REPEATED FIRES, CANOPY GAPS, AND TREE REGENERATION IN APPALACHIAN MIXED OAK FORESTS

Todd F. Hutchinson, Robert P. Long, Joanne Rebbeck, Elaine Kennedy Sutherland, and Daniel A. Yaussy[1]

Abstract—We studied the response of tree regeneration to a sequence of several low-intensity prescribed fires followed by canopy gap formation in southern Ohio. Advance reproduction was recorded in 52 gaps (average size = four dead canopy trees) that formed following a white oak decline event, 13 years after fires began and 5 years after the gaps had formed. Of the 52 gaps, 28 were in three burned stands and 24 were in three unburned stands. Unburned gaps were being filled by shade-tolerant saplings and poles. In contrast, shade-tolerant saplings had been greatly reduced in the burned stands and larger oak advance reproduction (>2 feet tall) was much more abundant in burned gaps, as was sassafras. Advance reproduction of shade-tolerant species was equally abundant in burned and unburned gaps. Results indicate that the regeneration potential of oaks can be improved with multiple prescribed fires followed by the creation of canopy gaps.

Recent analyses of data from the U.S. Forest Service's Forest Inventory and Analysis Program (FIA) indicate shifts in forest composition within the central hardwoods region, with oaks (*Quercus*) declining in some areas and other species such as red maple (*Acer rubrum*) increasing (Fei and Steiner 2007, Hanberry 2013). FIA data show that in Ohio oaks continue to dominate the overstory in many stands, but shade-tolerant species typically dominate the midstory and understory (Widmann and others 2009). In these stands, overstory oaks that die or are removed through harvesting will often be replaced by other species unless effective management strategies to favor oak regeneration are implemented.

In the past 20 years, there has been a growing interest in using prescribed fire to sustain oak forests (Arthur and others 2012, Brose and others 2008). Under certain circumstances, prescribed fire can improve the competitive status of oak regeneration relative to their competitors when a greater proportion of oaks survive and sprout after fire (Brose 2010, Brose and Van Lear 1998). The ability of oak seedlings to sprout from the root collar after topkill is a function of resources devoted to root development rather than height growth (Johnson and others 2009). Additionally for oak seedlings, the relatively deep location of root collar in the soil provides greater protection from fire damage (Brose and Van Lear 2004).

However, studies of prescribed fire effects on oak regeneration have had mixed results. Recently, Brose and others (2013) conducted a meta-analysis of 32 studies that reported the effects of prescribed fire in oak forests. They found that prescribed fire had the greatest positive impact on oak regeneration when burning was conducted during the growing season several years after a partial timber harvest, and they found that prescribed fires in closed canopy forests generally did not have a positive impact on oak regeneration in the short term, particularly when only a single fire was applied.

In 1995, we began a long-term study in southern Ohio mixed-oak forests to determine the effects of repeated prescribed fires on forest structure, tree regeneration, and other ecosystem properties (Sutherland and Hutchinson 2003). By 2002, repeated low-intensity dormant-season fires (2X or 4X) had greatly reduced the density of shade-tolerant saplings, thinned the midstory to a lesser degree, and had very little effect on the density of overstory trees (Hutchinson and others 2005). Oak seedlings generally remained small (<1 foot tall) as canopy cover continued to be >90 percent. We concluded that fire alone had not improved the competitive position of oak regeneration. In 2003, a white oak (*Quercus alba*) decline event became apparent at the Vinton Furnace State Experimental Forest (VFSEF), where two of the study sites were located. The death of overstory white oaks created small canopy gaps.

[1]Todd F. Hutchinson, Research Ecologist, USDA Forest Service, Northern Research Station, Delaware, OH 43015

Robert P. Long, Research Plant Pathologist, USDA Forest Service, Northern Research Station, Irvine, PA 16329

Joanne Rebbeck, Research Plant Physiologist, USDA Forest Service, Northern Research Station, Delaware, OH 43015

Elaine Kennedy Sutherland, Supervisory Research Biologist, USDA Forest Service, Rocky Mountain Research Station, Missoula, MT 59801

Daniel A. Yaussy, Research Forester Emeritus, USDA Forest Service, Northern Research Station, Delaware, OH 43015

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Several years after the gaps had formed, we observed the presence of larger oak advance reproduction, stems 2 to 4 feet tall, in several of the gaps that were located within stands that had been burned in the prescribed fire study. These canopy gaps provided an opportunity to study the response of advance reproduction to a series of repeated fires followed by the creation of small canopy openings. The sequence and type of disturbance events—repeated fires followed by small-scale gap formation—to the best of our knowledge had not been studied previously in oak forests.

The main objective was to determine whether the competitive position of oak regeneration, based on its size and abundance relative to competitors, was different in burned gaps than in unburned gaps. We also compared other characteristics of the burned and unburned gaps, such as soil moisture, gap size, sapling and pole density, and understory light levels. This paper summarizes the major findings of a recently published journal article (Hutchinson and others 2012a).

METHODS

Study Area

The study was located in the Vinton Furnace State Experimental Forest (VFSEF), Vinton County, OH. The VFSEF is owned by the Ohio Department of Natural Resources, Division of Forestry. The unglaciated landscape consists of narrow ridges and steep slopes. Bedrocks are primarily sandstones and siltstones. Soils are mostly sandy loams and silt loams that are moderately deep (20 to 40 inches to bedrock), acidic, and have low water-holding capacity (Lemaster and Gilmore 2004). Site quality is highly variable across the landscape. Black oak (*Quercus velutina*) site indices range from 55 feet on the driest ridges and upper south facing slopes to 80 feet on lower north facing slopes and stream terraces (Carmean 1965, Iverson and others 1997).

The entire landscape of the VFSEF was clearcut in the middle to late 1800s to provide charcoal to fuel iron production at the Vinton and Eagle Furnaces. Fires occurred frequently from 1880 to 1930 when forest stands were redeveloping after clearcutting (Hutchinson and others 2008, Sutherland 1997). However, fire suppression eliminated nearly all wildfires after 1935. Today's mature forests are dominated by oaks, primarily white oak, chestnut oak (*Quercus prinus*), and black oak, and hickories (*Carya* spp.). Yellow-poplar (*Liriodendron tulipifera*) and northern red oak (*Quercus rubra*) are common on higher quality sites. In the midstory (trees 4 to 10 inches diameter at breast height [dbh]), red maple is often prominent, and sugar maple (*Acer saccharum*) is also common on mesic sites. In the understory (trees <4 inches dbh), one or more shade-tolerant species are typically abundant, including red maple, sugar maple, blackgum, (*Nyssa sylvatica*), American beech (*Fagus grandifolia*), sourwood (*Oxydendrum arboreum*), and musclewood (*Carpinus caroliniana*).

The white oak decline event was characterized by the death of overstory white oaks, usually in patches of several trees and located on middle and lower slope positions. A combination of several factors, including insect defoliations, drought, excessive rainfall, and the exotic root rotting fungi *Phytophthora cinnamomi*, were implicated in the decline (Balci and others 2009, Nagle and others 2010). The white oak decline created small canopy gaps located throughout the forest.

Study Design

In 1995, a long-term study of prescribed fire was installed at two sites on the VFSEF and two additional sites located in Lawrence County, OH (Hutchinson and others 2005). From that larger study, we selected three burned stands and two unburned stands at VFSEF, where the oak decline even had occurred, for the present study of tree regeneration in canopy gaps. To increase sample size within the unburned treatment, we added a third unburned stand within VFSEF that was being used as an untreated control in another study (see Waldrop and others 2008). Pretreatment plot data show that oaks and hickories dominated the overstory, shade-tolerant species dominated the sapling layer, and oak plus hickory seedling densities averaged more than 2,000 per acre (table 1).

Among the three burned stands, two were burned five times and one was burned three times, all from 1996 through 2005 (table 2). In each burned stand, one of the fires occurred after gaps were formed. All but one fire was conducted in the spring dormant season, late March to mid-April, prior to substantial understory greening; the single fall fire occurred in early November. Fires were generally low-intensity, with flame lengths of 1 to 2 feet, and caused little mortality of overstory trees (Hutchinson and others, 2012b).

For this study, we selected 28 gaps in the three burned stands and 24 gaps in the three unburned stands. When choosing gaps to include in the study, we generally avoided single tree gaps. Gaps were on a variety of aspects, but nearly all were on midslope and lower slope positions. By chance, none of the gaps occurred within the 9 or 10 permanent vegetation plots located in each stand. To characterize soil moisture for each gap, based on its GPS-located landscape position, we used the Integrated Moisture Index (IMI) of Iverson and others (1997).

Field Data Collection

All data were collected in summer 2008. First, we established an approximate center point in each gap and flagged the perimeter of the gap. We then measured the length and width of the gap to estimate its area. All data were collected in metric units, but are reported here in English units. Within the perimeter of each gap, we recorded the species and diameter of standing dead trees ≥3.9 inches dbh, and also counted, by species, the number of saplings plus poles (stems 1.2 to 7.9 inches dbh). From the gap center point, we established four subplots, each 16.4 by 6.6 feet, to record advance reproduction. Each subplot was located halfway between the gap center and perimeter, along the length and width axes. In the subplots, we counted the number of stems of advance reproduction by species, in three size classes: 1.0 to 2.0 feet tall, 2.0 to 4.6 feet tall, and 4.6 feet tall to 1.1 inches dbh. Within each gap, we also measured light as a percentage of full sunlight, with a Decagon AccuPAR LP 80 ceptometer. For further details on field data collection, see Hutchinson and others (2012a).

Data Analysis

To test for significant differences between gaps in burned and unburned stands, we used generalized linear mixed models. Stand was the experimental unit and gaps within stands were the sampling units. Stand was treated as a random effect nested within the fixed effect of fire. We tested whether unburned and burned gaps were significantly different ($p < 0.05$) in several characteristics: soil moisture (IMI), size (area in acres), the number and size (dbh) of dead trees, sapling and pole density, and percentage of full sunlight. We also tested for significant differences in the density of several major species and species groups (oaks, hickories, sassafras, shade-tolerant species, other species), between burned and unburned gaps. A more comprehensive description of data analyses can be found in Hutchinson and others (2012a).

RESULTS

Characteristics of Gaps

Gaps in burned stands were similar ($p > 0.05$) to those in unburned stands, with respect to soil moisture (IMI), gap size, number of dead trees per gap, and dbh of dead trees (fig. 1). Overall, the mean IMI was 46.2, indicating intermediate soil moisture levels (Iverson and Prasad 2003). Gaps were small, averaging 0.06 acres (range = 0.03 to 0.12 acres). The mean number of dead white oak trees per gap was 4.0 (range = 1 to 10) and these trees averaged 16.6 inches dbh (range = 6.8 to 31.0).

Though similar in size and soil moisture, burned gaps had significantly fewer saplings and poles ($p = 0.002$), compared to unburned gaps (fig. 1). In unburned gaps, sapling and pole density averaged 404 stems per acre (range = 205 to 644); the most abundant species were American beech, red maple, sugar maple and blackgum. In burned gaps, sapling and pole density averaged 63 stems per acre and all but one burned gap had less than 200 stems per acre. Understory light levels were also significantly greater ($p = 0.033$) in burned gaps than in unburned gaps (fig. 1). Approximately 5 years after the gaps had formed, burned gaps averaged 18.7 percent of full sunlight compared to 7.3 percent in unburned gaps.

Advance Reproduction

In burned gaps, the density of advance reproduction (stems 12 inches tall to 1.1 inches dbh) for all species combined was more than twice that found in unburned gaps. Stem densities averaged 8,738 and 3,653 per acre in burned and unburned gaps, respectively. Among the major species and species groups, the density of oaks ($p = 0.036$) and sassafras (*Sassafras albidum*, $p = 0.002$) were significantly greater in burned gaps than in unburned gaps, while the density of shade-tolerant species was not different ($p = 0.810$) between burned and unburned gaps (fig. 2). Across the burned and unburned gaps, eight species comprised 96 percent of stems in the shade-tolerant group. These species were, in descending order of average density: red maple, white ash (*Fraxinus americana*), musclewood, blackgum, flowering dogwood (*Cornus florida*), American beech, sourwood, and downy serviceberry (*Amelanchier arborea*). For hickories, the average density in burned gaps was 2.2 times greater than in unburned gaps; however, that difference approached but did not meet statistical significance ($p = 0.086$).

The average density of oaks was 3.6 times greater in burned gaps (3,670 stems per acre) than in unburned gaps (1,021 stems per acre). Among the oaks in the burned gaps, white oak was the most abundant species, making up, on average, 67 percent of all oak stems, followed by black oak (17 percent), chestnut oak (7 percent), scarlet oak (*Quercus coccinea*, 6 percent), and northern red oak (3 percent). White oak was also the most abundant oak in the unburned gaps, making up 57 percent of oak stems.

In burned gaps, the greater densities of oak and hickory (combined) advance reproduction resulted from greater numbers of larger stems. While smaller oak and hickory stems (1 to 2 feet height) were equally abundant in burned and unburned gaps ($p = 0.537$), larger oak and hickory (2 feet height to 1.1 inches dbh) were significantly more abundant in burned gaps ($p = 0.018$, fig. 3). Burned gaps had an average density of 2,643 larger oak and hickory stems per acre, while unburned gaps averaged 318 larger stems per acre.

Among individual gaps in the burned stands, densities of larger oak and hickory were consistently high: 20 of 28 burned gaps had more than 2,000 larger stems per acre (fig. 4). Similarly, in unburned stands, densities of larger oak plus hickory were consistently low; nearly all (22 of 24) unburned gaps had fewer than 2,000 stems per acre. Larger sassafras occurred at very high densities in several burned gaps, but its abundance was more variable than oak and hickory; larger sassafras were absent from more than one third of burned gaps (fig. 4). In addition, the density of larger oak plus hickory stems was more than twice that of shade-tolerant species in over half of the burned gaps.

For the largest size class of advance reproduction, stems 4.6 feet tall to 1.1 inches dbh, oaks and hickories averaged 806 stems per acre in burned gaps compared to 55 per acre in unburned gaps. Oaks and hickories in this size class were present in 82 percent of the burned gaps but occurred in only 20 percent of unburned gaps. In burned gaps, the density of oaks and hickories >4.6 feet tall was 2.5 times greater than that of shade-tolerant species. By contrast, in unburned gaps, shade-tolerant stems were 5.3 times more abundant than oaks and hickories.

DISCUSSION

In this study we found that a series of low-intensity fires, conducted over about a decade, coupled with small canopy openings formed 7 to 8 years after fires began, resulted in high densities of larger (>2 feet tall) oak advance reproduction. Gaps in the burned stands had 84 percent fewer shade-tolerant saplings and poles and more sunlight was reaching the understory even 5 years after gap formation. The larger oak advance reproduction that developed consistently in the burned gaps will have a higher probability of being competitive after a stand-level disturbance compared to the smaller oak reproduction in the unburned stands (Loftis 1990, Sander 1971). The single fire that occurred after gap formation in each of the burned stands may also have been important in the development of larger oak reproduction (Brose and Van Lear 1998). However, because we did not follow individual seedlings through the sequence of repeated fires, gap formation, and the single fire after gap formation, the relative importance of the pre-gap fires vs. the post-gap fire is unclear.

In our study sites, oak and hickory seedlings were present at moderate densities (>2,000 per acre) before the prescribed fire treatments began, which was likely important for the ultimate development of larger oaks after the sequence of fires and gap formation (Johnson and others 2009). However, in a more mesic oak forest in West Virginia, with fewer and smaller oak seedlings, Schuler and others (2013) also found that repeated preharvest prescribed fires favored the development of larger oak reproduction. In their study, two dormant-season fires greatly reduced the dense layer of shade-tolerant saplings that had been present. Soon after the fires, a bumper crop of northern red oak acorns resulted in large numbers of new seedlings. Those new red oak seedlings grew larger in the burned areas where the sapling layer had been topkilled than in adjacent unburned areas. After the mast event, further fires were withheld to allow the new oak seedlings to develop. Their study highlights the importance of timing prescribed fires with acorn crops, particularly in mesic forests where oak seedlings fail to accumulate over time.

In addition to the oaks, sassafras advance reproduction was more abundant in burned gaps than in unburned gaps. Advance reproduction of sassafras often exhibits clonal growth (Burns and Honkala 1990). When fire topkills sassafras stems, densities typically increase as multiple new root sprouts are initiated (Alexander and others 2008). In our study, we hypothesize that the higher densities of sassafras in burned gaps resulted from clonal expansion and root sprouting after fires. Through the course of the prescribed burn study, newly germinated sassafras seedlings were seldom observed after fires (T. Hutchinson, personal observation). Although sassafras is abundant in a number of the burned gaps, it is unclear whether it would be a long-term competitor of the oaks if a stand-level disturbance were to occur. In the study region, advance reproduction of sassafras is common, particularly on drier sites, but sassafras is uncommon in the overstory of mature stands.

Management Considerations

In management areas where timber harvesting is not desired or permitted, our findings show that periodic prescribed fires can help create conditions favorable for the development of larger oak reproduction in relatively small canopy openings. However, the eventual recruitment of oak into the overstory may require larger gaps than those formed in our study (Loftis 2004). In stands where timber harvesting is planned, repeated fires conducted prior to the harvest could favor dominance by oaks after the harvest by reducing competition from shade-tolerant saplings. This will be most effective when oak seedlings are present at moderate densities initially and are also large enough to resprout after fires. In addition to prescribed fire, herbicide application may be necessary to kill larger saplings and poles (>6 inches dbh), those that are resistant to topkill by fire. However, after repeated fires have greatly reduced sapling densities, much less effort and cost are required to find and apply herbicide to the remaining stems not topkilled by fire.

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Table 1—Characteristics of the six stands before prescribed fire treatments were applied

		Overstory[a]		Saplings[b]		Seedlings[c]
Stand	Area (acres)	Basal area (ft^2/ac)	Basal area (% oak hickory)	Density (stems/ac)	Density (% tolerant)	Oak hickory (stems/ac)
Arch Rock unburned	59	113	83	812	87	5578
Watch Rock unburned	49	113	82	675	96	2159
REMA unburned	57	120	82	837	97	4049
Arch Rock 3X	59	119	91	766	96	4228
Arch Rock 5X	79	124	77	866	94	2834
Watch Rock 5X	77	102	82	724	78	3959

Note: Vegetation data were collected in 1995 from nine 0.3 acre plots in all stands other than REMA unburned, where data were collected in 2000 from ten 0.25 acre plots.

[a]Trees >3.9 inches d.b.h.

[b]Trees 4.6 feet height to 3.9 inches d.b.h.

[c]All stems <4.6 feet height.

Table 2—Dates of the 13 prescribed fires in relation to canopy gap formation

	Before gap formation				After gap formation	
Stand	1996	1997	1998	1999	2004	2005
Arch Rock 3X	April 18	–	–	March 26	–	April 15
Arch Rock 5X	April 19	April 2	April 6	March 26	April 17	–
Watch Rock 5X	April 21	April 3	April 6	March 27	November 9	–

– Dashes represent no fire occured in that location during that year.

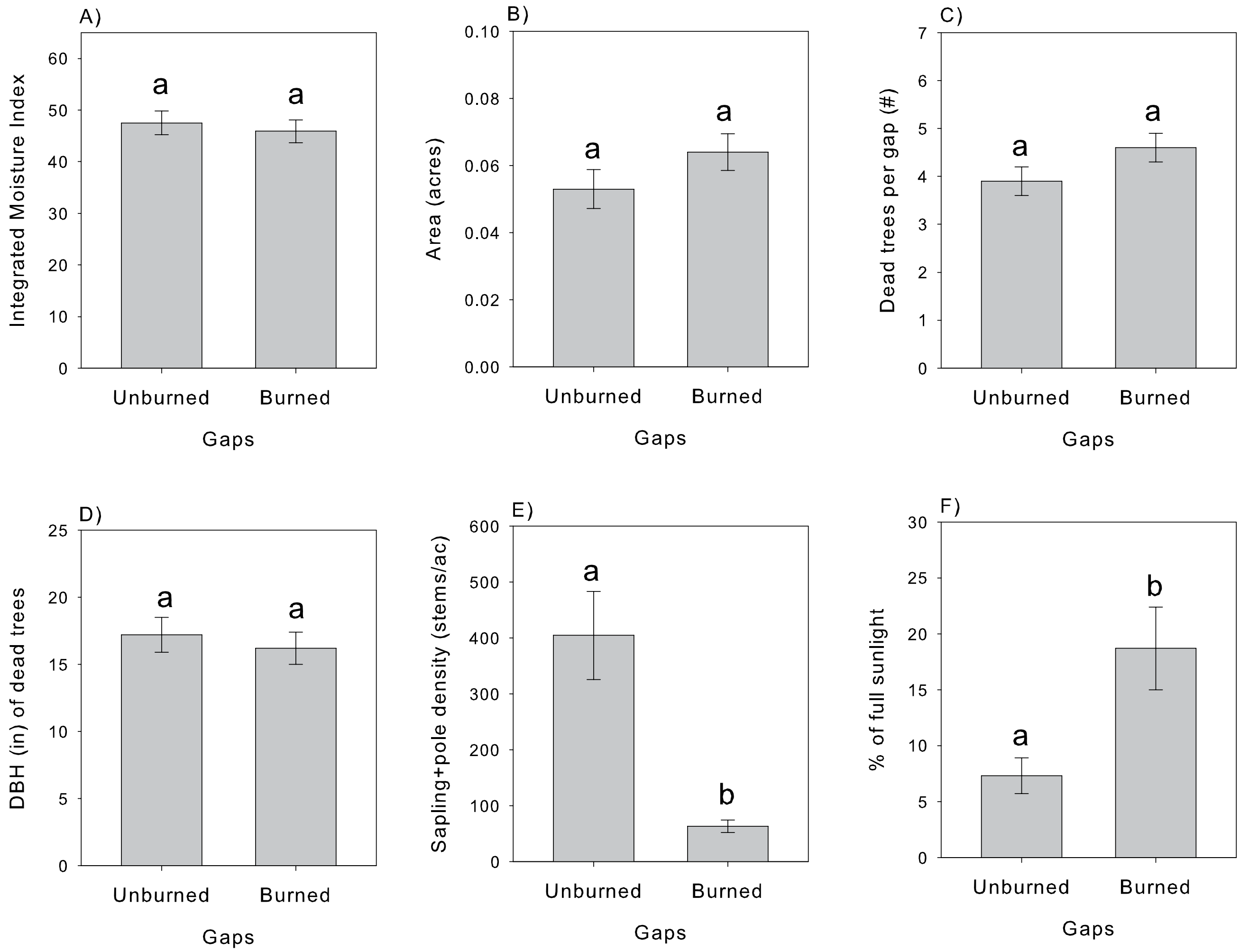

Figure 1—Mean values (±1 standard error) in unburned and burned gaps for A) Integrated Moisture Index (0 to 100 scale), B) area, C) number of dead trees per gap, D) dbh of dead trees, E) density of saplings and poles (stems 1.2 to 7.9 inches dbh), F) percentage of full sunlight. In each graph, different lower case letters above the two bars indicate a significant difference ($p < 0.05$) between unburned and burned gaps.

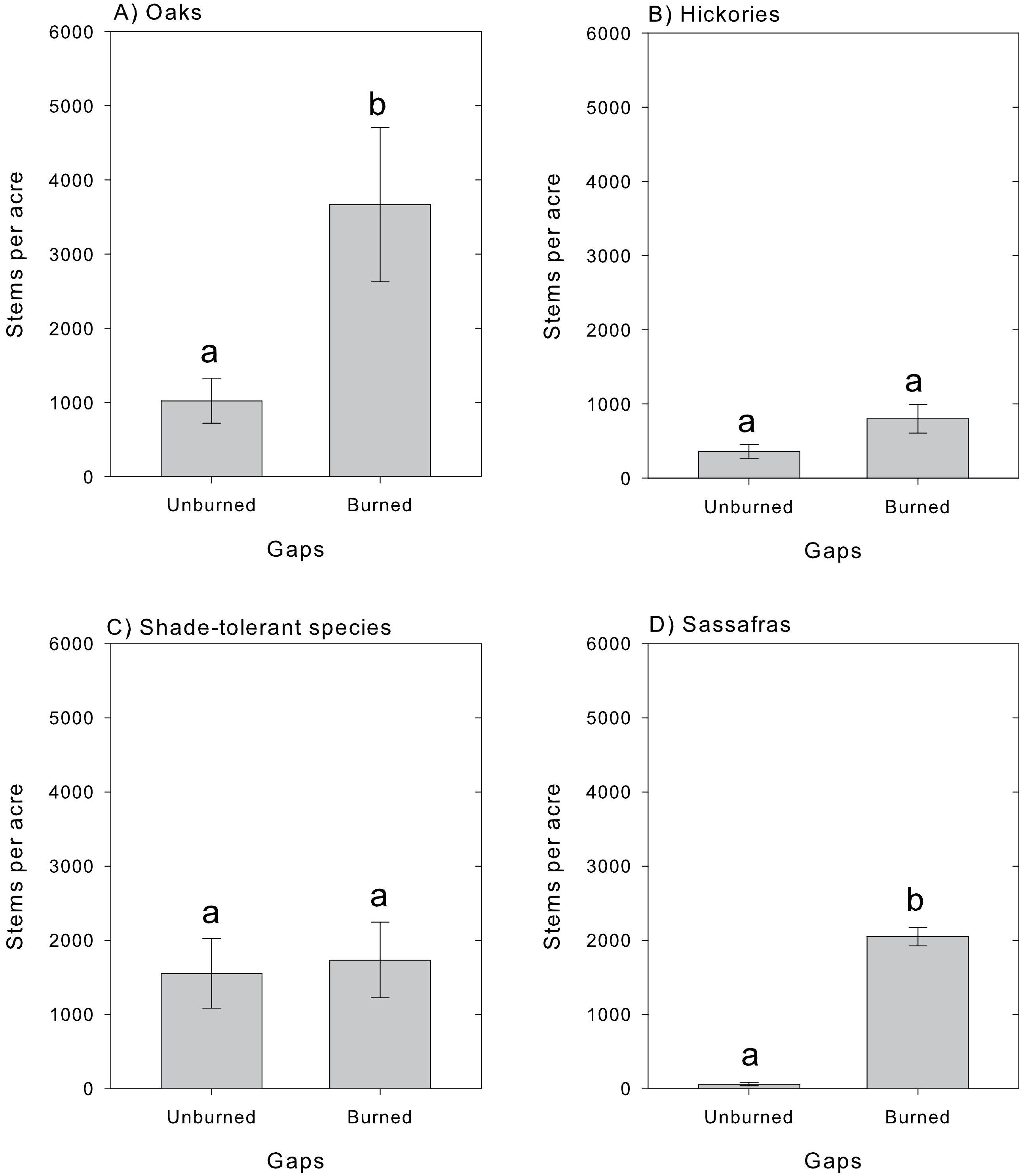

Figure 2—Mean values (±1 standard error) in unburned and burned gaps for the density of advance reproduction (stems 1 foot tall to 1.1 inches dbh) for four major species or species groups: A) oaks, B) hickories, C) shade-tolerant species, and D) sassafras. In each graph, different lower case letters above the two bars indicate a significant difference ($p < 0.05$) between unburned and burned gaps.

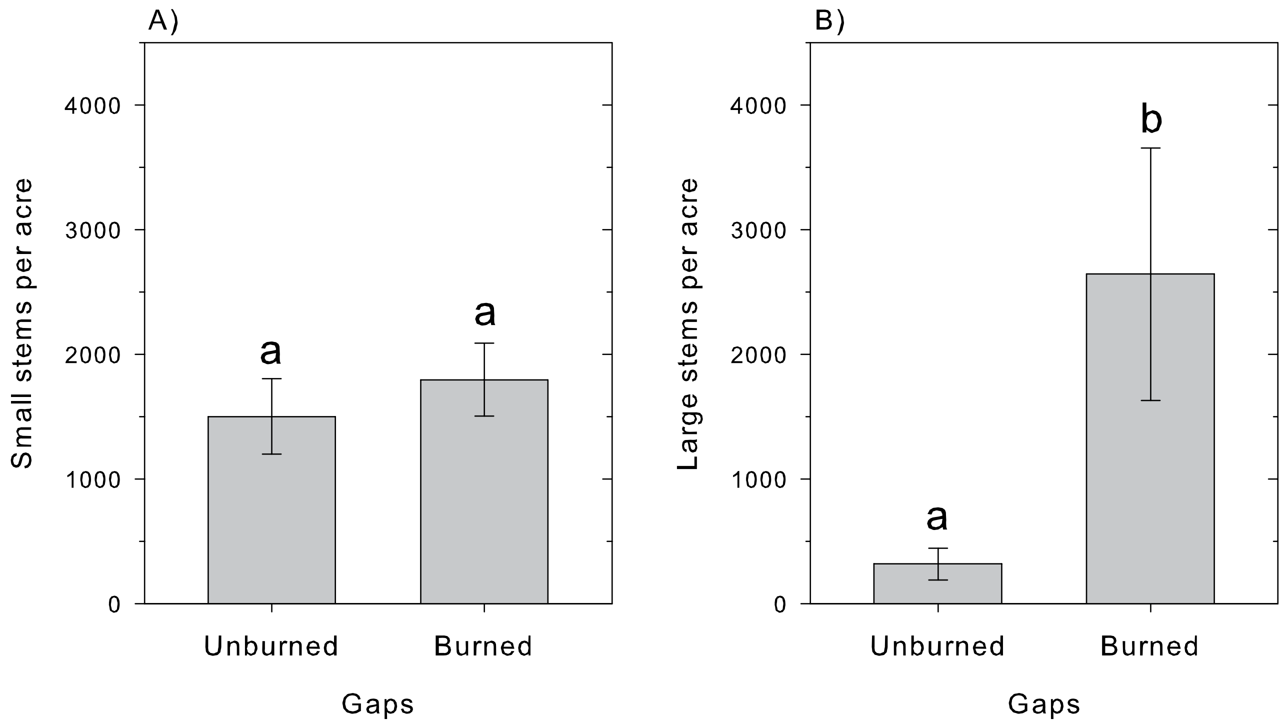

Figure 3—Mean values (±1 standard error) in unburned and burned gaps for the density of oak hickory advance reproduction for A) smaller stems (1 to 2 feet tall) and B) larger stems (2 feet tall to 1.1 inches dbh). In each graph, different lower case letters above the two bars indicate a significant difference ($p < 0.05$) between unburned and burned gaps.

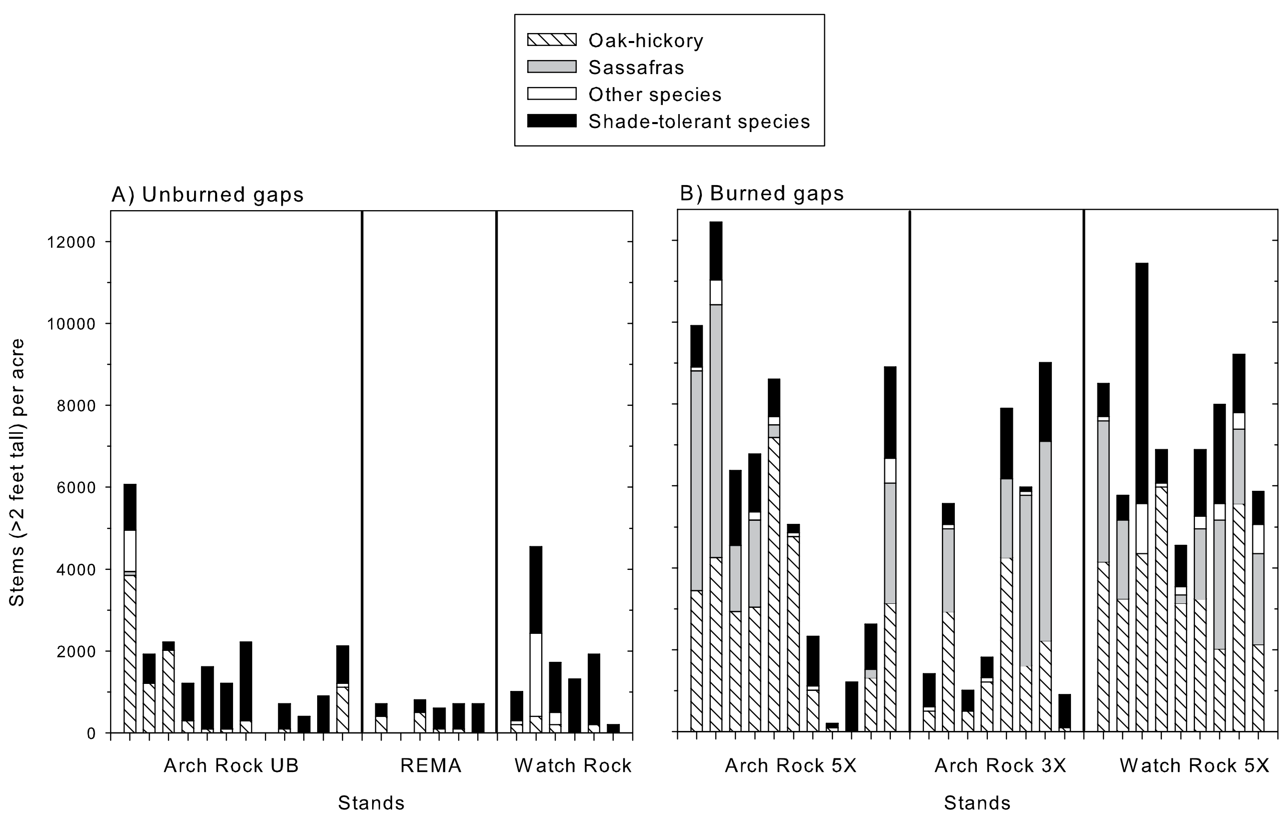

Figure 4—The density of larger advance reproduction (stems 2 feet tall to 1.1 inches dbh) in each gap for four major species groups in A) unburned gaps and B) burned gaps.