The Impacts of Mast Year and Prescribed Fires on Tree Regeneration in Oak Forests at the Mohonk Preserve, Southeastern New York, USA

Authors: Abrams, Marc D., and Johnson, Sarah E.

Source: Natural Areas Journal, 33(4) : 427-434

Published By: Natural Areas Association

URL: https://doi.org/10.3375/043.033.0405

RESEARCH ARTICLE

•

The Impacts of Mast Year and Prescribed Fires on Tree Regeneration in Oak Forests at the Mohonk Preserve, Southeastern New York, USA

Marc D. Abrams[1,2]

[1]Department of Ecosystem Science and Management
Penn State University
307 Forest Resources Building
University Park, PA 16802

Sarah E. Johnson[1]

•

[2] Corresponding author:
agl@psu.edu

Natural Areas Journal 33:427–434

ABSTRACT: This four-year study investigated the impacts of a 2010 mast year (for red oak; *Quercus rubra*) and spring 2009 and 2011 prescribed fires by comparing temporal variation in tree regeneration on seven burned and unburned sites at the Mohonk Preserve in the Shawangunk Mountains of eastern New York. The overstory of all stands was dominated to varying degrees by red oak, chestnut oak (*Q. montana*), and red maple (*Acer rubrum*). Seedling density for red oak was 4267/ha in 2009 compared with 23,000/ha in 2011 as a result of the 2010 mast year. By 2012, red oak seedling density decreased to 12,714/ha, suggesting the ephemeral nature of young oak seedlings, but remained higher than pre-mast year levels. Average seedling density was 31,030/ha on the burned sites and 23,189/ha on the unburned sites and dominated by red oak followed by chestnut oak. Red oak seedling density was much higher on burned than unburned sites (mean = 19,400 versus 9578/ha, respectively), whereas chestnut oak was moderately higher on unburned sites. The results of this study suggest that while prescribed burning stimulated red oak seedling density at the Mohonk Preserve, mast year played an even larger role over the short term (which included unburned sites). Moreover, a synergistic interaction of these factors may have resulted in burned sites having the highest red oak seedling density following a mast year.

Index terms: chestnut oak, mast year, prescribed fire, red oak, Shawangunk Mountains

INTRODUCTION

Forests of eastern North America experienced a dramatic increase in mesophytic and generally shade tolerant tree species during the twentieth century (Abrams 1998; Brose et al. 2001; Nowacki and Abrams 2008). These species have become nearly ubiquitous across subxeric sites throughout the temperate forest biome. This is thought to be related, at least in part, to the exclusion of fire in most forests, particularly those dominated by pyrogenic species, such as oak (*Quercus*), hickory (*Carya*), and pine (*Pinus*) (Buell et al. 1954; Lorimer 1985; Abrams 1992). In addition, differential deer (*Odocoileus virginianus*) browsing on oak (favored by deer) versus those species avoided by deer (such as red maple; *Acer rubrum*) has also acted to promote certain oak-replacement species (Abrams 1998; Abrams and Johnson 2012). Presently, later successional, mesophytic trees dominate the understory and mid-canopy of many forests, and it appears that they have the potential to cause widespread replacement of the historically dominant trees in the eastern United States. This process is also changing the forest microenvironment and reducing the likelihood of restoring the natural fire cycle in these ecosystems; thus, it has been termed "mesophication" (Nowacki and Abrams 2008).

Periodic burning of pyrogenic forests by Native Americans was arguably a key (but not the only) factor in their long-term sustainability, while limiting mesophytic tree dominance in the presettlement forests (Brose at el. 2001; Guyette et al. 2002; Abrams and Nowacki 2008). However, given current conditions of the ecology and management of eastern forests, the increasing importance of red maple and other species seems inevitable. The loss of oak, hickory, and pine dominance in eastern U.S. forests will be a primary consequence of the continued expansion of later successional tree species. Forest managers at nature preserves and natural areas throughout the eastern U.S. are concerned about the lack of regeneration of desired, native tree species that will form the next generation of canopy individuals (Abrams and Hayes 2008; Abrams and Sands 2010). The use of periodic understory prescribed burning to reduce forest floor litter depth and plant competition and increase understory light intensity, coupled with other ecosystem management practices (e.g., canopy thinning), may be an effective tool for restoring the ecological integrity of these forests while halting the "mesophication" process (Wang et al. 2005; Royse et al. 2010; Fan et al. 2012). These practices may also help prevent the formation of unwanted, novel ecosystems with no historic precedent (Hobbs et al. 2009).

This research investigated the status of oak regeneration on dry sites at the Mohonk Preserve in the Shawangunk Mountains of eastern New York, with a particular emphasis on red oak and chestnut oak forests (*Q. rubra* and *Q. montana*). After a century or more of fire suppression, prescribed fire was reintroduced to several sites at the Mohonk Preserve in 2009 and 2011. In addition, a mast year with abundant red oak acorn production occurred at Mohonk in the fall of 2010, which likely impacted oak seedling density. This research investigated the impacts mast year and prescribed fires, including possible synergism, by comparing temporal variation in tree regeneration on burned and unburned sites.

Site Description

This 2009 to 2012 research was conducted at the Mohonk Preserve (41°45'29"N, 74°09'28"W), which was established in 1869 in the Shawangunk Mountains of eastern New York (Figure 1). Pollen extracted from lake sediment showed an increase in oak and pine dominance throughout southeastern New York over the past 9000 years (Maenza-Gmelch 1997). This coincided with an influx of charcoal in lake sediments, suggesting that fire played an important role in the development of woodlands in this area. Delaware Indians inhabited the Hudson Valley and were known to deliberately burn forest areas (Buell et al. 1954; Josephson 2002). Throughout the nineteenth and early twentieth centuries, more extensive logging of forests occurred to supply wood to local sawmills for charcoal iron production and the tanning industry (Snyder and Beard 1981; Josephson 2002). This was followed by the harvesting of American chestnut (*Castanea dentata*), killed by the chestnut blight (*Cryphonectria parasitica*) in the early 1900s. The first outbreak of the gypsy moth (*Lymantria dispar*) on the Mohonk Preserve occurred in 1957, resulting in oak mortality on the ridges. More recently, fires have been common on the Shawangunk Ridge (Laing 1994). Chestnut oak and red oak forests cover approximately 1420 ha of the Mohonk Preserve.

We chose seven study sites that occurred on the Martinsburg shale bedrock of the Nassau-Manilus soil type, a shaly silt loam that is moderately deep and well drained (USDA Soil Conservation Service 1979;

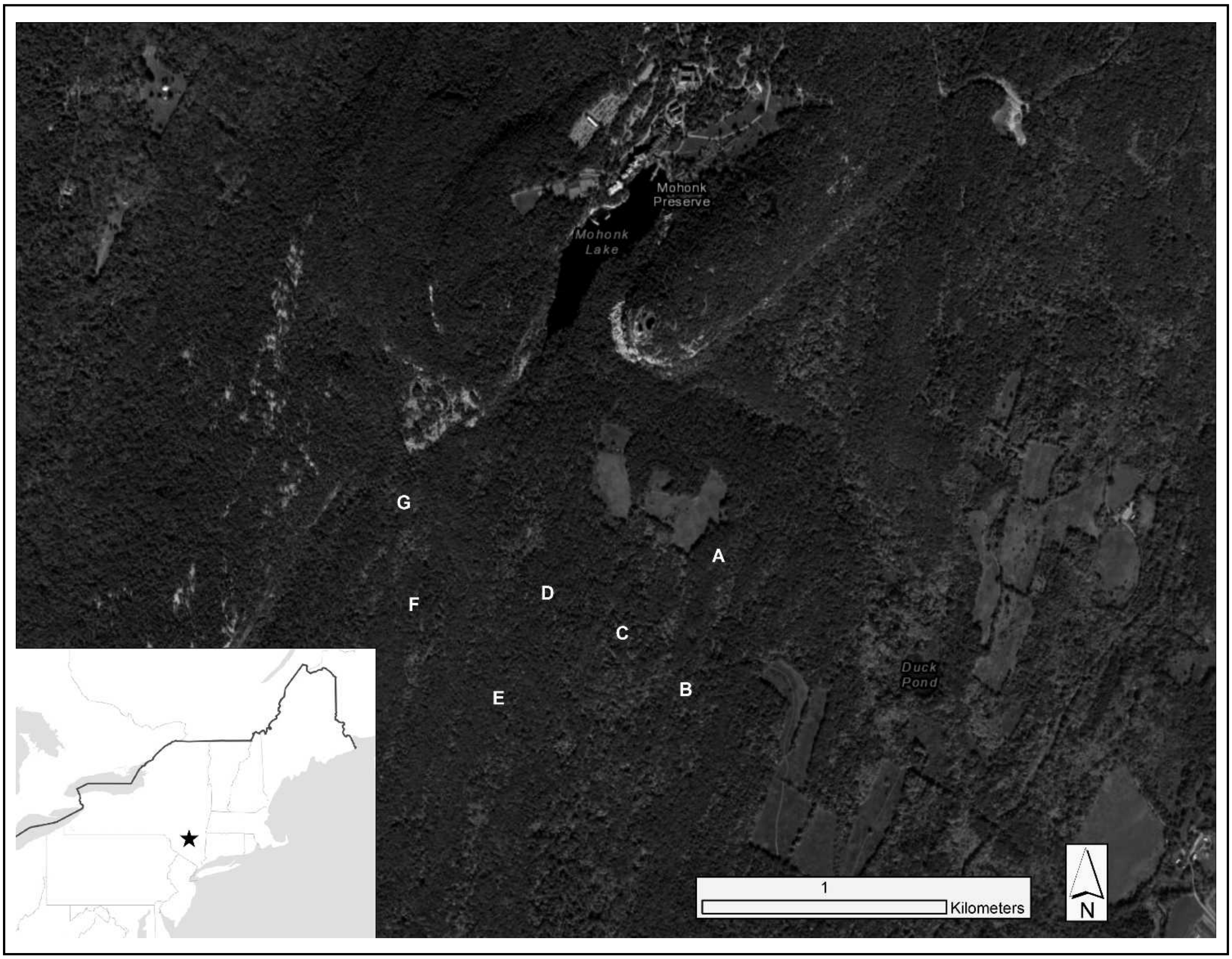

Figure 1. Location of Mohonk Preserve in southeastern New York (inset) and the seven burned and unburned study stands within the preserve (A = Old Stage 1; B = Glory Hill 2; C = Old Stage 2; D = Old Minnewaska 2; E = Old Minnewaska 1; F = Oakwood 2; G = Oakwood 3).

Table 1; Figure 1). These sites ranged from 267 to 357 m in elevation and occupied ridgeline to upper and middle side slope positions. Their aspect varied from east (mesic) to west (more xeric) and they had a slope of about 5% to 25%. Three of the study sites (Old Stage 1, Oakwood 2 (in 2009), and Oakwood 3) are unburned, whereas the understory of the five other sites were burned in the spring of 2009 (Oakwood 2) or spring 2011 (Table 2). Oakwood 2 is considered an unburned site in 2009 and a burned site in 2011 and 2012. The red oak acorns produced in the fall of 2010 did not germinate until after the spring 2011 burns.

Table 1. Study site names, burn status, and other physical features of the seven burned and unburned study sites on shale soils on the Mohonk Preserve..

Site	Slope Position	Burn Status	Elevation (ft)	Aspect	Slope (%)
*Old Stage 1	Ridgeline	Unburned	1140	East	~ 0-5
*Oakwood 2	Bench-Ridgeline	Burned 2009	980-1170	West	~ 5-25
*Oakwood 3	Upper sideslope	Unburned	1035	West	~ 5-10
Old Stage 3	Midslope	Burned 2011	1050	Southwest	~ 5-25
Glory Hill 2	Ridgeline-Sideslope	Burned 2011	965	Southeast	~ 0-10
Old Minnewaska 1	Upper sideslope	Burned 2011	960-1130	Southwest	~ 5-15
Old Minnewaska 2	Upper sideslope	Burned 2011	1170	South	~ 0-10

*indicates a stand surveyed in 2009

METHODS

During July 2011 and June 2012, regeneration surveys were conducted at the seven study sites within the Mohonk Preserve. Additionally, the three unburned stands were surveyed in May 2009. Ten permanently marked (in either 2009 or 2011), fixed-area plots located at approximately 15-m intervals along transects (typically 200 – 300 m in length) through the forest interior were used for vegetation sampling. The location of these plots was recorded by GPS, which was also used to locate a few of the plots with missing markers in 2012. Saplings and seedlings (excluding first year germinants) were counted in nested circular plots of 20 m^2 and 10 m^2, respectively, located at each plot center. Saplings are classified as tree species > 1.4 m in height but < 10.0 cm in dbh and seedlings were < 1.4 m. Tree species (≥ 10 cm dbh) density was recorded by species in a 200-m^2 circular plot at each understory plot center in July 2011. A general description of each site was recorded, including landscape position, soil type, elevation, and aspect.

RESULTS AND DISCUSSION

A total of 13 tree species were recorded in the overstory on the seven study sites in 2011 (Table 2). Tree density across all stands was fairly similar, averaging 553 trees per ha and ranging from 455 – 675 trees per ha. The 2009 and 2011 prescribed fires appeared to have little impact on overstory tree density via mortality. Overall the study sites were dominated by different combinations of red oak, red maple, chestnut oak, and white pine (*P. strobus*; Table 2 and Figure 2). The stands with the highest tree densities overall (Glory Hill 2 and Oakwood 2) were dominated by these two oaks. Red oak averaged 39% of the total tree density and dominated five stands. Red maple tree density averaged 21% (range from 0% – 46%) and dominated two stands. Chestnut oak averaged 18% of the total density and was not the number one dominant in any of the study sites. Pignut hickory (*C. glabra*) was present at low to moderate levels across all study sites.

A total of 13 tree species were recorded as seedlings with an average density of 19,300 per ha on the three unburned study sites in 2009 (including Oakwood 2; Table 3). This compares to an average density of 32,300 seedlings/ha in 2011 and 17,300 seedlings/ha in 2012. The large increase in seedlings in 2011 is due primarily to an increase in red oak following the 2010 mast year. Seedling density for the other oak species did not increase in 2011, which suggests that 2010 was a mast year for red oak only. Old Stage 1 and Oakwood 3 experienced a large drop in seedling density (mainly red oak) between 2011 and 2012 not seen at Oakwood 2, by which time the latter site had been burned (Tables 3 and 4). The other dominant seedling on unburned sites was chestnut oak, although it was almost nonexistent at Old Stage 1. In contrast, red maple, striped maple (*A. pensylvanicun*), sweet birch (*Betula lenta*), witch hazel (*Hamamelis virginiana*), white pine, and hophornbeam (*Ostrya virginiana*) seedlings were more important at Old Stage 1 than the other two unburned sites. Hophornbeam seedling density dramatically increased, while witch hazel seedlings decreased, at Old Stage 1 between 2009 and 2011.

A total of 15 tree species were recorded as seedlings on the five burned study sites (Table 4; Figure 2). Seedling density was highest at Old Minnewaska 2 in 2011 (60,500/ha) and lowest at Old Stage 3 in

Table 2. The total (#/ha) and percent density of trees species on the seven burned and unburned (Old Stage 1 and Oakwood 3) Mohonk study sites surveyed in 2011. OS = Old Stage; OW = Oakwood; GH = Glory Hill; OM = Old Minnewaska.

	Tree Density (#/hectare)													
	OS1		OW3		OW2		OS3		GH2		OM1		OM2	
Species	#/ha	% density	#/ha	% density	#/ha	% density	#/ha	% density	#/ha	% density	#/ha	% density	#/ha	% density
Quercus rubra	110	20.56	215	47.3	300	44.4	145	29.3	360	53.3	195	35.8	205	41.8
Quercus montana	20	3.74	100	22.0	265	39.3	35	7.1	180	26.7	80	14.7	70	14.3
Acer rubrum	245	45.79	65	14.3	5	0.7	160	32.3	-	-	125	22.9	165	33.7
Pinus strobus	85	15.89	-	-	5	0.7	-	-	125	18.5	-	-	-	-
Carya glabra	10	1.87	25	5.5	85	12.6	30	6.1	10	1.5	25	4.6	40	8.2
Acer saccharum	5	0.93	20	4.4	10	1.5	40	8.1	-	-	60	11.0	5	1.0
Quercus alba	5	0.93	-	-	-	-	5	1.0	-	-	10	1.8	-	-
Ostrya virginiana	30	5.61	25	5.5	5	0.7	30	6.1	-	-	-	-	5	1.0
Fraxinus americana	20	3.74	-	-	-	-	-	-	-	-	20	3.7	-	-
Tsuga canadensis	5	0.93	-	-	-	-	15	3.0	-	-	-	-	-	-
Amelanchier arborea	-	-	5	1.1	-	-	-	-	-	-	30	5.5	-	-
Liriodendron tulipifera	-	-	-	-	-	-	5	1.0	-	-	-	-	-	-
Fagus grandifolia	-	-	-	-	-	-	30	6.1	-	-	-	-	-	-
TOTAL trees/hectare	535		455		675		495		675		545		490	

2012 (10,000/ha). Red oak and chestnut oak were the dominant seedlings across all sites and years, with the exception of red maple at Old Stage 3 in 2011. Between 2011 and 2012, seedling density remained stable at Oakwood 2, increased by about 20% at Glory Hill 2 (mainly hophornbeam and chestnut oak), declined by 33% – 35% at Old Minnewaska 1 and 2, and declined by 68% at Old Stage 1. The decline in seedling density was mainly due to large reductions in red oak and red maple. This suggests the ephemeral nature of the many newly established seedlings produced as a result of a mast year or prescribed fire. This mortality has been attributed to low understory light levels and changes in the litter depth (Green et al. 2010; Royse et al. 2010; Greenberg et al. 2012), although deer browsing and insect and disease may also be casual factors at the Mohonk Preserve. It is interesting to note a relatively high number of red maple seedling on OS3 and OM1 that survived the 2011 fires also declined by 2012.

A total of eight tree species were present as saplings on the three unburned sites, dominated by witch hazel, striped maple, and red maple (Table 5). A total of ten tree species occurred as saplings at the five burned sites (Table 6). Old Minnewaska 2 had the highest sapling density (1950/ha in both 2011 and 2012), whereas Old Stage 3 in 2012 had the lowest density (350 saplings/ha). The dominant saplings were pignut hickory, striped maple, witch hazel, and red maple, depending on site. Across all seven sites, total sapling density was highest on the unburned Old Stage 1 (4850/ha) due to the amount of witch hazel. The low number of oak saplings at all burned and unburned sites is notable.

Average seedling density was higher on burned sites (31,030/ha versus 23,189/ha), while sapling density was higher on the unburned sites (2077 versus 995/ha; Tables 3 – 6). Red oak seedling density was generally higher on burned sites (mean = 19,400 versus 9578/ha, respectively) mainly due to its abundance on Old Minnewaska 1 and 2. Red maple seedling mean density was higher on the burned than unburned sites (2740 versus 778/ha). The increase in red maple on burned sites was also reported

Table 3. Tree seedling density (#/ha) in the unburned Old Stage 1 (OS1), Oakwood 3 (OW3) and Oakwood 2 (OW2) study sites at Mohonk in 2009, 2011, and 2012. Oakwood 2 was burned after our May 2009 survey.

	OS1			OW3			OW2
Species	2009	2011	2012	2009	2011	2012	2009
Quercus rubra	1400	16600	4500	2700	23600	11300	8700
Quercus alba	-	100	-	-	-	-	-
Quercus montana	-	100	-	11800	10500	8700	15700
Quercus ilicifolia	-	-	-	-	-	-	700
Carya glabra	-	100	-	100	-	100	-
Acer rubrum	2300	1700	1400	400	600	600	-
Acer pensylvanicum	1900	900	900	-	100	100	-
Fraxinus americana	300	100	600	-	-	-	-
Pinus strobus	100	700	600	-	-	-	-
Hamamelis virginiana	4400	1000	1000	500	500	400	200
Betula lenta	2900	-	-	-	-	-	-
Amelanchier arborea	200	300	-	400	-	-	200
Ostrya virginiana	100	6200	3000	2500	1500	1300	300
Prunus serotina	100	-	100	-	-	-	-
Total seedlings/hectare	13700	27800	12100	18400	36800	22500	25800

Table 4. Tree seedling density (#/ha) at the five burned study sites at Mohonk in 2011 and 2012. OW = Oakwood; OS = Old Stage; GH = Glory Hill; OM = Old Minnewaska.

	OW2		OS3		GH2		OM1		OM2	
Species	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Quercus montana	11500	12500	600	800	4500	7300	5200	4700	3500	1000
Quercus rubra	10800	8500	10500	3800	10800	10400	36600	20100	52100	30400
Quercus ilicifolia	400	400	-	-	-	100	-	-	-	-
Quercus alba	-	-	-	-	-	-	1100	400	-	-
Carya glabra	200	200	200	800	500	600	600	200	700	1200
Acer rubrum	100	-	17700	1200	300	100	3900	1200	1500	1400
Acer pensylvanicum	-	-	400	1000	-	-	400	2200	-	-
Fraxinus americana	-	-	1000	100	-	-	-	100	200	100
Ostrya virginiana	500	600	1100	1200	900	2200	1200	3200	900	2200
Amelanchier arborea	200	100	-	-	-	-	-	-	-	-
Sassafras albidum	-	100	-	-	-	-	-	-	-	-
Hamamelis virginiana	-	-	100	400	200	100	1600	1800	1400	2700
Castanea dentata	-	-	-	100	-	-	-	-	-	-
Liriodendron tulipifera	-	-	-	600	-	-	-	-	-	-
Prunus serotina	-	-	-	-	100	200	100	-	200	200
Total seedlings/hectare	23700	22400	31600	10000	17300	21000	50700	33900	60500	39200

Figure 2. From top left to bottom right- A) July 2011 overview of the spring 2011 prescribed fire in the forest understory at Glory Hill 2 site; B) Red oak and chestnut oak dominated forest at the unburned Oakwood 3 study site; C) Large cohort of red oak seedlings that germinated after the April burn in Old Minnewaska 2 site following a mast year in 2010; D) Large seedling sprouts of red oak and chestnut oak (in 2011) created after the 2009 fire on the Oakwood 2 site. The photos were taken by Marc Abrams, Penn State University.

Table 5. Tree sapling density (#/ha) on the three unburned study sites at Mohonk in 2009, 2011, and 2012.

	OS1			OW3			OW2
Species	2009	2011	2012	2009	2011	2012	2009
Quercus rubra	50	50	50	200	-	-	300
Quercus montana	-	-	-	50	-	-	50
Carya glabra	-	-	-	50	50	50	400
Acer rubrum	150	200	150	400	100	100	50
Acer pensylvanicum	1000	650	650	-	-	-	-
Acer saccharum	-	-	-	50	50	50	-
Hamamelis virginiana	3350	3750	3900	400	-	-	100
Ostrya virginiana	-	100	100	200	50	50	-
Total saplings/hectare	4550	4750	4850	1350	250	250	900

in the Cumberland Plateau in Kentucky, which was attributed to its vigorous sprouting ability (Chiang et al. 2005; Green et al. 2010). Lower sapling density on burned sites suggests, at least in part, they were killed or transformed to seedling sprouts by fire. Fire may act to increase the proportion of oak seedlings, but may cause an overall decline in total seedling density (Green et al. 2010; Royse et al. 2010). An increase in oak seedlings or seedling sprouts (either relative or total density) may occur following burning due to improved seedbed conditions for germination (e.g., exposed mineral soil, reduced litter layer), increased light and space, vigorous sprouting ability, and reduced competition (Lorimer 1985; Reich et al. 1990; Fan et al. 2012). Using repeated prescribed fire, coupled with

Table 6. Tree sapling density (#/ha) on the five burned study sites at Mohonk in 2009, 2011, and 2012.

	OW2		OS3		GH2		OM1		OM2	
Species	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Quercus rubra	150	150	-	-	50	50	-	-	-	-
Quercus montana	100	50	-	-	50	50	-	-	-	-
Carya glabra	350	350	-	-	-	-	-	-	50	50
Acer rubrum	50	50	-	-	50	50	300	300	650	650
Acer pensylvanicum	-	-	350	300	-	-	200	50	-	-
Acer saccharum	-	-	-	-	-	-	50	50	-	-
Fraxinus americana	-	-	-	-	-	-	50	50	-	-
Hamamelis virginiana	50	50	-	-	400	400	700	500	1150	1150
Amelanchier arborea	50	50	-	-	100	50	100	100	-	-
Ostrya virginiana	-	-	200	50	-	-	-	-	100	100
Total saplings/hectare	750	700	550	350	650	600	1400	1050	1950	1950

canopy thinning, may be more effective at stimulating oak regeneration compared with using only a single burn (McEwan et al. 2011).

One of the major findings of this study is the dramatic post-mast year increase in red oak seedling density in 2011 (an average of 23,000/ha versus 4267/ha in 2009). Red oak represented the dominant seedling in 2011 at six of seven burned and unburned study sites; whereas in 2009, it was subordinate to chestnut oak and red maple on most sites surveyed in this and a previous study (Abrams and Sands 2010). The prescribed fires in 2009 and 2011 appeared to positively impact red oak seedling numbers, as two burned sites had the highest number of red oak seedlings (mean density of 44,350/ha; Table 4, Figure 2). This suggests a synergistic interaction between fire and mast year for promoting oak seedling density. Indeed, the burned sites had higher average red oak density than the unburned sites, and appeared to be more successful in producing large seedling sprouts in the advance regeneration (Figure 2). However, red oak seedling density also increased by 15,200/ha and 20,900/ha between 2009 and 2011 on two unburned sites, suggesting the overriding importance of mast year on all sites.

The spring 2011 prescribed fires did not negate the beneficial impacts of the 2010 mast years via acorn mortality. Acorn losses likely occurred as a result of the fire, but many of them survived to greatly elevate oak seedling density. A Pennsylvania study reported that about 40% of red oak acorns were killed by a typical fire for the region (Auchmoody and Smith 1993). Significant losses of red oak and white oak acorns following prescribed fires of increasing intensity were also reported in North Carolina forests (Greenberg et al. 2012). On average, nearly 50% of the newly established red oak seedlings in 2011 were lost by 2012 on the burned and unburned sites. Nonetheless, red oak seedling density in 2012 remained 300% higher than that in 2009. Therefore, the impact of the 2010 mast year in stimulating red oak regeneration was still evident two years later. The results of this study indicate the importance of mast years and prescribed fire, both individually and collectively, in stimulating oak regeneration.

ACKNOWLEDGMENTS

We thank the Loewy Family Foundation for support of this research through the Loewy-Mohonk Preserve Liaison Fellowship. We also thank John Thompson and Ethan Pierce for their help in planning and facilitating this study.

Marc D. Abrams is the Steimer Professor of Forest Ecology and Tree Physiology in the Department of Ecosystem Science and Management at Penn State University, University Park, PA.

Sarah Johnson is a Ph. D. student in the Department of Ecosystem Science and Management at Penn State University, University Park, PA.

LITERATURE CITED

Abrams, M.D. 1992. Fire and the development of oak forests. Bioscience 42:346-353.

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

Abrams, M.D., and V.L.W. Hayes. 2008. Impacts of contrasting land-use history on composition, soils, and development of mixed-oak, coastal plain forests on Shelter Island, New York. Journal of the Torrey Botanical Society 135:37-52.

Abrams, M.D., and S.E. Johnson. 2012. Long-term impacts of deer exclosures and land-use history on forest composition at the Valley Forge National Historical Park, Pennsylvania. Journal of the Torrey Botanical Society 139:167-180.

Abrams, M.D., and G.J. Nowacki. 2008. Native Americans as active and passive promoters of mast and fruit trees in the eastern USA. The Holocene 18:1123-1137.

Abrams, M.D., and B.A. Sands. 2010. Oak forest composition on contrasting soil types at the Mohonk Preserve, eastern New York. Northern Journal of Applied Forestry 27:105-109.

Auchmoody, L.R., and H.C. Smith. 1993. Survival of northern red oak acorns after fall burning. Research Paper NE-678, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Radnor, Pa.

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

Buell, M.F., H.F. Buell, and T.A. Small. 1954. Fire in the history of Mettler's Woods. Bulletin of the Torrey Botanical Club 81:253-255.

Chiang, J.M., M.A. Arthur, and B.A. Blankenship 2005. The effect of prescribed fire on gap fraction in an oak forest understory on the Cumberland Plateau. Journal of the Torrey Botanical Society 132:432-444.

Fan, Z., Z. Ma, D.C. Dey, and S.D. Roberts. 2012. Response of advance reproduction of oaks and associated species to repeated prescribed fires in upland oak-hickory forests, Missouri. Forest Ecology and Management 266:160-169.

Green, S.R., M.A. Arthur, and B.A. Blankenship. 2010. Oak and red maple seedling survival and growth following periodic prescribed fire on xeric ridgetops on the Cumberland Plateau. Forest Ecology and Management 259:2256-2266.

Greenberg, C.H., T.L. Keyser, S.J. Zarnoch, K. Connor, D.M. Simon, and G.S. Warburton. 2012. Acorn viability following prescribed fire in upland hardwood forests. Forest Ecology and Management 275:79-86.

Guyette, R.P., R.M. Muzika, and D.C. Dey. 2002. Dynamics of an anthropogenic fire regime. Ecosystems 5:472-486.

Hobbs, R.J., E. Higgs, and J.A. Harris. 2009. Novel ecosystems: implications for conservation and restoration. Trends in Ecology and Evolution 24:599-605.

Josephson, R. 2002. Mohonk Mountain House and Preserve. Arcadia Publishing, Portsmouth, N.H.

Laing, C. 1994. Vegetation and fire history of the dwarf pine ridges, Shawangunk Mountains, New York. Final Report. The Nature Conservancy, New York.

Lorimer, C.G. 1985. The role of fire in the perpetuation of oak forests. Pp. 8-25 *in* J.E. Johnson, ed., Challenges in Oak Management and Utilization. Cooperative Extension Service, University of Wisconsin, Madison.

Maenza-Gmelch, T.E. 1997. Vegetation, climate, and fire during the late-glacial-Holocene transition at Spruce Pond, Hudson Highlands, south-eastern New York, USA. Journal of Quaternary Science 12:15-24.

McEwan, R.W., J.M. Dyer, and N. Pederson. 2011. Multiple interacting ecosystem drivers: toward an encompassing hypothesis of oak forest dynamics across eastern North America. Ecography 34:244-256.

Nowacki, G.J., and M.D. Abrams. 2008. Demise of fire and mesophication of eastern U.S. forests. BioScience 58:123-138.

Reich, P.B., M.D. Abrams, T.J. Tabone, D.S. Ellsworth, and E.L. Kruger. 1990. Fire affects ecophysiology and community dynamics of central Wisconsin oak forest regeneration. Ecology 71:2179-2190.

Royse, J., M.A. Arthur, A. Schorgendorfer, and D.L. Loftis. 2010. Establishment and growth of oak (*Quercus alba, Quercus prinus*) seedlings in burned and fire-excluded upland forests on the Cumberland Plateau. Forest Ecology and Management 260:502-510.

Snyder, B., and K. Beard. 1981. The Shawangunk Mountains: a History of Nature and Man. Walden Printing Company, Walden, N.Y.

USDA Soil Conservation Service. 1979. Ulster County N.Y. Soil Survey. USDA Soil Conservation Service, Washington, D.C.

Wang, G.G., D.H. Van Lear, and W.L. Bauerle. 2005. Effects of prescribed fires on first-year establishment of white oak (*Quercus alba* L.) seedlings in the Upper Piedmont of South Carolina, USA. Forest Ecology and Management 213:328-337.