Final Report to the Joint Fire Science Program

Project Title: A Synthesis of Fire and Oak Restoration in the Northeastern U.S.

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ABSTRACT

We reviewed the literature to synthesize what is known about the use of fire to maintain and restore oak forests, woodlands, and savannas of the upper Midwestern United States, with emphasis on Minnesota, Wisconsin, and Michigan. Included are (1) known physical and ecological effects of fire on oaks from acorn through seedling, established sapling, and mature stages of the life cycle; (2) the use of fire to modify competitive interactions between oaks and mesic forest species (e.g., maple), between oaks and pines, and between oaks and grasses; (3) interaction of fire with other disturbances such as wind-throw and harvesting, invasive species, and deer browsing; and (4) climate change. Throughout the report, we discuss the advantages and limitations of fire use in oak forests. We incorporate lessons learned from long-term experiments with fire, from historical evidence of fire over the centuries, and processes in areas where natural disturbances occur. We provide a brief summary of the use of fire to restore mixed oak-maple forests, mixed oak forests, mixed pine-oak forests, and oak savannas, along with take-home lessons about the complex relationships between oaks and fire.

BACKGROUND AND PURPOSE

Oak forests and savannas provide valuable ecosystem services – including timber production and wildlife habitat – so maintaining or increasing the abundance of oaks is a desirable goal for forest management in the Lake States of Minnesota, Wisconsin, and Michigan. Fire and climate played important roles in the development, maintenance, and geographical distribution of oak forests before and after European settlement. However, changes in fire frequency and severity, shifting forest management practices, and invasive species have produced significant changes in forest structure and composition over the past century in many formerly oak-dominated ecosystems, such that long-term sustainability of oak forests is in doubt.

Prescribed fire use or restoration of natural fire regimes may help to restore, maintain, or increase the dominance of oaks in these temperate deciduous forests, but efforts to restore oak forests using prescribed fire are constrained by social attitudes toward fire, and uncertainties about the fire frequency and severity needed to reverse past changes. Efforts to restore oak ecosystems with fire may be further complicated by changes in atmospheric carbon dioxide concentrations, climatic changes, biological invasions (e.g., earthworms, buckthorn), and herbivore impacts, which may alter plant resource requirements, resource availability, biotic interactions, forest fuel dynamics, and potential fire behavior.

To better inform science-based restoration and management, we reviewed and synthesized existing scientific knowledge about 1) the role of fire in oak forests, 2) other factors that influence oak-fire relationships, and 3) possible approaches for using fire in restoration-based management of oaks in temperate deciduous forests of the Upper Midwest and northeastern United States. We introduced the concept of ecologically significant fire and reviewed the mechanisms by which fire historically regulated the balance between oaks and other species at different life-history stages. We then reviewed how different stand-development stages, exotic species, plant-animal interactions, and climate change could alter forest structure and composition, forest fuels, fire behavior and effects, and the potential effectiveness of fire as a restoration tool. We concluded by discussing approaches to restoring fire in a variety of contemporary oak forest types, including mixed oak forests, oak-maple forests, oak-pine forests, and oak savannas.

This final report to the Joint Fire Science Program summarizes some of the findings and management implications from the study. However, we direct end users and others interested in this topic to the primary synthesis publication (Frelich et al. 2015) for full details and source references.

Study Description and Location

The primary area of interest for this study was the upper Midwest region of the United States – including the states of Minnesota, Wisconsin, and Michigan – but the review also considers relevant literature from throughout eastern North America.

Key Findings

1. **Fire historically influenced the development and maintenance of oak ecosystems.** Fire has been a major contributor to the development and maintenance of oak forests for thousands of years. Historically, the region of heavy oak dominance was bounded by grasslands with very frequent fires (generally 1- to 5-year return intervals) to the west, and mesic forests with infrequent fires (generally fire-return intervals of 100+ years) in the northeastern portion of the Lake States. Within this region however, topographic barriers to the spread of fire created local variability in fire frequency that, in turn, produced a mosaic of vegetation types that included prairie grasslands, oak savannas and woodlands, mixed-oak forests, and mesic deciduous forests (e.g., maple-basswood forests).
2. **Humans have a long history of influencing fire regimes and oak abundance.** It is known that human enhancement of fire frequency, such as burning by Native Americans, can convert mesic forest to oak forest or savanna. Changes in fire frequency and intensity since early settlement of the region have produced significant changes in formerly oak-dominated ecosystems. Harvesting and burning of mesic forests early in the settlement period favored oaks over more shade-tolerant but disturbance-sensitive species. In other areas, reductions in fire frequency—caused by fewer human ignitions, landscape fragmentation, and agricultural land conversion—led to the conversion of grasslands and oak savannas to closed-canopy oak forests and allowed shade tolerant mesic species to invade and become dominant in formerly oak-dominated forests.
3. **Oak dominance is influenced by mean fire return intervals and variability in fire return intervals.** For centuries, or perhaps millennia, fire has modulated the interaction between oak as a dominant species and three main vegetation types: mesic forests of maple, hemlock, basswood, and yellow birch; cold-temperate and boreal forests of pine and spruce-fir; and grasslands, portrayed conceptually as the 'Oak Triangle'. Fire frequency regulates the balance between oak and grass, with long-term, high frequency

fire (mean return intervals of 1-5 years) leading to lack of oak recruitment and replacement by grasses with some shrubs, medium frequency fire (5 to 15 years) leading to shrubby savanna-woodland vegetation types, and low frequency fire (> 15 years) leading to woodland and forest types with few grasses. Under low frequency fire regimes, low variability in fire return intervals favors oaks, while high variability in fire return intervals can allow shade tolerant tree species to establish and reach the fire refuge stage.

4. **Fire season can influence oak regeneration through its effects on acorn development, oak establishment, plant-animal interactions, and competitor species.** Fire season interacts with regeneration phenology to determine direct fire effects on acorns and seedlings. Fire season also alters plant-animal interactions, such as the caching of acorns by squirrels. Finally, fire season may influence the relative dominance of oaks and competitor species through differential fire effects on regeneration and survival.
5. **Mesophication poses an increasing challenge to restoration of oak ecosystems.** Many forests formerly dominated by white oak or red oak have been invaded by maple in recent years. This mesophication process has been fostered not only by fire suppression and exclusion, but by higher deer populations that prefer oaks over maples for winter browsing, a wetter summer climate in the last several decades, changes in the physical and chemical environment of the forest floor caused by maple invasion and, in some locations, invasive plant species such as buckthorn. All of these changes favor maple and other mesic-forest species which are more shade-tolerant than oaks. In particular, the more shade-tolerant red maple is expanding rapidly and can tolerate many of the same environmental conditions as the oaks.
6. **"Ecologically significant fire" is needed for successful oak restoration with fire.** A fire is ecologically significant in this context if it removes or reduces abundances of competitors of oak or keeps those competitors from entering the stand; (2) damages existing oak as little as possible; and (3) creates conditions for future recruitment of oak to the canopy. Ecologically significant fire is largely context-dependent because the factors limiting oak dominance and persistence vary among biophysical settings, stand-development stages, and forest types. Multiple fires may be needed to fully meet these standards for ecologically significant fire.
7. **Bark thickness is an important factor in the use of fire to restore oak ecosystems.** Species and age-related differences in bark thickness and heat conductance among trees produce differences in tree mortality rates in response to fire. Because saplings and shrubs that compete with oak—such as buckthorn, red maple, ironwood, and hazel—often have paper-thin bark, it is easy to discriminate against them using prescribed fires in mature oak forests, leaving the oak seed source and an open understory for oak seedling development. However, oak seedlings and saplings also have thin bark and can be killed or damaged by fire, while mature maples and other oak competitor species can have sufficiently thick bark to survive low intensity prescribed fires. Bark thickness differs among oak species as well as between oaks and maples. Growing to a size that provides bark thick enough to resist surface fires is known as reaching a size refuge.

8. **Fuels have a strong effect on prescribed fire intensity and effects in oak ecosystems.** Horizontal fuel connectivity is needed to carry prescribed fire, while available fuel loadings regulate fire intensity, duration, and severity. Fuel amounts (loadings) depend on local productivity, deposition rates, and decomposition rates. Other fuel properties – like fuel-bed depth, packing, and moisture retention – are influenced by overstory canopy structure and understory vegetation structure and composition.
9. **Invasion of European earthworm species is altering fuel loads and fire effects in deciduous forests.** Invasive earthworms change soil structure and function by consuming the organic horizon (or leaf litter), increasing bulk density and mixing of the mineral horizons, thereby affecting nutrient and water cycling in the soil. The two most relevant changes for oak forests caused by earthworms are their impacts on the understory environment, including competing vegetation, and on the forest-floor fuel bed. Forest-floor conditions created by earthworms favor germination of grasses and sedges, and also favor other invasive plant species (e.g., buckthorn and garlic mustard). Detritivore earthworm species, such as nightcrawlers and leaf worms, can also significantly reduce duff portion of fuel loads in deciduous forests, making it harder to carry fire through these stands and precluding fire from damaging oak competitor species.
10. **Climate change could alter oak species distributions and relationships between oaks and fire.** In the northernmost region of occurrence for the oak species group, oaks could benefit substantially from a warmer climate owing to longer growing seasons and warmer winter temperatures. Most analyses of future climate point to a longer fire season. However, it is unknown how this will affect the number of days that meet conditions for prescribed fire in oak forests.

Management Implications

1. **Restoration of oak ecosystems with prescribed fire alone will not always be possible.** There are constraints on the use of prescribed fire on modern landscapes, including continuing social bias favoring fire suppression, continued expansion of the wildland-urban interface, air quality laws, and lack of funding. Where fire can be used, it may not be effective for restoring oak dominance within typical management timeframes owing to persistence of large trees of mesic species that serve as local seed sources, feedbacks of mesic species on understory microclimate and fuels, persistence of exotic species associated with closed-canopy forests (e.g., buckthorn, earthworms), and resource constraints on understory oak regeneration and persistence.
2. **Managers may need to consider diverse approaches for restoring oak ecosystems.** A gradient of forest restoration options are available to oak forest managers, including: planting oak seedlings after removing competing vegetation and fencing out deer until the saplings are beyond their reach; thinning to remove undesirable tree species combined with mechanical preparation of the soil surface; thinning combined with fire; prescribed fire alone; and no intervention, or "letting nature take its course." The individualistic nature of plant communities over time and space, including forests,

precludes the possibility of standardized silvicultural or fire-use prescriptions that will be effective in all stands over an entire region.

3. **Management of fire frequency may be important in oak forest ecosystem restoration.** Fire frequency influences the number of fires during the lifespan of a plant, the length of the recovery period between fires, and (often) fire intensity and severity. High fire frequencies place a premium on fire resistance or tolerance, and therefore favor mature oaks with thick bark that can protect themselves from injury. High fire frequencies can also favor trees, like oak seedlings and saplings, with very high post-fire resprouting rates. However, high frequency fire regimes can prevent oak seedlings and saplings from reaching fire refuge size, so occasional longer fire intervals are needed to allow oak reproduction to develop sufficient height and bark thickness to resist being top-killed by subsequent fires. Lower frequency fire regimes allow a wider range of species to persist, but may still favor oaks over competitors.

RELATIONSHIP TO OTHER RECENT FINDINGS AND ONGOING WORK

This synthesis complements another oak synthesis – "The fire-oak literature of eastern North America: synthesis and guidelines (Brose et al. 2014) – that was also funded by the Joint Fire Science Program under task statement JFSP-2010-2, "Synthesis of existing knowledge."

FUTURE WORK NEEDED

DELIVERABLES CROSS-WALK

Proposed	Delivered	Status
Manager-friendly synthesis	Frelich et al. 2015. *Fire in Upper Midwest Oak Forest Ecosystems: an Oak Forest Restoration and Management Handbook. USDA Forest Service Gen. Tech. Rep. PNW-GTR-914.*	Completed
Workshops (3) for regional forest managers	One-day workshops on "A synthesis of fire and oaks" hosted by the University of Minnesota Sustainable Forests Education Cooperative • Rochester, MN, September 21, 2011 • Cloquet, MN, November 16, 2011	Completed
	Keynote address entitled "The role of oak within the context of a changing climate" given at a two-day workshop on oak forest management, organized by the University of Minnesota Sustainable Forests Education Cooperative at St. John's University, Collegeville, MN, June 13-14, 2012.	Completed

DVD of workshop presentation	Produced a webinar for the Great Lakes Fire Science Consortium, initially presented on March 15, 2012. The recording is available at: http://lakestatesfiresci.net/webinar_3_15_12.htm	Completed
	Produced and presented a webinar for the University of Minnesota Extension Forestry team, "MyMinnesotaWoods," on Tuesday, October 25, 2016, a recording of which is available on YouTube (https://youtu.be/8-NOACWtEgM)	
Review paper – peer-reviewed journal	Frelich et al. *In review*. The changing role of fire in Lake States oak forests.	In review

REFERENCES:

Frelich, L.E.; Reich, P.B.; Peterson, D.W. 2015. Fire in upper Midwest oak forest ecosystems: an oak forest restoration and management handbook. Gen. Tech. Rep. PNW-GTR-914. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 64 p.