MORTALITY, SURVIVAL, AND GROWTH OF INDIVIDUAL STEMS AFTER PRESCRIBED BURNING IN RECENT HARDWOOD CLEARCUTS

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ABSTRACT.— A study began in 1999 to examine the effect of prescribed fire following final overstory removal on the survival and growth of mixed hardwood regeneration. Two species and one species group were examined: black birch (*Betula lenta*), red maple (*Acer rubrum*), and mixed oak (*Quercus* spp.). Mortality differed by species and height class. Mortality was much higher for black birch (76 percent) than for the other species, regardless of height class. Oak survival was high for all height classes, averaging over ninety percent. Red maple survival was influenced by initial height class. Nearly half of the red maples less than three feet tall were killed by the fires while taller stems survived at a significantly higher rate. Interestingly, height of sprouting stems did not differ among the species in this study. Although sprout height was significantly correlated with initial height, few stems were taller than two feet the first year after the prescribed burn. Thus, prescribed burning reduced the size of larger maple sprouts to a height comparable to that of sprouting oak seedlings.

Introduction

Throughout the Central Hardwood Region, there is increasing interest in and use of prescribed fire to manage oak-dominated (*Quercus* spp.) forests (Yaussy 2000). This incorporation of fire into oak management is driven by increased recognition of the historical role fire played in perpetuating mixed-oak forests and the chronic, widespread difficulty of regenerating this forest type. As an oak regeneration tool, prescribed fire takes two roles. First, it is used in mature stands as a site preparation tool, paving the way for establishment of new oak seedlings by reducing litter depth, increasing light levels, decreasing density of competing understory vegetation, and controlling acorn insect pests. Its second use is in regenerating stands as a release treatment. In this role, fire selects for oak reproduction and against regeneration of other hardwood species based on differences in germination and early growth strategies, causing a shift in species composition between the two groups (Brose and Van Lear 1998; Brose and others 1999). Fire also accelerates early height growth of oak sprouts and improves their form. Currently, most use of fire as a release treatment to alter species composition and enhance oak's competitive status is in a 2-step shelterwood sequence; the shelterwood – burn technique. Unfortunately, there is little research of fire effects on hardwood regeneration after final overstory removal or following a clearcut (Augspurger and others 1987).

Fire in the aftermath of hardwood clearcuts is nothing new. Many historic photographs from the early 1900s show clearcuts in this period were followed by wildfires. The few existing studies suggest that burning of hardwood clearcuts could shift species composition towards oak dominance. Carvell and Tyron (1961) studied a mixed-hardwood sapling stand in West Virginia burned by a spring wildfire. Species composition shifted from cove hardwoods to mixed oak. Brown (1960) and Ward and Stephens (1989) documented the long-term development of mixed-oak forests in southern New England that originated from stand replacing wildfires. They found the stands that originated in the aftermath of severe wildfires had a significantly higher proportion of oak in the overstory than neighboring stands that had not burned. Wildfires in the early 1900s, in conjunction with other crucial forest events (near extirpation of white tail deer (*Odocoileus virginiana*) and loss of American chestnut (*Castanea dentata*), had profound effects on the successional trajectories of many eastern hardwood forests. From these studies, it appears that differences in species composition that start early in stand development, i.e., the stand initiation (seedling/sapling) stage, endure throughout that rotation.

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Table 1.—Initial distribution of regeneration density (stems/acre) by species group and height class.

	Species	Regeneration height class				
Prescribed burn site	group	<1 ft	1-3 ft	3-6 ft	>=6 ft	Total
Star Lake, CT	Oak	225	475	70	68	838
	Maple	125	425	225	698	1,473
	Birch	800	1,475	1,300	930	4,505
	Other	6,150	3,850	2,815	698	13,513
	Total	7,300	6,225	4,410	2,393	20,328
Goodwin, CT	Oak	n/a	1,450	333	38	1,820
	Maple	n/a	675	923	788	2,385
	Birch	n/a	6,125	12,263	2,093	20,480
	Other	n/a	525	135	105	765
	Total	n/a	8,775	13,653	3,023	25,450

While the aforementioned studies provide ample evidence that prescribed fire can increase the proportion of oak, few studies have examined the mechanisms of this change. Some possible mechanisms include: a higher proportion of oak than other species survive a fire, i.e., the stems are not top-killed, a higher proportion of oak than competitors sprout after a fire, and the height growth of sprouting oaks is faster than that of other species. The objective of this small-scale study was to examine for evidence of these causal mechanisms.

Study Areas

Two study areas (Goodwin and Star Lake) were established in Connecticut in formerly fully-stocked, mature, mixed-oak stands that had been completely harvested by the 2-step shelterwood process. The harvesting of these two stands created seedling/sapling stands containing a mix of hardwood regeneration. Before the prescribed fire, reproduction was abundant, tall, and widespread at all sites but primarily comprised of black birch (*Betula lenta*) and red maple (*Acer rubrum*), especially at the Goodwin site (Table 1). The oak component (*Quercus rubra, Q. velutina*, *Q. alba*, and *Q. prinus*) was scarce relative to the other species and lagging behind in height. Sites had a moderate ericaceous shrub component consisting of blueberry (*Vaccinium* spp), huckleberry (*Gaylussacia* spp), and mountain laurel (*Kalmia latifolia*).

Methods

To determine preburn seedlings densities, 20 pairs of nested plots were systematically located at both sites to ensure uniform coverage of the stands. The interior of each pair of nested plots was a circular milacre and in it all hardwood regeneration < 4-ft tall was identified to species and tallied by 1-ft height classes. The outer plot was 1/300 acre and in it all hardwood regeneration >= 4-ft tall was identified to species and tallied by 2-ft height classes. Initial regeneration inventories were conducted before the prescribed fires.

Additional sampling was used to study the influence of prescribed fire on mortality and sprouting on individual stems. Oak, red maple, and black birch stems were selected across a range of size classes. Selected stems were tagged, flagged, and the initial height was measured in one foot height classes. A total of 576 individual stems were included in this study. The number of oak, red maple, and black birch was 175, 217, and 184 stems, respectively.

Stems were inspected for mortality and sprouting following the first growing season after each fire. Postburn seedling status was divided into three categories: live top, sprout, and mortality. Live tops were stems that survived the fire, i.e., were never top-killed. Sprouts were stems that had been top-killed but produced at least one new stem from the base. Mortality were stems that were top-killed and failed to sprout. Re-growth, the height of resprouted stems, was measured to the nearest 0.4 inch. Re-growth heights reported here were for two growing seasons at the Star Lake burn site and one growing season at the Goodwin burn site.

Table 2.—Environmental conditions and fire behavior for the prescribed fires.

	Star Lake, CT	Goodwin, CT
Date of Burn	May 5, 2000	April 19, 2002
Time of Burn	11 AM – 2 pm	12 – 2 pm
Burn Area (acres)	19	5
Aspect	North	East
Slope (percent)	0 – 10	0 – 5
Slope Position	Upper 1/3	Upper 1/3
Fuel Model	6	6
Air Temperature (° F)	n/a	66 – 72
Relative Humidity (percent)	44 – 60	48 – 66
Cloud Cover	Sunny	Cloudy
Mid-flame Wind Speed (mph)	3 – 5	8
Wind Direction	West	Southwest
Days since last Rain	2	2
Flame length (ft)	2 – 6	1 – 2
Rate of spread (chains/hr)	~30	4.3

Data were analyzed as a 2x3x3 factorial consisting of 2 sites, 3 species (birch, maple, and oak), and 3 size classes (<3 ft, 3-6 ft, ≥ 6 ft). Analysis of variance with Tukey's HSD test was used to test differences in sprout height among species groups, size classes, and sites with Bonferroni adjusted probabilities used when species group was found to be a significant factor. Differences were judged significant at $p \leq 0.05$. For the individual burns sites, only cells with at least four initial seedlings for each species group/initial height combination were included in the analysis. Only cells with at least twenty stems were included in the analysis of the combined prescribed burn sites.

Differences in seedling mortality and sprouting rates among species groups, study area, initial size class were tested using procedures in Neter et al. (1982, p 325-329). Again, differences were judged significant at $p \leq 0.05$ using Bonferroni adjusted probabilities. To avoid redundancy in data presentation, a table with sprouting rates is not provided. Because almost all stems were top-killed, sprouting rates can be determined by subtracting the mortality rate from 100%.

Fire Behavior

For all burns, fuels consisted of hardwood slash mixed with ericaceous shrubs (Table 2). Connecticut DEP-Division of Forestry personnel conducted the two burns in that state on May 5, 2000 and April 19, 2002. For both, drip torches were used to light a ring fire. This technique consists of igniting a backing fire along the downwind or uphill side to create a black line. Once a secure black line was established, flanking fires were lit along each side. Finally, once adequate black lines were secure on three sides, a head fire was ignited. Fire behavior at the Star Lake burn was recorded by video camera. Post-fire analysis indicated a moderately intense fire with average flame length of 4 feet and a rate of spread (ROS) of 30 chains/hour. Fire behavior at the Goodwin burn was monitored with thermocouples and data-loggers. They recorded that the fire was of low intensity (1-2 ft flame lengths) and slow moving (median ROS of 4 chains/hour).

Results

All of the black birches were top-killed by the prescribed fires. A small proportion of oaks (6 percent) and red maples (2 percent) survived without being top-killed. However, there were no significant differences among the species in the proportion that were top-killed in any of the size classes examined.

Mortality differed among species (Table 3). Mortality was higher for black birch than oak and red maple at both sites. For the combined sites, red maple mortality of stems less than three feet tall was higher than for oak, 45 percent and 8 percent, respectively. Mortality differed among size classes for oak and red maple, but not black birch. For both species, mortality was higher for stems that had been 3-6 ft tall prior to the burn than for > 6 ft tall stems.

Table 3.—Mortality (%) of regeneration following prescribed fire by species group and height class (feet) before the prescribed burn. Within each burn site, mortality values within a given height class (column) that are followed by different letters are significantly different at p<0.05.

	Height class before prescribed burn				Height classes comparison		
Species group	< 3 feet	3-6 feet	>=6 feet	Total	Chi-Square	df	Prob
			Star Lake, CT				
Oak	14% a	36% a	0% a	18% a	5.86	2	0.053
Maple	100% b	100% b	0% a	45% b	33.00	2	0.000
Birch	-	82% b	75% b	79% c	0.85	2	0.654
			Goodwin, CT				
Oak	6% a	11% a	0% a	7% a	2.92	2	0.232
Maple	37% b	5% a	0% a	9% a	48.00	2	0.000
Birch	86% c	66% b	77% b	75% b	3.68	2	0.159
			Combined sites				
Oak	8% a	16% a	0% a	9% a	7.68	2	0.021
Maple	45% b	24% a	0% b	15% a	58.02	2	0.000
Birch	88% c	70% b	77% b	76% b	2.79	2	0.247

This difference in mortality rates among species can be directly attributed to the prescribed burns and not normal mortality. On adjacent unburned control plots, survival of all species was much higher, ranging from 96 percent for oak to 98 percent for red maple.

Differences in sprouting rate were found between the two sites. Sprouting rates for maple and oak were higher at Goodwin than at Star Lake and the difference for maple, 90 percent at Goodwin and 55 percent at Star Lake, was significant. No differences in sprouting rate were detected for birch and oak although the trend for oak was towards lower proportion sprouting at Star Lake than Goodwin.

The proportion of stems that sprouted after the fires differed among species. Oak had the highest rate of sprouting. On average, 90 percent of oak rootstocks sent up a new stem. Conversely, black birch was the poorest sprouter as only 24 percent of top-killed stems produced a new stem. Maple was an intermediate sprouter. At Goodwin, 90 percent of the red maple sprouted, a proportion equal to oak, but at Star Lake only 55 percent of the red maple sprouted – significantly less than that of oak.

Pre-burn stem size had little apparent influence on sprouting rates for oak and black birch. Regardless of initial stem size, oak stems sprouted at between 62 – 100 percent and black birch sprouted at 13 – 30 percent. Only one significant difference was noted for these two species after Bonferroni correction. The sprouting rate for oaks 3-6 feet (86 percent) on the combined sites was lower than for oaks $\geq$ 6 feet tall (100 percent) ($Z=2.55$, $p\leq0.048$). Red maple did exhibit differences in sprouting rates among size classes. Red maples $\geq$ 6 feet tall sprouted more often than stems < 3 feet, 100 percent and 53 percent, respectively ($Z=8.04$, $p\leq0.001$). Red maples > 6 feet tall also sprouted more often than 3-6 feet tall, 76 percent ($Z=5.57$, $p\leq0.001$).

No significant differences in the height of sprouting stems were found among species at either site (Table 4). However, height growth of sprouting stems was correlated with initial height for all three species at both sites ($F=19.6$, d.f.=4, $p<0.001$). Generally, few stems were taller than two feet the first year after the prescribed burn.

Discussion

The results of this study suggest that prescribed burning can increase the amount of oak in the regeneration pool via differences in sprouting rate among species. Oak regeneration is more likely to sprout than other hardwood reproduction, especially as fire severity increases and burns occur in the growing season (Brose and Van Lear 1998). This is evident by comparing sites. The Star Lake fire occurred later in

Table 4. –Mean height (feet) of sprouting stems by species group and height class of sprouting regeneration. Within each burn site, mean values within a given row (species) that are followed by different letters are significantly different at p<0.05.

	Height class before prescribed burn			
Species group	<3 feet	3-6 feet	>=6 feet	Total
			Star Lake, CT	
Oak	2.2 A	2.6 AB	4.2 B	3.2
Maple	-	-	4.1	4.1
Birch	-	-	5.0 A	4.4
			Goodwin, CT	
Oak	1.0 A	1.5 B	2.4 C	1.5
Maple	1.2 A	1.5 A	2.1 B	1.9
Birch	-	1.8 A	2.2 A	1.9
			Combined*	
Oak	1.6 A	2.2 B	3.5 C	2.5
Maple	1.9 A	2.2 A	3.1 B	2.4
Birch	-	2.6 A	3.3 A	2.6

*Least square means are presented for the combined sites.

the spring and was a considerably more intense burn than the one at Goodwin based on flame length and ROS. Consequently, mortality (no sprouting) was higher for all species there than at Goodwin (Table 3). Birch and maple mortality ranged from 37 – 100 percent in the smallest size class (< 3 ft). Conversely, oak mortality for the smallest size class was only 14 percent at the hotter Star Lake burn. The same relationship existed between birch and oak in the largest size classes ($\geq$ 6 ft). Few, if any, oaks failed to sprout while mortality averaged 24 percent for birch. Clearly, the birch component at both sites has been considerably reduced while 82 -93 percent of the oak stems are still intact.

While not examined in this study, the differences in mortality rates among species at Star Lake are likely due to differences in germination and early growth strategies (Brose and Van Lear 2004). Acorns have hypogeal germination, i.e., cotyledons remain in the shell and serve as a belowground energy source for seedling development. Black birch and red maple seeds have epigeal germination, i.e., cotyledons emerge and rise above the shell to form the first photosynthetic leaves. This difference in germination strategy places the root collar of oak seedlings, and the accompanying dormant buds, lower in the soil profile than that of black birch and red maple.

This basic difference in germination strategy is accentuated by wildlife. Acorns are routinely buried an inch or more into the forest floor by birds and small mammals, while seeds from black birch and red maple typically are not cached. Thus, an oak seedling generally will have a deeper root collar than a black birch or red maple seedling because of seed burial and hypogeal germination.

Another important silvical difference between oak and black birch/red maple reproduction is the developmental rate of the root system. Upon germinating, oaks send a strong radicle deep into the soil to establish a taproot and emphasize root development over stem growth (Kelty 1988, Kolb and others 1990). Black birch and red maple take the opposite approach; root development is sacrificed to promote rapid stem growth. Thus, oak regeneration usually is shorter than its competitors, but have larger root systems. It is these two silvical characteristics, hypogeal germination and emphasis on root development, and seed burial by wildlife that allows oak regeneration to be favored over reproduction of their competitors in a periodic fire regime.

The second mechanism by which prescribed burning can alter species composition is that oaks may have adaptations that allow a higher proportion of stems to survive a fire with live tops. In this study, some oaks survived the fires while many of their competitors did not. The intact tops of these surviving stems should confer a competitive advantage to them over sprouting seedlings as no height growth was lost to the fire and, thus, does not have to be recovered. In addition, an intact top does not necessitate the use of stored starch reserves in the root system to produce a new sprout.

Our results do not suggest the height growth of sprouting stems is a mechanism that will cause a long-term change in species composition. No significant differences in height growth were found among species. However, these results are for the first two years only and may not be conclusive in demonstrating a significant difference among species. The major impact of prescribed burning appears to be an equalizing of heights among the species. While there was a wide range in pre-burn heights, and corresponding wide range in crown widths, most seedlings were of a similar size after the prescribed burns.

The equalization of seedling size suggests a final mechanism, albeit a speculative one, that may benefit oak in a periodic fire regime. In a post-fire environment oak seedlings are released temporarily from competition with larger red maple saplings. The sprouting oaks that were less than three feet tall prior to the burn were still shorter than sprouting maples that had been $\geq$ 6 ft tall before the burn. However, after the burns the average height difference between the species was now less than two feet. As a result of this equalizing of size, most oaks were growing in direct sunlight and were not shaded by neighboring, taller red maple stems. Height growth and root development of oak regeneration growing in full sun is generally better than for oaks growing in shade and for maple (Smith 1983). Therefore, it is likely that a proportion of those oak seedlings that had been growing in close proximity to taller red maples prior to the burn will now be able to maintain height growth rates comparable to red maple and form part of the upper canopy at crown closure. We will continue to monitor these plots to determine the long-term impact of prescribed burning in seedling stands on stand structure.

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