor (Fig. 1). Acorns placed in the leaf litter had overwintering survival rates of 15.7 to 22.6 percent while buried acorns survived at significantly higher rates (73.0 to 91.5 percent). Addition of deer fencing and/or hardware cloth did not alter overwintering survival rates, regardless of whether the acorn was in the litter or buried in the forest floor. Examination of the red oak acorns placed in the leaf litter that failed to germinate revealed differences among the four mortality agents (Fig. 2). Winter weather, specifically desiccation, killed 48 percent of the acorns, the most of any of the mortality agents. Disease and insects each accounted for 15 percent of the overwintering losses. Two percent of the acorns were not recovered and their removal is attributed to consumption by wildlife.

Deer fencing and reducing dense understory shade affected survival of the new red oak seedlings from 2002 to 2009 (Fig. 3). Seedlings in dense shade and exposed to deer browsing had the lowest survival rate, regardless of year; by 2009, only 2 percent of the seedlings were still alive. There was no difference in seedling survival rates between fencing and partial shade removal, regardless of year, as both increased seedling survival rates relative to the control. This difference became evident in 2005 and persisted until 2009, when the average survival rate of the two treatments was 26 percent. The combination of fencing and partial shade removal had the highest survival rate (56 percent) of the four treatments. The difference between fence/shade reduction and the other treatments became evident in 2003 and persisted to the end of the study. Acorn crops from 2002 to 2008 were almost nonexistent and no new oak seedling establishment was observed in any of the plots.

Table 1.—Acorn production (mean ± 1 SE) of six mixed-oak stands at Clear Creek State Forest in Fall 2001. Means followed by different letters *within a column* are statistically different at the 0.05 level.

Stand	Red oak	White oak	Total	Sound
	1000/acre			(%)
Edeburn	10 ± 3d	162 ± 37a	172 ± 38a	83 ± 7a
Jimtown	80 ± 11bc	160 ± 40a	241 ± 38a	94 ± 8a
Lonestar	67 ± 8bc	106 ± 40ab	173 ± 35a	80 ± 5a
McNeil	125 ± 17ab	119 ± 41ab	244 ± 40a	95 ± 7a
Pine Run	172 ± 43a	75 ± 7b	247 ± 41a	92 ± 8a
Sp. Creek	118 ± 30ab	51 ± 14b	169 ± 36a	82 ± 5a

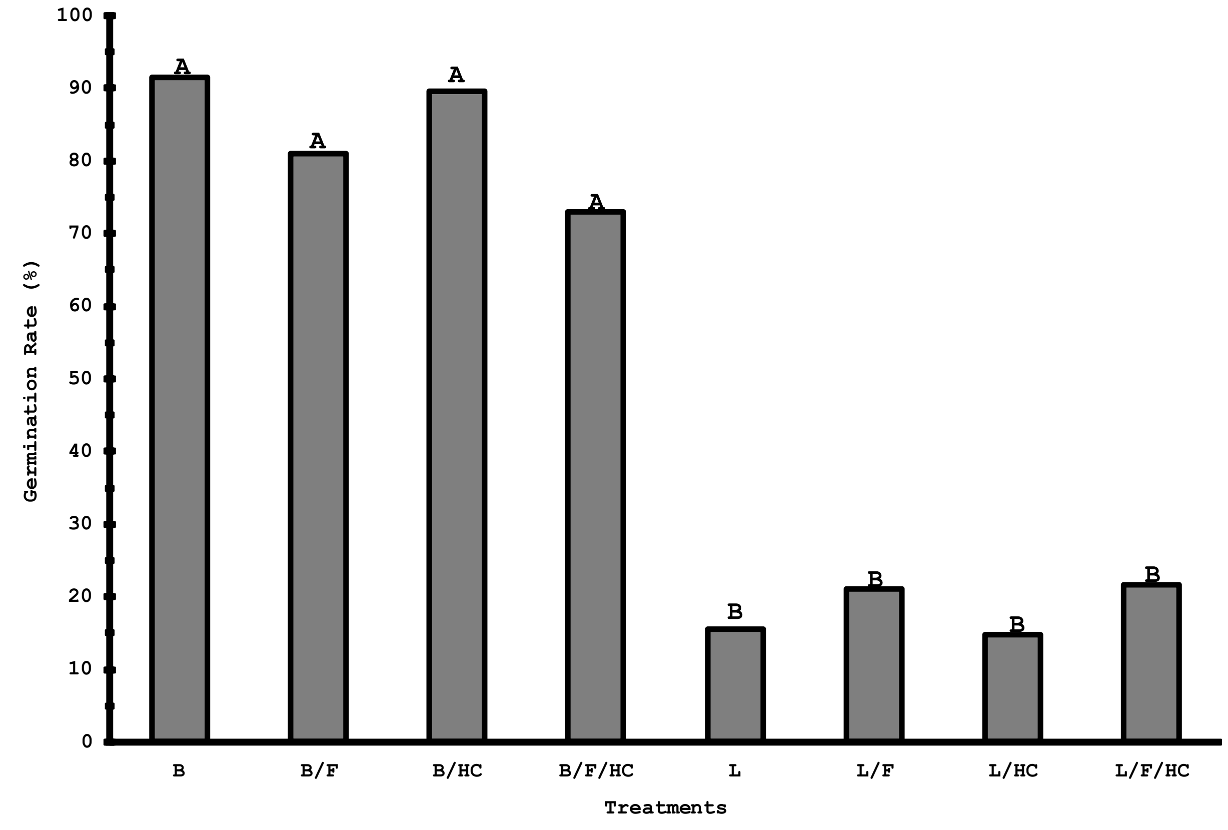

Figure 1.—The effects of position (B and L) and protection from wildlife (F and HC) on the overwintering survival and subsequent germination of red oak acorns at Clear Creek State Forest, Pennsylvania. Treatment abbreviations are: B = Buried in soil, L = placed in leaf litter, F = inside a deer fence, and HC = covered with hardware cloth. Bars with different letters above them are statistically different at the 0.05 level.

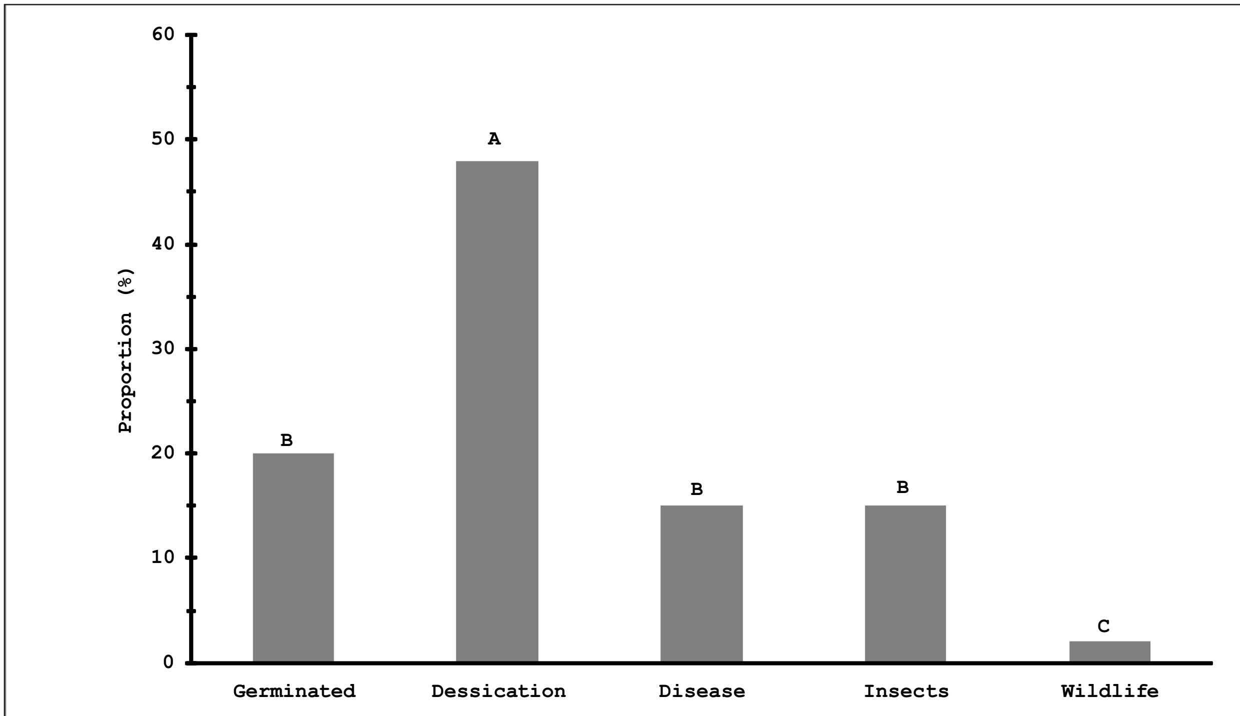

Figure 2.—Overwintering fate (germinated, desiccated, infected by disease, infested by insects, lost to wildlife) of red oak acorns placed in forest floor litter during the 2001-2002 winter at Clear Creek State Forest, Pennsylvania. Bars with different letters above them are statistically different at the 0.05 level.

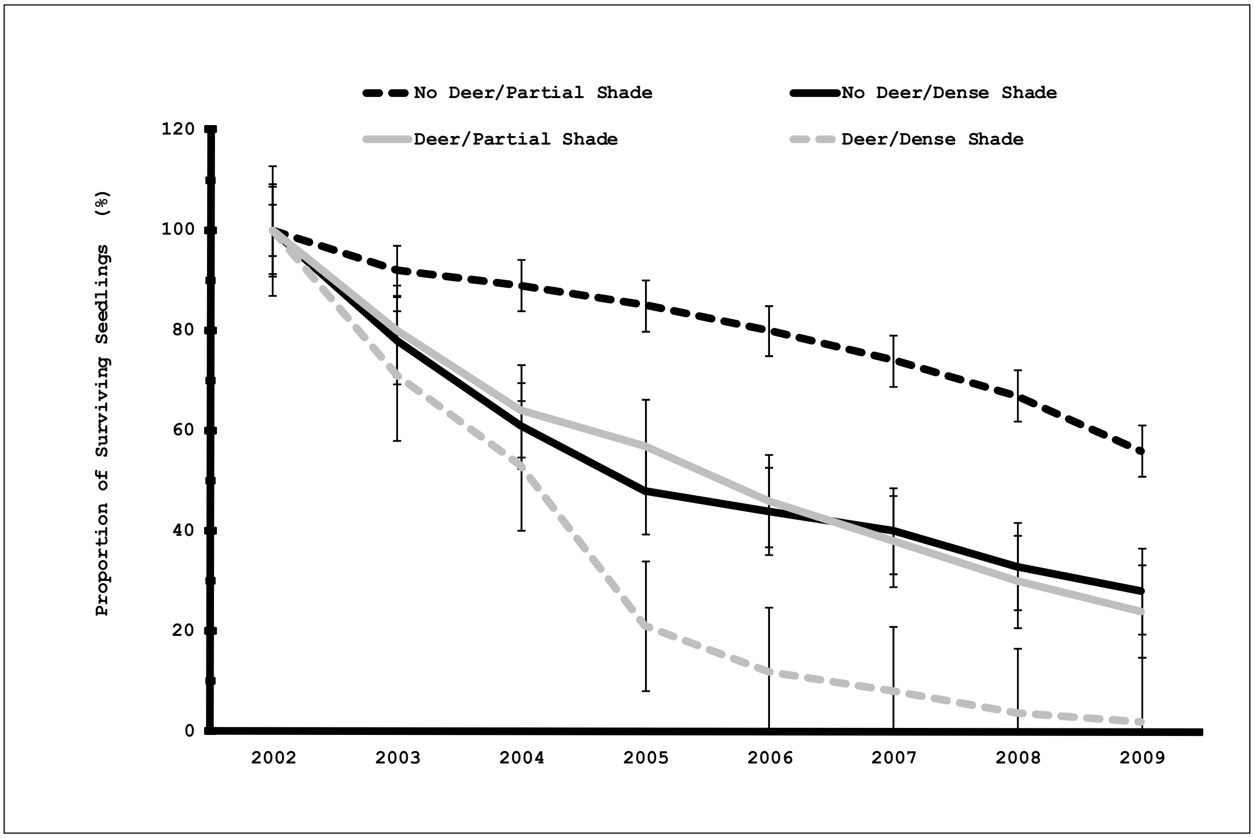

Figure 3.—Survival trends by treatment for red oak seedlings from 2002 to 2009 at Clear Creek State Forest, Pennsylvania. Vertical bars represent one standard error.

DISCUSSION

A critical part of sustainable oak management is the periodic establishment of new cohorts of oak seedlings. Without that occurrence, many oak stands will eventually convert to other forest types because post-harvest sprouting from stumps is usually insufficient to provide enough new stems to ensure a comparable oak stand in the future. Therefore, understanding the factors that limit acorn survival and the ensuing new seedlings is important in prescribing appropriate silvicultural treatments to maintain mixed oak forests. This study reiterates some well known facts about acorn production and survival and places that information in a context important to managers.

The estimate of a 169,000 to 247,000 acorns per acre is conservative. Acorns were tallied only once in each stand, not collected continuously in acorn traps. Counting acorns in quadrats misses those already removed by wildlife and those still in the trees. In a nearby state forest, an oak regeneration study that used seed traps estimated the 2001 mast crop to be 250,000 to 300,000 acorns per acre (pers. comm., Kurt Gottschalk, Research Forester). Furthermore, work scheduling dictated that the Edeburn, Lonestar, and Spring Creek stands were inventoried in mid-October before all the acorns had fallen. Thus, these three stands had fewer tallied acorns than did the other stands.

The small loss of acorns to insects and wildlife is considerably less than the 46 to 87 percent rate reported in other oak literature for Pennsylvania (Marquis and others 1976, Galford and others 1991, Steiner 1995). This discrepancy is likely due to four factors: 1) the phenomenon of masting (Koenig and Knops 2002); 2) timing of acorn placement; 3) changes in hunting laws; and 4) the probability of consumption. In masting, several consecutive years of poor seed crops cause low populations of acorn insects and small mammals. Then, a mast year literally "floods the market" with more acorns than the baseline insect and wildlife populations can possibly use, ensuring that some of the acorns survive to germinate and become seedlings. This phenomenon was present in this study. The 2001 acorn crop was a bumper crop; the previous mast year occurred in 1991 and there were no or poor crops during the intervening years (pers. comm., Herb Landes, District Forester). Regarding timing, acorns were placed in the plots in early November. By that time, some small mammals such as chipmunks (*Tamias striatus*) and tree squirrels (*Sciurus* spp.) had nearly completed their seed caching and were becoming less active. Moreover, the Pennsylvania Game Commission had recently changed its deer hunting laws, resulting in larger doe harvests. Finally, the probability of consumption is that the chance that wildlife would eat any particular acorn decreases as the total number of acorns increases. With so many acorns on the ground, the probability that wildlife would consume those placed on the plots was small. If the 2001 acorn crop had not been so massive, if the study had started earlier in the fall, or if the deer hunting laws had not changed, the relative losses to insects and wildlife probably would have been much higher.

The finding that only one out of every five red oak acorns germinated even after a mast year was startling, especially given the modest losses to insects and wildlife. This study suggests that desiccation during the winter was the primary culprit. Red oak acorns must maintain at least 30-percent moisture content to remain viable (Olsen 1974, Sander 1990) and dissection of the ungerminated acorns in 2002 revealed that nearly half of them had simply dried out during the 2001-2002 winter. Weather during those months was cold and windy with little snowfall (NCDC 2003). The lack of snow cover allowed the wind to move the leaf litter and expose the acorns, presumably resulting in their desiccation and death. Conversely, buried acorns were protected from desiccation and germinated at greater than an 80 percent rate. This huge disparity in germination rates between buried and unburied acorns indicates that forestry operations such as a timely harvest or site scarification that incorporates freshly fallen acorns into the upper few inches of forest soil may be valuable treatments in protecting acorns and overcoming this obstacle in the oak regeneration process (Zaczek and Lhotka 2004).

Johnson and others (2002) describe oak forests as either intrinsic or recalcitrant accumulators. Intrinsic forests always have oak reproduction present as seedlings or seedling sprouts. Recalcitrant forests have ephemeral oak seedling cohorts that form immediately after bumper acorn crops and then disappear within a few years. At Clear Creek State Forest, browsing pressure of white-tail deer and the degree of dense understory shade determine whether an oak stand is intrinsic or recalcitrant. When both of these factors were present, only 2 percent of the red oak seedlings survived for 8 years. Surviving seedlings were small and nonvigorous, and had underdeveloped root systems. Excluding deer with a woven-wire fence or harvesting the midstory and some overstory trees increased 8-year survival rates to 28 and 24 percent, respectively. Oak seedling development was better than that observed in the control but still unsatisfactory for stand regeneration purposes. When deer were excluded and there was a partial timber harvest, more than half of the 2002 red oak seedling cohort was still alive in 2009. Equally important, these surviving seedlings were developing vigorous roots and stems so they would be able to successfully compete against reproduction of other tree species following a final overstory harvest. Clearly, ongoing forest management that controls deer populations and dense understory shade is better than no management for sustaining oak forests.

Continuous forest management is rarely done on private land, however, it is not even always feasible on public lands. This study offers some insight on how to handle neglected stands. The oak seedlings in the control treatment did not succumb all at once. Rather, the major die-off occurred in 2004 and 2005, suggesting that a management window does exist in chronically neglected stands for a couple of years immediately after a bumper acorn crop. If site preparation work (removing undesirable seed sources, controlling low shade, reducing deer impact) is not possible, then do no timber harvesting until after a bumper acorn crop has fallen. Because such crops are sporadic and unpredictable, advance planning of a timber harvest is not possible. The 2- to 3-year post-bumper-crop management window nevertheless allows sufficient time to complete a timber sale. Again, ongoing forest management is preferable to this reactionary approach, but this post-bumper-crop strategy is clearly superior to timber harvesting with no regard to the oak regeneration process.

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LITERATURE CITED

Auchmoody, L.R.; Smith, H.C.; Walters, R.S. 1994. **Planting northern red oak acorns: Is size and planting depth important?** Research Paper NE-693. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

Brose, P.H. 2008. **Root development of acorn-origin oak seedlings in shelterwood stands on the Appalachian plateau of northern Pennsylvania: 4-year results.** Forest Ecology and Management. 255: 3374-3381.

Galford, J.R.; Auchmoody, L.R.; Walters, R.S.; Smith, H.C. 1991. **Insects affecting establishment of northern red oak seedlings in central Pennsylvania.** In: McCormick, L.H.; Gottschalk, K.W., eds. Proceedings, 8th Central hardwood forest conference; 1991 March 6-8; State College, PA. Gen. Tech. Rep. NE-148. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 271-280.

Galford, J.R.; Auchmoody, L.R.; Walters, R.S.; Smith, H.C. 1992. **Millipede damage to germinating acorns of northern red oak.** Research Paper NE-667. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 5 p.

Johnson, P.S.; Shifley, S.R.; Rogers, R. 2002. **The ecology and silviculture of oaks.** New York, NY: CABI Publishing. 503 p.

Koenig, W.D.; Knops, J.M. 2002. **The behavioral ecology of masting in oaks.** In: McShea, W.J.; Healy, W.M., eds. Oak forest ecosystems: Ecology and management for wildlife. Baltimore, MD: John Hopkins Press: 129-149.

Loftis, D.L. 2004. **Upland oak regeneration and management.** In: Spetich, M.A., ed. Proceedings, Upland oak ecology symposium: history, current conditions, and sustainability; 2002 October 7-10; Fayetteville, AR. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 163-167.

Marquis, D.A.; Eckert, P.L.; Roach, B.A. 1976. **Acorn weevils, rodents, and deer all contribute to oak-regeneration difficulties in Pennsylvania.** Research Paper NE-356. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 5 p.

Olsen, D.F. 1974. ***Quercus* L. Oak.** In: Schopmeyer, C.S., tech. coord. Seeds of woody plants in the United States. Agric. Handbk. 450. Washington, DC: U.S. Department of Agriculture, Forest Service: 692-704.

Sander, I.L. 1990. ***Quercus rubra* L. Northern red oak.** In: Burns, R.M.; Honkala, B.H., tech. coords. Silvics of North America. Volume 2, Hardwoods. Agric. Handbk. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 727-733.

Schultz, C.H., ed. 1999. **The geology of Pennsylvania.** Harrisburg, PA: Department of Conservation of Natural Resources, Geological Survey. 888 p.

Sharp, W.M. 1958. **Evaluating mast yields in the oaks.** Bull. 635. University Park, PA: Pennsylvania State University Agriculture Experiment Station. 22 p.

Steiner, K.C. 1995. **Autumn predation of northern red oak seed crops.** In: Gottschalk, K.W.; Fosbroke, S.L.C., eds. Proceedings, 10th Central hardwood forest conference; 1995 March 5-8; Morgantown, WV. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 489-494.

Steiner, K.C.; Joyce, B.J. 1999. **Survival and growth of a *Quercus rubra* regeneration cohort during five years following masting.** In: Stringer, J.W.; Loftis, D.L., eds. Proceedings, 12th Central hardwood forest conference; 1999 February 28, March 1-2; Lexington, KY. Gen. Tech. Rep. SRS-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 255-257.

Zaczek, J.J.; Lohtka, J.M. 2004. **Seedling reproduction established with soil scarification with an oak overwood after overstory removal.** Northern Journal of Applied Forestry. 21(1): 5-11.

Zarichansky, J. 1964. **Soil survey of Jefferson County, Pennsylvania.** Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 91 p.