EFFECTS OF DIFFERENT MANAGEMENT REGIMES ON SURVIVAL OF NORTHERN RED OAK UNDERPLANTINGS IN THE RIDGE AND VALLEY PROVINCE

Adam E. Regula, David W. McGill and Cynthia D. Huebner[1]

Abstract--While dominant throughout much of the eastern United States, a recent decline in oak regeneration has merited substantial research. Ultimately, successful regeneration entails the establishment of advance reproduction of sufficient size and density to provide a high probability of ascendancy to dominant or co-dominant status. Potential prescriptions for achieving this include manipulation of light infiltration and control of competing vegetation through shelterwood harvests and prescribed burning. Diameter-limit cutting is a method used on private forests which creates diverse post-harvest conditions which can favor fast-growing, shade-intolerant competition or shade-tolerant species depending on initial stand structure and diameters harvested. This study examines the effect of five management regimes on northern red oak (*Quercus rubra* L.) underplantings through a 2-year assessment of 1+0 bareroot seedlings. Treatments consist of: (1) control sites with no disturbance for at least 40 years; (2) a single prescribed burn; (3) repeat prescribed burns; (4) shelterwood harvests (average 25 percent residual basal area); and (5) diameter limit cuts removing merchantable trees of a minimum diameter. Each treatment is replicated on two sites within the Ridge and Valley physiographic province of West Virginia and Virginia. Transects are established on the east-northeast and south-southwest aspect of each site. Deer fences were constructed on half of all plots to test for the effect of deer herbivory. Survival after the first and second growing seasons is presented. No statistically significant differences in survival were found among management regimes in either year. Both first- and second-year results showed fencing to significantly increase survival. The fence x management regime interaction was also significant in both years. Survival on south-southwest aspects was statistically greater than on east-northeast aspects after two growing seasons.

INTRODUCTION

Oaks (*Quercus spp.*) are an important species group throughout the forests of the eastern United States. In the Ridge and Valley physiographic province, oak-hickory and oak-pine are the most prevalent forest types (Eyre 1980, McNab and Avers 1996). Associated with this prevalence and geographic extent is ecological and economic importance. However, despite widespread dominance in eastern deciduous forest ecosystems, the future status of oak is in question. On many sites, the size and quantity of advance reproduction is inadequate for successful regeneration and the perpetuation of oaks as a major component of future stands (Widmann and others 2012, Woodall and others 2008). This is a concern and has prompted research to better understand the origin of oak dominance, the drivers behind the inadequacy of reproduction, and prescriptions which address this inadequacy. However, widely applicable and consistently successful solutions have proven elusive, and continued research is necessary (Dey and others 2009, 2010; Johnson and others 2002; Loftis 2004).

Prescribed burning and shelterwood harvests are two of the most widely researched and implemented prescriptions to promote the establishment and growth of oak advance reproduction. Intermittent low intensity burning by Native Americans is frequently cited as a major factor contributing to the historical dominance of oak (Abrams 1998; Brose and others 2001; Guyette and others 2006; Hart and Buchanan 2012; Hutchinson and others 2008; Nowacki and Abrams 2008; Pyne 1997, 2001). Not surprisingly, the reintroduction of fire, in the form of prescribed burning, has garnered attention. The shelterwood method is intended to facilitate the growth of large oak advance reproduction by incrementally removing the overstory. This maintains sufficient canopy and shading to curb the establishment and growth of fast-growing shade-intolerant competitors while favoring oaks (Brose and Van Lear 2011; Dey and Parker 1997; Dey and others 2008, 2010; Downs and others 2011; Hannah 1988; Iverson and others 2008; Johnson and others 2002; Loftis 1990; Nyland 2007; Schlesinger and others 1993). However, research on the effectiveness of prescribed fire and the shelterwood method has yielded mixed results. In addition, both methods require patience and flexibility for full and proper implementation. When time and flexibility are not available, or oak advance reproduction is insufficient to meet management objectives even following implementation, then augmenting natural oak reproduction with underplantings may be desired

[1]Master's Candidate and Professor, respectively, West Virginia University, Division of Forestry and Natural Resources, Morgantown, WV 26506; and Research Botanist, USDA Forest Service, Northern Research Station, Morgantown, WV 26505.

Citation for proceedings: Holley, A. Gordon; Connor, Kristina F.; Haywood, James D., eds. 2015. Proceedings of the 17th biennial southern silvicultural research conference. e–Gen. Tech. Rep. SRS–203. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 551 p.

(Johnson and others 1986, Sander 1971, Sander and others 1976, Schuler and Robison 2010).

In addition to these silvicultural practices, diameter-limit cutting is primarily guided by short-term economic considerations as opposed to efforts to manage future species composition and regeneration (Nyland 2005). As a result, the environmental conditions created by diameter-limit cuts can be highly variable. In some cases, diameter-limit cutting may contribute to what Abrams and Nowacki (1992) refer to as post-logging accelerated succession. It perpetuates the transition to more shade-tolerant species composition by failing to create openings of sufficient size to promote the development of shade-intolerant species. When large portions of the overstory are removed, accumulated advance reproduction of shade-tolerant species in the understory is released (Abrams and Nowacki 1992; Dey and others 2010; Johnson and others 2002; Nyland 2005, 2007). Because of the widespread use of diameter-limit cutting, its effect on oak advance reproduction and the potential viability of underplanting in the absence of desirable reproduction merits study.

This study examines the 2-year survival of northern red oak (*Q. rubra* L.) underplantings under five different forest management regimes: (1) control sites which were characterized by no harvesting or evident disturbance within 40 years, (2) a single prescribed burn, (3) repeat prescribed burns, (4) diameter-limit cuts, and (5) the seedcut of a shelterwood harvest. In addition, the effects of aspect and fencing to exclude deer were tested, as well as the interactions of all three factors.

MATERIALS AND METHODS

Study Area and Site Description

Ten sites, two replicates of each management regime, were located within the Ridge and Valley physiographic province of Virginia and West Virginia. The province is bounded to the west by the Appalachian Plateau's Allegheny Front and by the Blue Ridge Mountain province to the east. Topography is dominated by long, parallel, southwest-northeast oriented ridges and broad valleys. Oak-hickory and oak-pine are the predominant forest types (Eyre 1980). Mean annual temperatures and precipitation specific to study sites were estimated using National Climate data from nearby weather stations. In the Franklin, WV and Harrisonburg, VA area, mean annual temperature is 11.3 °C and mean annual precipitation is 91.5 cm. Estimated mean annual temperature and precipitation are 12.5 °C and 103.9 cm for sites in the vicinity of Moorefield, WV and Front Royal, VA, respectively (NOAA 2012).

Soils are predominantly silt-loams of the Calvin, Cateach, Dekalb, Berks, Opequon, Faywood, Schaffenaker-Drall, Lehew-Hazleton-Dekalb, and Shouns series. These are classified as moderately deep and well-drained to excessively well-drained with moderate to rapid permeability (NRCS 2012). Site indices for these soils range from 18.3 to 21.3 m for northern red oak, base age 50.

Basal area on control sites averaged 27 m^2/ha and was dominated by mixed oaks and a lesser component of pines. Single-burn sites received one spring prescribed burn within 10 years prior to planting while repeat burns were burned twice within that time period. Basal area on single- and repeat-burn sites was comparable to that on control sites, averaging 26 m^2/ha and 28 m^2/ha, respectively.

Overstories on single-burn sites were almost exclusively oak-dominated. Overstories on repeat-burn sites were oak-dominated as well, though one site had a notable component of sugar maple (*Acer saccharum* Marsh.). Diameter-limit cut sites varied in regard to minimum diameter harvested. Guidelines at one site called for all hardwoods > 35.6 cm in diameter at breast height (d.b.h.) to be harvested and softwoods left standing in 2009. The resulting stand had a basal area of 19 m^2/ha with overstories dominated by mixed oaks and a component of hemlock [*Tsuga canadensis* (L.) Carrière] and white pine (*Pinus strobus* L.). On the other diameter-limit cut site, only merchantable timber 45.7 d.b.h. and greater was harvested in 2007 and 2008. Basal area on this stand was 25.5 m^2/ha following harvest. Oaks were dominant in the overstory here as well, with a sizable component of red maple (*Acer rubrum* L.). Shelterwood sites were reduced to 25 percent residual basal area in 2008, resulting in oak-dominated stands with an average basal area of 2 m^2/ha.

Experimental Design and Statistical Analysis

Each site consisted of two 100-m transects, one each on east-northeast and south-southwest aspects, making a total of 20 transects. Actual aspect of east-northeast transects ranged between 350° and 176° azimuth. South-southwest aspects ranged between 182° and 280° azimuth. This design provided two replicates of each management regime plus aspect combination. Six 0.001-ha plots were established on a given transect. Of these six plots, three were randomly selected and fenced using 1.2-m-high woven-wire fencing. Fences were constructed around plots in a 3.8- by 3.8-m square. It is recognized that it is within a deer's ability to jump over fences of this height. However, given the relatively small area enclosed, it was assumed that this height posed a sufficient deterrent to deer. Three 1+0 bareroot oak seedlings were planted within each plot in alignment with cardinal directions. Initial designs called for 10 plots per transect to be planted with four seedlings per plot. This was adjusted due to time constraints during planting. Therefore, those transects planted first included a greater number of plots and seedlings, resulting in a total of 146 plots and 478 seedlings.

Seedlings were purchased from Clements State Tree Nursery in West Columbia, WV in March 2011 and stored at 5 °C until planting. Seedlings were of unimproved stock and grown from seed collected throughout West Virginia and southern Ohio. Planting was conducted during April and May 2011. Seedlings were kept damp and shaded during planting. The spring of 2011was cool and wet, with much of the study area receiving above average rainfall in April and May making for good planting conditions (NOAA 2012).

Survival was recorded as a binary response variable. Survival at the end of the first growing season was recorded during October and November 2011. Survival at the end of the second growing season was recorded during October through December of 2012.

Mixed linear models were tested using the MIXED procedure in SAS 9.3®. This allowed for the inclusion of site and plot in the model as random effects. Fixed effects included management regime, aspect, and fencing. As plots were the experimental units, survival was averaged at the plot level. Percent survival was arcsine-square root transformed to assure homogeneity of variances.

RESULTS

Year One

The overall survival rate at the end of one growing season was 72 percent. Among management regimes, the highest survival rate was found on repeat-burn sites (86 percent), followed by shelterwood sites (79 percent), single-burn sites (74 percent), control sites (61 percent), and finally diameter-limit cut sites (58 percent). Survival on south-southwest aspects was nearly identical to that on east-northeast aspects (72 versus 71 percent, respectively). Fenced plots experienced a high average survival rate of 85 percent relative to 62 percent on unfenced plots (table 1). Only fencing ($P < 0.0001$) and the regime x fence interaction ($P = 0.0059$) were statistically significant at $\alpha = 0.05$ (table 2).

Table 1--Mean survival by factor level for years 1 and 2

	Percent survival (standard error of mean)	
Treatment level	Year 1	Year 2
Control	61.5 (5.6)	46.9 (5.6)
DLC	58.3 (7.8)	56.9 (8.1)
Repeat burn	85.9 (4.6)	74.4 (5.3)
Single burn	73.6 (4.9)	70.8 (5.8)
Shelterwood	79.2 (4.2)	79.4 (3.8)
Unfenced	62.5 (4.0)	57.3 (4.2)
Fenced	81.1 (2.7)	74.8 (3.2)
Northeast	71.2 (3.5)	61.6 (3.8)
Southwest	72.2 (3.6)	70.8 (3.7)
Total	71.9 (2.5)	66.2 (2.7)

Table 2--Type III test of fixed effects on survival in years 1 and 2

Effect	Num DF	Den DF[a]	F Value	Pr > F
	----------------------------Year 1-------------------------------			
Regime	4	5.39	1.9	0.2409
Fence	1	130	19.04	<0.0001
Aspect	1	130	0.28	0.5968
Fence x Regime	4	130	3.8	0.0059
	----------------------------Year 2--------------------------------			
Regime	4	5.12	1.26	0.3931
Fence	1	129	19.45	<0.0001
Aspect	1	129	5.03	0.0266
Fence x Regime	4	129	3.85	0.0054

[a]Denominator degrees of freedom adjusted using Satterthwaite's adjustment.

Comparing average survival rates on fenced versus unfenced plots within a given management regime revealed a statistical difference to be present only on diameter-limit cut sites (P = 0.0002). On these sites, survival on fenced plots averaged 83 percent compared with 33 percent on unfenced plots. When comparing survival rates between management regimes in the absence of fencing, both unfenced repeat-burn (82 percent) and shelterwood plots (77 percent) experienced statistically greater survival than unfenced diameter-limit cut plots (33 percent). When only fenced plots were examined, tests showed no statistical differences between management regimes.

Year Two

The overall survival rate decreased to 66 percent following two growing seasons. Among management regimes, the highest survival rate was found on shelterwood sites (79 percent), followed by repeat-burn sites (74 percent), single-burn sites (71 percent), diameter-limit cut sites (57 percent), and control sites (47 percent). Survival on south-southwest aspects was greater than on east-northeast aspects (71 versus 62 percent). Average survival on fenced plots (75 percent) remained higher than on unfenced plots (57 percent) (table 1). Fencing (P < 0.0001), aspect (P = 0.0266), and management regime x fence interaction (P = 0.0054) were statistically significant (table 2).

As with first growing season results, only under diameter-limit cuts were survival rates greater in fenced plots (83 percent) than unfenced plots (31 percent, P < 0.0001). Among fenced plots, there were no statistically significant differences between management regimes after two growing seasons. This was true among unfenced plots as well.

DISCUSSION

Results from this study are mixed. The significance of the fence effect, particularly on diameter-limit cut sites, is evidence of the ability of deer herbivory to negate the effects of cultural prescriptions. Estimates from the 2012 hunting season and communication with resource managers placed deer densities in the region at approximately 7 to 7.5 deer/km^2. While this is not extremely high, studies have shown 7.9 deer/km^2 to be the threshold at which herbivory initiates a shift in species composition and negatively affects regeneration (Tilghman 1989). Such regional estimates may be of limited use, however, as density is difficult to quantify and varies across space and time. Further, browse pressure is not simply a function of density but also the appeal and "apparency" of plants in relation to the surrounding species and landscape (Seagle and Liang 1997). As with many management regimes, diameter-limit cutting creates visible disturbances on the landscape and produces browse attractive to deer. In addition, one diameter-limit cut site consisted of multiple stands located on larger properties which were harvested intermittently. This landscape-level disturbance regime may have produced browse to support larger deer populations relative to more contiguous mature forests. On the other diameter-limit cut site, the landowner was known to feed deer, increasing density in the immediate vicinity. It is therefore possible that higher deer densities specific to these diameter-limit cut sites, and not the regime per se, were responsible for the significant management regime x fence interaction. In addition to the management regime x fence interaction, lower 2-year survival on northeast aspects reflected more mesic conditions associated with greater interfering vegetation on these sites, making them less conducive to oak regeneration.

The lack of statistical differences in survival between management regimes was contrary to expectations. However, this is likely the result of the limited number of replicates, making statistical significance difficult to achieve. Though not significant, higher survival under the shelterwood and burn regimes is consistent with the objective of the prescriptions. A study with a greater number of replications may show a stronger statistical relationship between survival and regimes. While the average survival rate among diameter-limit cut sites was low, it was relatively high on fenced plots. This suggested that, when deer browse was limited, conditions for underplanting within diameter-limit cuts were comparable to those under these other management regimes.

CONCLUSION

As oak regeneration remains problematic, continued research on methods to promote sufficient advance reproduction is needed. Establishing this through a natural regeneration system is possible on more xeric sites such as those within the Ridge and Valley (Larsen and Johnson 1998). However, prescriptions such as prescribed burning and the shelterwood method require patience and do not guarantee the desired size and quantity of reproduction. Further, diameter-limit cutting may leave stands exhausted of seed trees of desired species and quality.

The results of this study are encouraging regarding the use of underplanting in conjunction with these management activities when deer herbivory is not a concern. However, caution should be exercised when drawing conclusions about the long-term success of these seedlings. In the absence of data on the current state of competition, speculation on their future performance is tenuous. Keeping this in mind, this study supports continued research on the use of underplanting in the Ridge and Valley as more tools and flexibility are desired in promoting oak regeneration.

LITERATURE CITED

Abrams, M.D. 1998. The red maple paradox. BioScience. 48: 355-364.

Abrams, M.D; Nowacki, G.J. 1992. Historical variation in fire, oak recruitment, and post-logging accelerated succession in central Pennsylvania. Bulletin of the Torrey Botanical Club. 119: 19-28.

Brose, P.; Schuler, T.; Van Lear, D.; Berst, J. 2001. Bringing fire back: the changing regimes of the Appalachian mixed-oak forests. Journal of Forestry. 99: 30-35.

Brose, P.H; Van Lear, D.H. 2011. Responses of hardwood advance regeneration to seasonal prescribed fires in oak-dominated shelterwood stands. Canadian Journal of Forest Research. 28: 331-339.

Dey, D.C.; Douglass, J.; McNabb, K. [and others]. 2008. Artificial regeneration of major oak (*Quercus*) species in the eastern United States: a review of the literature. Forest Science. 54: 77-106.

Dey, D.C.; Parker, W.C. 1997. Overstory density affects field performance of underplanted red oak (*Quercus rubra* L.) in Ontario. Northern Journal of Applied Forestry. 14: 120-125.

Dey, D.C.; Royo, A.A.; Brose, P.H. [and others]. 2010. An ecologically based approach to oak silviculture: a synthesis of 50 years of oak ecosystem research in North America. Revista Columbia Forestal. 13: 201-222.

Dey, D.C.; Spetich, M.A.; Weigel, D.R. [and others]. 2009. A suggested approach for design of oak (*Quercus* L.) regeneration research considering regional differences. New Forests. 37: 123-135.

Downs, J.D.; Williams, R.A.; Downs, J.A. 2011. The effects of shelterwood harvesting on oak regeneration two years after harvest in southern Ohio. In: Fei, S.; Lhotka, J.M.; Stringer, J.W. [and others], eds. Proceedings of the 17th central hardwood forest conference. Gen. Tech. Rep. NRS-P-78. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station: 262-269.

Eyre, F.H., ed.1980. Forest cover types of the United States and Canada. Bethesda, MD: Society of American Foresters. 148p.

Guyette, R.P.; Dey, D.C.; Stambaugh, M.C.; Muzika, R. 2006. Fire scars reveal variability and dynamics of eastern fire regimes. In: Dickinson, M.B., ed. Fire in eastern oak forests: delivering science to land managers. Proceedings of a conference. Gen. Tech. Rep. NRS-P-1. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station: 20-39.

Hannah, P.R. 1988. The shelterwood method in northeastern forest types: a literature review. Northern Journal of Applied Forestry. 5: 70-77.

Hart, J.L.; Buchanan, M.L. 2012. History of fire in eastern oak forests and implications for restoration. In: Dey, D.C.; Stambaugh, M.C.; Clark, S.L.; Schweitzer, C.J., eds. Proceedings of the 4th fire in eastern oak forests conference. Gen. Tech. Rep. NRS-P-102. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station: 34-51.

Hutchinson, T.F.; Long, R.P.; Ford, R.D.; Sutherland, E.K. 2008. Fire history and the establishment of oaks and maples in second-growth forests. Canadian Journal of Forest Research. 38: 1184-1198.

Iverson, L.R.; Hutchinson, T.F.; Prasad, A.M.; Peters, M.P. 2008. Thinning, fire, and oak regeneration across a heterogeneous landscape in the eastern U.S.: 7-year results. Forest Ecology and Management. 255: 3035-3050.

Johnson, P.S.; Dale, C.D.; Davidson, K.R.; Law, J.R. 1986. Planting northern red oak in the Missouri Ozarks: a prescription. Northern Journal of Applied Forestry. 3: 66-68.

Johnson, P.S.; Shifley, S.R.; Rogers, R. 2002. The ecology and silviculture of oaks. Wallingford, Oxon: CABI Publishing. 580 p.

Larsen, D.R.; Johnson, P.S. 1998. Linking the ecology of natural oak regeneration to silviculture. Forest Ecology and Management. 106: 1-7.

Loftis, D.L. 1990. A shelterwood method for regenerating red oak in the Southern Appalachians. Forest Science. 36: 917-929.

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

McNab, H.W. and Avers, P.E. 1996. Ecological subregions of the United States. USDA Forest Service. http://www.fs.fed.us/land/pubs/ecoregions/. [Date accessed December 19, 2013].

NOAA [National Oceanic and Atmospheric Administration]. 2012. National Climatic Data Center. http://www.ncdc.noaa.gov/cdo-web/. [Date accessed: February 12, 2013].

NRCS [Natural Resource Conservation Service]. 2012. Soil data mart. http://soildatamart.nrcs.usda.gov/. [Date accessed: June 12, 2012].

Nowacki, G.J.; Abrams, M.D. 2008. The demise of fire and "mesophication" of forests in the eastern United States. BioScience. 58: 123-138.

Nyland, R.D. 2005. Diameter-limit cutting and silviculture in northern hardwoods. In: Kenefic, L.S.; Nyland, R.D., eds. Proceedings of the conference on diameter-limit cutting in northeastern forests. Gen. Tech. Rep. NE-342. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station: 16-23.

Nyland, R.D. 2007. Silviculture: concepts and applications: 2d ed. Long Grove, IL: Waveland Press. 704 p.

Pyne, S.J. 1997. America's fires: management on wildlands and forests. Durham, NC: Forest History Society. 54 p.

Pyne, S.J. 2001. Fire: a brief history. Seattle: University of Washington Press. 204 p.

Sander, I.L. 1971. Height growth of new oak sprouts depends on size of advance reproduction. Journal of Forestry. 69: 809-811.

Sander, I.L.; Johnson, P.S.; Watt, R.F.1976. A guide for evaluating the adequacy of oak advance reproduction. Gen. Tech. Rep. NC-23. St. Paul, MN: U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station. 7 p.

Schlesinger, R.C.; Sander, I.L.; Davidson, K.R. 1993. Oak regeneration potential increased by shelterwood treatments. Northern Journal of Applied Foresty. 10: 149-153.

Schuler, J.L.; Robison, D.J. 2010. Performance of northern red oak enrichment plantings in naturally regenerating southern Appalachian hardwood stands. New Forests. 40: 119-130.

Seagle, S.W.; Liang, L-Y. 1997. Bottomland forest composition and seedling diversity: simulating succession and browsing by overabundant deer. In: McShea, W.J.; Underwood, H.B.; Rappole, J.H., eds. The science of overabundance: deer ecology and population management. Washington, DC: Smithsonian Institution Press: 346-365.

Tilghman, N.G. 1989. Impacts of white-tailed deer on forest regeneration in northwestern Pennsylvania. The Journal of Wildlife Management. 53(3): 524-532.

Widmann, R.H.; Cook, G.W.; Barnett, C.J. [and others]. 2012. West Virginia's forests 2008. Resour. Bull. NRS-61. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station. 64 p.

Woodall, C.W.; Morin, R.S.; Steinman, J.R.; Perry, C.H. 2008. Status of oak seedlings and saplings in the northern United States: implications for sustainability of oak forests. In: Jacobs, D.F.; Michler, C.H., eds. Proceedings of the16th central hardwood forest conference. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northern Research Station: 435-542.