IMPACT OF SOIL SCARIFICATION ON THE COMPOSITION OF REGENERATION AND SPECIES DIVERSITY IN AN OAK SHELTERWOOD

James J. Zaczek, Joseph Harding, and James Welfley[1]

Abstract: This study was conducted in a fenced 1-yr-old 70-acre mixed-oak shelterwood to determine the impact of soil scarification on species composition and the production of oak regeneration from abundant northern red oak (*Quercus rubra* L.) acorns. In October 1993, seven replicates were established and randomly divided into control and scarified plots. Pretreatment sampling showed that control and scarified treatments had statistically similar numbers of advance regeneration in various species categories (including total seedlings - 4,085/acre) as well as similar numbers of acorns (48,463/acre). Species composition was dominated by red maple (*Acer rubrum* L.) (45%), followed by oaks (27%), acceptable low value species (24%), and other desirable hardwoods (4%) with 14 tree species found in each treatment. Plots were lightly scarified using a brush rake-equipped crawler dozer in an attempt to incorporate acorns into the soil (scarification seeding) after dissemination but prior to leaf fall.

One year later, the number of seedlings in scarified plots (16,870/acre) was significantly greater than that in control plots (9,614/acre). The number of seedlings increased for all species categories in control plots and for all but red maple in scarified plots. Species composition shifted as a result of treatments with the result that scarified plots totaled significantly more northern red oak (11,596/acre) and fewer red maples (1,106/acre) compared to control plots (1,002/acre, and 3,973/acre, respectively). Composition of other desirable hardwoods (4% of total) and low value species (15% and 11%, respectively) were similar for control and scarified plots. Based on the Shannon-Weiner index, species diversity of the tree seedling community slightly increased from 1.73 to 1.81 in control plots, in part, reflecting more balanced numbers of red maple and oaks. Species diversity in scarified plots decreased from 1.96 to 1.30 reflecting the greatly increased dominance of northern red oak. This decrease occurred in scarified plots despite an increased tree species richness and increased numbers of seedlings in 13 of 15 species suggesting that care must be taken when interpreting diversity values relative to regeneration success. Results show that soil scarification scheduled with recently disseminated acorns prior to leaf fall can significantly improve species composition of seedling regeneration by decreasing red maple and increasing oak seedlings.

INTRODUCTION

Oaks presently dominate many of the mature upland hardwood forests in the Central Hardwoods Region and in Eastern North America. Oak forests are highly valued for providing essential high-quality wood, wildlife habitat, clean water, varied recreational opportunities, and other resources. In Pennsylvania and in other areas, succession to shade tolerant species, in particular red maple, is occurring in many oak stands in response to disturbance such as gypsy moth (*Lymantria dispar*) induced mortality or cutting (Widmann 1995). The same is true in undisturbed stands except on the most xeric sites (Nowacki and Abrams 1991). The lack of regeneration and failure of oak restoration is a serious problem raising concerns about the composition, quality, and value of future forests.

A key factor in the regeneration of oak hinges on the ability of acorns to successfully germinate and competitively grow with other vegetation. However, relatively few acorns of the total production in a stand ever germinate into seedlings let alone survive and grow to maturity. Steiner (reported in Zaczek 1994) monitoring 2 years of northern red oak seed production in five Pennsylvania mixed oak stands, found that 0.6% of acorns resulted in live seedlings 18 months after dissemination. Acorns are high value food and fall prey to many animals and insects (DeLong 1994, Galford and others 1991, Marquis and others 1976). Environmental factors such as desiccation and freezing

[1] Senior Research Assistant, Forest Supervisor, and Assistant Forest Supervisor, respectively, School of Forest Resources, Pennsylvania State University, University Park, PA 16802.

can seriously impact viability (Olson and Boyce 1971, Young and Young 1992) and surface-seeded acorns are more exposed to lethal cold temperatures and desiccation than those seeded below the soil surface (Bowersox, reported in Zaczek 1994, Sluder and others 1961). DeLong (1994) found that over 2 years less than 1% of planted acorns produced seedlings, and that surface-seeded acorns were located and preyed upon more easily by small mammals.

Scarification using various methods has the potential to incorporate acorns into the soil for added protection. However, results of scarification have been variable depending on the circumstances and methods employed. Scarification has sometimes shown to be beneficial to oak regeneration but impractical to implement on a operational basis (DiMarcello 1986) or to be operationally sound but of little benefit to oak regeneration (Bundy and others 1991). Additionally, little is known about the impact of scarification on species composition and species diversity on treated areas. This study was established to determine if soil scarification would affect the germination of recently disseminated acorns as well as the composition of the regeneration and species diversity in a recently created mixed-oak shelterwood.

METHODS

Study Area

This study was conducted in a 1-yr-old 70-acre mixed-oak shelterwood located on the Pennsylvania State University's StoneValley Experimental Forest in Huntingdon County, Pennsylvania. Prior to cutting, the stand was estimated to contain 11,035 board feet of volume per acre and 88.1 ft^2 of basal area per acre of all tree species. Of the total board foot volume 76% was oak (ca. 43% *Quercus velutina* Lam., 13% *Q. rubra* L., 10% *Q. coccinea* Munch., 6% *Q. alba* L., and 5% *Q. prinus* L.), 9% white pine (*Pinus strobus* L.), 7% yellow poplar (*Liriodendron tulipifera* L)., 5% Virginia pine (*Pinus virginiana* Mill.), 2% red maple, 1% other hardwoods. The shelterwood was established by whole-tree harvesting the stand in the autumn/winter of 1992/1993 leaving a estimated residual of 50 ft^2 of basal area per acre. In the spring of 1993, after harvesting, the shelterwood was enclosed in a 6-wire electric fence.

Study Design

On 14 October 1993, after acorn dissemination but prior to leaf fall, seven relatively stump-free replicates sized approximately 6 ft x 300 ft were established within a poorly regenerating section of the shelterwood. Because of the virtual lack of natural acorn production within the shelterwood, northern red oak acorns that had been recently collected off-site and float tested for soundness were scattered evenly across the surface of the litter in all of the replicates. Each replicate was divided in two (6 ft x 135 ft) with a buffer zone (30 ft) located between plots. Soil scarified (described below) or unscarified (control) treatments were randomly assigned to the plots in each replicate.

Prior to scarification, 134 circular sample plots (4 ft diameter or 1/3,466.4 acre) were taken at even spacing in each treatment (ca. 19 sample plots per treatment/replicate combination) to estimate the number of acorns and stems of tree regeneration present. Each regeneration stem < 2" diameter at breast height was recorded indicating species and height (classes: 0" - 2", 3" - 12", 13" - 48", >48"). At this time, a representative sample of acorns was collected (n=93), stratified in a refrigerator at 30° F over winter, and sowed in a greenhouse the following spring. Germination was 84%. Herbaceous and woody shrub vegetation was not quantified but visual estimates indicated that there was little present.

The soil scarification treatment was accomplished using a brush rake-equipped crawler dozer (John Deere model 350D). The 6-toothed brush rake was 6.0 ft wide with teeth 1.2 ft apart and 1.0 ft long. The tracks on the dozer were 1.2 ft wide and 2.9 ft apart. The dozer was driven forward with the brush rake lightly scraping the soil surface in an attempt to maintain a scarification depth of 4 inches. After scarification, many of the acorns were not visible and apparently were incorporated below the soil surface. Care was taken not to enter the control plots.

Just over 1 year later, on 19 November 1994, replicates were again sampled for the number of stems of regeneration by species and height class. Approximately 70 circular (4 ft diameter) sample plots were recorded for each treatment.

Data Analysis

Comparisons of the number of acorns present prior to treatment were made between treatments (and replicates) using analysis of variance at the P=0.05 level. For pre- and post-treatment data, comparisons of the total number of stems for the individual species of northern red oak and red maple and species groups (all other oaks, other desirable hardwoods, other acceptable trees, and all seedlings) across all height classes and the total number of stems in each height class across all species were made between treatments (and replicates) using analysis of variance at the P=0.05 level. Other desirable hardwoods include: white ash (*Fraxinus americana* L.), black cherry (*Prunus serotina* Ehrh.), yellow poplar (*Liriodendron tulipifera* L.), and hickory (*Carya spp).* Though some of the following species may be classified as undesirable for various reasons, in this stand, because of their relatively low frequency, we considered eastern white pine (*Pinus strobus* L.), Virginia pine (*Pinus virginiana* Mill.), American beech (*Fagus grandifolia* Ehrh.), sweet birch (*Betula lenta* L.), serviceberry (*Amelanchier arboria* Michx. f.), hawthorne (*Crataegus spp.*), flowering dogwood (*Cornus florida* L.), and bigtooth aspen (*Populus grandidentata* Michx.) as acceptable low value species for maintenance of diversity. Summaries and results are estimates of the number of stems of regeneration presented on a per acre basis. Species diversity of the tree seedling community was estimated using the Shannon-Weiner (H') index (Barbour and others 1987).

RESULTS

In 1993, prior to treatment, the number of acorns on the ground averaged 48,463/acre and did not significantly differ (P>0.05) between control (49,705/acre) and scarified (47,220/acre) treatments or among replicates. Additionally, areas designated for control and scarification did not statistically differ in the total number of regeneration stems (3,863/acre and 4,308/acre, respectively) or in the numbers of northern red oak, red maple, other oaks, desirable hardwoods, or acceptable species (Figure 1). The number of stems for most of the above species tended to be evenly distributed across the study area as significant differences among replicates were found only for the other oaks and total stems groups. Red maple was the dominant species making up 45% of the total number of stems.

One year after treatment, every species or species group in the control treatment had increased numbers of stems compared to the previous year (Figure 1). In the scarified treatment, most species or groups also increased in number except for red maple which decreased by 652 stems/acre.

Despite the decrease of red maple, the total number of stems of regeneration in the scarified areas (16,870/acre) was significantly greater than in the control areas (9,614/acre). Most strikingly, there were significantly more northern red oak seedlings in the scarified treatment than in the control (11,596/acre vs. 1,002/acre, respectively). However, the scarified treatment also had significantly fewer numbers of other oaks and red maples than the control treatment. Numbers of desirable hardwoods and acceptable species remained statistically similar among control and scarified areas after treatment.

Pretreatment sampling determined that 95% of regeneration was less than 12 inches in height and only 1% was taller than 48 inches which was comparable for control and scarified treatments (Figure 2). Within a height class, both treatments had similar numbers of seedlings except for the 3" to 12" class in which there were significantly more stems in scarified plots (3,343/acre) than in control plots (2,610/acre). A significant replicate effect was also present only in this height class indicating unequal distribution of 3" to 12" stems across the study site. In 1994, after treatment, significantly more regeneration stems in this height class were present in scarified plots (13,354/acre) compared to control (6,320/acre). This occurred without a significant replicate effect indicating relatively even distribution of the number of 3" to 12" stems across the site after scarification. Though control plots had somewhat more regeneration stems in the tallest height class (>48"), 79% of the stems were either red maple or acceptable low value species.

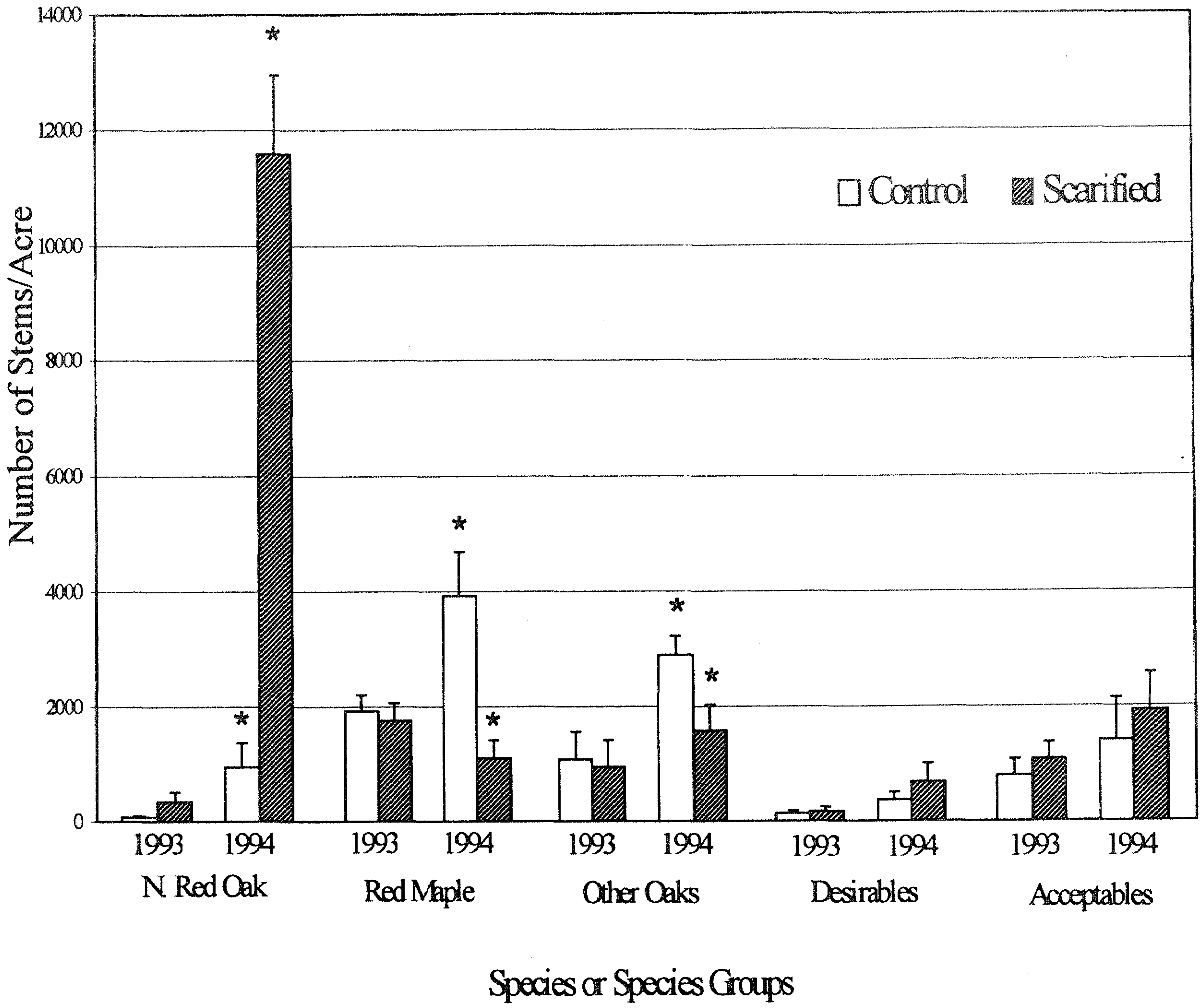

Figure 1. The mean number of regeneration stems per acre (and standard error bars) for species and species groups in control and scarified plots prior to (1993) and after (1994) treatment. Paired bars for a species or species group in a year with asterisks are significantly different at P=0.05.

Species diversity (H') for tree species regeneration prior to treatment was 1.73 and 1.96 in control and scarified treatments, respectively. Species richness was equivalent in both treatments with 14 species present. Following treatment, species diversity in control plots increased slightly to 1.81 while richness decreased to 13 species. In the scarified treatment, species diversity decreased to 1.30 while richness increased to 15 species.

DISCUSSION

The number of acorns per acre that were disseminated across plots in this study was found to be slightly higher than a 4-year average (41,779) and well within the range (from 540 to 198,510) found previously in five mature uncut mixed-oak stands in Pennsylvania (Steiner 1995). Considering this stand was a shelterwood with a residual of ca. 50 ft^2 of basal area of mostly oak, the number of acorns on the ground prior to treatment could be considered somewhat above average but well below the potential maximum oak mast production.

The pretreatment total number of regeneration stems was relatively low (4,085/acre) and generally small-sized. Of the total regeneration, species composition was similar across areas designated for control and scarification and was dominated by red maple (45%), followed by oaks (27%), acceptable species (24%) and desirable hardwoods (4%).

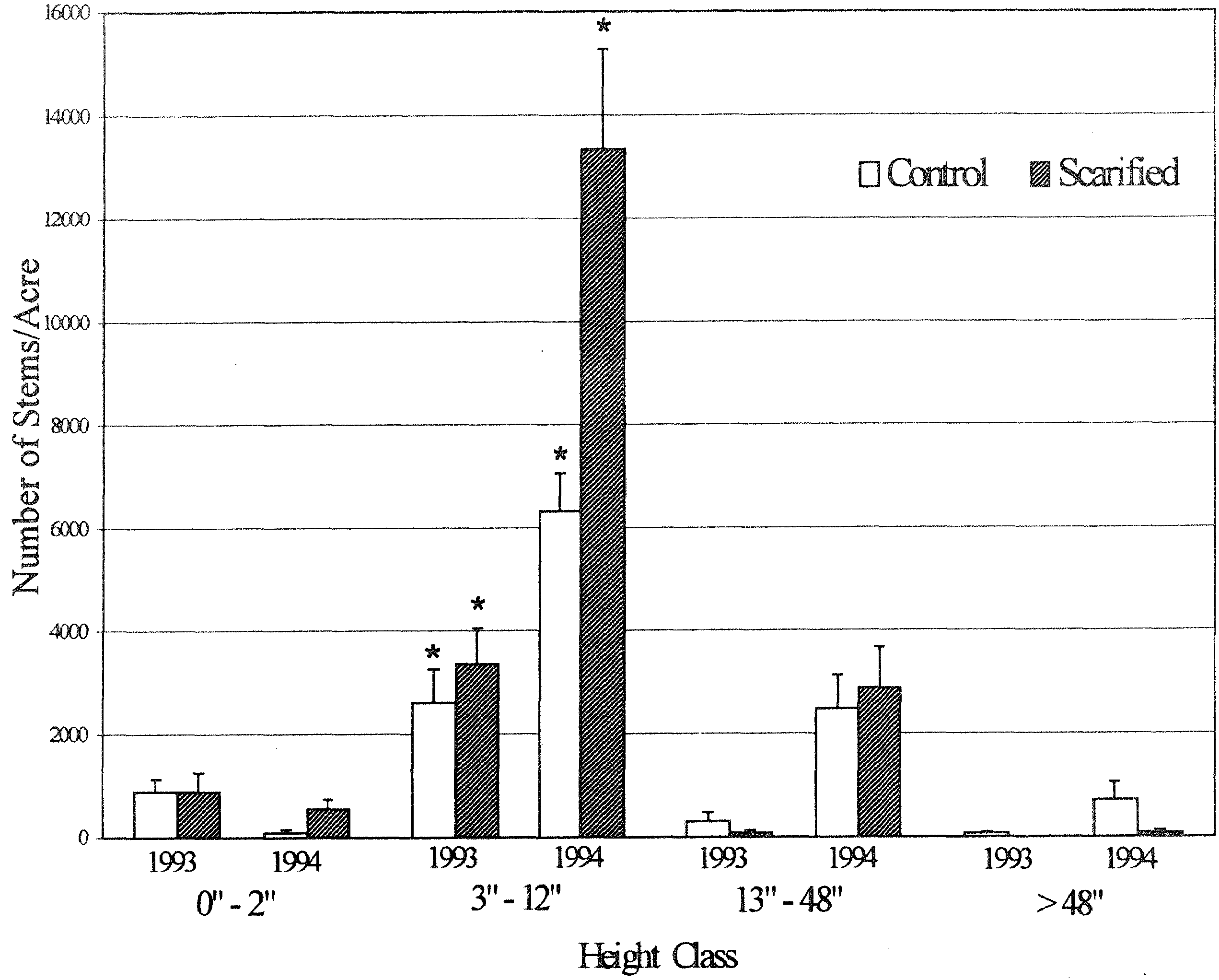

Figure 2. The mean number of regeneration stems per acre (and standard error bars) by height class for control and scarified treatments prior to (1993) and after (1994) treatment. Paired bars in a height class and year with asterisks indicate significant differences between scarified and control treatments at P=0.05.

Even with above average numbers of acorns and the relative lack of red maple seed source within the shelterwood prior to treatment, the regeneration in control plots continued to be dominated by red maple (41%) which more than doubled in number 1 year later. Red maple dominance in control plots may reflect the ability of its seeds to either germinate immediately after dissemination or remain dormant and viable in the soil for at least 1 year until chilling requirements are met (Young and Young 1992). Additionally the wind disseminated nature of the light maple samaras may allow for seed to enter the shelterwood from considerable distances. The numbers of northern red oak stems also increased in control plots but represented the germination of only 2% of the potential viable acorns present at the time of treatment.

One year after treatment, the species composition of regeneration in the scarified plots with 69% oak and 7% red maple more closely resembled the species composition of the trees in the uncut mature stand prior to the shelterwood. In fact, scarification actually reduced the numbers of red maple by 72% while increasing numbers of oaks 12-fold, compared to control plots. The considerable reduction of red maple stems in scarified treatments arises both from a reduction of existing seedlings present before the treatment and from a relative lack of recruitment of new seedlings from seed. This suggests that advance regeneration of red maple may be relatively susceptible to disturbance-induced damage or mortality and that seedbed conditions created by scarification may be less favorable to germination and emergence of its seed compared to undisturbed conditions.

Allowing for the number of pretreatment northern red oak seedlings and the estimated maximum potential rate of acorn germination under controlled conditions, a considerably greater percentage of acorns in the scarification treatment (28%) produced a seedling than was found in control (2%). In a recently harvested red pine (Pinus resinosa Ait.) plantation, DiMarcello (1986) found higher percentage germination of seeded northern red oak acorns in soil scarified with a rototiller than in unscarified plots. In other studies, northern red oak acorns seeded at least 1" below the soil surface showed better germination, were found to be preyed-upon less often by insects and small mammals (Auchmoody and others 1994, DeLong 1994) and experienced less severe micro-environmental temperature and desiccation extremes (Bowersox, reported in Zaczek 1994) than surface-seeded acorns although planting depths below 4" can reduce oak seedling emergence (Smiles and Dawson 1995). Additionally, scarified soils under an uncut hardwood-hemlock stand were found to be between 60° and 100° F warmer and experienced a longer duration of optimum temperatures during spring and early summer compared to unscarified areas in the same stand (Godman and Mattson 1980). Apparently, germination rates can be higher for acorns incorporated into the soil due to improved environmental conditions for overwintering and germination and added protection from predation.

Scarification tended to break stems and uproot some of the advance seedlings resulting either in resprouting or in mortality as has been previously reported using an aboveground scarification technique (Bundy and others 1991). In our study, except for northern red oak, other oaks had reduced numbers of stems in response to soil scarification suggesting that viable seed must be present to germinate into new seedlings to offset the losses that occur from breakage and uprooting of existing seedlings.

Many oak species are episodic seed producers and produce large mast crops every 2 to 6 years and may fail to produce seed in the intervening years (Downs and McQuilkin 1944, Koenig and others 1991, Steiner, 1995, Sork and others 1993). Under natural conditions, acorns are generally considered to be viable only for the first growing season after seed fall (Crow 1988) though a small percentage of planted acorns (1.4%) were observed germinating more than 1 year after sowing (Steiner and others 1990). Thus scarification as a successful seeding treatment to increase numbers of oak seedling regeneration must be thoughtfully implemented to coincide with abundant acorn crops of high viability.

In central Pennsylvania, acorn seed fall is typically completed by the end of October (Zaczek, unpublished data) and large losses to predation can occur rapidly. Steiner (1995) reported that the number of viable acorns remaining on the ground in November was 53.5% of average annual production. Of the 46.5% loss, 38.6% was removed by vertebrates and 7.9% was attributed directly to insect attack or by fungal or bacterial infection after insect damage. Deer predation accounted for nearly half of the removals by vertebrates. This suggests that timing of the scarification treatment should be carried out soon after the majority of the mast crop has fallen to the ground. Scarification after leaf fall could disrupt natural protection by disturbance of the leaf litter layer (Bundy and others 1991). Therefore to maximize acorn germination, optimal timing of soil scarification treatment should be implemented after acorn dissemination but prior to leaf fall.

Planting seedlings or direct-seeding can be used to actively reestablish an oak regeneration component in a harvested mixed-oak stand (Zaczek and others 1993, Zaczek and others in press). Compared to planting seedlings, planting acorns is a more cost effective way of establishing or supplementing oak (Bullard 1992, Countryman and others 1995) on intensively prepared sites or in old-fields. Countryman and others (1995) found that if more than 12% of planted purchased acorns established seedlings, hand planting northern red oak acorns is economically superior to hand planting purchased seedlings. Additionally, they found that machine planted acorns can be from 11 times to 27 times cheaper per acre than hand planted acorns. Since over half the cost of machine planting acorns is for the purchase of seed (Countryman and others 1995), coupling scarification with naturally occurring acorns in a forested situation should result in an even more economical way of establishing oak regeneration.

Based on the decrease in the Shannon-Weiner species diversity values alone, one may conclude that scarification may be detrimental to the genetic diversity and regeneration of the stand. Essentially, the decrease in species diversity for the scarified treatment is a functional result of the tremendous increase in northern red oak seedlings relative to all other tree species. However, scarification increased total numbers of regeneration stems for most species or species groups (including a twelve-fold increase of northern red oak), increased species richness, restored prominence of the oak component and undercut the red maple dominance to levels mirroring the uncut mature forest. Additionally, scarification also tended to set back the height and reduce numbers of larger well-established advance regeneration of shade tolerant and low value species, perhaps reducing their competitive advantage over more recently established germinants of oak. In this mixed-oak shelterwood with a relatively open canopy, scarification tended to arrest succession and inhibit successional momentum toward shade tolerant regeneration increasing the potential of restoring a significant oak component in the stand. Because of the former results and considerations, we stress that care must be taken when interpreting calculated diversity values relative to the regeneration in managed oak forests.

CONCLUSIONS

This study demonstrated that soil scarification concomitant with recently disseminated northern red oak acorns significantly increased the oak component in the species composition of regeneration in a mixed-oak shelterwood. Shallow soil scarification is recommended in stands with above average numbers of acorns and low numbers of desirable advance regeneration to effectively plant or scarification-seed acorns to improve germination while effectively disturbing, disrupting, and destroying established stems of less desirable species. Timed application of scarification soon after dissemination but prior to leaf fall should afford maximum protection and improve germination rates of northern red oak mast crops.

LITERATURE CITED

Auchmoody, L.R., H.C. Smith, and R.S. Walters. 1994. Planting northern red oak acorns: is size and planting depth important? USDA Forest Service Res. Pap. NE-693. 5 p.

Barbour, M.G., J.H. Burk, and W.D. Pitts. 1987. Terrestrial plant ecology. Benjamin/Cummings, Melno Park, CA. 634 p.

Bullard, S., J.D. Hodges, R.L. Johnson, and T.J. Straka. 1992. Economics of direct seeding and planting for establishing oak stands on old-field sites in the south. South. J. Appl. For. 16: 34-40.

Bundy, P.B., A.A. Alm, and M.J. Baughman. 1991. Red oak regeneration following "scarification" and harvesting: a case study. North. J. Appl. For. 8: 173-174.

Countryman, D.W., R. Bardon, and S. Tate. 1995. Economics of direct seeding northern red oak in southern Iowa. Abstract. 6th workshop on seedling physiology and growth problems in oak plantings. Sept. 17-20, 1995. Rhinelander, WI.

Crow, T.R. 1988. Reproductive mode and mechanisms of self-replacement of northern red oak (*Quercus rubra*)—a review. For. Sci. 34: 19-40.

DeLong, C.A. 1994. Relative abundance of small mammals and seed predation on planted acorns in three forest treatments in central Pennsylvania. M.S. Thesis. Pennsylvania State University. 96 p.

DiMarcello, D.B. 1986. Effects of site preparation on establishment of northern red oak and Japanese larch following clearcutting of a mature red pine plantation. Thesis. Pennsylvania State University. 86 p.

Downs, A.A. and W.E. McQuilkin. 1944. Seed production of southern Appalachian oaks. J. For. 42(12): 913-920.

Galford, J.R., L.R. Auchmoody, H.C. Smith, and R.S. Walters. 1991. Insects affecting establishment of northern red oak seedlings in central Pennsylvania. In (L.H. McCormick and K.W. Gottschalk, eds.) Proceedings, 8th central hardwood forest conference, March 4-6, 1991, University Park, PA. USDA Forest Service Gen. Tech. Rep. NE-148.

Godman, R.M. and G.A. Mattson. 1980. Low temperatures optimum for field germination of northern red oak. Tree Planters Notes. 31: 32-34.

Koenig, W.D., W.J. Carmen, M. T. Stanback, and R.L. Mumme. 1991. Determinants of acorn productivity among five species of oaks in central coastal California. USDA Forest Service Gen. Tech. Rep. PSW-126.

Marquis, D.A., P.L. Eckert, and B.A. Roach. 1976. Acorn weevils, rodents, and deer all contribute to oak regeneration difficulties in Pennsylvania. USDA Forest Service Res. Pap. NE-356. 5p.

Nowacki, G.J. and M.D. Abrams. 1991. Community and edaphic analysis of mixed oak forests in the Ridge and Valley Province of central Pennsylvania. In (L.H. McCormick and K.W. Gottschalk, eds.) Proceedings, 8th Central Hardwood Forest Conference, March 4-6, 1991, University Park, PA. USDA Forest Service Gen. Tech. Rep. NE-148.

Olson, D.F., Jr. and S.G. Boyce. 1971. Factors affecting acorn production and germination and early growth of seedlings and seedling sprouts. Oak symposium proceedings, August 16-20, 1971, Morgantown, WV. USDA Forest Service Northeastern For. Exp. Sta.

Sluder, E.R., D.F. Olson, Jr. and T.W. Jarrett. 1961. Tests on direct seeding of oak in the Piedmont and Southern Appalachians of North Carolina. USDA Forest Service Stn. Pap. 134. 12 p.

Smiles, W.A. and J.O. Dawson. 1995. Planting depth effects and water potential effects on oak seedling emergence and acorn germination. Abstract. In (K.W. Gottschalk and S.L.C. Fosbroke, eds.) Proceedings, 10th central hardwood forest conference, March 5-8, 1995, Morgantown WV. USDA Forest Service Gen. Tech. Rep. NE-197. p. 495.

Sork, V.L., J. Bramble, and O. Sexton. 1993. Ecology of mast-fruiting in three species of North American oaks. Ecology 74: 528-541.

Steiner, K.C., T.E. Kolb, and T.W. Bowersox. 1990. Second-year emergence of direct-seeded northern red oak. North. J. Appl. For. 7: 138-139.

Steiner, K.C. 1995. Autumn predation of northern red oak seed crops. In (K.W. Gottschalk and S.L.C. Fosbroke, eds.) Proceedings, 10th central hardwood forest conference, March 5-8, 1995, Morgantown WV. USDA Forest Service Gen. Tech. Rep. NE-197. p. 489-494.

Widmann, R.H. 1995. Forest resources of Pennsylvania. USDA Forest Service Resour. Bull. NE-131. 41 p.

Young, J.A. and C.G. Young. 1992. Seeds of woody plants in North America. Dioscorides Press. Portland, OR. 407 p.

Zaczek, J. J. 1994. Understanding oak regeneration: A research summary. In (E.A. Manno, ed.) School of Forest Resources annual report. Pennsylvania State University. Vol. 10. 1994. 46 p.

Zaczek, J.J., K.C. Steiner, and T.W. Bowersox. 1993. Performance of northern red oak planting stock. North. J. Appl. For. 10: 105-111.

Zaczek, J.J., K.C. Steiner, and T. W. Bowersox. Northern red oak planting stock: 6-year results. New For. (in press).