RESTORING AND SUSTAINING EASTERN OAK FORESTS

WITH PRESCRIBED FIRE

FINAL REPORT OF PROJECT 10-2-01-1

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ABSTRACT

There is growing interest and use of prescribed fire as a management tool in eastern oak forests to meet a wide array of resource objectives. However, many practitioners are lacking the historical basis to justify prescribed fire programs and guidelines on how to correctly use fire to restore or sustain oak forest ecosystems. We conducted a literature review and synthesis to fill both of these knowledge gaps. From 50 dendrochronology studies utilizing fire-scarred snags and stumps, we found strong historical support for burning by American Indian tribes especially in the midwestern and southern states. Such studies are lacking in the northeastern states, but we were able to conduct a fire scar study in northern Pennsylvania to help fill that gap. That study showed burning occurred periodically before European settlement commenced in 1800, became quite frequent between 1800 and 1920, and vanished almost entirely after 1920.

We performed meta-analysis on the data reported in 50 fire effects studies. The results showed that fire does promote oak reproduction at the expense of mesophytic hardwood reproduction, especially when growing-season fires are conducted in recently-harvested stands. Fire also reduces the density of midstory stems and encourages establishment of new oak seedlings and height growth of existing oak reproduction. Guidelines on using prescribed fire to help regenerate eastern oak forests are presented based on these findings.

INTRODUCTION

The role of fire in eastern oak (*Quercus* spp.) forests has become of tremendous interest to many natural resource professionals over the past 20 to 30 years. Much of that interest has been driven by the chronic "oak regeneration problem"; the phenomena of oak-dominated forests changing to other forest types when they undergo a stand-replacing disturbance and the realization that many oak-dominated forests originated during a time of frequent wildfires. The research aspect of the interest in fire in eastern oak forests centers on (1) understanding the history of fire, especially before European settlement; (2) the effects of fire on the many hardwood species as well as other ecosystem attributes; and (3) developing guidelines on using fire to meet diverse oak forest management objectives. Funding to support research into the role of fire in eastern oak forests has been generous and diverse. Federal programs such as the Joint Fire Sciences Program (JFSP), the National Fire Plan (NFP), National Science Foundation (NSF), and others have funded a myriad of large-scale, multidisciplinary research projects and conferences since the 1980s. Likewise, state and private institutions have also funded many smaller, focused studies as well as contributed to conferences and workshops. All of this research has produced a wide array of scientific articles ranging from simple case studies in conference proceedings to complex studies published in peer-reviewed journals. In 2010, the JFSP decided that there was enough published scientific literature on fire in eastern oak forests (defined as east of the 100th meridian) to merit synthesis of the subject matter and they issued a request for proposals to that end. This project was approved to review and synthesize the existing fire-oak literature with the desired outcome being formulation of guidelines for natural resource professionals interested in using prescribed fire to restore and sustain eastern oak forests.

We organized our synthesis using the fire-oak hypothesis and regional fire consortiums as templates. The fire-oak hypothesis consists of four parts: (1) fire has been an important disturbance in eastern oak forests for millennia; (2) oaks are well suited to take advantage of a periodic fire regime, (3) cessation of that fire regime in the early 20th century is a major factor causing the current oak regeneration problem; and (4) prescribed fire can be used in some situations to regenerate oak-dominated forests. The consortiums organize the eastern oak biome into three regions: central/southern Appalachian Mountains, Great Lakes, and Midwest. To those, we added a fourth region – the Northeast – to complete the coverage of the eastern oak biome. Our synthesis consists of four sections; a review of the fire history studies, presentation of a new fire history study, a meta-analysis of the fire effects studies, and development of guidelines for using prescribed fire to restore and sustain eastern mixed-oak forests based on the findings of the meta-analysis. This final report presents the highlights of each of those four sections organized by region when appropriate.

REVIEW OF FIRE HISTORY STUDIES

With the assistance of our collaborators at the Missouri Tree-Ring Laboratory, we identified 10 paleoecological (charcoal/pollen) studies and 50 dendrochronology (fire scar) studies conducted in the eastern mixed-oak biome (Table 1). Almost all of these studies occurred in the past 20 years and have been published in a wide variety of outlets ranging from masters' theses to high-quality, peer-reviewed journals. Considering these studies collectively reveals numerous commonalities and trends that provide new insight into the fire regimes of eastern oak forests that are useful for managers and researchers. Those findings are:

1. Fire has been a part of eastern oak forests for millennia. The paleoecological studies provide a multi-century record of fire and oak co-occurrence from coastal New England to the southern Appalachian Mountains (Patterson 2006, Hart and Buchanan 2012). Such studies are lacking for the Midwest and Great Lakes regions. There is little doubt that the former has a long-term association between fire and oak species, but such a relationship is questionable for the latter (Clark et al. 1996). While the ignition source for these ancient fires is not exactly known, they were likely caused by the humans inhabiting the eastern oak biome at those times.
2. Based on the dendrochronology studies, pre-settlement (1500 to ~1800 A.D.) fires were widespread throughout the eastern oak biome. We found studies providing pre-1800 data in 18 states and 1 province. Additionally, we found references to pre-settlement fire scars in four other states. Those studies and references occurred from Texas to Minnesota to Vermont to Alabama.
3. The frequency of these pre-settlement fires varied considerably among and within the four regions of the eastern oak biome. Just about every conceivable fire frequency could be found somewhere – from annual fires in the Midwest to century-long fire-free periods in the Great Lakes and Northeast regions. This tremendous variability suggests that

lightning was not the primary ignition source otherwise fire occurrence would have been less variable. The variability was likely the result of social upheavals in the many American Indian tribes as they came into pre-settlement contact with European influences beginning in the 1500s. The introduction of exotic diseases, life-easing inventions (flint & steel), and demand for pelts and skins, and migrations disrupted American Indian societies and led to highly variable fire frequencies. The multi-decadal fire-free periods support the contention of Russell (1983) that fires only occurred where and when there were American Indian tribes. In the absence of American Indian activity, fire was a rare occurrence, especially where climate and topography limited fire spread.

4. Despite this variability, there is a south to north gradient of decreasing pre-settlement fire frequency. Pre-1800 mean fire intervals (MFI) ranged from a low of 2 to 3 years in Alabama to 30 to 40 years in Michigan and Pennsylvania. This gradation reflects the climate influence. There are simply fewer burning windows as latitude increases. There is a less obvious gradient from west to east. Generally, MFIs are shorter in the central states (Illinois, Missouri, and Oklahoma) than they are in the Appalachian states (Maryland, Tennessee, and Vermont), although there are some notable exceptions such as Virginia. This gradation likely also reflects climate, droughts are more common and severe in the Midwest, as well as differences in fine fuels (grasses versus leaf litter).
5. Pre-settlement fires mostly occurred during the dormant season. Of the 33 studies that determined fire seasonality, 26 (78.8%) found that the pre-1800 fires burned during the dormant season. The average distribution of dormant- and growing-season fires in those 26 studies was 85% dormant and 15% growing season. When growing-season fires did occur, the scar was situated in the earlywood, suggesting that a dry spring may have extended to spring fire season into the early summer. The predominance of dormant-season fires also indicates that American Indians started these fires as lightning is generally restricted to the summer months.
6. Growing-season fires were the dominant fire type in the western Great Lakes region. In this area, growing-season fires typically comprised 60 to 85% of the pre-settlement fires. This reflects the abundance of pines (*Pinus* sp.), short-duration spring fire season, seasonal droughts, and lightning as an ignition source. Another area where growing-season fires may have been historically important is in the xeric pine-oak-heath forests of the Appalachians. Recent research at Great Smoky Mountains National Park on unsuppressed lightning fires shows that this forest type can maintain ignite from lightning strikes and maintain fires for weeks despite precipitation (Cohen et al. 2007). Such fires can eventually cover hundreds of acres.
7. Most of the studies (73%) showed three distinct fire regimes in terms of MFIs. Collectively, these studies had a pre-settlement MFI of 12.9 years. During European settlement, the overall MFI dropped to 6.3 years. Since the advent of fire exclusion policies in the early 1900s, the overall MFI has risen to 45.2 years. Only 13% of the

studies showed the reverse pattern of MFIs increasing with European settlement and in all of these livestock grazing was the probable factor for this trend.

8. For researchers, several findings are pertinent. First, the most suitable species for recording fire scars for centuries are the resinous pines [longleaf (*P. palustris*), pitch (*P. rigida*), red (*P. resinosa*), shortleaf (*P. echinata*), and Table Mountain (*P. pungens*)] and the white oak group [bur (*Q. macrocarpa*), chestnut (*Q. montana*), post (*Q. stellata*), and white (*Q. alba*)] due to their longevity and ability to compartmentalize wounds. White pine (*P. strobus*) is of lesser value because it is more prone to rot after wounding. The functional time span of these species seems to be about 500 years as only 2 studies had samples dating to 1500 or earlier. Finally, high-quality fire history studies are lacking for the Northeast region. The few that do exist suffer from lack of sample size or some methodological problems and these limit their value.

PENNSYLVANIA FIRE HISTORY

The realization that fire history studies were lacking for the Northeast region sparked interest in filling this knowledge gap. In late 2010, an opportunity arose to do that with the discovery of three oak stands containing remnant, fire-scarred red pine snags and stumps in northern Pennsylvania. A fire history project was organized with the Missouri Tree-Ring Laboratory. The three stands were searched for living and dead fire-scarred red pines. When a suitable snag or tree was found, a partial or full cross section was cut from the fire scar and the sampled was transported to the Missouri Tree-Ring Laboratory in Columbia, MO. There, the samples were prepared, aged, and measured using standard dendrochronological procedures (Speer 2010).

A total of 132 samples were obtained from the three sites. Of these samples, 93 were sufficiently intact and had at least 100 annual rings to permit cross-dating and determination of fire dates and season-of-burn. Even though the three sites were 10 miles from each other, they all displayed similar fire histories. Therefore, the data were combined to produce a fire history for the entire area (Figure 1). Their chronologies covered from 1600 to 2010, contained 55 fire years, and displayed the three temporal fire regimes (pre-settlement, post-settlement, and modern) reported in most of the other eastern fire history studies. During the pre-settlement era, fire was a rare occurrence. Before 1800, fires happened in two temporal clusters separated by an 85-year fire-free period. The first fire period was 1620 to 1650 and the second occurred from 1735 to 1770. Because of this fire-free period, the pre-settlement MFI was 14.5 years. Another fire-free period from 1770 to 1800 marked the transition to the post-settlement era. Between 1800 and 1920, fires became quite common, reducing the MFI to 3.2 years. After 1920 (modern era), fires ceased to occur except for a single fire in 2008. The vast majority of the fires occurred during the dormant season, regardless of era. Fire severity, expressed as the proportion of trees scarred by each fire, varied considerably, but did not appear to change through time.

This new fire history helps fill an obvious knowledge gap for the Northeast region. Overall, it most closely resembles the fire histories of the Great Lakes region with periodic fire occurring in

distinct temporal clusters and long fire-free periods prior to European settlement. After 1800, fire becomes quite frequent then virtually vanishes in the early 1900s. This pattern is not surprising. This part of northern Pennsylvania was a boundary zone between the Iroquois and Susquehannock tribes and was largely uninhabited so the probability of an ignition was low. European settlement brought large-scale logging as northern Pennsylvania forests were dominated by white pine and eastern hemlock (*Tsuga canadensis*) and logging begat fire starts. The sudden end of frequent fire in the early 190s corresponds to the end of logging as well as the advent of fire control policies. Other fire-free periods correspond to important local history events such as the Beaver Wars (1650 to 1725) and the Revolutionary War (1775 to 1782). One difference between this fire history and those of the Great Lakes region is the Pennsylvania fires were mostly dormant-season events. This further supports the hypothesis that humans, not lightning, were the primary ignition source before and after European settlement. The lack of fires before 1800 also suggests that fires were largely limited to where Indians lived.

SYNTHESIS OF FIRE EFFECTS LITERATURE

A major focus of this fire-oak synthesis project was to make sense out of the numerous publications reporting the responses of oak and mesophytic hardwood reproduction to fire. In those papers, literally any result imaginable can be found. Consequently, guidelines for using fire in eastern oak forests are slow to develop and there is hesitancy by some resource managers to utilize prescribed burning while others employ it with negative results. To conduct this synthesis, we used meta-analysis to identify those conditions when fire promoted oak reproduction as well as those situations that limited the effectiveness of burning.

Meta-analysis is a family of statistical tests by which the results of individual studies can be compared to detect relationships and trends. To do this, we selected publications from 32 prescribed fire studies reporting the responses of oak and mesophytic hardwood reproduction (Table 2). Additionally, these papers described the fire behavior and site conditions and had sufficient replication to permit statistical analysis. We analyzed the 50 publications using log-response ratios for (1) reduction of midstory tree density, (2) differential sprouting between oak reproduction and mesophytic hardwood reproduction, (3) relative abundance of oak in the reproduction pool, (4) difference in relative height between these two groups, and (5) establishment of new oak seedlings. The results of each of these 5 analyses were further tested by summary analysis (a procedure similar to ANOVA) to elucidate the effects of season-of-burn, status of oak reproduction (suppressed or released), number of fires, midstory stem size class (sapling or pole), and duration of study.

Results of the meta-analysis confirmed much of what is already widely accepted regarding the responses of oak and mesophytic hardwood reproduction while identifying critical qualifications to those responses. Fire clearly reduces midstory density, but those reductions are concentrated in the smaller saplings (< 3” dbh). Larger diameter stems are relatively unaffected by single fires, but multiple fires do eventually reduce their density, especially if some or all of the

subsequent burns occur during the growing season. Overall, oak reproduction sprouts post-fire at a greater rate than mesophytic hardwood reproduction, but this response hinges on season-of-burn and status of the oak reproduction. Oak has a much higher sprouting rate than mesophytic hardwoods when the oak has been released for a few years and the fire occurs in the growing season. Conversely, oak reproduction has a lower sprouting rate than mesophytic hardwoods when the oak is suppressed and the fire occurs during the growing season. Dormant-season burns of released oak reproduction show a small advantage in sprouting rate to oak while there is virtually no difference between the two groups when the oak reproduction is suppressed. These varied responses are due to the differences in root development between oak seedlings and their competitors. The differential sprouting rates did not translate into an increase in the relative abundance of oak in the regeneration pool because of mesophytic hardwood seedlings arising from the seed bank or colonizing the burn site from nearby trees. Burning does equalize the height growth rates between oak and mesophytic hardwood reproduction and increase the establishment of new oak seedlings from acorns, but both of these need several years to occur.

FIRE-OAK MANAGEMENT GUIDELINES

Based on the meta-analysis, prescribed fire appears to fit into two places in the oak regeneration process. The first is at the beginning of the regeneration process as a seedbed preparation tool. The second is near the end of the regeneration process as a release tool. In either case, the first step in using fire is an inventory of the abundance and size of the oak reproduction, overstory conditions, and potential stand renewal obstacles such as competing and interfering vegetation, browsing pressure by white-tail deer (*Odocoileus virginianus*), and site limitations. The inventory may be a comprehensive examination as is done with stand prescription programs such as SILVAH (Brose et al. 2008) or less-intensive assessment of stand conditions. But it must be done to determine whether there is enough oak reproduction to proceed with stand regeneration. The determination of the adequacy of oak reproduction is highly stand-specific; what is sufficient oak reproduction for one stand may be inadequate for another based on several extenuating factors such as site characteristics, composition of the competing species, and impact of white-tail deer.

Mature, closed-canopy oak stands that lack adequate oak reproduction are at the beginning of the regeneration process. Burning can decrease midstory density; thereby increasing understory light and can reduce the thickness of the forest floor, especially the litter layer, which can be a barrier to germination and seedling establishment (Korstian 1927, Barrett 1931, Carvell and Tryon 1961, Wang et al. 2005). Site preparation burning may also negatively impact populations of acorn pests such as weevils (*Curculio* spp.) (Wright 1986, Riccardi et al. 2004) and xerify the upper layers of the soil (Barnes and Van Lear 1998), making it a less hospitable seed bed for mesophytic hardwoods. This approach will likely take a decade or more because the benefits of burning are initially small and multiple burns are needed to create the desired understory

conditions. This appears to be especially true with low-intensity fires conducted in the dormant season. In comparing winter and spring burns, Barnes and Van Lear (1998) concluded that three dormant-season fires were needed to equal the impact of one growing-season burn for intermediate-quality sites in the upper Piedmont region of western South Carolina. Regardless of fire seasonality and fire intensity, seedbed preparation burning will likely be a long-term endeavor because oak seedling establishment is dependent on an acorn crop and masting in oaks can be highly sporadic due to several intrinsic and extrinsic factors. Furthermore, leaf litter re-accumulates within a few years postburn so the benefit of litter reduction is short-lived. Our conclusion is that seedbed preparation is a fair- to good-use of prescribed fire in oak management, but the time required to achieve satisfactory results may be a major disadvantage. Reducing midstory shade with herbicides (where permitted) may be a more efficient approach with less potential damage to residual canopy trees.

Oak stands with an adequate density of oak reproduction that have received a heavy partial cut or have been completely harvested are well into the regeneration process because the reproduction is no longer limited by shading. In this context, prescribed burning to release the oak reproduction from the competing mesophytic species appears to be an excellent use of fire as long as the competing stems are less than 10 cm dbh. Of the studies included in this meta-analysis, those that occurred in stands that had been partly to completely harvested several years prior to the fires showed consistently strong positive benefits to the oak component. The oak reproduction survived at a higher rate than the mesophytic competitors, oak relative abundance increased postfire, and the oak sprouts grew at a rate comparable to the mesophytic hardwoods. In release burning, fire seasonality and fire intensity matter. The strongest benefits to oak were associated with moderate- to high-intensity growing-season fires. In practical application, when an oak stand has adequate oak reproduction to proceed with the regeneration process, we recommend harvesting the overstory via a two-cut shelterwood sequence or a final removal cut and then burning either between the shelterwood harvests or after the overstory is completely removed. The key is to wait several years after the harvest to burn so that the oak reproduction has adequate time to develop their root systems and increase their probability of vigorous sprouting following future burns (Brose 2008, 2011).

Our review of fire-oak literature suggested several special circumstances that may alter or curtail burning plans. One is that prescribed fires can damage and kill overstory trees some of which may be high-value crop trees. While this negative effect has been known for years (Nelson et al. 1933, Paulsell 1957, Berry 1969, Wendel and Smith 1986), it is especially true when burning during a shelterwood sequence because of the elevated fuel loads (Brose and Van Lear 1999). In such cases, slash management (lopping, scattering or removal from the bases of crop trees) is essential to prevent unacceptable losses. Another fire damage caveat is when an oak stand is in the stem exclusion stage of development. Sapling- and pole-size oaks are quite susceptible to fire scarring and subsequent value loss with little change in species composition (Carvell and

Maxey 1969; Ward and Stephens 1989; Maslen 1989). Acorns appear to be quite susceptible to fire damage (Auchmoody and Smith 1993) so we advise against burning shortly after an acorn crop if the germinants from those acorns are needed to become oak advance reproduction. A closely related caveat pertains to small oak seedlings. Prescribed fires will kill suppressed oak reproduction, especially growing season burns. Although this meta-analysis did not examine the influence of seedling size on the outcome of the studies, it was apparent from the few studies with detailed height data that sprouting rate was affected by size. Large oak reproduction sprouted postfire at consistently higher rates than small oak reproduction, especially when the fire occurred in the growing season, and initially larger stems grew taller after burning under any given overstory stocking and burn treatment. Initial diameter and size of oak reproduction are good indicators of its ability to survive fire and are good predictors of future competitive capacity (Brose and Van Lear 2004, Dey and Hartman 2005). Consequently, when the oak component of the regeneration pool is mostly small reproduction, land managers should consider using low-intensity dormant-season burns to minimize losses or opt for other silvicultural practices such as a shelterwood preparatory cut or individual stem herbicide treatments to move the oak stand forward in the regeneration process.

Two non-oak caveats are invasive species and deer browsing. Some plant species such as the native hay-scented fern (*Dennstaedtia punctilobula*) and the exotic tree-of-heaven (*Ailanthus altissima*) can spread rapidly after a fire (Rebbeck et al. 2010, Gottschalk et al. 2012) so their presence in or near the burn unit may require pre-emptive control measures to prevent their spread. Similarly, white-tail deer will be attracted to burned areas and excessive browsing can quickly turn a potential regeneration success into a failure. Potential deer problems should be identified and mitigated before burning.

SCIENCE DELIVERY

(* denotes a promised deliverable)

Publications

Brose, P.H., Dey, D.C., Phillips, R.J., and T.A. Waldrop. In press. A meta-analysis of the fire – oak hypothesis: does prescribed burning promote oak reproduction in eastern North America? Forest Science.*****

Brose, P.H., Dey, D.C., Guyette, R.P., Marschall, J.M., and M.C. Stambaugh. In review. A comparison of American Indian and European settler fire regimes in former conifer-dominated forests of northern Pennsylvania. Canadian Journal of Forest Research.

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Brose, P.H., Dey, D.C., Guyette, R.P., and M.C. Stambaugh. In preparation. Review of fire history studies conducted in the oak forests of eastern North America. International Journal of Wildland Fire.

Presentations

Brose, P.H., Dey, D.C., Guyette, R.P., Marschall, J.M., and M.C. Stambaugh. 2012. A 400-year fire history for northern Pennsylvania. 5th International Fire Ecology Conference, Portland, OR.

Dey, D.C., Brose, P.H., and T.A. Waldrop. 2012. Integrating fire and silviculture in oak forest management and restoration. 5th International Fire Ecology Conference, Portland, OR.

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*The meta-analysis results have already been incorporated into the curriculum of the SILVAH-oak training session. This silviculture shortcourse is taught 2 to 4 times a year at various locations in the mid-Atlantic region to a wide variety of practicing natural resource professionals.

*Work continues on the filming of various types of prescribed fires in eastern oak forests with the eventual development of a training CD to accompany the Forest Service General Technical Report. Once the CD is finished and the General Technical Report is published, a series of 1-day workshops will be held for practitioners via the Appalachian, Great Lakes, and Midwest fire consortiums.

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Table 1. Characteristics of the 50 fire scar studies used in the history synthesis.

Authors	State	Recorder Species	Sample Size	Chronology Years	Fires	Pre-MFI	Post-MFI	Modern MFI	Season*
McClain et al.	IL	Post oak	36	1770-1996	118	2	1.4	2.5	not determined
Guyette et al.	AL	Longleaf pine	24	1550-1940	106	2.7	2.6	75	DS - 92%
Cutter & Guyette	MO	Post oak	24	1734-1991	45	2.7	8.3	30	not determined
Guyette et al.	AL	Longleaf pine	26	1547-2006	113	3.2	2.5	4.2	DS - 97%
Guyette et al.	LA	Longleaf pine	19	1650-1902	120	3.3	1.3	100	GS - 60%
Guyette & Cutter	MO	Post oak	47	1656-1989	43	4.3	6.4	12.5	DS - 97%
Stambaugh et al.	OK	Post oak	52	1712-2006	60	4.4	5.2	4	DS - 97%
Wolf	WI	White oak	16	1804-2000	57	4.5	8.6	4	DS - 53%
Guyette et al.	IA	White oak	20	1699-1860	20	5	?	?	DS - 85%
Guyette & Stambaugh	MO	Shortleaf pine	12	1604-1996	81	5.7	3.7	4.8	DS - 90%
Guyette et al.	TN	Shortleaf pine	28	1790-2005	32	6	4.5	55	DS - 96%
Aldrich et al.	VA	Upland pines	63	1704-2003	42	6	5	70	DS - 90%
Guyette et al.	KY	Upland pines	31	1742-2005	38	6.3	3.7	85	DS - 65%
Lafon et al.	VA	Upland pines	172	1700-2000	227	6.4	3.5	7.4	DS - 85%
Guyette et al.	WI	Red pine	28	1706-2005	24	6.5	19.7	75	DS - 85%
Stambaugh et al.	MO	Bur oak	33	1671-2004	60	6.6	1.6	25	DS - 97%
Stambaugh et al.	TX	Post oak	49	1681-2007	30	6.6	6.3	75	DS - 90%
Guyette & Dey	MO	Shortleaf pine	9	1695-1930	67	7.1	2.2	75	not determined
Armbrister	TN	Upland pines	9	1776-2000	37	7.5	6.7	15.3	not determined
Stambaugh & Guyette	AR	Shortleaf pine	26	1725-2001	92	7.7	2.1	4	DS - 90%
Guyette et al.	ONT	White pine	13	1700-1850	15	8.3	?	?	not determined
Guyette et al.	WI	Red pine	15	1705-1870	24	8.6	6	?	DS - 85%
Shumway et al.	MD	White oak	20	1600-2000	42	8.8	8	14.8	DS - 90%
Guyette et al.	KY	Post oak	36	1688-2005	46	9	4.2	60	DS - 100%
Guyette et al.	MI	Red pine	30	1494-1914	27	10.2	6.4	?	DS - 97%
Dey & Guyette	ONT	White pine	32	1721-1937	14	10.8	12.7	100	not determined

Authors	State	Recorder Species	Sample Size	Chronology Years	Fires	Pre-MFI	Post-MFI	Modern MFI	Season
Guyette & Spetich	AR	Shortleaf pine	45	1670-2000	171	11.2	2.8	80	DS - 75%
Guyette & Dey	ONT	Red pine	26	1665-1780	8	14	?	?	not determined
Frisell	MN	Red pine	unknown	1650-1922	32	14.6	6.1	50	not determined
Guyette & Cutter	MO	Shortleaf pine	168	1558-1993	41	15.5	3.7	60	DS - 97%
Heinselman	MN	Red pine	178	1542-1972	71	19.7	3.3	15	GS - 85%
Stambaugh et al.	MO	Shortleaf pine	23	1634-1974	97	22.4	1.7	70	DS - 90%
Dey & Guyette	ONT	White pine	15	1689-1849	9	22.5	?	?	not determined
Cwynar	ONT	Red pine	unknown	1696-1960	25	22.8	8.65	50	GS - 85%
Guyette et al.	IN	Post oak	27	1654-1999	41	23	5.3	7.6	not determined
Mann et al.	VT	Red pine	32	1504-1851	18	23.1	12.3	100	GS - 61%
Dey & Guyette	ONT	White pine	18	1634-1875	7	25.2	?	?	not determined
Guyette & Dey	ONT	Red pine	18	1636-1994	11	28.3	22.5	64	not determined
Drobyshev et al.	MI	Red pine	248	1707-2006	217	28.5	14.3	20	GS - 53%
Guyette et al.	MI	Red pine	38	1500-2000	19	31.2	11.7	100	GS - 60%
Lutz	PA	White pine	unknown	1725-1925	6	37.6	19.5	75	not determined
Guyette et al.	MI	Red pine	23	1600-1900	11	41.4	17.2	100	GS - 85%
Engbring et al.	AR	Shortleaf pine	94	1823-2002	61	?	2	2.6	not determined
Abrams	KS	Bur oak	19	1862-1983	23	?	15.7	?	not determined
Hutchinson et al.	OH	White oak	137	1870-1984	28	?	4.7	24.3	DS - 97%
Hoss et al.	VA	Upland pines	73	1794-2005	53	?	2.1	4.3	DS - 94%
Engstrom & Mann	VT	Red pine	20	1815-1987	17	?	5.1	90	not determined
Hessl et al.	WV	Upland pines	36	1868-1953	9	?	8.3	55	DS - 65%
Schuler & McClain	WV	No. red oak	17	1846-2002	7	?	13.3	28	not determined
Maxwell & Hicks	WV	Upland pines	21	1898-2005	25	?	3	5	DS - 97%

* - DS = Dormant Season; GS = Growing Season

Table 2. Publications of the prescribed fire studies used in the meta-analysis. For studies producing Multiple publications, the primary publication used in the meta-analysis is listed first. Abbreviations are: NF = National Forest, WMA = Wildlife Management Area, SF = State Forest, EF = Experimental Forest, NRA = National Recreation Area, R = Reproduction, M = Midstory

Study	Location	State	Publications	Data Available
1	Daniel Boone NF	KY	Alexander et al. 2008.	R
2	Clemson Forest	SC	Barnes and Van Lear 1998.	M
3	Horsepen WMA	VA	Brose 2010; Brose and Van Lear 2004; Brose et al. 1999; Brose and Van Lear 1998.	R
4	State Game Land 29	PA	Brose 2012.	R
5	Allegheny NF	PA	Brose 2012.*	R
6	Clear Creek SF	PA	Brose et al. 2007.	R
7	Westvaco Forest	WV	Collins and Carson 2003.	M
8	Purdue Forest	IN	Dolan and Parker 2004.	R
9	Chilton Creek Tract	MO	Fan et al. 2012; Dey and Hartman 2005; Sassen and Muzika 2004.	R
10	Land / Lakes NRA	KY	Franklin et al. 2003.	R
11	Clemson Forest	SC	Geisinger et al. 1993.	R
12	Moshannon SF	PA	Gottschalk et al. 2012; Brose et al. 2007.	R
13	Red River Gorge	KY	Green et al. 2010; Blankenship and Arthur 2006; Gilbert et al. 2003; Arthur et al. 1998	R/M
14	Univ. MO Forest	MO	Huddle and Pallardy 1996; Paulsell 1957.	M
15	Bankhead NF	AL	Huntley and McGee 1983, 1981; McGee 1980, 1979.	R
16	Vinton Furnace EF	OH	Hutchinson et al. 2012, 2005; Sutherland and Hutchinson 2003.	R/M

Table 2 continued

Study	Location	State	Publications	Data Available
17	Powhatan WMA	VA	Keyser et al. 1996.	R
18	Jordan Timberlands	WI	Kruger and Reich 1997.	R
19	Dinsmore Woods	KY	Luken and Shea 2000	R
20	Duke Forest	NC	Maslen 1989.	R/M
21	Broome County	NY	McGee et al. 1995.	R
22	Morgan SF	IN	Merritt and Pope 1991.	R/M
23	Schmeeckle Reserve	WI	Reich et al. 1990.	R
24	Fernow EF	WV	Schuler et al. 2012.	R
25	Ft Indiantown Gap	PA	Signell et al. 2005.	R/M
26	Clemson Forest	SC	Stottlemyer 2011.	R
27	Univ. TN Forest	TN	Stratton 2007; DeSelm et al. 1991; Thor and Nichols 1973.	R/M
28	Sumter NF	SC	Teuke and Van Lear 1982.	R
29	Green River WMA	NC	Waldrop et al. 2008.	R/M
30	Zaleski SF	OH	Waldrop et al. 2008; Iverson et al. 2008; Albrecht and McCarthy 2006.	R/M
31	Goodwin SF	CT	Ward and Brose 2004.	R
32	Baxter Hollow	WI	Will-Wolf 1991.	M

* Unpublished data on file at the Forestry Sciences Lab, Irvine, PA.

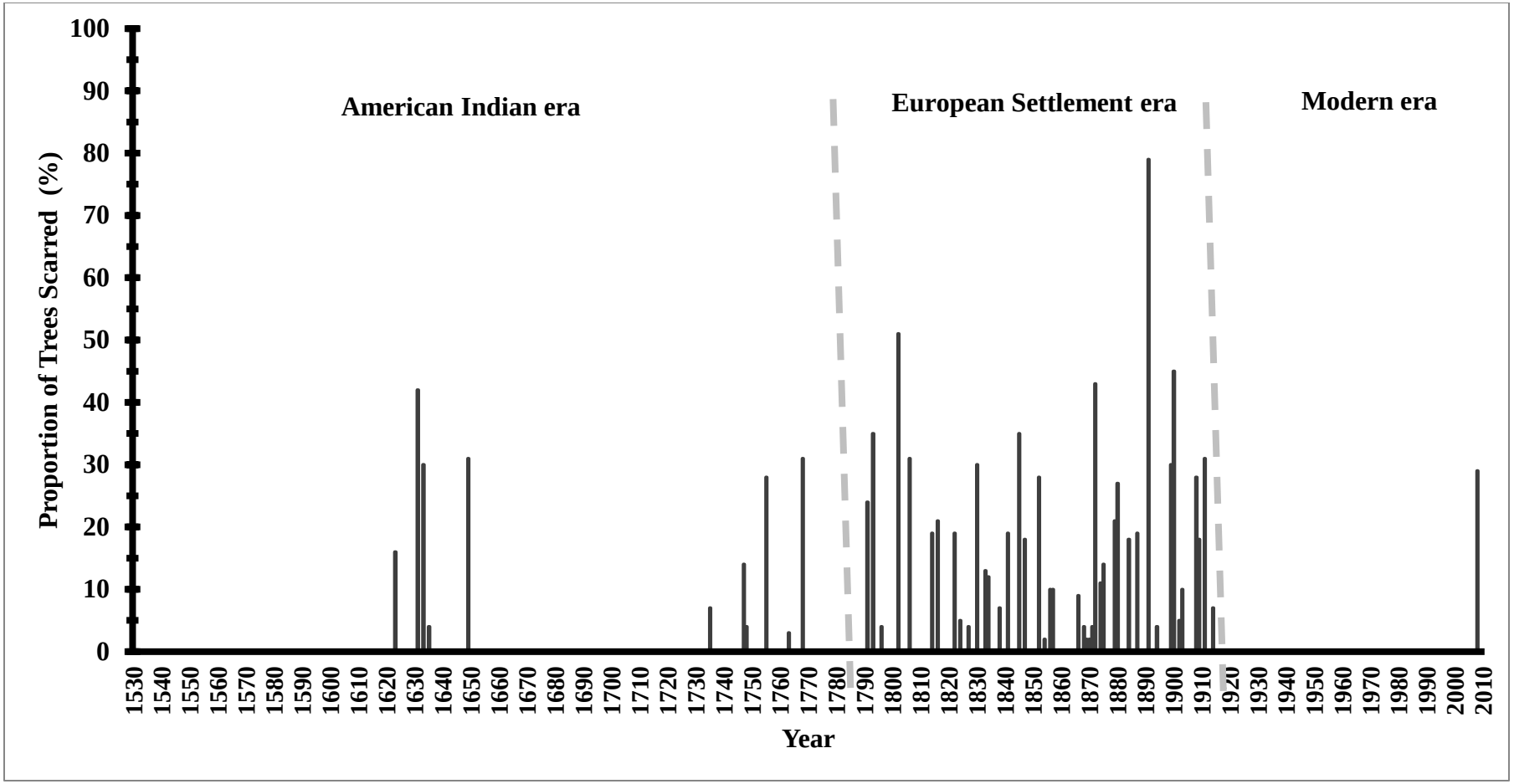

Figure 1. A composite fire chronology of the three study sites in northern Pennsylvania. The vertical bars denote when a fire occurred and its relative severity expressed as the proportion of trees scarred. Note the temporal clustering of fires during the American Indian era, the multi-decadal fire-free periods, and how the frequency of fires increase with European settlement before virtually vanishing in the Modern era.