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The Effect of Fire on Multiple Tree Species in the Eastern Deciduous Forest

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Abstract: Fire is a disturbance that serves to maintain the diverse mosaic of vegetation in the Eastern Deciduous Forest. However, our ability to reconstruct fire occurrence from hardwood tree scars still lags far behind our expertise in reconstructing fire history from conifers in the western United States. This study examines the fidelity of fire scaring in multiple tree species in the Big Oaks National Wildlife Refuge in Indiana, which is located in the central hardwood region of the Eastern Deciduous Forest. All 15 species, except for red oak, showed evidence of past fires, and most samples recorded multiple fire events. No fire scars were recorded in the latewood of the samples. Most of the fires scars occurred in the earlywood (May) suggesting the dormant season fires are likely associated with fires in March to April before the growing season begins. No synchronous fires were recorded across all sites, but fires occurred in 1981, 1982, 1984, 1985, and 1988 across multiple sites. This suggests that these were larger spreading fires. Establishment pulses were documented in association with fire events in 1981, 1984, and 1995, suggesting that fire may benefit the establishment or root sprouting of some hardwood species. Fourteen of the fifteen species that we sampled preserved fire scars, suggesting that the diverse suite of species in the Eastern Deciduous Forest is a viable sampling pool for examining fire history across this forest type.

Keywords: fire history; angiosperm; Eastern Deciduous Forest; dendrochronology; hardwood trees

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1. Introduction

The Eastern Deciduous Forest covers a third of the United States, and little is understood about the role of fire in this extensive habitat. Previously, researchers have documented fire history in the Eastern Deciduous Forest using primarily oak [1–11] and pine species (specifically table mountain pine (*Pinus pungens* Lamb.)) that occasionally occur in this biome [12–18]. Grissino-Mayer [16] noted that fire scars were found in the mesic hardwood stands that were located in a broader landscape of pine-dominated stands in the southern Appalachians. He further noted that fire-scarred hardwoods were common in mixed hardwood forests, but fire history data was much more difficult to extract from hardwood trees. Very few publications have dealt with fire scars in hardwood tree species [19–21]. Smith and Sutherland [19] examined fire scars in red maple (*Acer rubrum* L.), pignut hickory (*Carya glabra* (Mill.) Sweet), as well as in three oak species (white (*Quercus alba* L.), chestnut (*Q. prinus* L.), and black (*Q. velutina* Lam.)). Ascoli and Bovio [20] examined fire scars on *Betula pendula* (Roth) and *Populus tremula* (L.) in Italy to explore forest encroachment in heathland as a result of burning by local pastoralists. Other than pine species in their study area in Virginia, Silver et al. [20] noted fire scars on blackgum (*Nyssa sylvatica* Marshall), sourwood (*Oxydendrum arboreum* L.), American chestnut (*Castanea dentata* (Marshall) Borkh.), *Quercus* spp., black locust (*Robinia pseudoacacia* L.), and pignut hickory, with multiple fire scars found on the first four species. Considering this limited pool of literature where fire scars on angiosperms other than oak trees were examined suggests that further investigation is required to document the extent to which fire shapes this diverse habitat. This oak-dominated fire history research in deciduous forests has mainly concluded that oak woodlands were maintained by fires, but much of the rest of the hardwood forests did not tolerate fire [2,9,22]. This conclusion has been suggested without an extensive study of the effects of fire on the rest of the Eastern Deciduous Forest tree species. In this paper, we strive to demonstrate the ability to record fires that affect a large variety of hardwood tree species. It is important for future management efforts to understand how these species deal with fire, how they record fires, and how they survive fires in these forests.

This research examines the fire history of multiple Eastern Deciduous Forest hardwood species in controlled conditions of known prescribed fires in the Big Oaks National Wildlife Refuge (Big Oaks NWR) in southern Indiana. The rings and scars on cross-sections from hardwood trees were examined in conjunction with known fire dates to determine their reliability as fire recorders using standard dendrochronological techniques. The full length of the chronology, or series of accurately dated tree rings, was also examined for older fire scars before the prescribed fires were implemented. The terminology used in this paper to describe the scar and subsequent wood response and microbial infection is that proposed by Smith and Sutherland [19].

Objectives

To aid the managers of central hardwood forests, we reconstructed the fire history of fourteen eastern deciduous tree species at the Big Oaks NWR. We described the tree responses to prescribed fires, including the development of wood decay associated with scars.

2. Materials and Methods

2.1. Study Site

The Big Oaks NWR was established as an overlay NWR on the closed Jefferson proving ground (JPG) in 2000. At approximately 20,234 ha, it is the largest continuous area of the Eastern Deciduous Forest in southeastern Indiana. The United States army (army) acquired the land from landowners in 1940. Much of this land was in small farms at the time, although some of it existed as small woodlots. Most of the trees in the Big Oaks NWR have the potential to be approximately 80 years old based on when this became a protected site, although some stands extend back into the 1800s. The army tested various types of munitions throughout the history of the JPG and did not want uncontrolled fires to spread as a result of these detonations. Because of this, fine fuels were controlled through prescribed burns, the disking of impact fields, and the spraying of herbicides through 1995, when it was closed as a munitions testing facility. Once the Big Oaks NWR was established, the United States Fish and Wildlife Service (USFWS) continued to burn many of its parcels to maintain them as wildlife habitats. The USFWS has systematically burned different tracts and has kept a detailed record of where and when each fire burned from 1997 to the present. This known fire history is recorded by each tract and enables us to document the effect of known fires so that we can confidently interpret the undocumented fires that have occurred in the past. We used the US Fish and Wildlife Service databases of fire events that extended back to 1997 to select sites and compare the known fires to our fire scar events. The fires ranged from 9 to 1014 ha (24–2508 acres). We collected samples in the following tracts: B7, B8, B27, B36, B40, B41, B46, B52, and B75 (Figure 1).

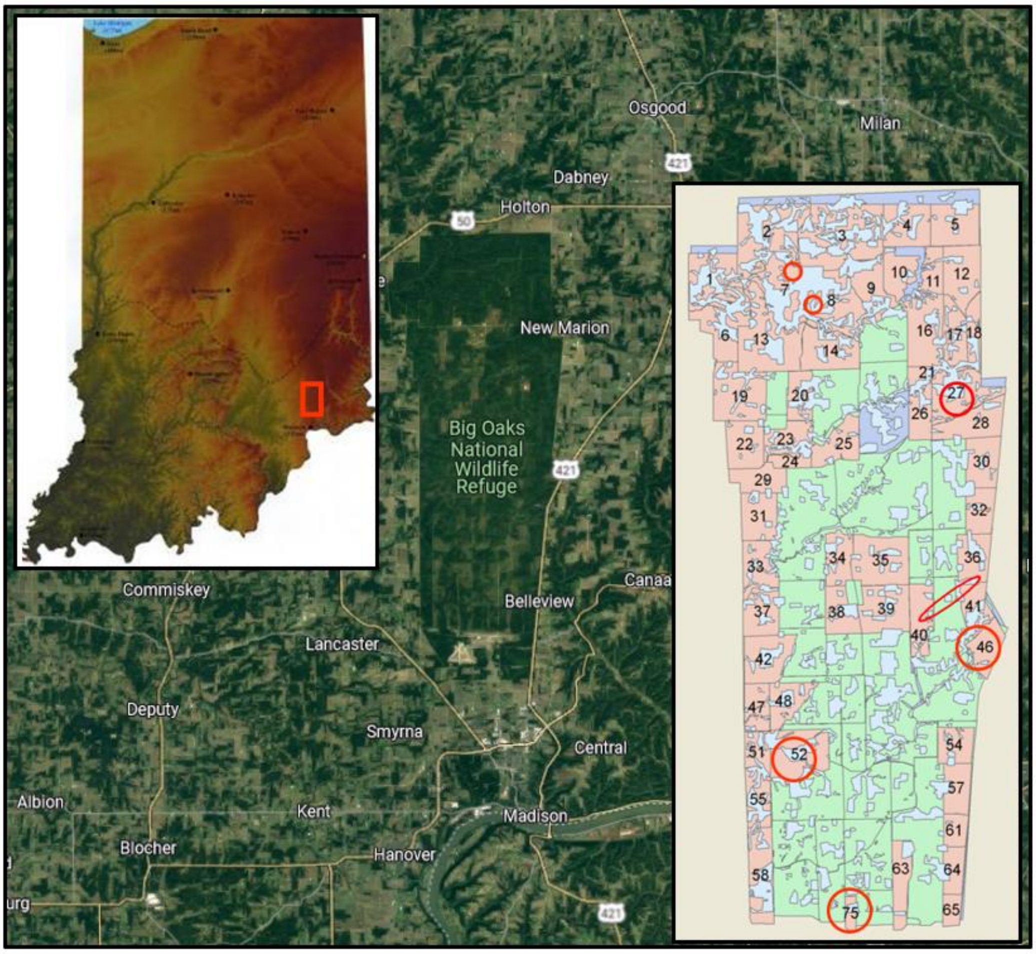

Figure 1. Site map for the Big Oaks National Wildlife Refuge. The Indiana map is showing elevation and the satellite imagery shows the greenness of the forest vegetation. The management tracts are each numbered, and our work was conducted in sections 7, 8, 27, 36, 40, 41, 46, 52, and 75. The red circles show the general areas that we sampled, with the oval on the right side of the image showing the approximate 1999 tornado track (Basemap created from Google Maps and the US Fish and Wildlife Service and shared with the authors in 2006, Big Oak National Wildlife Refuge).

2.2. Field Methods

A suite of Eastern Deciduous Forest tree species was sampled in previous prescribed burns at the Big Oaks NWR. We sampled 15 tree species in seven sites within the refuge, which included red maple, ironwood (*Carpinus caroliniana* Walter), shagbark hickory (*Carya ovata* (Mill.) K. Koch), flowering dogwood (*Cornus florida* L.), persimmon (*Diospyros virginiana* L.), American beech (*Fagus grandifolia* Ehrh.), ash species (*Fraxinus* spp., undetermined on dead and down wood but likely ash species, including green (*F. pennsylvanica* Marshall), white (*F. americanaI* L.), and blue ash (*F. quadrangulata* Michx.)), sweetgum (*Liquidambar styraciflua* L.), tulip poplar (*Liriodendron tulipifera* L.), white oak, pin oak (*Q. palustris* Münchh.), red oak (*Q. rubra* L.), black oak, black locust, and sassafras (*Sassafras albidum* (Nutt.) Nees) (Table 1).

Table 1. Fifteen tree species were sampled, along with the oldest age and the greatest number of fire scars on an individual sample. Many samples had smaller injury scars, some of which even coincided with fire scars on other samples, but those were not counted in the number of fire scars. We present the percentage of samples recording a fire scar, although the sample depth in each species ranged from 1 to 24 specimens in a species that could have potentially recorded a fire. The max columns represent the maximum number of scars on an individual tree within each species, and the % samples scarred column represents the number of trees dated versus the number that had any type of scar present.

Common Name	Scientific Name	Oldest Sample	Number of Trees Dated	Max Fire Scars	Max Injuries	Max Total per Tree	Dated Samples with No Scars	% Samples Scarred
Red Maple	*Acer rubrum*	1926	6	2	3	3	0	100%
Ironwood	*Carpinus caroliniana*	1967	1	1	2	2	0	100%
Shagbark Hickory	*Carya ovata*	1912	8	2	4	5	2	75%
Flowering Dogwood	*Cornus florida*	1956	2	1	2	3	0	100%
Persimmon	*Diospyros virginiana*	1958	2	1	2	3	0	100%
Beech	*Fagus grandifolia*	1787	6	3	7	7	0	100%
White Ash	*Fraxinus americana*	1918	5	2	1	3	0	100%
Tulip Tree	*Liriodendron tulipifera*	1882	12	1	10	10	0	100%
Sweetgum	*Liquidambar styraciflua*	1898	24	3	3	5	1	96%
White Oak	*Quercus alba*	1958	3	3	1	3	0	100%
Pin Oak	*Quercus palustris*	1995	1	1	0	1	0	100%
Red Oak	*Quercus rubra*	1911	2	0	1	1	1	50%
Black Oak	*Quercus velutina*	1970	1	3	0	3	0	100%
Black Locust	*Robinia pseudoacacia*	1941	4	2	1	2	1	75%
Sassafras	*Sassafras albidum*	1945	9	2	4	5	0	100%

The research team surveyed the designated areas and located the scarred trees. We collected samples based on visual evidence of scarring, accessibility for removal without tree felling, and the presence of sufficient sound wood for observation. In the end, we sampled the majority of the scars that we found during reconnaissance. Partial cross-sections were collected from each species in prescribed fire-burned areas for the identification of fire scars during known fire events. Partial cross-sections were collected from the base of each tree where an external fire scar was evident, and the exact height of the sample depended upon the shape and preservation of the cat face (the burn scar at the base of the tree) [23,24]. All samples were taken below one meter in height on the stem. These sections provided the calibration data set for the identification of scar morphology and quantification of the reliability of each species as a fire recorder.

Samples were also collected from ca. 1850 forests at sites B40 and B75. B40 was damaged from a tornado in 1999, which destroyed many of the mature trees. Many trees in B75 were blown over by strong winds from Hurricane Ike in 2008, which was a category 1 hurricane that passed through southern Indiana. The opportunistic sampling of these two sites from wind-thrown trees enabled us to obtain a longer history for this multi-species fire history reconstruction in a hardwood interior forest.

2.3. Laboratory Methods

All samples were air dried for at least a week, then belt sanded and palm sanded with a series of progressively finer sandpaper grits from ANSI 80 grit (177–210 µm) to ANSI 400 grit (20.6–23.6 µm) [25,26]. We also hand-sanded the samples with 30 µm sanding film to remove the scratches left from mechanical sanding. The final surfaces were clear of scratches, and each individual cell could be examined under a microscope. We used skeleton plots, a visual dating technique, to date each individual sample and built master chronologies for each species on the site [25,27]. These master chronologies were then used to help date other samples of that same species from subsequent sites. After the samples were dated, the fire scar and injury dates were noted for each sample, and the scars were photographed. The scars were assigned as being fire scars rather than injuries based on the following criteria: the scar resulted from cambial mortality rather than mechanical damage that may remove rings before a scar formed, the event caused enough damage for wound wood to form after the injury, and the injury may be repeated around the circumference of the cross-section. If these criteria were not clear (with the third criterion of repetition around the circumference not being mandatory), then the wound was identified as an injury. We were conservative in our identification of fire scars, and some wounds identified as an injury may also have been caused by a fire. These dates were entered into the FHX2 and FHAES software packages for the visualization of the fire events across each site [27]. When examining the site as a whole, we did not identify anything as a stand-level fire unless it scarred two or more trees. Some injuries were more likely to be attributed to being caused by fires if they occurred on two or more trees in a stand in the same year. These criteria provided us with confidence that we were identifying spreading fire events rather than an injury due to mechanical damage to one tree (such as abrasion from a nearby tree fall) or a lightning strike starting a small fire that may have only affected one tree.

We determined the general season when fires burned in the past from the position of the scar within the annual ring, as Swetnam and Baisan [28] demonstrated for western pine species. We adapted this to the growing season in Indiana partially based on dendrometer band data (Darrin Rubino unpublished data). Fire scars were assigned to a season based on the portion of the ring that had been produced at the time of the fire. Leaf-out occurs in April, and early earlywood scars occur in early spring (approximately from May to early June); middle earlywood scars are likely to occur in June; late earlywood scars occur in July; and latewood scars occur in August. The growing season for each species varies widely, and even individual tree species vary in their growing season from year to year, rendering these broad estimates at best for the timing of fire seasonality. Dormant season fires occur when the trees are not actively depositing secondary growth on the stem from the end of the growing season in autumn until the beginning of the growing season the following spring. Because the main prescribed fire season in this area is March and April, we assigned dormant season fires to this time period (it is possible that dormant season fires in the past could have occurred from October to November as well, but we did not see any evidence of this). Undetermined scars were the ones where the season could not be determined because of rotten wood or damage from wood-boring insects.

Establishment dates can be approximated when the pith of the tree is present on the sample, and the samples are taken near the root collar. Most samples were taken within 30 cm of the ground, so we expected them to be within a few years from seed break or when vegetative sprouting was initiated. Some trees had heart rot, which prevented us from determining the establishment dates, and these samples were excluded from this part of the analysis.

3. Results

Fifteen hardwood species were sampled for fire history reconstruction on five sites in the Big Oaks NWR, and fourteen of the species showed evidence of past fires (Figure 2). Only *Quercus rubra* did not show evidence of fire, but we only collected two cross-sections from this species. We collected samples from 145 trees from these sites and presented the results from 79 of those trees that were dated and had scars. We dated a total of 86 samples, with some of the remaining samples not dated because they were in poor condition with too few rings to date. The other seven dated samples did not have scars present. The oldest stand-level fire that we recorded was in 1902. The B75 site provided the longest chronology and the most fire events, with 11 fires documented (1902, 1947, 1958, 1962, 1965, 1982, 1984, 1988, 1996, 2001, and 2004) (Figure 3). The year 2009 recorded a white ring in the earlywood for trees that were blown down and stripped of leaves by Hurricane Ike in September 2008 but did not completely die until the summer of 2009. White rings often form after severe defoliation when the cell walls are not thickened due to a lack of resources [29]. The B52 site had four fires documented (1981, 1985, 1995, and 2003), with only the 2003 and 1995 fires being previously documented as prescribed fires. The B40 site had fires in 1963, 1981, 1984, 1988, 1989, 1992, and 1994, with the only recent prescribed fires recorded by the Fish and Wildlife Service occurring in 2007 after our sampling. Along with the B75 site, we were able to extend our chronology back in time with older trees from the B40 site, which were killed by the 1999 tornado. Our oldest samples at this site started growing in the 1910s. The B46 site had fires recorded in 1982, 1985, and 2000, with the 2000 fire being the only documented prescribed fire recorded by these trees. Prescribed fires were also set on this site in 2003 and 2005 but were not recorded in this study. Only a few scarred samples were found on the B8 site, so we were only able to document one possible fire scar (1990) and one previous injury from this site. No well-preserved fire-scarred samples were found in B7, and only wind-blown *Populus grandidentata* Michx. cross-sections were collected, none of which had scars present. Every species that we sampled recorded one to three fire scars over their lifetime (Table 1), except for the two *Quercus rubra* samples that showed no evidence of fire scars.

3.1. Season of Fires and Injuries

The known fires from the prescribed burns were evident on many of the scarred samples, with most of the fire scars appearing in the dormant season between the end of growth in the fall (around September) and cambium activation in the spring (around May). Most prescribed fires are currently set in the early spring in March or April, explaining the prevalence of dormant season scars at these sites, although historical fires could have also occurred during the dry period in October to November. Most fire scars (81%) occurred during the dormant season of tree growth. Six percent of the fire scars occurred in the early earlywood, three percent occurred in the middle earlywood, and five percent occurred in the late earlywood. Five percent of the scars were undetermined for the season because of preservation issues in the wood. No fires were recorded in the other seasons. Because most of the fire scars that were assigned a season occurred in the early earlywood period and because the main fire season is from March to April in this area, the dormant season fires were assigned to the year that would correspond with an early springtime fire.

The seasonality of combined injuries and fire scars had the highest percentage (68%) of seasonality during the dormant season, although more injuries occurred throughout the growing season than with fire scars. Ten percent of the injuries occurred in the early earlywood, seven percent in the middle earlywood, four percent in the late earlywood, four percent in the latewood, and seven percent were an undetermined season because of wood preservation.

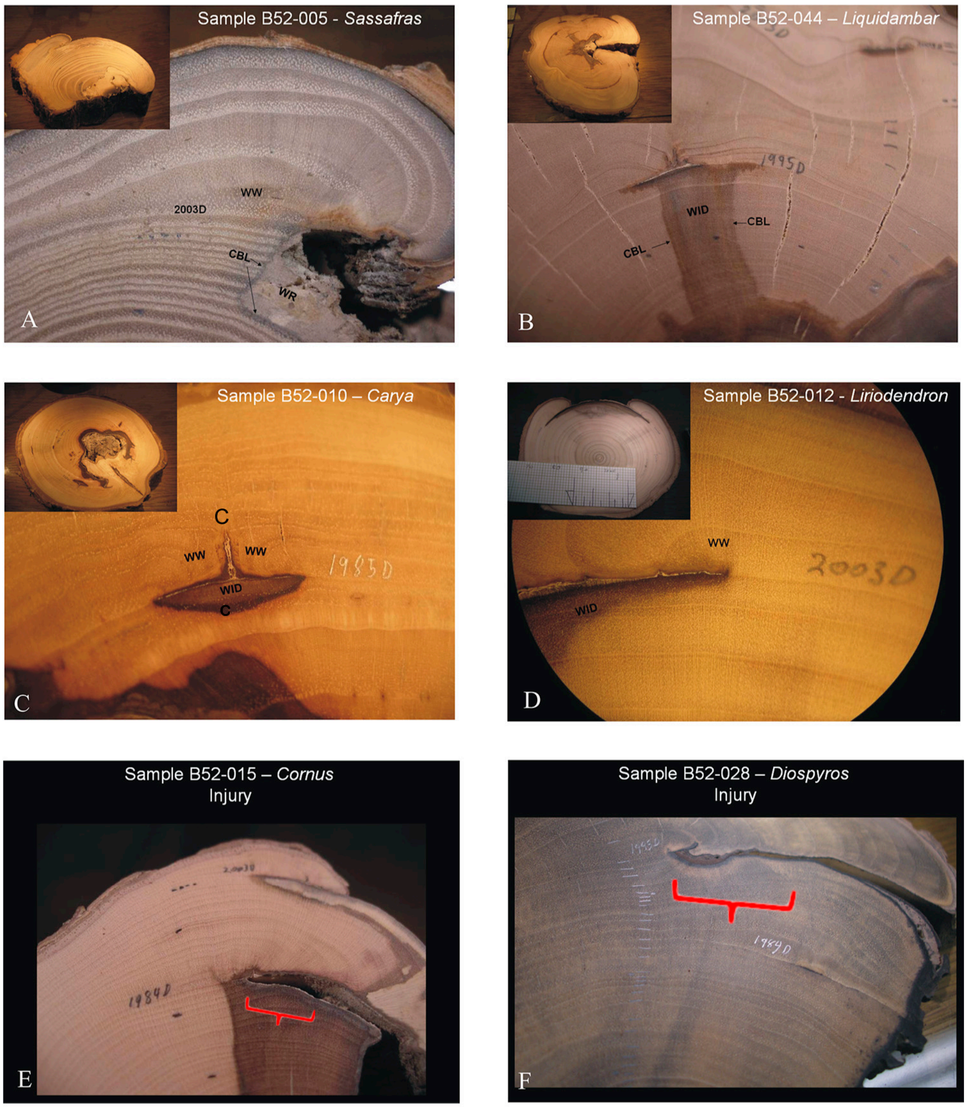

Figure 2. Samples of fire scars from (**A**) sassafras, (**B**) sweetgum, (**C**) hickory, and (**D**) tulip poplar, along with samples of injuries from (**E**) dogwood and (**F**) persimmon. Note the bracket on E showing where the wood was removed due to an injury in 1984 and where the wood was removed again in F at the 1993 scar. WW = wound wood; WR = white rot; CBL = chemical boundary layer = the black line where the tree develops a chemical boundary against fungal spread; WID = wound-induced decay; C = closure (included bark that resulted from the closure of wound wood ribs). A year (e.g., 2003D) indicates the date and season of the injury, where D means dormant.

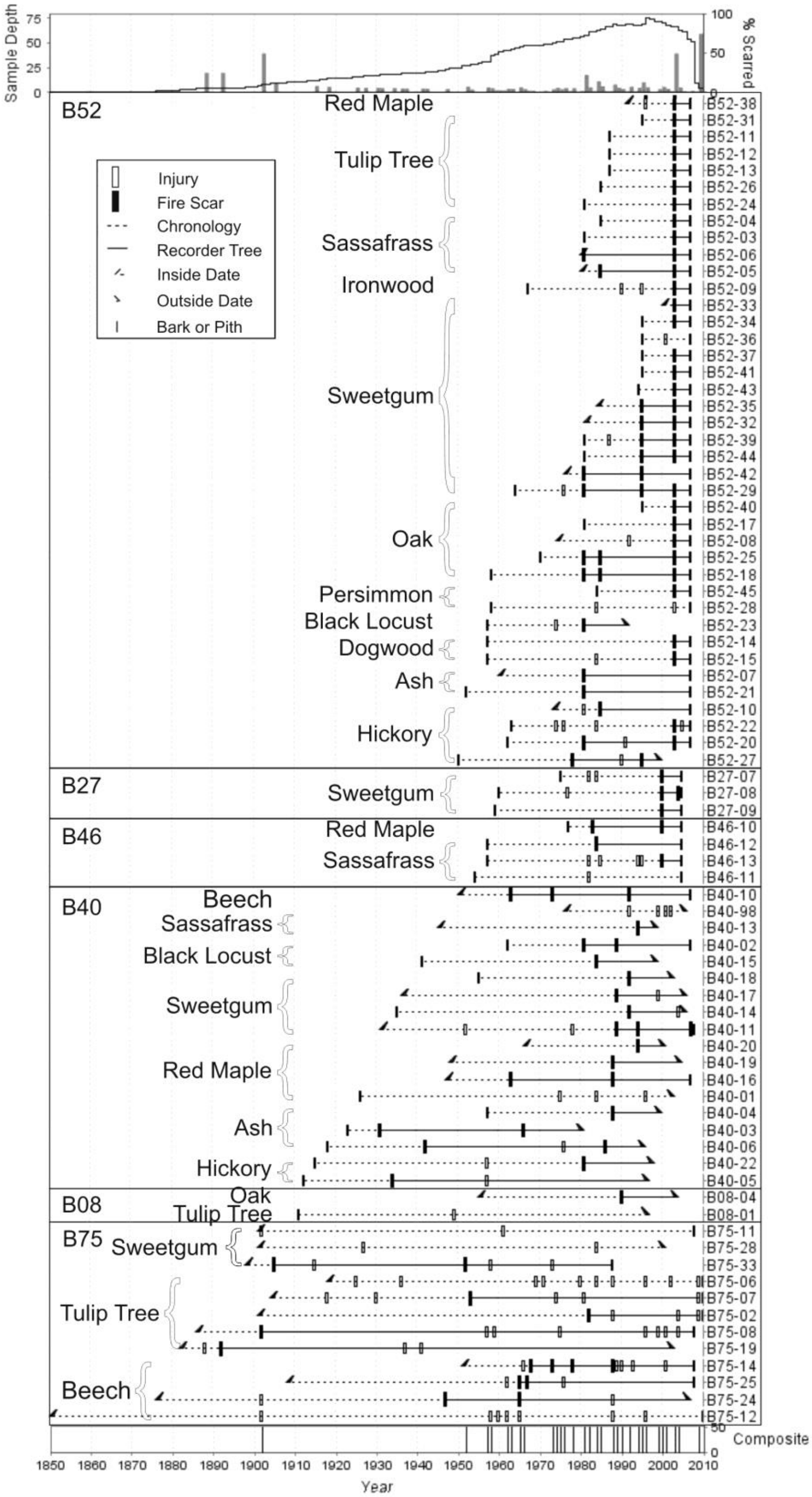

Figure 3. Fire history chart developed in FHAES with the FHX2 Excel input protocol. A tree becomes a recorder tree after it records its first fire because it is more likely to record subsequent fires. The figure at the bottom is the composite of all fires affecting two or more trees.

3.2. Establishment Dates

Because site B52 was being cleared as a habitat for grassland wildlife, we could destructively sample this area, which resulted in more extensive establishment date information;

therefore, we concentrated this analysis on B52. Establishment pulses occurred in 1958 (2 trees), 1981 (5 trees), 1985 (2 trees), 1987 (3 trees), and 1995 (6 trees), solely based on the cross-sections that had a pith on site B52. We did not record fires as far back as 1958, but fires were documented in 1981, 1985, and 1995. A prescribed fire was set in 2003 and was recorded in the samples, but because we did not sample saplings, we did not record if this particular fire caused an establishment pulse. The sample depth shows the number of trees recorded through time and shows clear establishment pulses associated with 1981, 1985 and 1995 fire events (Figure 4). Thirteen of the eighteen trees that had a pith after 1981 established the year of fire. The other five trees established in 1984 (1 tree), 1987 (3 trees), or 1994 (1 tree). All of these were a year before a fire, which could be advanced regeneration that was missed by the fire, or two years after a fire, which could have been due to missing the first years of growth because of sampling higher on the stem. The species established within the year of the fires were sweetgum (6), tulip poplar (3), sassafras (2), or oak (one white oak and one red oak). All of the other forty trees were dated as established prior to 1981 or did not have a pith for accurate determination of age.

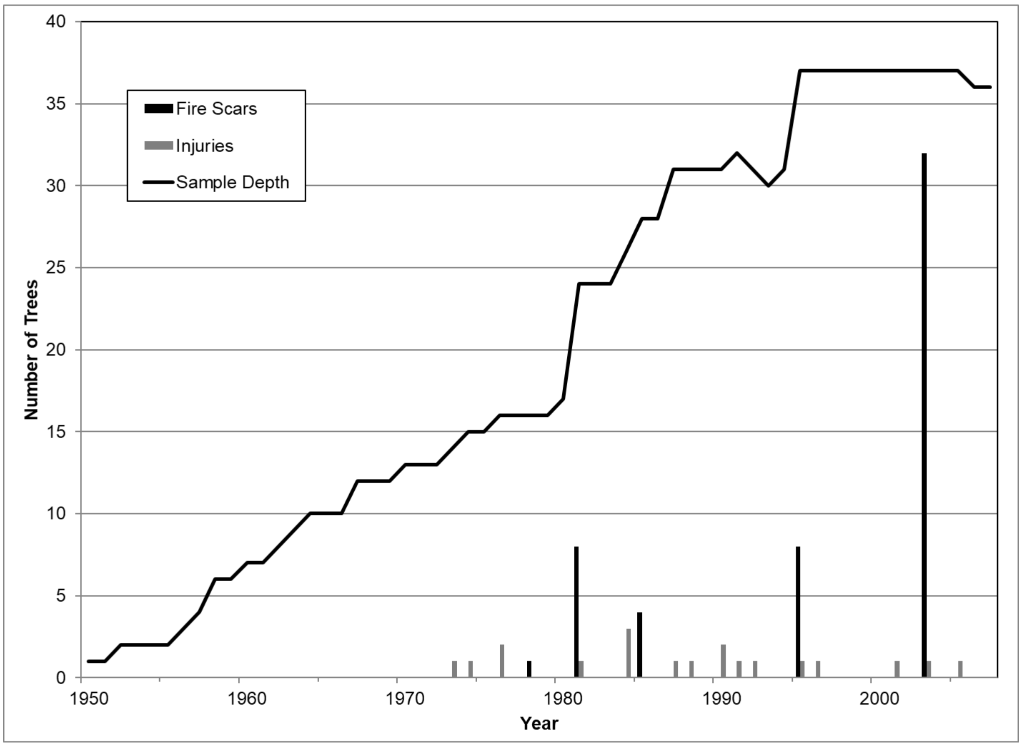

Figure 4. Sample depth chart along with percentage of trees scarred at site B52. Note the increases in the sample depth during the fire events, which illustrate the establishment pulses. We were not able to measure the establishment that occurred after the 2003 fire because saplings were not sampled.

4. Discussion

Every species that we sampled, with the exception of red oak, showed evidence of past fires, indicating that many Eastern Deciduous Forest hardwood species survive and record fire exposure in their tree-ring record. Some rot and compartmentalization were also evident on every sample, showing that these trees are actively protecting themselves from the spread of wood-destroying fungus [19]. These fungi make longer-term fire histories more difficult to determine in the hardwood species, but the functional compartmentalization of the hardwoods makes fire scar preservation possible. The accelerated decomposition rates compared with western forests makes the development of long-term fire reconstructions challenging [30–32].

We were able to document 36% of the known prescribed fires since 1997 on our sites. This low number is likely due to a mismatch between the spatial locations of our samples in the research plot versus the area burned in the research plot. Future fire history work at the Big Oaks NWR would benefit from taking GPS locations of each individual sampled tree to compare to past fire spread maps, which we recently acquired that extend back to 1981. We were able to document elevated fire activity in the 1980s, which was not known by the researchers prior to the completion of this work. Many more fires than had previously been documented have been identified in this study. Fires in 1981, 1982, 1984, 1985, and 1988 were recorded on at least two different tracks and indicate more extensive fires that occurred periodically either via munition testing or prescribed fires ignited by the army staff at the JPG.

Based on the prevalence of dormant and earlywood fire scars, the main fire season has been from March through April for the entire length of this fire history extending back to 1902, although October to November fires would also appear as dormant seasons if they occurred in the past. This March to April fire season has been observed by the authors on our sites and documented by others (such as [33]) on other sites in the eastern United States. Future studies need to be conducted to determine how this season of fire affects the life cycle of plant species on these sites and contrasted with late growing season fires.

Site B52 clearly shows establishment pulses after the 1981, 1985, and 1995 fires. This suggests that infrequent fires (from four to ten years) may not be the best means to maintain open wildlife areas, although frequent fires are likely to increase the grasses while keeping the hardwood species in check [33]. More work needs to be conducted with stand-age structure analyses to determine the effects of the recent prescribed fires set by the Big Oaks NWR. Different burn units within the Big Oaks NWR have been burned zero to six times from 1997 to 2006. This provides an excellent opportunity to study the frequency of prescribed fires on the grass, herb, and tree populations on these sites.

Nuttle et al. [34] found that fire on its own on study sites in West Virginia did not increase tree diversity or density but did change these parameters when combined with gaps and deer browse. Fire, combined with deer browsing, caused the greatest increase in the relative abundance of maple trees [34]. Arthur et al. [10] reported that many of the hardwood genera resprout after fire, including *Acer*, *Carya*, *Castanea*, *Cornus*, *Fagus*, *Liquidambar*, *Liriodendron*, *Nyssa*, and *Ulmus*. Matlack [35] argued that fire studies have over-reported the occurrence of fire in the eastern United States because of targeted sampling, although Stambough et al. [36] provided a cogent rebuttal that argued that Matlack went too far in arguing that fire should not be used east of the prairie lands [36]. Our work supports Arthur et al.'s [10] findings that most of the hardwood genera that we sampled resprouted after fires.

Many national public lands have fire management plans and use prescribed fire to maintain habitats and enhance plant diversity such as the following: Great Smoky Mountains National Park, Shawnee National Forest, Congaree National Park, Cuyahoga Valley National Park, and the Hoosier National Forest. Fire has been demonstrated as a useful tool in the Eastern Deciduous Forest that helps to maintain some forest types. Lafon et al. [37] demonstrated through dendropyrochronology that fire occurred every few years on many landscapes of the central Appalachians prior to the fire-exclusion period and that vegetation is currently adjusting to this period of lower fire occurrence.

Our conservative approach documented 20 unique fire dates from five sites, which indicates that the Eastern Deciduous Forest has experienced a large number of fires in the past 100 years and continues to thrive. Because of the preponderance of dormant season injury events (the same predominant season of fire events), many of these injuries could be due to past undocumented fires. A conservative approach to fire history designation, especially in this environment where previous fire history recording has not been attempted, is probably the appropriate approach for fire documentation in the near future. The reader, however, should be aware that any estimates of fire frequency using this approach will underestimate the number of fire events over time. As more fire histories are attempted in the Eastern Deciduous Forest using all of the tree species present, we will gain a better understanding of the role of fire in this habitat, as has been achieved with multiple species climate reconstructions in eastern North America [38,39]. Nearly all of the fires documented in this study were human-caused via controlled burns or munitions testing, rendering a more frequent fire occurrence than would occur in a deciduous forest with less human influence. The results from this study demonstrate that these trees can survive and may have benefitted from fire based on the observed establishment pulses. The analysis of satellite images over time indicates that prescribed fires and other management techniques at the Big Oaks NWR have maintained some management units as early seral stages similar to army-prescribed fires [40], but other forest openings have reverted to forests [40]. We found similar induced responses in all of the hardwood species that Smith and Sutherland [19] found in their research, suggesting that these genera can survive fires, protect themselves from fungi that enter the tree, and thrive under these conditions. Prescribed fire seasons are currently limited at the Big Oaks NWR between September 15 to April 15 due to restrictions to reduce impacts to federally listed endangered and threatened bat species found at the Big Oaks NWR.

5. Conclusions

This research has demonstrated that all of the sampled Eastern Deciduous Forest tree species are capable of recording past fire events. Many of these species recorded two or three past fire events and preserved the scars. Many of the genera that we sampled (*Fagus*, *Liriodendron*, and *Liquidambar*) were scared more than 100 years ago and were surviving at the time of sampling, suggesting that these trees can be injured via fire and still live long lives. This history of fires on the land managed by the Big Oaks NWR provides a longer land-use history for these sampled tracts. It shows the preponderance of a March to April fire season that supports their current efforts in fire management on this site. While these fires are often set to reduce the growth of tree species in wildlife areas, we found that many of these trees are established as a result of these fire events. Limitations to only allowing prescribed fires in the dormant season due to restrictions for endangered and threatened species could perhaps be overcome by decreasing the prescribed fire intervals in grassland or savanna units. If the management goal of prescribed fires is to remove woody species, we recommend that more frequent fires (i.e., <3-year intervals) should be used to prevent the regeneration pulses observed in management units. Cutting off individual trees was also being used to stop regeneration and maintain open grasslands on properties in some cases. This study has demonstrated the potential for using 14 of the 15 tree species that we sampled in the Eastern Deciduous Forest as reliable (if conservative) indicators of past fires, and we suggest that more researchers conduct fire histories from tree genera other than pine and oak in the future to provide a more complete understanding of fire in hardwood forests.

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Conflicts of Interest: The authors declare no conflicts of interest.

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