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Notes and Discussion Piece

Conserving Large Oaks and Recruitment Potential while Restoring Midwestern Savanna and Woodland

Abstract.—Restoring Midwestern oak savannas and woodlands over the long term requires balancing mortality of large oaks with recruitment of oaks into large size classes. At restoration sites in northwestern Ohio, we tracked survival of large oak trees ($\geq$20 cm in stem diameter) and recruitment between 2002 and 2015 after initial tree thinning and prescribed burning treatments. The 24 study sites spanned a gradient of canopy cover from unrestored forests to restored woodlands and savannas. Of 141 large black oak (*Quercus velutina*) and white oak (*Quercus alba*) trees alive in 2002, 79% were alive 14 y later. Large oak survival varied among vegetation types, with restored savannas not losing a single tree, compared with 18% mortality in unrestored forests and 28% mortality in restored woodlands. At least some mortality in the woodlands was associated with a tornado that damaged two sites. Diameter distributions changed over the 14 y in all three vegetation types. Unrestored forests shifted toward proportionally greater large and fewer small diameter oaks. Meanwhile, restored woodlands, despite having the highest mortality of large oaks, still exceeded, via recruitment of new large oaks, the reconstructed pre-Euro-American-settlement tree density. Restored woodlands and savannas exhibited four-fold increases in oak recruitment potential (saplings 1 to 10 cm in diameter) between 2002 and 2015. Ecological restoration processes have been compatible with conserving large oaks and sustaining oak recruitment potential.

Introduction

Since the early 1900s, oak (*Quercus*) dominated ecosystems in eastern North America have been transitioning to dominance by other tree species (Lorimer, 1993; Abrams, 2005; Arthur *et al.*, 2012). This conversion is related to several factors, such as cessation of fires that historically promoted oak, introduced pests and diseases that afflict oaks, high levels of deer herbivory, and perhaps disruption of animal-oak relationships (McEwan *et al.*, 2011). Although the "replacement" ecosystems, such as those with red maple (*Acer rubrum*), can provide certain wildlife habitat values, there are negative effects of losing oak trees (Greenberg *et al.*, 2011). Acorns provide a unique food source for over 100 vertebrate species in the eastern United States (Brose *et al.*, 2014). Additionally, the abundant foliage of oaks combined with their rough bark, contrasting with the smooth bark of replacement tree species, affords unique habitat to invertebrates and birds (Rodewald and Abrams, 2002; Tallamy and Shropshire, 2009).

With recognition of the values of oaks at risk, interest has heightened since the 1980s in conserving and restoring oak ecosystems (*e.g.,* Packard, 1993; Abella *et al.*, 2001; Hutchinson *et al.*, 2012). One such case is the eastern prairie-forest transition zone, supporting oak savannas and woodlands in the Midwest. Here, 99.98% of the savanna/woodland habitat present before Euro-American settlement was eliminated by 1985 (Nuzzo, 1986). During the 1900s, when fuel connectivity was reduced via landscape fragmentation (*e.g.*, road building, clearing for agriculture), intentional burning by humans was curtailed, and fire suppression became U.S. government policy, oak savannas/woodlands not converted to other land uses transitioned to mixed species forests (Brudvig *et al.*, 2011). As a result, there is particular interest in restoring oak savannas and woodlands within now-forested landscapes, because the open savannas and woodlands provide unique habitat on their own and landscapes containing mixtures of all three vegetation types can support more species than landscapes containing only one or two of these vegetation types (Grundel *et al.*, 2015).

To restore Midwestern savannas and woodlands within landscapes of mixed species forests, practitioners must implement treatments that remove most tree canopy cover, while allowing for retention of large oaks and oak recruitment potential, but not *too much* recruitment that compromises re-establishing open ecosystems (Cole *et al.*, 1992; Dey and Hartman, 2005; Haney *et al.*, 2008). This task is challenging, because oaks rarely regenerate in closed canopy conditions, but losing too many large oaks during restoration can preclude savanna tree patterns, acorn production, and future oak recruitment potential (Knapp *et al.*, 2015). Ironically, the processes needed to restore oak ecosystems can also threaten large oaks via fire introduced for the first time in typically over a century, creation of open stands that may increase susceptibility to wind damage, and disturbance to sites that could expose oaks to pests (Peterson and Reich, 2001; Allstadt *et al.*, 2013). On the other hand, creating conditions too optimal for oak recruitment, resulting in dominance of woody plants at the expense of herbaceous plants, can negate restoration efforts by limiting development of sunny and shady microsites characteristic of savannas and woodlands (Leach and Givnish, 1999). A balance of large oak mortality and recruitment of new trees into larger size classes is fundamental to sustaining oak savannas and woodlands that have undergone restoration.

We assessed survival of large oaks and recruitment potential during 14 y of ongoing restoration of oak savanna and woodland habitats in the Midwestern United States. Our primary objective was to compare large oak survival among unrestored forests and restored woodlands and savannas. Our secondary objective was to evaluate change in tree size distributions during restoration, including availability of oak saplings as recruitment potential. We focused on tree dynamics in restored ecosystems after initial tree thinning and burning treatments were purposely implemented to reduce tree density, under a restoration goal of favorably changing habitat for species benefitting from open-structured ecosystems.

METHODS

Our study occurred within the 40,000 ha Oak Openings region, centered 25 km southwest of the city of Toledo, in northwestern Ohio, and extending 15 km into southeastern Michigan. The region is an eastern patch of the prairie-forest transition zone (Anderson, 1998) and occupies deep sands deposited during the Wisconsin Glaciation by lakes larger than contemporary Lake Erie (Moseley, 1928). Based on analyzing U.S. General Land Office records, Brewer and Vankat (2004) distinguished three main plant communities present in the Oak Openings region during 1817 to 1832 surveys. Wet prairies, occupying lowlands, were mostly treeless. Uplands contained oak savannas and woodlands, with white oak (*Quercus alba*) and black oak (*Quercus velutina*) pre-dominating. Oak savannas contained 4 to 43 trees/ha larger than 13 cm in diameter (the typical minimum size of tree recorded in the survey), while woodlands contained more than 43 trees/ha and averaged 90 trees/ha (Brewer and Vankat, 2004).

We conducted the study at the 1497 ha Oak Openings Preserve (41°33′N, 83°51′W), managed by the Metroparks of the Toledo Area and the largest protected area in the Oak Openings region (Schetter and Root, 2011). Our study sites were on the Ottokee and Oakville soil series, classified as mixed, mesic Aquic and Typic Udipsamments (Stone *et al.*, 1980). Climate, recorded from 1955 through 2015 at the Toledo Airport (1 km east of the preserve), has averaged 85 cm/y of precipitation (40% from May through August), daily highs of 0 C in January and 29 C in July, and daily lows of –9 C in January and 16 C in July (Midwestern Regional Climate Center, Champaign, Illinois). During our study, summer (May through August) rainfall from 2002 through 2015 averaged 110% of the 34 cm/y long term average. Summer rainfall mirrored total yearly precipitation: total precipitation from 2002 through 2015 averaged 92 cm/y, 109% of average.

We established a one-way experimental design in which treatments were implemented to create three vegetation types (untreated forests as controls and woodlands and savannas undergoing restoration), with eight replicate sites per type. The 24 sites, 0.5 ha to 5 ha in size, were distributed across the landscape. Dominant oak trees ranged in age from 70 y to over 300 y among sites (Brewer and Vankat, 2004). In 1998, 16 of the sites, representing encroached oak savanna or woodland based on their reconstructed distribution at the time of the 1817 to 1832 land survey (Brewer and Vankat, 2004) were identified for ecological restoration. The restoration sites contained overstories with some oak, plus several hundred stems per hectare of nonoak species, and were in areas where managers could safely perform prescribed burning. The structural goal of the restoration was to re-establish savannas and woodlands containing oak densities that were approximately within the range found during the 1817 to 1832 land survey. Sites containing the fewest oak trees in the 1990s were targeted for savanna restoration, while sites with the highest oak densities were targeted for woodland restoration. In addition to making treatments easier to implement, we believed using contemporary stand structure was justified because tree density in savannas and woodlands was likely dynamic historically across the landscape and through time, probably linked with droughts and variations in fire frequency or severity (Chapman and Brewer, 2008). As a result, a site may have supported either savanna or woodland at different times. At restoration sites in 1999, nonoak trees were cut using chain saws, plus as needed on savanna restoration sites, overstory oaks were thinned to a density of less than 100 trees/ha under a prescription of retaining the largest oaks. Logs and slash were moved off site.

To re-introduce fire as a process sustaining woodlands and savannas, each restoration site was burned three times: 1998 or 1999; 2003 or 2004; and 2006, 2007, or 2008, depending on the site. The purpose of these burns was to establish and maintain open conditions and to avoid multi-decade fire-free intervals when tree recruitment could again convert woodlands and savannas to forests with tree densities exceeding those found during the 1817 to 1832 land survey (Brewer and Vankat, 2004). Burns were conducted during the dormant season (March–April or November–December) by Metroparks of the Toledo Area staff. Typical burns had fire behavior similar to the dormant season burns widely described in the literature: surface fires with flames mostly less than 2 m high and not reaching canopies of overstory oaks (*e.g.*, Cole *et al.*, 1992; Peterson and Reich, 2001; Hutchinson *et al.*, 2012).

In 1998, before initial thinning and burning treatments, the woodland sites averaged 474 trees/ha (53% oak) and 30.4 m^2/ha of basal area (80% oak). By 2002, after the initial treatments, tree density was reduced by 42% (and post treatment density increased to 82% oak) and basal area by 8% (and increased to 90% oak) in restored woodlands. In 1998 savanna sites averaged 426 trees/ha (52% oak) and 13.0 m^2/ha of basal area (35% oak). After initial treatments by 2002, tree density was reduced by 68% and basal area by 54% in restored savannas, and the oak component increased to 81% of tree density and 99% of basal area. Our study of survival of individual large oaks and recruitment dynamics began in 2002, to examine the fates of trees remaining in the restored ecosystems after the initial treatments had removed trees to re- establish woodland and savanna structure (Fig.1).

We established a 0.05 ha (20 m $\times$ 25 m) permanent plot in the center of each site, for a total of 24 plots. On each plot in 2002 and 2015, we inventoried the species, status (alive or dead), and diameter (dbh, at 1.4 m) of all oak stems $\geq$ 1 cm in diameter. We tracked the fate of individual oak trees $\geq$ 20 cm in diameter.

For statistical analyses we defined oaks $\geq$ 20 cm in diameter as "large," because these oaks could form upper canopies and produce the most acorns (Rose *et al.*, 2011). From the individual tree data for large oaks, we compared the frequency of large oaks surviving between 2002 and 2015 across vegetation types (forest, woodland, or savanna) using a chi-square test of independence. To examine changes in tree size structure, we calculated a diameter distribution for each vegetation type by averaging tree density among plots in 10 cm diameter classes. We compared distributions between 2002 and 2015 within vegetation types using Kolmogorov-Smirnov tests. Using one-way analyses of variance, with plots as replicates, we compared the mean change in density (2015 minus 2002 trees/ha) separately for small and large oaks among vegetation types. We used SAS 9.3 for statistical analyses.

RESULTS

In total 79% (113 of 143) of large oak trees ($\geq$20 cm in diameter in 2002) survived between 2002 and 2015 (Fig. 2). Most of the large oaks were black oak (67%) and white oak (31%). The remaining two trees (both of which survived) were pin oak (*Quercus palustris*). The arithmetic mean diameter of large oak trees in 2002, which thereafter died by 2015, was 36 $\pm$ 17 cm ($\pm$SD), compared to 44 $\pm$ 15 cm in 2002 for trees still alive in 2015. Quadratic means were similar: 40 cm in 2002 for oak trees dead by 2015 and 47 cm in 2002 for trees alive in 2015.

Survival of large oaks differed among vegetation types ($\chi^2 = 6.6$, $P = 0.037$). Survival ranged from 72% in oak woodland to 100% in oak savanna (Fig. 2). The lower survival in woodland primarily resulted from two plots—both of which contained only black oak—where 46% of oak trees died (12 of 26 trees).

Oak diameter distribution changed between 2002 and 2015 in all three vegetation types including oak forest (Kolmogorov-Smirnov statistic, KSa = 1.5, $P = 0.021$), woodland (KSa = 1.4, $P = 0.033$), and savanna (KSa = 2.8, $P < 0.001$). In oak forests diameter distribution shifted toward proportionally greater stems in larger size classes and fewer in small size classes (Fig. 3). A similar shift occurred in oak woodlands, with increases in trees larger than 40 cm in diameter, as small trees grew in diameter over the 14 y. In oak savannas the number of stems 1–10 cm in diameter quadrupled between 2002 and 2015, reinforcing the skewed pattern toward small stems unique to savannas.

FIG. 1.—Examples of change between 2002 (top row) and 2015 (bottom row) within vegetation types in Oak Openings Preserve, northwestern Ohio. Vegetation types, from left to right, are oak forest, woodland, and savanna. Photos by S. R. Abella

The net result of changes between 2002 and 2015 via mortality and recruitment was that forests and woodlands lost large oak trees $\geq$ 20 cm in diameter, while savannas gained large oak trees (Fig. 4). Forests lost 20 large oak trees/ha (25 trees/ha died, 5 trees/ha recruited into the $\geq$20 cm diameter class). Woodlands lost 42 large oak trees/ha (50 trees/ha died, 8 trees/ha recruited into the $\geq$20 cm diameter class). With 100% survival of large oaks and recruitment of 10 trees/ha into the $\geq$20 cm diameter class, savannas gained 10 large oak trees/ha. Because of tree growth and recruitment balancing out mortality, stand-level oak basal area changed little, increasing by an average of 1.3 (forest), 1.5 (woodland), and 2.5 m^2/ha (savanna) from 2002 to 2015. In 2015 oak basal area was 29.7 $\pm$ 4.6 (mean $\pm$ SEM) in forest, 26.8 $\pm$ 4.0 in woodland, and 8.5 $\pm$ 2.2 m^2/ha in savanna.

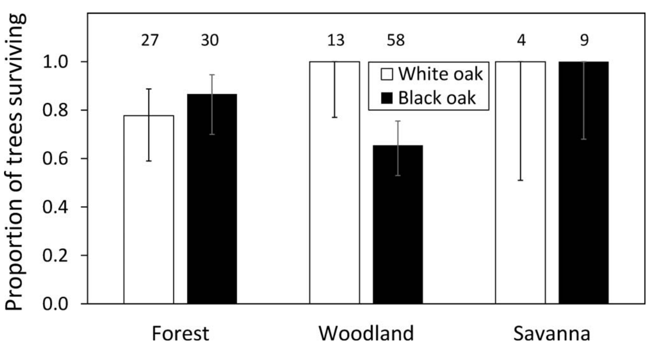

FIG. 2.—Survival of large oak trees ($\geq$20 cm in diameter) between 2002 and 2015 among vegetation types in Oak Openings Preserve, northwestern Ohio. Error bars are the lower and upper limits of 95% confidence intervals around the proportions. Numbers at the top of bars are the total numbers of trees within categories. In addition to these 141 black and white oak trees shown in the figure, two pin oak trees (both of which survived) inhabited plots in the savanna

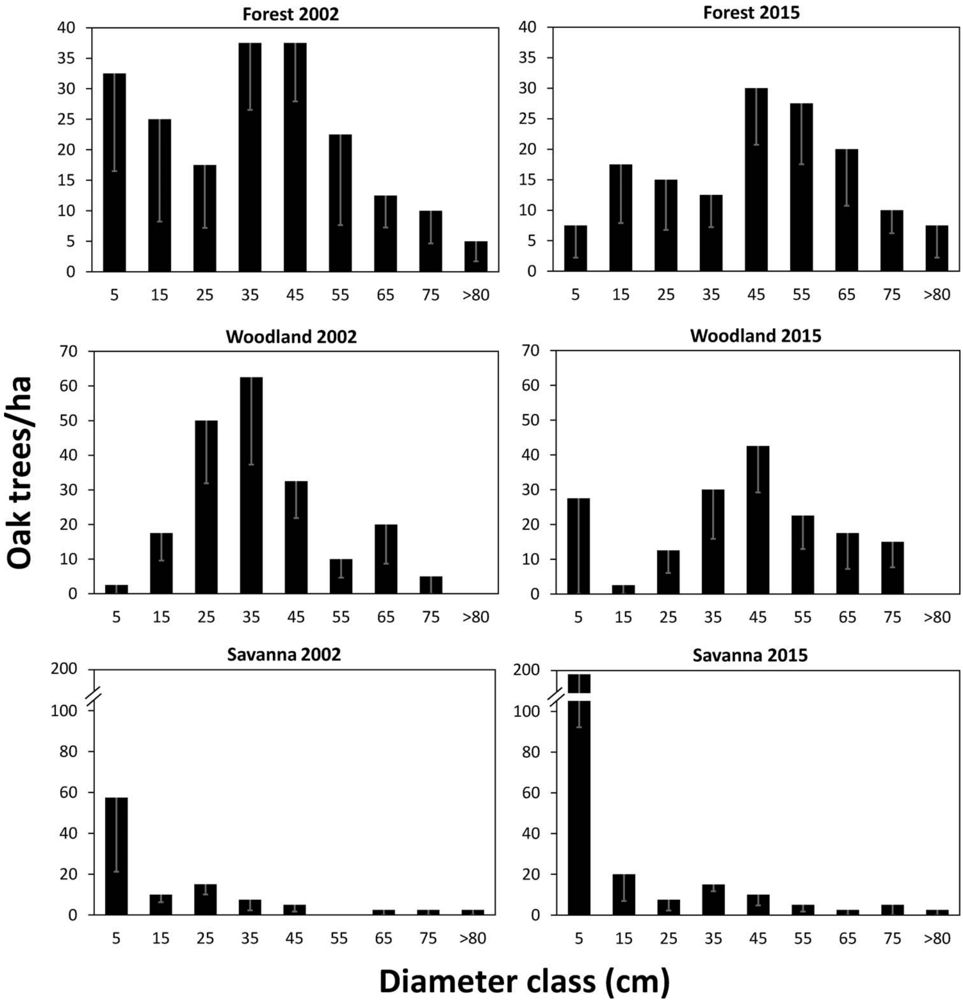

FIG. 3.—Average diameter distribution of oak trees between years within vegetation types in Oak Openings Preserve, northwestern Ohio. Midpoints of diameter classes are shown on the *x*-axis (*e.g.,* the 45-cm class represents trees ≥ 40 cm to <50 cm in diameter). Error bars are standard errors of means

DISCUSSION

There are several reasons why the net loss of large oaks during the 14 y period in woodlands might actually be beneficial from a restoration perspective, at least in the short term. First, the average density of 140 live trees/ha in 2015 for oaks ≥ 20 cm in diameter exceeded the average of 90 trees/ha recorded in woodlands during pre-Euro-American settlement land surveys (Brewer and Vankat, 2004). Second, mortality was concentrated in moderately large oaks, not the largest oaks, as the average diameter in 2002 of oaks that subsequently died was smaller than for oaks that lived. While moderately sized oaks can be the greatest acorn producers (Rose *et al.*, 2011), extremely large oaks afford unique habitat values (Anderson, 1998) and generally were conserved. Third, the complete failure of oak to recruit into larger size classes often observed in eastern forests (*e.g.*, Lorimer, 1993; Abrams, 2005; Arthur *et al.*, 2012) did

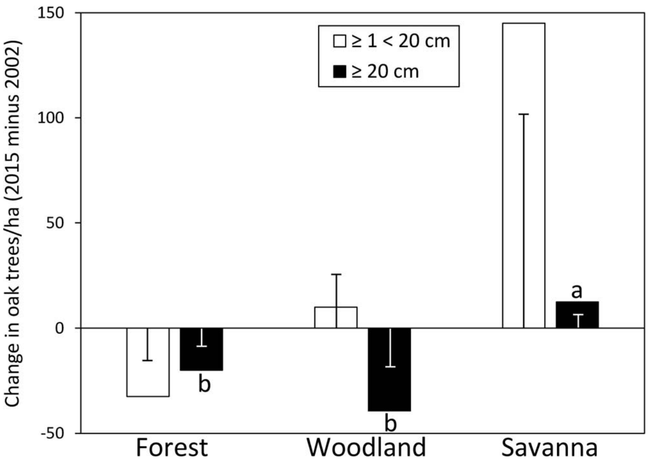

FIG. 4.—Change in density of small (≥1 <20 cm in diameter) and large (≥20 cm in diameter) oak trees between 2002 and 2015 within vegetation types during restoration in Oak Openings Preserve, northwestern Ohio. Mean change in large oak density differed among vegetation types (one-way analysis of variance, $F_{2,21} = 4.2$, $P = 0.029$), and means without shared letters differ at $P < 0.05$ (Tukey's test). Change in small oak density did not differ among vegetation types ($F_{2,21} = 2.1$, $P = 0.143$). Error bars are SE of means

not occur in our study. With 8 trees/ha recruiting into the ≥20 cm class in 14 y, woodlands were on pace to recruit 57 large oaks/ha/century. If these trees survive to the >200 y potential life spans of black and white oaks (Greenberg *et al.*, 2011), the new recruits alone suffice to sustain a density of at least 90 trees/ha. Fourth, over half the mortality of large oaks in woodlands occurred on two plots damaged in 2010 by a tornado, an unplanned factor in our study but a periodic natural disturbance and source of oak mortality in pre settlement savannas (Burley and Waite, 1965). These plots exhibited partial resistance to this disturbance, because both plots still contained 140 large oak trees/ha in 2015.

While our results were encouraging for the persistence of oaks, tree pests warrant attention for their potential to influence future dynamics in oak structure. Two of the introduced pests afflicting oak trees reported as present in northwestern Ohio by the U.S. Forest Service are the Eurasian insect gypsy moth (*Lymantria dispar*) and a fungus causing oak wilt (*Ceratocystis fagacearum*; Forest Health Technology Enterprise Team, Fort Collins, Colorado). Since its 1869 introduction to Massachusetts, gypsy moth populations have had irregular temporal outbreaks in North America (Allstadt *et al.*, 2013). Irregular outbreaks may be associated with interactions between gypsy moths and population cycles of various pathogens and small mammals that reduce gypsy moth populations (Allstadt *et al.,* 2013). Oak restoration activities, such as thinning and prescribed fire, could influence these interactions in ways poorly understood (Muzika *et al.,* 2004). The main population front of gypsy moths only relatively recently reached northwestern Ohio in the 1980s/1990s (Bigsby *et al.,* 2011), and an outbreak occurred in 2013 within 200 ha of oak forests in Oak Openings Preserve. Defoliations by gypsy moths do not always kill oaks, but they can weaken them (Allstadt *et al.*, 2013).

Oak wilt's nativity to the United States is unclear, as the fungus may have originated in Central or South America and was possibly introduced to the United States long before the species was noted in the mid-1900s (Juzwik *et al.*, 2011). Among oaks, white oak appears to be the most resistant to oak wilt, whereas members of the red oak group (including black oak) are readily killed (Juzwik *et al.*, 2011). In 2014–2015 surveys were initiated for oak wilt in the study area, resulting in 12 suspected but unconfirmed cases (Metroparks, Toledo, Ohio; unpubl.). It remains unclear how gypsy moths, oak wilt, or other tree pests could affect long-term oak restoration projects, which may increasingly require integrating the early detection and management of tree pests for conserving oaks.

The dynamic nature of the sapling layer also creates uncertainties in long-term tree recruitment in restored savannas and woodlands. We found the density of oaks 1–10 cm in diameter tripled in restored savannas, suggesting restoration at least temporarily created conditions conducive to oak regeneration. The most recent burn in the restored savannas was 7 y before the 2015 remeasurement, a time window sufficient for oak sprouts and potentially even seedlings to grow to >1 cm in diameter between burns (Peterson and Reich, 2001; Knapp *et al.*, 2015). Previous studies in Midwestern oak ecosystems have reported sapling densities fluctuate via interactions of burn severity, number of fires within a period, and maximum interval between fires. For example annual or biennial burning has essentially precluded a sapling layer (Peterson and Reich, 2001; Dey and Hartman, 2005; Knapp *et al.*, 2015). More moderate fire frequencies of 2–3 burns/decade, with less than 10 y between fires, have resulted in dense sapling layers usually top-killed by fires but that quickly resprout to create thickets (of oaks and other species) exceeding 1–2 m tall and persisting until the next burn (Haney *et al.*, 2008; Knapp *et al.*, 2015). Low fire frequencies, with only 1–2 burns/decade and where fire intervals have exceeded 10 y, can also produce dense sapling thickets, in addition to enabling some saplings to grow to fire-resistant sizes (Cole *et al.*, 1992; Peterson and Reich, 2001). It is possible the effects on the sapling layer of one or a few severe fires are similar to the effects of multiple low-severity burns within one to two decade time spans (Haney *et al.*, 2008). Research that further identifies how combinations of fire frequency, extended fire-free intervals, and fire severity influence dynamic habitat structures and oak recruitment may assist with sustaining restored oak ecosystems.

Our results suggest restoration activities were favorable for the persistence of oak during the first two decades of restoration. Results also highlighted a role for future research to examine influences of tree pests and fire management strategies on the long-term dynamics of oak savanna-woodland ecosystems undergoing restoration.

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