OAK ADVANCED REGENERATION FOLLOWING SEASONAL PRESCRIBED FIRES IN MIXED HARDWOOD SHELTERWOOD STANDS[1]

Roderick D. Cooper, David H. Van Lear, and Patrick H. Brose[2]

Abstract—Regeneration of oaks (*Quercus*) on productive upland sites is a long-standing silvicultural problem due to aggressive competition from faster growing indetetminant species. We hypothesized that a single prescribed fire 3-5 years after an initial shelterwood cut would increase the competitive position of oak regeneration. Three productive oak-dominated shelterwood stands in the Virginia Piedmont were divided into control, spring-,summer-, and winter-bum treatments. Density and stocking of competitive oaks were greater in burned areas than in the unburned control, especially where medium to high intensity bums occurred during the spring and summer. Oak regeneration was evenly distributed over the burned areas while yellow-poplar (*Liriodendron tulipifera* L.). oak's primary competitor on these sites, occurred in small clumps. Results of this study indicate that areas receiving a single prescribed bum of medium to high intensity during the growing season will develop into oak-dominated stands. Other combinations of tire intensity and season-of-burn will produce mixed hardwood stands with varying proportions of oak.

INTRODUCTION

Regeneration of oaks on productive upland sites is a long standing problem in the hardwood forest of eastern North America (Beck and Hooper 1986; Pallardy and others 1988; Hix and Lorimer 1991). Harvest of mixed hardwood stands on higher quality mesic sites often results in a shift of species composition favoring non-oak indeterminate hardwoods (Beck and Hooper 1986, Loftis 1983, McGee 1979). Some of the contributing factors to oak regeneration failure are acorn supply, seedling density, insects, disease and animal depredation (Loftis and McGee 1992). The primary cause of oak regeneration failure is thought to be the slow growth of oak reproduction relative to aggressive intolerant species (Beck and Hooper 1986; Johnson and others 1989; Loftis and McGee 1992). In the early years of development, oak regeneration allocates more photosynthate to root development while intolerant species such as yellow-poplar (*Liriodendron tulipifera* L.) allocate more to shoot development (Kolb and others 1990). These differing growth strategies result in oaks being suppressed in the shaded understory while intolerant species move to dominance of the overstory.

If oaks are to be regenerated as the dominant component of a future stand, managers must develop silvicultural prescription to favor oaks. Loftis (1983) found that shelterwood harvests alone would not produce oak-dominated stands. Carvell and Tryon (1961) found that burned areas possess greater reservoirs of oak regeneration. Hannah (1987) suggested prescribed fires as a follow-up treatment for shelterwood harvests.

Johnson and others (1989) proposed that the key to oak regeneration might be competition control rather than long regeneration periods. Sander (1988) stated that multiple understory burns at 2-3 year intervals might be required for effective control of hardwood competition. The frequency of fire is thought to be as important as fire intensity for reduction of fire-susceptible species (De Selm and others 1973).

Recent research indicates that prescribed fire a few years after a shelterwood harvest can enhance the competitive position of oak regeneration (Keyser and others 1996, Brose and Van Lear 1998). Brose and Van Lear (1998) found that oak (Quercus) and hickory (Carya) regeneration vigorously resprout with improved stem form after such burns while yellow-poplar (Liriodendron tulipifera) and other competitors succumbed more easily. This current study is a follow up to Brose and Van Lear's (1998) original study of oak advanced regeneration using a shelterwood cut followed several years later by seasonal prescribed fires. In this study we examined the competitive status of advanced oak regeneration in 1997, three years after the 1995 treatments of seasonal prescribed fires of varying intensities described in Brose and Van Lear (1998). We attempted to define those conditions of fire intensity and timing of bum that would result in adequate free-to-grow oak regeneration in an oak dominated shelterwood stand.

STUDY SITE

This study was conducted in the Piedmont of central Virginia and located in the Horsepen Wildlife Management Area. This land is owned and managed by the Virginia Department of Game and Inland Fisheries. Topography consists of broad gently-rolling hills between 150 and 180 m elevation. Mean annual precipitation is 110 cm, distributed evenly throughout the year. The average growing season is 190 days. Mean annual temperature for the area is 14°C with a January mean of 4°C and a July mean of 24°C.

The study area consists of three mature oak dominated hardwood sands with a white oak site index 75 (base age 50). The stands are similar in site characteristics and species composition. Overstory trees in the preharvest stand numbered approximately 200/ha, with approximately 75 percent being upland oaks [white oak (Quercus *alba* L.), northern red oak (*Q. rubra* L.), Black oak (Q. *Velutina* Lam.), scarlet oak (Q. *coccinea* Muenchh.), and chestnut oak (Q. *prinus* L.)]. The remaining 25 percent were yellow-poplar, pignut hickory (*Carya glabra* (Mollier) Sweet), and mockemut hickory (C. *tomentosa* (Poiret) Nuttall). Common

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-16, 1999.

[2] Research Assistant and Professor. Clemson University, Department of Forest Resources, Clemson, SC; and Forestry Technician, USDA Forest Service, Southern Research Station, Clemson, SC, respectively.

midstory hardwoods included red maple (*Acer rubrum* L.). blackgum (*Nyssa sylvatica* Ma-shall). American beech (*Fagus grandifolia* Ehrhart). American hornbeam (*Carpinus caroliniana* Walter), and sourwood (*Oxydendrum arboreum* L.). There were approximately 2500 stems/ha with most species represented although beech. dogwood, hornbeam. and red maple were most abundant (Brose and Van Lear 1998).

These stands had grown in an undisturbed condition for over 30 years until two of me stands were shelterwood cut in 1990 and the third in 1992 removing 50 percent of each stands overstory. Fifty to 75 dominant oaks and hickory were retained with residual basal areas averaging 13 m^2/ha. Each stand was previously divided into four 2-5 ha treatment areas and subjected to tinter, spring, and summer bums in 1995. One treatment area in each stand was left unburned as a control

STUDY DESIGN AND MEASUREMENTS

This study was conducted in a randomized complete block design using the same treatments as Brose and Van Lear (1996) to examine the density, stocking and spatial pattern of oak and yellow-poplar. The design replicates me four treatments: I) winter bum. 2) spring bum. 3) summer bum, and 4) unburned control In each of the three shelterwood stands. Thirty plots (2.6 m diameter) were systematically located in each treatment area with a plot density of 6-15 plots/ha. We set size and stem form sampling requirements for oak and yellow-poplar because we were interested in the oaks that would have optimal growth and competitiveness.

An acceptable oak had a straight stem and was >1.37 m tall in the control and winter bum treatments, >1.O m tall in the spring bum treatment. and >0.7 m tall in the summer bum treatment. Sanders and other (1976) showed that oak regeneration must be >1.37 m tall to be competitive after release. Our height specifications vary as a result of differences in the amount of growing time due to seasons of burning. An acceptable yellow-poplar was at least half me required oak height for the treatment (0.7, 0.5, and 0.35 m tall in winter and control, spring, and summer treatments, respectively). These height requirements were allocated because of yellow-poplar's ability to outgrow oak on these sites (Beck and Hooper 1986. Johnson and other 1989).

Densities (stems/ha) were obtained by counting all acceptable oak and yellow-poplar stems in each plot Stocking of oak and yellow-poplar was measured by determining the proportion of plots containing an acceptable representative. The T-square sampling method was used to determine the spatial pattern of oaks and yellow-poplar in the treatment area (Ludwig and Reynolds 1966). An index was calculated separately for oak and yellow-poplar using distance measurements (+- 0.1 m) from plot center to nearest species and then to next nearest species to determine if regeneration was clustered, random, or uniformly distributed.

Competition of ma present advance oak regeneration was measured in the diit treatment areas. We examined these inter-species spatial relations using a modified Heygi competition index (Clinton and others 1997). The largest most competitive oak was visually selected and ik height recorded. Heights of all competitors and their distance from selected oak were measured within a 3-m radius of the target oak. These measurements were used to calculate a competition value.

A competitor was defined as a yellow-poplar seedling at least half the height of the oak located within a 1.5-m radius of the oak and any yellow-poplar stump sprout within a 4.5. m radius. A competitor will also be any of the following species that are of equal or greater height and within a 3-m radius of the oak: hickory. cherry (*Prunus serotina* Ehrhart), sweetgum (*Liquidambar styraciflua* L.). yellow-poplar. loblolly pine (*Pinus taeda* L.). ash (*Fraxinus* L.). locust (*Robinia* L.), and red maple stump sprouts with a 2 inch or greater ground-line diameter. Species mat only occupy midstory upon maturity such as blackgum, flowering dogwood, and hornbeam, were not considered major competitors because oak will eventually surpass them .(Nix 1969. Waldrop 1997).

A 3-m radius was used because it corresponded to Heygi's index and provides at least 50 percent of the growing space needed at maturity for the target oak. Target oaks with no competitors were considered free-to-grow (Nix 1989).

Due lo varying fire intensities within treatments (Brose and Van Lear 1998), plots in the burned treatment areas were assigned to one of four levels of fire intensity. Fire intensities were based on fuel consumption during the prescribed bums. Brose (1997) documented tire behavior, fire intensity. and changes in fuel loading within each treatment area as follows. Low-intensity fires (name lengths ≤0.3 m) partially consumed litter and small woody debris (<0.6 cm diameter). and lop-killed <75 percent of me advanced regeneration. Low-medium-intensity fire (flame lengths between 0.3 and 0.75 m) completely consumed litter and small fuels and top-killed 75-100 percent Of the regeneration. Medium-high-intensity fire (flame length 0.75-1.2 m) topkilled all regeneration. visibly reduced loading of 2.5-7.5 cm diameter fuels. caused approximately 50 percent mortality of midstory trees, and scorched bark on occasional overstory trees. High-intensity fire (flame lengths 21.2 m) visibly reduced woody debris >7.5 cm diameter. killed most midstory bees. charred bark 0" most overstory trees, and caused . occasional mortality of an overstory tree. A 3x4 factorial design. with three fire seasons and four fire intensity levels. was used to examine the effects of different fire-intensity levels.

STATISTICAL ANALYSIS

Analysis of variance with Student-Newman-Kuel mean separation test was used to compare season-of-bum treatments for differences In density and clustering of oak and yellow-poplar regeneration (SAS Institute 1993). Competitive condition of oak was tested with analysis of covariance and least-squares mean separation with regeneration age as me covariate (SAS institute 1993). Analysis of variance with least-squares mean separation was used b test for differences among these variables as fire intensity interacted with season-of bum (SAS Institute 1993). Chi-square analysis was used to compare differences in stocking among treatments and among fire intensities within season-of-bum (SAS Institute 1993). In all tests, α=0.05 and data were rank-transformed as needed to correct unequal variances and non-normality of residual values.

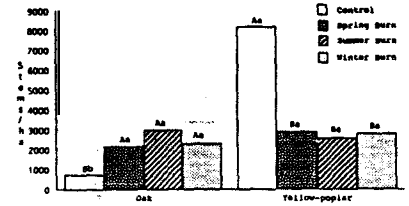

Figure 1—Density of oak and yellow-poplar advanced regeneration after seasonal prescribed fires in shelterwood stands in the Virginia Piedmont. Bars with different uppercase letters are different for that species (alpha=0.05). Bars with different lowercase letters are different for that treatment (alpha=0.05).

RESULTS

Density

Oak density was significantly greater in the bum treatments with three times as many oak stems (fg. 1). The burned treatments had half as many yellow-poplar as the unburned control. In the burned areas yellow-poplar and oak had equivalent densities while in the unburned control yellow-poplar out-numbered oak 8:1.

Oaks were most abundant in high intensity spring and low-to-medium intensity summer bums (Table 1). Yellow-poplar had significantly hiiher densities in the low intensity areas Of all seasons of bum, especially in the winter bum. Oak and yellow-poplar density were equivalent in the medium intensity areas while oak was significantly greater in high intensity fires.

Table I-Density (mean stems/ha ±1 se) of oak and ye
levels of fire intensity in the Virginia Piedmont

	Fir	
Species	Low	Low mediur
Spring bum		
Oak	1694±800C^{a}b^b	1709±571B
Yellow-poplar	5567±1887AB^{a}a^b	2776±682B
Summer bum		
Oak	2724±813BC^{a}b^b	4945±1077
Yellow-poplar	4051±1037B^{a}a^b	3631±1158
Winter bum		
Oak	2006±737C^{a}b^b	1955±436B
Yellow-poplar	9077±2418A^{a}a^b	2823±714A

[a] Means with different uppercase letters are different within that c
[b] Means with different lowercase letters are different within that r

Table 2—Stocking percent (mean ±1 se) of oak and yellow-poplar regeneration after four different levels of fln Intensity In the Virginla Piedmont

species	Fire intensity levels			
	LOW	Low medium	Medium high	Hiih
Spring bum				
Oak	64±25AB[a]ab[b]	63±13AB[a]ab[b]	53±9Bb	48±15Aa
Yellow-poplar	83±27AB[a]a[b]	58±16AB[a]ab[b]	44±10B[a]ab[b]	21±15CD[a]b[b]
Summer bum				
Oak	54±8B[a]b[b]	79±11A[a]a[b]	56±18B[a]b[b]	42±20BC[a]b[b]
Yellow-poplar	72±12B[a]a[b]	45±12B[a]a[b]	13±D[a]b[b]	10±10D[a]b[b]
Winter bum				
Oak	50±8B[a]b[b]	47±11B[a]b[b]	67±5A[a]a[b]	52±14B[a]b[b]
Yellow-poplar	92±8A[a]a[b]	56±6B[a]b[b]	49±5C[a]c[b]	14±14D[a]c[b]

[a] Means with different uppercase letters are different within that column (α = 0.05).
[b] Means with different lowercase letters are different within that row (α = 0.05)

Intra-Species Spatial Pattern
The spatial arrangement of oak and yellow poplar regeneraticn differed from each other in all the treatments. The oaks scored between 0.27-0.39 on a 0-1 spatial index indicating that oak regeneration was uniformly distributed over all treatments. Yellow-poplar Scored between 0.64-0.73 indicating that yellow-poplar regeneration was clustered. The spatial patterns within species were not affected by treatments or fire intensities.

Intra-species Competitive **Relationship**
Oaks in the bum treatments had significantly lower competition (Hegyi index=0.24) than oak in the unburned control (index-0.35) (Table 3). The number of competitors was highest in unburned control and lowest in the spring and summer bum treatments. Distance to nearest non-oak competitors was also significantly closer in the unburned treatment than in the burned treatments. There was no difference in competition between seasons of bum. As fire intensity increased within the burned treatments density of competitors decreased.

There were significantly more free-to-grow oak in the spring and Summer bum treatments (425 and 363 stems/ha. respectively) than in the winter bum and unburned control (62 and 141 stems/ha. respectively) (fig. 3). The high intensity spring bum areas (632 stems/ha) had the most free-to-grow oaks. The medium intensity summer bum areas (551 and 453 stems/ha) had the next largest quantity of free. to-grow oak followed by the medium intensily spring fires (321 and 373 stems/ha). Free-to-grow oaks were nearly absent in the low intensity spring and winter bum areas with

Table 3—Competitive status (mean ±1 se) of oaks 3 years after seasonal prescribed flms In shelterwood stands In the Virginia Piedmont

Treatment	Oak height	Number of competitors	Competitor height	Distance to nearest competitor	Heygi competition index
	m	*Stems/plot*	*m*	*m*	
Control	2.4±1A[a]b[b]	7.6±0.8A[a]	2.9±0.1A[a]a[b]	0.8±0.1B[a]	0.35A[a]
Spring bum	1.6±1C[a]b[b]	5.3±0.3C[a]	2.0±0.1C[a]a[b]	1.3±0.1A[a]	.25B[a]
Summer bum	1.1±1D[a]b[b]	4.7±0.3C[a]	l .5±1.0D[a]a[b]	1.3±0.1A[a]	.23B[a]
Winter bum	1.9±1B[a]b[b]	6.0±0.1B[a]	2.5±0.1B[a]a[b]	1.2±0.1A[a]	.25B[a]

[a] Means followed by different uppercase letters are different within that column (α = 0.05).
[b] Height means followed by different lowercase letters are different from each other within that row (α = 0.05).

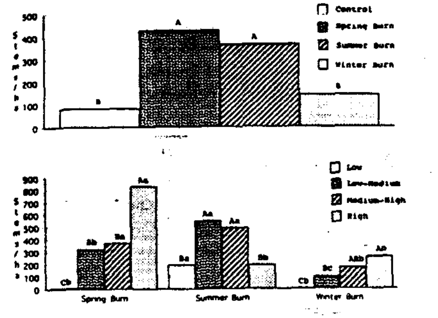

Figure 3—Density of free-to-grow oaks among treatments and among fire intensity levels within season-of-burn in shelterwood stands in the Virginia Piedmont. Bars with different uppercase letters are different for that species (alpha=0.05). Bars with different lowercase letters are different for that treatment (alpha=0.05).

less than 5 stems/ha. There were 101 and 173 stems/ha in the medium intensity winter bum areas and 259 stems/ha in the high intensity winter areas.

Stocking of free-to-grow oak were higher in the spring and summer bum (24 and 20 percent. respectively) than in the tinter bum and control (8 and 4 percent. respectively) (fig. 4). The high intensity spring bum areas had the highest stocking (46 percent) while the low intensity area in the spring and winter bum had the lowest stocking (I percent). The two medium and high intensity bum areas in the summer bum had equivalent stocking.

DISCUSSION
Disturbance of the stand and increased lighting of the forest floor after shelterwood harvest results in tremendous numbers of yellow-poplar. Preburn densities of yellow-poplar in our study area reached 10.000 stems/ha while oak was around 2.000 stems/ha in all treatments (Bmse and Van Lear 1996) Yellow-poplar seed banks can remain viable in the forest floor up to seven years (Beck 1961) and profusely germinate upon disturbance.

Prescribed fire drastically reduced the density and stocking of yellow-poplar in all bum treatments white increasing that of oak. Burning reduced competition in the stand and resulted in smaller clusters of yellow-poplar.

Acorns am usually buried by animals and have hypogeal germination (cotyledons remain in seed) which places the mot collar and its dormant buds below the surface. Yellow-poplar seeds have epigeal germination, generally placing the mot collar and its accompanying dormant buds above the soil surface (Beck 1961). This difference in germination strategy makes yellow-poplar more susceptible to lethal temperatures at or above ground level. Oaks also allocate more carbon to development of a large tap root in their early

Figu
fire-i
Virg
that
diffe

yea
Thi
fav
top

Fire
affe
inte
an
oak

CO
Oa
fre
hig
nu
bu
un
als
inc
bu
re
int
hig
Ot
of

RE
Be

Be

Br

Brose, P.H.; Van Lear, D.H. 1998. Response of hardwood advance regeneration to seasonal prescribed fires in oak-dominated shelterwood stands.

Carvell, K.L.; Tryon, E.H. 1961. The effect of environmental factors on the abundance of oak regeneration beneath mature oak stands. Forest Science. 7: 98-105.

Clinton, 8.0.; Elliott, K.J.; Swank, W.T. 1997. Response of planted eastern white pine (*Pinus strobus* L.) to mechanical release, competition, and drought in the Southern Appalachians. Southern Journal of Applied Forestry. 21: 19-23.

Oe Selm, H.R.; Clebsch, E.E.C.; Nichols, G.M.; Thor, E. 1973. Response of herbs, shrub and tree sprouts in prescribed-bum hardwoods in Tennessee. In: Proceedings, Tall Timbers fire ecology conference 13; 1973 March 22-23; Tallahassee, FL: 331-344.

Hannah, P.R. 1987. Regeneration methods for oaks. Northern Journal of Applied Forestry. 4: 97-101.

Hix, D.M.; Lorimer, C.G. 1991. Early stand development on former oak sites in southwestern Wisconsin. Forest Ecology and Management 42: 169193.

Johnson, P.S.; Jacobs, R.O.; Martin, A.J.; Godei, E.D. 1989. Regenerating northern red oak: three successful case studies. Northern Journal of Applied Forestry. 6: 174-178.

Keyser, P.D.; Brose, P.H.; Van Lear, D.H.; Burtner, K.M. 1996. Enhancing oak regeneration with fire in shelterwood stands: preliminary trials. Transactions of the North American Wildlife and Natural Resources Conference. 61: 216-219.

Kolb, T.E.; Steiner, K.C.; McCormick, L,H.; Bowersox, T.W. 1990. Growth response of northern red oak and yellow-poplar seedlings to light, soil moisture, and nutrients In relation to ecological strategy. Forest Ecology & Management. 38: 65-78.

Loftis, D.L. 1983. Regenerating Southern Appalachian mixed hardwood stands with the shelterwood method. Southern Journal of Applied Forestry. 7: 212-217.

Loftis, David L.; McGee, Charles E., eds. 1993. Oak regeneration: a summary. In: Loftis, David L.: McGee, Charles E., eds. Oak regeneration: serious problems, practical recommendations: Symposium proceedings: 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 316-319.

Ludwig, J.A.; Reynolds, J.F. 1966. Statistical ecology. John Wiley.

McGee, C.E. 1979. Fire and other factors related to oak regeneration. in: Holt, H.A.; Fischer, B.C., eds. Regenerating oaks in upland hardwood forests. Lafayette, IN: Purdue University, John S. Wright Forestry Conference: 75-81.

Nix, L.E. 1969. Early release of bottomland oak enrichment plantings appears promising in South Carolina. In: Miller, James H., comp. Proceedings of the fifth biennial southern silvicultural research conference; 1988 November 1-3; Memphis, TN. Gen. Tech. Rep. SO-74. New Orleans: U.S. Department of Agriculture, Forest Service. Southern Forest Experiment Station: 379-383.

Pallardy, S.G.; Nigh, T.A.; Garrett, H.E. 1988. Changes in forest composition in central Missouri: 1968-1982. American Midland -Naturalist. 120:380-390.

Sander, Ivan L. 1988. Guidelines for regenerating Appalachian oak stands. In: Proceedings guidelines for regenerating Appalachian hardwood stands; 1988 May 24-26; Morgantown. WV. SAFF Publ. 88-03. Morgantown, WV: West Virginia University Books. Office of Publications: 189-198.

SAS institute Inc. 1993. SAS user's guide: statistics. Version 8. Cary, NC: SAS Institute Inc.

Waldrop. T.A. 1997. Four site-preparation techniques for regenerating pine-hardwood mixtures in the Piedmont. Southern Journal of Applied Forestry. 21: 116-122.