Perspectives on oak savanna restoration in Minnesota: a dendroecological approach

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Abstract

Anthropogenic disturbances have diminished the extent of oak savannas throughout the Midwest and altered what few remnants remain. Although oak savanna restoration is of great interest to the public and reserve managers, scientists do not fully understand the intricate dynamics of the ecotone, leaving land stewards without solid restoration models. This study examined the age structure and historical fire frequency at four remnant savannas in Minnesota. A total of 846 tree cores were used to reveal temporal changes in savanna structure and 42 wedges and cross-sections were cut from oaks to date fire scars. Northern pin oak *(Quercus ellipsoidalis)* dominated in the southeast, grading to bur oak (*Quercus macrocarpa)* dominance in the northwest. Oaks were the oldest trees at each site, with relatively recent recruitment of more shade-tolerant, fire-intolerant species. Few oaks predated Euro-American settlement. High bur oak establishment during the late 1800s-early 1900s was followed by a period of low oak establishment in the 1930s and 40s. Northern pin oak establishment increased rapidly in the mid-1900s, while bur oak establishment appears to have decreased, displaying a shift from bur oak dominated establishment to northern pin oak dominated establishment over the past 200 years. Whereas bur oak dominated the seedling layer, northern pin oak dominated the sapling size class. Open and healed fire scars from prescribed burns were abundant at all sites, but no fire scars predated settlement. These results suggest that many areas we currently designate as "oak savanna" may not have many (or any) oaks predating European settlement of the area due to previous land-use, climatic conditions, or species specific life history characteristics. Nevertheless, the scarcity or absence of older oaks in these areas (regardless of oak species) does not directly imply that these areas were not pre-settlement oak savanna. Anthropogenic land-use has heavily shaped the savanna community composition and structure since European settlement. Throughout Minnesota in the late 1800s, the implementation of continuous cattle grazing increased bur oak establishment and survival. Periods of logging have reduced the presence of old oaks and heavy grazing reduced oak establishment. Canopy cover has increased at all sites due to fire suppression and the maturation of earlier surges of oak establishment. The most apparent and, perhaps, threatening trend to savanna structure and composition, is the recent shift from bur oak dominated savannas to northern pin oak dominated savannas due to a combination of springtime prescribed burns, fire suppression, increasing deer populations and squirrels. A conclusive pre-settlement average fire return interval for Minnesota oak savannas could not be deduced from the fire history aspect of this study due to an insufficient number of pre-settlement fire scars. Prescribed burns are probably scarring trees more frequently than historic fires did and have failed to reduce the number of mesic, fire-intolerant species. This study demonstrates the variation between and heterogeneity within Minnesota oak savannas, exemplifying the problems inherent in extrapolating patterns and management implications from site-specific case studies. Future oak savanna management in Minnesota should focus on thinning areas before prescribed burning to decrease scarring frequency, performing summer or fall burns to increase bur oak regeneration, as well as increasing our knowledge of land-use patterns before determining land management objectives.

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CHAPTER I: An introduction to oak savanna ecosystems and their importance

What is an oak savanna?

Idealized by stout and gnarly oak trees strategically, yet haphazardly, scattered throughout a grassy landscape, the oak savanna is, above all, aesthetically pleasing. Nevertheless, specifying the structure, composition and disturbance regime of this dynamic zone between the treeless prairies to the west and the dense deciduous forest to the east remains elusive to scientists and land managers. Definitions for the ecotone range from a sparse "1 tree per acre" (Curtis 1959) to "5-15 trees per acre" (Bray 1955) to as much as "100% canopy cover" (Botts et al. 1994). So, while prairie and forest can be separated from savanna, no definition that clearly separates savanna from prairie and forest has been developed (Proceedings of the Great Lakes Ecosystem conference 1994).

While the criteria for Midwestern oak savannas vary tremendously in the literature, embedded in all of them is the notion that the oak savanna is a transitional ecosystem, maintained by a periodic, intermediate fire frequency. Fires burn too frequently for the fire-intolerant species characteristic of deciduous forests to persist, but not so often that oaks (*Quercus* spp.), with their thick, fire resistant bark, can establish and survive.

Why are oak savannas important?

The patchy nature of savannas creates a unique mosaic of microsites, enabling the oak savanna to house prairie species, woodland species as well as specialized savanna species (species limited in most part to oak savannas) (Packard 1988, Leach and Givnish 1999, Meisel et al. 2002). Unfortunately, the neighboring tallgrass prairie ecosystem to the west is equally as threatened as the oak savanna (Henderson 1995), and Minnesota deciduous forests to the east are often severely altered (Augustine and Frelich 1998). So, in an agriculturally dominated landscape, and at a time of increasing land development and land fragmentation, Midwestern oak savannas serve as a collective home to a diverse array of species, making oak savanna conservation an efficient way to preserve biodiversity.

The eastern United States is experiencing a virtual cessation of oak regeneration due to fire suppression, deer browsing and native and exotic invasive species (Nowacki and Abrams 1992, Abrams 1992, Abrams 2003). Similarly, oak decline has been a chronic problem throughout the Missouri Ozarks (Law and Gott 1987, Kabrick et al. 2008) as well as the northern United States (Woodall et al. 2008). Conserving oak savannas is an excellent way to promote oak regeneration for the future.

Under a warmer, drier climate, Minnesota oak savannas are predicted to shift to the north and east, expanding further into the deciduous forests, covering a large proportion of the state (Carstensen et al. 2008). In a study of oak mortality following drought, Faber-Langendoen and Tester (1993) found decreased mortality in oak woodlands compared to savannas, suggesting that savannas are less stable than oak woodlands with respect to drought. However, in a study comparing the effects of fire, Anderson and Brown (1986) found increased oak mortality in oak woodlands compared to savannas, suggesting that savannas are more stable than oak woodlands with respect to fire disturbance. While looming predictions of increased drought may make the future stability of oak savannas seem bleak, a warmer and drier climate also may bring with it more fire (Westerling et al. 2006), ultimately favoring savanna stability. So, while it is hard to predict how oak savannas may fare under a different climate, conserving present-day oak savanna remnants for future research and reference will certainly benefit land managers and researchers in the future.

The oak savanna is a picturesque, iconic landscape. Its open, park-like appeal attracted early settlers, who wrote, "among the oak openings you find some of the most lovely landscapes of the west, and travel for miles and miles through varied park scenery of natural growth, with all the diversity of gently swelling hill and dale; here the trees are grouped or standing single, and there arranged in long avenues, as though by human hands, with strips of open meadow between" (Ellsworth 1837). With its somewhat orderly and artificially-landscaped appeal, the oak savanna has the ability to attract a diverse array of people, immersing them in the scattered oak canopies and diverse herbaceous understory and, hopefully, generating a new appreciation or sparking an existing love for nature.

What did oak savannas look like in the past?

Original perceptions of oak savanna structure were shaped by Native American accounts, early land surveyor notes, various letters and journals from early settlers and explorers, and aerial photos (Gleason 1913, Cottam 1949, Bray 1955, Curtis 1959, Williams 1981). Settlers described these oak areas as a park-like savanna of widely spaced mature oaks with a wide range of shrub cover above the forb and graminoid ground layer (Stout 1946 cited in Merzenich et al. 2005, Cottam 1949). Canopy cover varied from 10 to 60% (Merzenich et al. 2005) and was dominated by oak species (Lanman 1871 cited in Merzenich et al. 2005, Cottam 1949). Examinations of aerial photos from the early 1930s show relatively sparse canopy cover with open-grown, scattered oaks (Faber-Langendoen and Davis 1995, Bowles and McBride 1998). Often, oaks are dispersed in the understory as fire-suppressed grubs (Bowles and McBride 1998, Anderson and Bowles 1999) and shrubs are commonly scattered or clumped in the understory. Cottam (1949) and Curtis (1959) suggested that oak savannas originated when prairie fires spread into nearby oak forests with enough intensity to create open canopy conditions. Other researchers proposed that savannas originated following the invasion of prairie by oaks during extended fire-free periods (Grimm 1984, Anderson and Bowles 1999).

These initial perceptions of oak savanna structure, composition and dynamics guided subsequent researchers and organizations to select land remnants that have these visual characteristics and/or meet certain requirements and label them as “oak savannas” (Leach and Givnish 1998). In general, scientists have grouped Midwestern oak savannas into two categories: 1) mesic savannas dominated by bur oaks (*Quercus macrocarpa*), white oaks (*Q. alba*), northern red oaks (*Q. rubra*) and swamp white oaks (*Q. bicolor*) - these are often the iconic, more picturesque savannas - and 2) xeric savannas, occuring on sandier soils, dominated by fire-stunted Hill’s oak (a.k.a. northern pin oak) (*Q. ellipsoidalis*), post oak (*Q. stellata*), and/or black oak (*Q. velutina*). Several studies and organizations have further subdivided the oak savanna community along successional, geographic and physiographic gradients (Will-Wolf and Stearns 1999, Haney and Apfelbaum 1993, Minnesota Department of Natural Resources 2005).

What do oak savannas look like today?

Over the past 150 years, numerous anthropogenic disturbances have adversely impacted Midwestern oak savannas. After years of fire suppression, many savannas have advanced successionally to closed-canopy oak and mixed-species forests (White 1983, Faber-Langendoen and Tester 1993, Bowles and McBride 1998). Grazing and agriculture have altered soil composition, vegetation composition and regeneration patterns (Knops and Tilman 2000, Karnitz and Asbjornsen 2006), non-native species are replacing native species and threatening to alter fire-vegetation patterns (Miesel et al. 2002) and, most noticeably, fast-paced development and other forms of land fragmentation have closed in on the small remaining savannas. With less than 0.02 percent of pre-settlement oak savannas left in the Midwest, we are on the verge of losing this ecosystem completely (Nuzzo 1986).

It is widely accepted that, in the absence of fire, current oak savanna remnants, regardless of their location and type, have developed greater overstory tree density and larger basal areas compared to historical conditions (Gleason 1913, Bray 1955, Curtis, 1959, White 1986, Inouye et al. 1994). Aerial photos of Helen Allison Savanna in east central Minnesota reveal that canopy cover increased from 7% to 25% between 1938 and 1960 (Faber-Langendoen and Davis 1995). Although the process has been gradual, woody encroachment (Whitford and Whitford 1971, Faber-Langendoen and Davis 1995) has altered light availability, reducing the number of light-demanding grasses and forbs (Peterson, Reich and Wrage 2007) and changing overstory species composition (Abrams 1992).

Dendrochronological studies performed in Midwestern oak savannas have all been site-specific, elucidating changes in a *specific* site's forest structure and composition over time. Nevertheless, they all convey the idea that these once oak-dominated systems have recently been invaded by more mesophytic and also fire-intolerant species. For example, in a black oak woodland in northwestern Indiana, Henderson and Long (1984) found an increase in late-successional, fire-sensitive species in recent decades and an overall increase in stand density.

A dendroecological study in central Iowa found no trees predating settlement, with the oldest tree (a white oak) at 145 years old (Karnitz and Asbjornson 2006). The majority of non-oaks were younger than 50 years old, coinciding with the time that grazing and other cutting activities ceased. Karnitz and Asbjornson (2006) argue that some of what we consider to be remnant "oak savannas" based on characteristic large, gnarly oaks may actually be post-colonial in origin.

At Helen Allison Savanna in east central Minnesota, Faber-Langendoen and Davis (1995) found that the age classes of the two oak species, bur and northern pin, barely overlapped. Bur oaks ranged in age from 20-200 years old, while most northern pin oaks were less than 30 years old. They conjectured that bur oak recruitment was sporadic over the last 150 years. Although northern pin oaks may have been present in 1850, few or none survived. Ziegler et al. (2008) also noted that bur oak recruitment was sporadic, and hypothesized that oaks at Helen Allison recruited during climatically dry periods.

Perceptions of oak savannas as "prairies with trees" (Bray 1955, Curtis 1959) belie the unique qualities and biological diversity of the oak savanna understory. This skewed perception has also skewed management objectives which have overemphasized prairie species. In fact, Mendelson et al. (1992) and Curtis (1959) both argued that because savannas were merely ecotones between the prairie and the forest (having mostly prairie species in the understory) they are not a priority for conservation and restoration. Bray's initial characterization of the savanna understory may have been an artifact of sampling because he selected his savanna sites based on the presence of prairie grasses, skewing the study towards a graminoid-dominated system (Leach and Givnish 1999).

These studies, along with idealized notions of "grassy understories" have prompted most restoration goals to focus on maximizing prairie species. Recent studies, however, have questioned that notion and have claimed that oak savannas have their own unique attributes and are, in fact, incredibly diverse, having both prairie and forest species as well as species unique to oak savannas (Ko and Reich 1993, Leach and Givnish 1999, Meisel et al. 2002). Forb cover actually exceeds gramminoid cover in all but the sandiest, brightest environments (Bowles and McBride 1998, Leach and Givnish 1999). Packard (1988, 1993) and Miesel et al. (2002) identified several herbaceous savanna specialists (bimodal species that thrive in environments with high and low light availability) – many of which had been marginalized or locally extirpated by fire suppression.

What forces have acted to shape the oak savanna system?

Prior to European settlement, frequent fire was probably one of the most important forces that shaped and maintained oak savannas. By consuming dead and decaying vegetation, fire enriched the soil. Fire also produced bare ground, creating germination sites for oaks or herbaceous species to colonize and giving the sun a chance to warm the ground in early spring, triggering establishment. Fire prevented canopy closure and fire-killed or top-killed smaller diameter trees and shrubs, slowing the growth of trees and shrubs in the savanna (Leitner et al. 1991).

Historically, Native Americans played an integral role in the fire regime, accidentally and/or intentionally setting fire to prairie and savanna ecosystems (Grimm 1984, Bowles and McBride 1998, Anderson and Bowles 1999, Kay 2007). In fact, some scholars suggest that anthropogenic ignitions were the primary source of fire in savannas (Guyettte et al. 2003).

Another force that may have helped shape and maintain the open oak savanna structure was grazing from large herbivores (i.e., elk and bison). Ritchie et al. (1998) suggest that by consuming nitrogen-fixing and woody plants, herbivores indirectly control productivity, N cycling and succession. Transient grazing likely inhibited the succession of savanna to woodland (Vera 2000).

Because of a scarcity of old trees available for fire history research, much of our knowledge of fire dynamics and fire history in the oak savanna transition zone is derived from early surveyors' descriptions and from paleoecology. Charcoal and pollen records from lake sediments confirm the role of fire in influencing landscape vegetation patterns at the prairie-forest border (Grimm 1983, Umbanhower 2004). Grimm (1984, 1985) reported that, prior to European settlement in the 1850s, fires were relatively frequent in southern Minnesota, ranging from annual to 30-year intervals, depending on topography, firebreaks and the presence of Native Americans. The coarse resolution of these lakesediment studies provides only rudimentary and rough estimates of fire frequency and fails to provide information on the timing and spatial extent of individual fires.

Dendroecology serves as a fine scale, natural archive of annually resolved ecological information over long periods (Kipfmueller and Swetnam 2001). Fire scars in tree rings enable researchers to reconstruct the historical fire regime (Smith and Sutherland 1999, Guyette and Stambaugh 2004). A 200-year fire history in a remnant bur and white oak savanna in southeastern Wisconsin found a median fire return interval of 4.59 years, although fire frequency did fluctuate during different periods of settlement (Wolf 2004). Guyette et al. (2006) reported a mean fire interval of 5.2 years in a post oak savanna in northwestern Missouri. Guyette and Cutter (1991) calculated a fire interval of 4.3 years spanning 300 years in a post oak savanna in southern Missouri. Dey et al. (2004) found a mean fire interval (MFI) of approximately 4 years in a 292-year fire history in a mosaic of oak forest, savanna and fen in Missouri. These site-specific studies seem to agree upon a 4-5 year MFI. While knowledge of the MFI is important, the intensity and extent of the fire is equally important. Depending on environmental factors, stand structure and the fuel load available, a fire will burn at different intensities and extents (Swetnam and Baisan 1996).

What management steps have been taken?

Oak savanna restoration is forefront on the minds of conservationists and conservation agencies throughout the Midwest. Numerous restoration techniques using prescribed burning, mechanical thinning and native seeding, or combinations thereof, have attempted to restore “degraded” savanna remnants (i.e., reduce canopy cover and non-oak species and increase prairie species).

Most management goals focus on reducing overstory tree density, reducing basal area (the cross-sectional area of a tree trunk at breast height), suppressing understory shrubs and trees and maximizing prairie species in the understory (Peterson and Reich 2001). A burning schedule of annual to biennial fires has been shown to produce the most effective reduction in tree canopy density (White 1983, Henderson and Long 1984, Tester 1989, Faber-Langendoen and Davis 1995, Peterson and Reich 2001). Additionally, this level of frequent burning has prevented the development of a sapling layer and favored bur oak survival over northern pin oak survival in some landscapes (Peterson and Reich 2001). However, these changes are relatively slow processes. White (1983) found that reversing the trend from oak woodland to oak savanna may take more than 13 years of annual prescribed burning. Similarly, after 25 years of burning, Faber-Langendoen and Davis (1995) found that the effect of different fire return intervals on reducing canopy cover was not particularly strong. Others caution against putting too much emphasis on the fire return interval, and recommend focusing more on fire intensity, behavior and dynamics (Leitner et al. 1991, Faber-Langendoen 1995, Nielsen et al. 2003).

Restoration in Midwest oak savannas may be difficult because many trees (including oak grubs and fire-intolerant species such as green ash, box elder and American elm) have reached a size where they are now fire-resistant and, therefore, unresponsive to prescribe burning attempts (White 1983, Tester 1989, Kline and McClintock 1994, Faber-Langendoen and Davis 1995, Bowles and McBride 1998). In areas where thicker woodland has developed, mechanical thinning may be necessary (Peterson and Reich 2001, Bowles and McBride 1998).

What information is still needed to better implement management plans and what does my study aim to do?

After decades of restoration, land managers are repeatedly confronted with the same questions: What did these savannas really look like before European settlement? What particular snapshot in time do we aim to mimic – pre-fire suppression or pre-European settlement altogether? On what data/scientific studies/historical accounts are we basing our current management plans and objectives? Is our current management plan achieving our set objectives?

The questions above remain mostly unanswered throughout the Midwest, but particularly in Minnesota. Of the limited scientific research completed on Minnesota oak savannas, most derives from Cedar Creek Ecosystem Science Reserve (CCESR), formerly known as Cedar Creek Natural History Area (CCNHA) in south-central, Minnesota. These CCESR studies analyzed the effects of different prescribed burn frequencies on savanna composition and structure. While these studies are, indeed, crucial to performing efficient savanna management, they fail to provide insight into what pre-settlement savannas actually looked like or how they functioned. If the ultimate goal of oak savanna management is to mimic these historic natural processes, it follows that studies revealing pre-settlement structure and dynamics should be a priority. Current management programs base their prescribed burning, mechanical thinning and reseeding programs on data from the few studies that have been performed elsewhere in the

Midwest, other reserves' management programs or on personal recommendations and observations. Oak savanna structure and dynamics are extremely variable, so site-specific case studies performed in, for example, southeastern Wisconsin or northern Missouri likely cannot be reliably extrapolated to Minnesota oak savannas. In fact, I argue that, although fire suppression is overwhelmingly considered to be the biggest threat to Minnesota oak savannas, the implementation of prescribed burning and other forms of management without sufficient knowledge of the local historical disturbance regime may be the biggest threat of all. Alterations from this historical range of variability can have negative effects on biological diversity and stand structure (Morgan et al. 1994). With that in mind, this study explores the following questions pertaining to Minnesota oak savannas:

1) What is the current and historic age structure and forest composition?
2) What is the natural range of variability for disturbances?
3) Are current management objectives within this natural range of variability for disturbances as well as savanna structure and composition?
4) Under current management programs, will the desired "oak savanna" be attained?

It is not the aim of this study to define what a Minnesota oak savanna should look like. On the contrary, this paper characterizes remnants already labeled and managed as oak savannas, and emphasizes the varied nature of the characteristics and histories of Minnesota's remnant oak savannas. Using dendroecological methods, this study draws out patterns within and among four oak savannas in Minnesota, identifying past and present environmental variables that have shaped and continue to change these savannas.

Ultimately, it is hoped that this research will provide a framework and context for land managers attempting to restore oak savanna remnants in Minnesota.

Admittedly, it may seem contradictory to define and lay out boundaries to ecosystems that are dynamic and transitional. These ecosystems are not static and should not be managed in that manner. Accordingly, this study will not merely assess whether current management programs are attaining their goals, which often require the ecosystem to remain at a static state; it will also reinforce the idea that there is a range of variability in disturbance patterns and savanna structure as well as composition.

It is further acknowledged that we, as a society, have fragmented our landscape and altered ecosystem processes to the point that simply re-instating original conditions (assuming original conditions are known) may not result in the desired return to an oak savanna (Mickley 2007). This is a form of hysteresis, where significant changes in ecosystem processes can shift an ecosystem toward a different type (i.e. oak savanna to deciduous woodland forest), preventing a return to the original ecosystem (Mayer and Rietkerk 2004). It is, therefore, prudent to question not only whether the time and money spent on trying to restore "degraded" savannas could be better used for other purposes, but also whether research such as this is needed. These questions were not ignored; they were simply dwarfed by the recognition that despite the complications involved in filtering out all of the compounding perturbations, there is inherent value in furthering our understanding of historical ecology and disturbance variability (Landres et al. 1999, Swetnam et al. 1999, Kipfmueller and Swetnam 2001).

CHAPTER II: Research setting

Description of study sites

Site specific oak savanna case studies are important for capturing detailed interactions and dynamics at a small scale, but they fail to capture the range of variability between and among savannas. Therefore, examining numerous oak savannas across the Minnesota landscape will enable me to better detect and understand oak savanna dynamics.

To analyze Minnesota oak savanna dynamics at a landscape scale, I chose four sites spanning the extent of oak savannas prior to European settlement (Figure 1). From the northwest to the southeast, those sites are: Ordway Prairie (The Nature Conservancy (TNC)), Minnesota Valley National Wildlife Refuge (Fish and Wildlife Service (FWS))/Carver Rapids State Park (Minnesota Department of Natural Resources (MN DNR), Helen Allison Savanna (TNC) and Weaver Dunes (TNC). Each chosen site is listed by its respective agency as an "oak savanna" remnant. While these sites have many similarities, they also have distinct structural, compositional and environmental differences between them. To accurately analyze and identify oak savanna dynamics at a landscape as well as a site-specific scale, I accounted for site differences such as climate, soil type, land-use history and management history. Below is a short description of each site, its ecological setting, and its unique history.

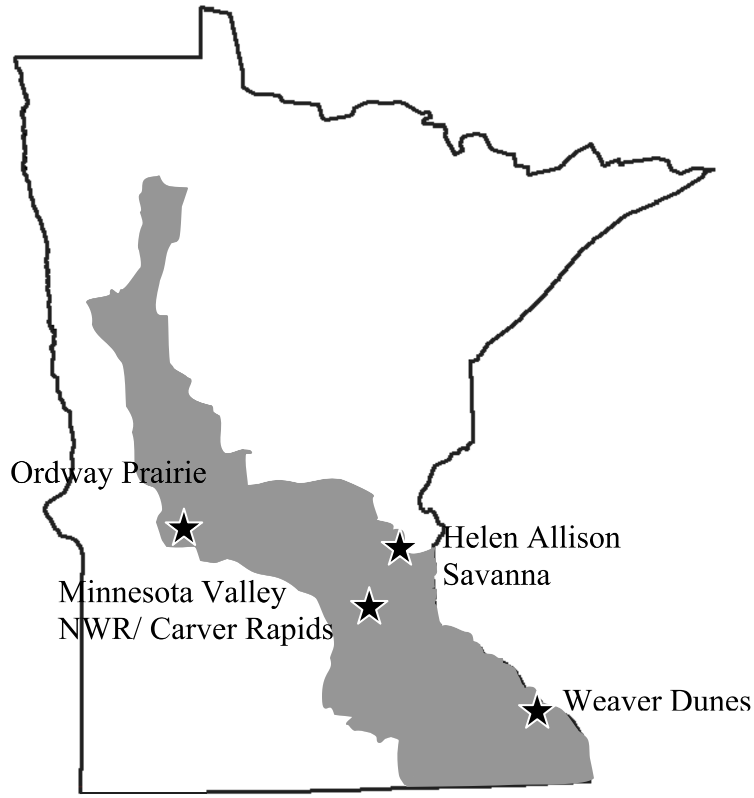


Figure 1. Geographic extent of the prairie-forest border in the state of Minnesota (grey area). Stars indicate locations of oak savannas studied for this research.

Ordway Prairie

Setting and Ecological Description

Located 33 miles south of Alexandria, MN in Pope County, Ordway Prairie is a 581 acre preserve assembled from various land purchases by TNC in the early 1970s. Ordway Prairie's rolling hills display a mosaic of prairie grasslands, woodlands and wetlands (Figure 2). The undulating, patchy landscape gives rise to distinct ecological communities. The northwest corner of the preserve is a dense thicket of relatively evenly spaced bur oaks, uniform in size. On top of Ordway's glacially deposited hills, lies dry prairie with tall grasses, virtually no trees, and, often, an abundance of sumac. Low areas often have standing water and are important habitat for many wetland species. Ordway Prairie has a diversity of nesting birds, butterflies and rare and uncommon plants such as Hill's thistle (*Cirsium hillii*), prairie dropseed (*Sporobolus heterolepis*) purple coneflower (*Echinacea angustifolia*) and various blazing stars (*Liatris* spp.) (The Nature Conservancy 2000). The predominant tree is bur oak.

Ordway Prairie consists mostly of deep, well-drained Entisols that have developed in calcareous loam till (Diedrick 1972). The soil organic matter content is relatively low, the water capacity is high and permeability is moderate. Erosion is high and fertility is low, so the soil is poorly suited for crops. In some parts of the prairie, shallow, excessively drained soils developed in loamy outwash material and in underlying calcareous sand and gravel. In these soils, the organic matter content is medium, available water capacity and fertility are very low, and water erosion is high. Based on instrumental climate data from 1886-2006, the average annual precipitation for the area immediately around Ordway Prairie is 24.1 cm, the average maximum July temperature is 81.8 degrees F and the average minimum January temperature is -1.3 degrees F (United States Historical Climatology Network).

Figure 2: Ordway Prairie from north end of preserve, looking south, June 2007.

Land-use history

European settlers arrived in the area in 1861, but were quickly driven out by Sioux tribes in the uprisings of 1862. After the uprisings (around 1865), Fort Lake Johanna was built at the north end of the preserve. Old wagon trails crossing the preserve are still viable. The preserve is a collection of many tracts of land (each tract was owned by a different family). It is reported that ten farmers once grazed cattle communally in the area and, at night, each head cow would lead the rest of the herd back to his/her respective farm (The Nature Conservancy 2000). Cattle grazed the Ordway Prairie area until the 1960s (Jared Culbertson, pers. comm.).

Current Management

The preserve is burned periodically to control invasive natives such as sumac (*Rhus glabra*) and aspen (*Populus tremuloides*) that have increased in density and extent, as well as non-natives such as Kentucky bluegrass (*Poa pratensis*). Cutting and girdling of aspen and sumac is also common to further protect areas from woody encroachment. No oaks have been cut on the preserve and the area has not been grazed since the 1960s. Current management is also focused on eradicating European buckthorn (*Rhamnus cathartica*).

Helen Allison Savanna

Setting and Ecological Description

Helen Allison Savanna is an 86 acre tract of land located just southwest of East Bethel, Minnesota in Anoka County. The preserve is directly across the road from Cedar Creek Ecosystem Science Reserve (CCESR) a 5,460-acre research station owned and managed by the University of Minnesota. CCESR has been the site of many research studies on oak savanna dynamics and the effects of different prescribed burning frequencies on savanna composition and structure.

Helen Allison is considered to be a very high quality oak savanna remnant (The Nature Conservancy 2000). Despite its small size, the preserve contains areas characterized as oak savanna (Figure 3), oak woodland, dune blowouts, and wet meadows in a beautiful patchy mosaic. Soils are fine sands, low in organic matter and nutrient-poor and low water holding capacity (Chamberlain 1977). The predominant tree species are bur oak and northern pin oak, with occasional clusters of green ash (*Fraxinus pennsylvanica*). Based on instrumental climate data from 1891-2006, the average annual precipitation for Helen Allison is 27.6 cm, the average maximum July temperature is 83.2 degrees F and the average minimum January temperature is 4.4 degrees F (United States Historical Climatology Network).

Figure 3: Helen Allison Savanna in July 2007.

Land-use history

Swedish immigrants arrived in the area around 1864 and cleared most of the land for farming. In the early 1900s, the eastern two thirds of Helen Allison was used for grazing horses, while the western third was planted with corn (The Nature Conservancy 2000). TNC acquired the land in 1960 and began management in 1962.

Previous Studies

Although numerous research studies at CCESR have revealed important disturbance-vegetation relationships, few studies have investigated savanna structure and dynamics at Helen Allison. Faber-Langendoen and Davis (1995) studied the effects of fire frequency on tree canopy cover in Helen Allison and found that the age classes of the two oaks species, bur and northern pin, barely overlapped. Bur oaks ranged in age from 20-200 years old, while most northern pin oaks were less than 30 years old. Although the ages of bur oaks spanned two centuries, they found surprisingly fewer bur oaks in the younger age classes when compared with numbers of bur oaks in older age classes as well as the number of northern pin oaks in younger age classes. They conjectured that bur oak recruitment was sporadic over the last 150 years. Although northern pin oaks may have been present in 1850, few or none survived. Ziegler et al. (2008) analyzed the relationship between climate and tree establishment and noted that bur oak recruitment was sporadic, and hypothesized that oaks at Helen Allison recruited during climatically dry periods.

Current management

In 1962, Helen Allison became the first site where TNC introduced prescribed burning. Additionally, the western end of the savanna (the section that had previously been planted with corn) was hand seeded with prairie species in the 1960s and 1970s.

The Nature Conservancy still frequently performs prescribed burns on the preserve, but no mechanical thinning has ever been implemented.

Weaver Dunes

Setting and Ecological Description

Located on the banks of the Mississippi River in the southeastern portion of Wabasha County, Weaver Dunes is a 592 acre tract of land acquired by The Nature Conservancy in 1980. The preserve lies on a sand terrace formed by deposits of glacial meltwaters. Unlike the rest of the state, southeastern MN, known also as the "driftless area", has relatively dramatic topographic relief because it was untouched by glaciers in the last ice age.

The soil at Weaver Dunes consists mostly of loose, sandy material blown about by the wind, called Dune Land (Harms 1965). The soils are well-drained to excessively drained with low fertility (Neid 1999). Based on instrumental climate data from 1903-2006, the average annual precipitation for Weaver Dunes is 29.2 cm, the average maximum July temperature is 82.2 degrees F and the average minimum January temperature is 1.7 degrees F (United States Historical Climatology Network).

Weaver Dunes' landscape is heterogeneous, containing areas classified as Midwest Dry-Mesic Sand Prairie, Dry Oak Savanna as well as Oak-Mixed Deciduous Forest (Minnesota Department of Natural Resources 2005). The bulk of the preserve is sand prairie, with oak savanna remnants located along the edges (Figure 4). As the name implies, Weaver Dunes' sand prairie contains numerous dunes and blowouts. Northern pin oak clearly dominates the forest/savanna canopy, but green ash (*Fraxinus* *pennsylvanica*), quaking aspen (*Populus tremuloides*) and American plum (*Prunus americana*) trees are very common and bur oak is occasionally present. Though many jack pine and red pine (originally planted as windbreaks) have been removed, some persist.

Previous Studies

Soon after TNC purchased the land, Susan M. Galatowitsch created an extensive floristic list and land-use history for Weaver Dunes for completion of her Master's thesis. In 1982 and 1983, she established permanent vegetation monitoring plots and assessed the effects of land-use on the vegetation (Galatowitsch 1984). Galatowitsch (1984) found that Weaver Dunes has a diverse flora of 331 species of vascular plants and that grazing and cultivation have had the greatest influence on vegetation composition. In 1999, Stephanie Neid resampled many of Galatowitsch's vegetation plots and found that native sand prairie vegetation has successfully rebounded since the onset of management in 1983 (Neid 1999).

Land-use history

While Weaver Dunes is not thought to have been grazed, cultivated or burned extensively by Native Americans, Dakota Indians did hunt on the land (buffalo and elk were reported to have been feeding nearby) (Galatowitsch 1984). Irish settlers arrived around 1855 and used the land for hunting and fishing as well as farming. Records show that melon, corn, oats, rye, hay, buckwheat and soybeans were grown on the western half of the preserve between 1856 and 1940 (Galatowitsch 1984). However, most of the land (including the entire eastern half) was used for grazing cows, horse and sheep. After the 1940s, the predominant crops were melon, corn and squash, while the predominant grazers were cows and horses. Galatowitsch (1984) noted that the Weaver Dunes area saw a myriad of grazing intensities. Some areas were heavily grazed while others were only lightly grazed. The eastern oak savanna strip was moderately grazed while the western oak savanna cluster was lightly grazed and parts of it farmed for corn. In both sections, grazing ceased in 1981 and farming ceased in 1982. Jack pine and red pine were planted as windbreaks between 1950 and 1970 to combat soil erosion caused by farming and grazing.

The fire history of the area is relatively unknown. A large part of the land burned in the spring of 1954 (the fire was thought to have been started by sparks from a passing train). Local farmers report other, less extensive fires in 1928, 1942 and 1966 (Galatowitsch 1984).

Current Management

The Nature Conservancy began prescribed burns in 1986 and has been burning sub-sections of the area approximately every 4 years since. Most of the non-native pines have been removed as well as junipers and other woody species that were originally planted as wind breaks. In the late 1990s to 2003, Anna Travaglione coordinated efforts to seed prairie species on the preserve. A Conservation Action Plan was developed for TNC's management of Weaver Dunes in the early 2000s. The plan identified the operation of dams or reservoirs, fire suppression, home development, invasive alien species and channelization of the Zumbro river as the highest threats to the integrity of Weaver Dunes.

Figure 4: A cluster of northern pin oak trees at Weaver Dunes in August 2007.

Minnesota Valley NWR and Carver Rapids SP

Setting and ecological description

Minnesota Valley's Louisville Swamp unit is a 2,600 acre area acquired by the United States Fish and Wildlife Service (USFWS) around 1970 (Figure 5). It is located on the east bank of the Minnesota River, just north of the city of Jordan. The Carver

Rapids State Wayside is a 300 acre park acquired by the Minnesota Department of Natural Resources in the early 1970's, from Northern States Power Company (Figure 6).

USFWS staff members estimate that Louisville Swamp floods three out of every five years, and trail closures are common. A water control structure helps regulate the outflow into Sand Creek, a short course that flows into the Minnesota River. The unit also includes dry lands above the bluffs which feature old agricultural fields, prairie, and oak savanna.

Soils in the Louisville swamp unit are characterized in as "stony land" and "silty-loamy deposits" with shallow soil and frequently exposed bedrock (Harms 1959). The soil at Carver Rapids is similar, but characterized as "sandstone outcrops" as well as "stony land" (Harms 1959). Here, there is 6 inches or less of soil material with frequently exposed bedrock. In general, the soils are well-drained to excessively drained. Based on instrumental climate data from 1891-2006, the average annual precipitation for the area immediately around MN Valley/Carver Rapids is 27.6 cm, the average maximum July temperature is 83.2 degrees F and the average minimum January temperature is 4.4 degrees F (United States Historical Climatology Network).

Land-use history

Before European settlement, there was a Wahpeton Sioux village called Inyan Ceyaka Otonwe, or Little Rapids, on the east bank of the Minnesota River near Louisville Swamp. Jean-Baptiste Faribault built a fur trading post near the village in 1802 and lived here for seven years. While the exact site of the village and trading post is unknown, the remains of two historic farmsteads are still visible; the Ehmiller Farmstead is in ruins, but the Jabs Farmstead is still standing and two buildings have been restored. The Jabs barn was built in 1880 by Robert and Anna Riedel. Frederick Jabs bought the 379 acre (1.5 km^2) farmstead in 1905 and his family lived there as subsistence farmers until 1952 (http://www.stateparks.com/minnesota_valley.html).

Land-use on the Carver Rapids unit was limited to cutting hay, grazing and some limited crop farming (Mark Cleveland, pers. comm.). Woodcutting for local use was also likely on both the Carver Rapids unit as well as the Louisville Swamp unit. Minnesota State Parks has no records of fire activity before it acquired the property.

Current management

Minnesota Valley NWR began prescribed burning the Louisville Swamp unit in 1984, whereas managers at Carver Rapids began burning in 1979. Although I had access to written prescribed burn records for Louisville Swamp, only a verbal account was available for Carver Rapids. The verbal record was provided by former park manager, Frank Knoke, former Minnesota Valley State Recreation Manager, Chuck Kartak and current Central Region Rescource Specialist for the MNDNR, Mark Cleveland.

In addition to prescribed burning, parts of both Louisville Swamp and Carver Rapids have been mechanically thinned with a large tree feller called a hydro axe (at least three separate hydroaxe removals occurred at Louisville swamp and at least two separate hydroaxe removals occurred at Carver Rapids). The purpose of the tree removal was to thin the overgrown area and open the canopy. Heavy fuels (many dead, downed trees and branches) remained through 2000 in the hydro axed area of Carver Rapids. Consequently, a prescribed fire under droughty conditions was more intense than anticipated and resulted in high mortality of bur oaks (Pers. Comm. Mark Cleveland). Additionally, many areas in Carver Rapids were treated extensively with herbicide to deter sumac growth (Mark Cleveland, pers. comm.).

Figure 5: Minnesota Valley Louisville Swamp unit, August 2007. This site has been hyroaxed.

Figure 6: Carver Rapids State Park, August 2007.

CHAPTER III: Forest structure, age structure and fire history of remnant oak savannas in Minnesota

Introduction

Specifying the structure, composition and disturbance regime of oak savannas, the dynamic zone between the treeless prairies to the west and the dense deciduous forest to the east, remains elusive to scientists and land managers. The criteria for classification of Midwestern oak savannas vary tremendously, however, embedded in all of them is the notion that the oak savanna is a transitional ecosystem, maintained by periodic fire.

Over the past 150 years, numerous anthropogenic disturbances have adversely impacted Midwestern oak savannas. After years of fire suppression, many savannas have advanced successionally to closed-canopy oak and mixed-species forests (White 1983, Faber-Langendoen and Tester 1993, Bowles and McBride 1998). Grazing and agriculture have altered vegetation composition and regeneration patterns (Tilman 1987, Pogue and Schnell 2001), non-native species are replacing native species and threatening to alter fire-vegetation patterns (Miesel et al. 2002, Brooks et al. 2004) and, most noticeably, fast-paced development and other forms of land fragmentation have closed in on the small remaining savannas. With less than 0.02 percent of pre-settlement oak savannas left in the Midwest, we risk losing this ecosystem completely (Nuzzo 1986).

Numerous restoration techniques using prescribed burning, mechanical thinning and native seeding, or combinations thereof, have attempted to restore “degraded” savanna remnants (i.e., reduce canopy cover and non-oak species and increase prairie species). Yet, after decades of restoration, land managers are repeatedly confronted with the same questions: What did these savannas look like before European settlement? What particular snapshot in time do we aim to mimic – pre-fire suppression or pre-European settlement altogether? On what data/scientific studies/historical accounts are we basing our current management plans and objectives? Is our current management plan achieving our set objectives?

These questions remain mostly unanswered throughout the Midwest, but particularly in Minnesota. Current management programs base their prescribed burning, mechanical thinning and reseeding programs on data from the few studies that have been performed elsewhere in the Midwest, other reserves' management programs or on personal recommendations and observations. Oak savanna structure and dynamics are extremely variable, so site-specific case studies performed in, for example, southeastern Wisconsin or northern Missouri likely cannot be reliably extrapolated to Minnesota oak savannas. In fact, I argue that, although fire suppression is overwhelmingly considered to be the biggest threat to Minnesota oak savannas, the implementation of prescribed burning and other forms of management without sufficient knowledge of the local historical disturbance regime may be the biggest threat of all. Alterations from this historical range of variability can have negative effects on biological diversity and stand structure (Morgan et al. 1994). With that in mind, this study explores the following questions pertaining to Minnesota oak savannas:

1) What is the current and historic age structure and forest composition?
2) What is the natural range of variability for disturbances?
3) Are current management objectives within this natural range of variability for disturbances as well as savanna structure and composition?

4) Under current management programs, will the desired “oak savanna” be attained?

It is not the aim of this study to define what a Minnesota oak savanna should look like. On the contrary, this paper characterizes remnants already labeled and managed as oak savannas, and emphasizes the varied nature of the characteristics and histories of Minnesota’s remnant oak savannas. Using dendroecological methods, this study draws out patterns within and among four oak savannas in Minnesota, identifying past and present environmental variables that have shaped and continue to change these savannas. Ultimately, it is hoped that this research will provide a framework and context for land managers attempting to restore oak savanna remnants in Minnesota.

Study sites

To analyze Minnesota oak savanna dynamics at a landscape scale, I chose four sites spanning the extent of pre-settlement oak savannas (Figure 7). Each chosen site is listed by its respective agency as an “oak savanna” remnant. While these sites have many similarities, they also have distinct structural, compositional and environmental differences between them (Table 1).

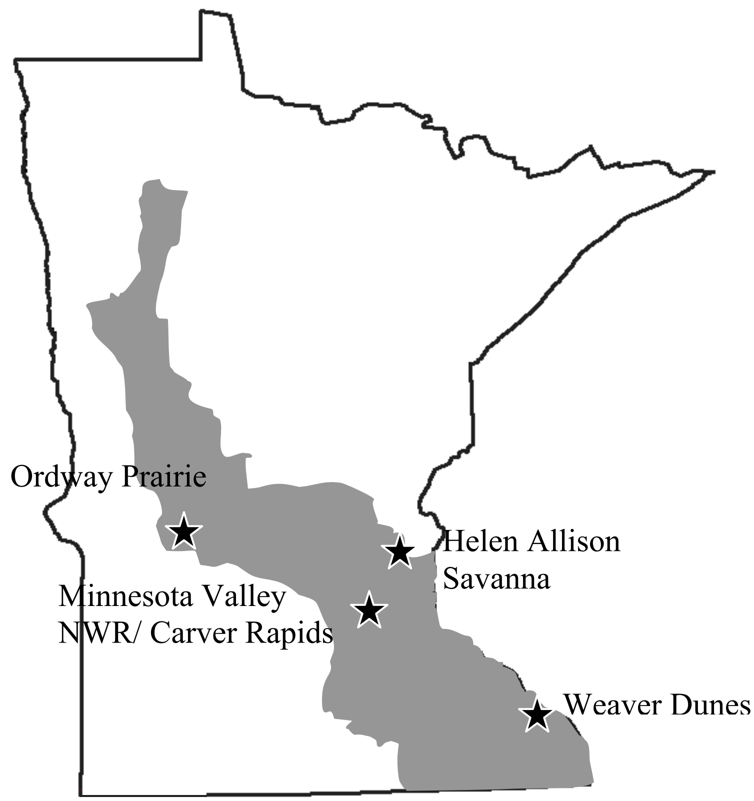


Figure 7. Geographic extent of the prairie-forest border in the state of Minnesota (grey area). Stars indicate locations of oak savannas studied for this research.

Table 1: Summary of study site characteristics.

	Ordway Prairie	**Helen Allison**	**Weaver Dunes**	**MN Valley/C. Rapids**
Agency	TNC	TNC	TNC	USFWS/MN DNR
Size	581 acres	86 acres	592 acres	2,600/300 acres
settlement	mid-1860s	1864	1855	1802
Known historical land use	Cattle grazing	Horse grazing, farming on W tract	Cattle and horse grazing, farming	Farming, cattle grazing
Avg. annual rainfall	24.1 cm	27.6 cm	29.2 cm	27.6 cm
Avg. max. July temp.	81.8°F	83.2°F	82.2°F	83.2°F
Avg. min. Jan. temp.	-1.3°F	4.4°F	1.7°F	4.4°F
Soil	Entisol, low-med. soil organic matter, moderate permeability	Entisol, low soil organic matter, high permeability	Dune land, low soil organic matter, high permeability	Stony land, loamy in some parts, low-med. soil organic matter, high permeability
Yr purchased by agency	1970s	1960	1980	1970s / 1970s
Yr. mgmt began	1970s	1962	1980	1984 / 1979
Current and past Management	prescribed burning, cutting of aspen and sumac, buckthorn eradicatrion	prescribed burning, hand-seeded with prairie species	prescribed burning, removal of non-native pines, junipers and other non-native woody species, hand-seedling of prairie species	prescribed burning, hydro-axed, sumac removal in Carver Rapids

Methods

Fieldwork

Forest structure analysis:

Aerial photographs of each site were obtained from respective agencies. Using Global Positioning System (GPS) software, plots spaced 200 meters apart were systematically gridded across the full extent of oak savanna occurrences at each site (Figures 8, 9, 10 and 11). Given the size of each site, sampling at each plot was unfeasible. I initially selected a subset of plots falling within areas specifically labeled on maps or verbally identified by land stewards as "oak savanna" and/or occurred in areas with established prescribed burning histories. Plot selection was reassessed once in the field. Fieldwork was performed during summer of 2007.

In all, sixty-five circular plots (one-tenth hectare with radius of 17.8 m) were sampled – 12 at Ordway, 9 at Helen Allison, 16 at Weaver Dunes and 26 at Minnesota Valley NWR/Carver Rapids SP. Within each plot, we tallied all trees, recorded their species, measured their diameter-at-breast-height (dbh), and noted any scarring or other markings on the tree bole. Trees under 5cm dbh and over 1.5m in height were considered saplings and were counted throughout the plot (and species recorded). Woody species smaller than sapling-size were considered seedlings. Due to the difficulty of counting *all* seedlings in the entire plot, a quadrant "pie-slice" originating from the center of the plot was selected in a random direaction. The quarter-plot pie-slice subsection had a radius of 5 m and extended outward from the center of the plot. This small sample was scaled up (by multiplying by 51) to account for the entire plot. Throughout the entirety of each plot, all snags (dead standing trees), fallen dead trees and stumps were noted.

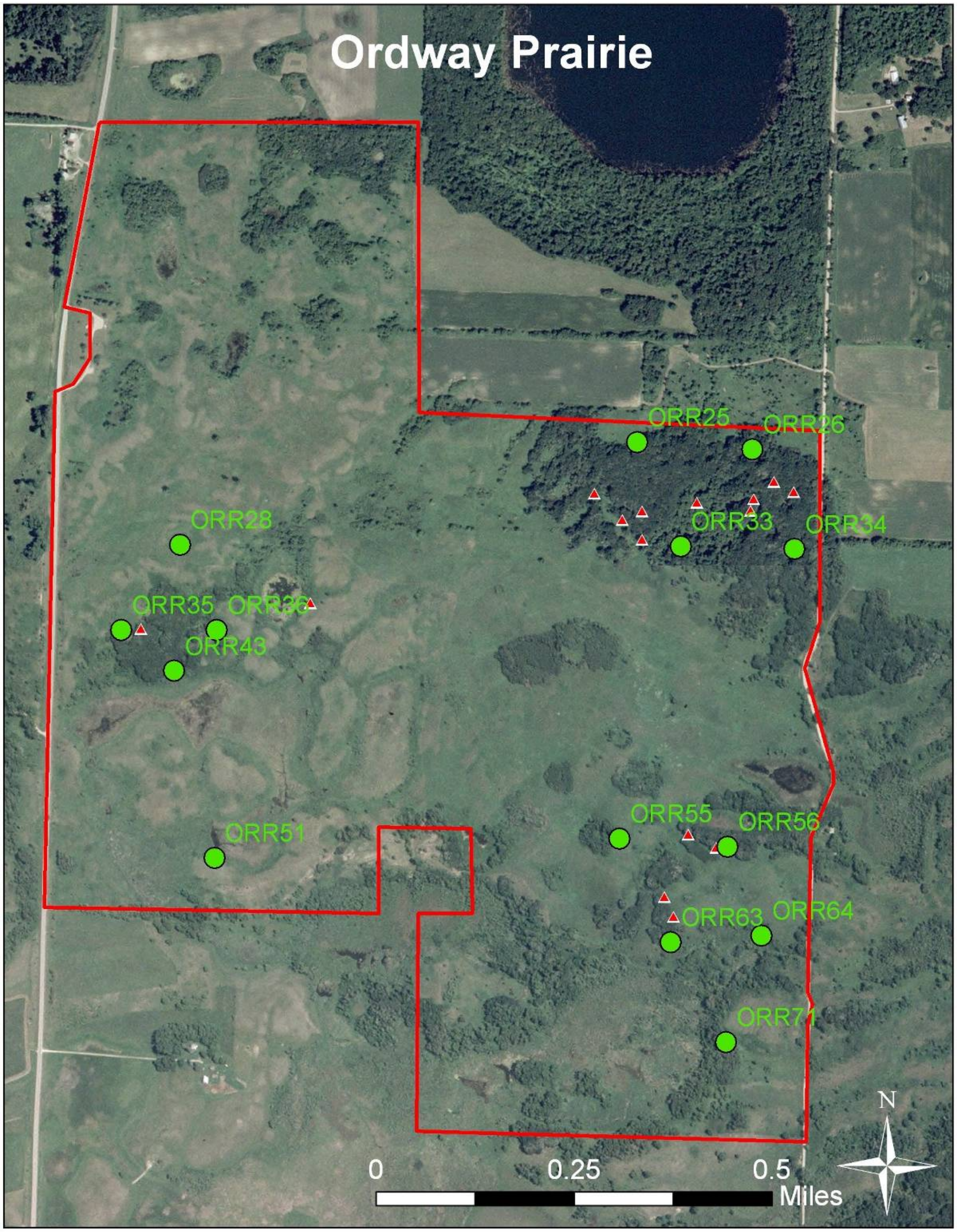


Figure 8: Aerial map of Ordway Prairie in Pope County. Red boundary line marks borders of Ordway Prairie owned by TNC. Green circles indicate plot locations and red triangles indicate location of trees sampled for fire scars. Source of photo: The Nature Conservancy.

Figure 9: Aerial map of Helen Allison Savanna in Anoka County. Red boundary line marks borders of Helen Allison owned by TNC. Green circles indicate plot locations and red triangles indicate location of trees sampled for fire scars. Source of photo: The Nature Conservancy.

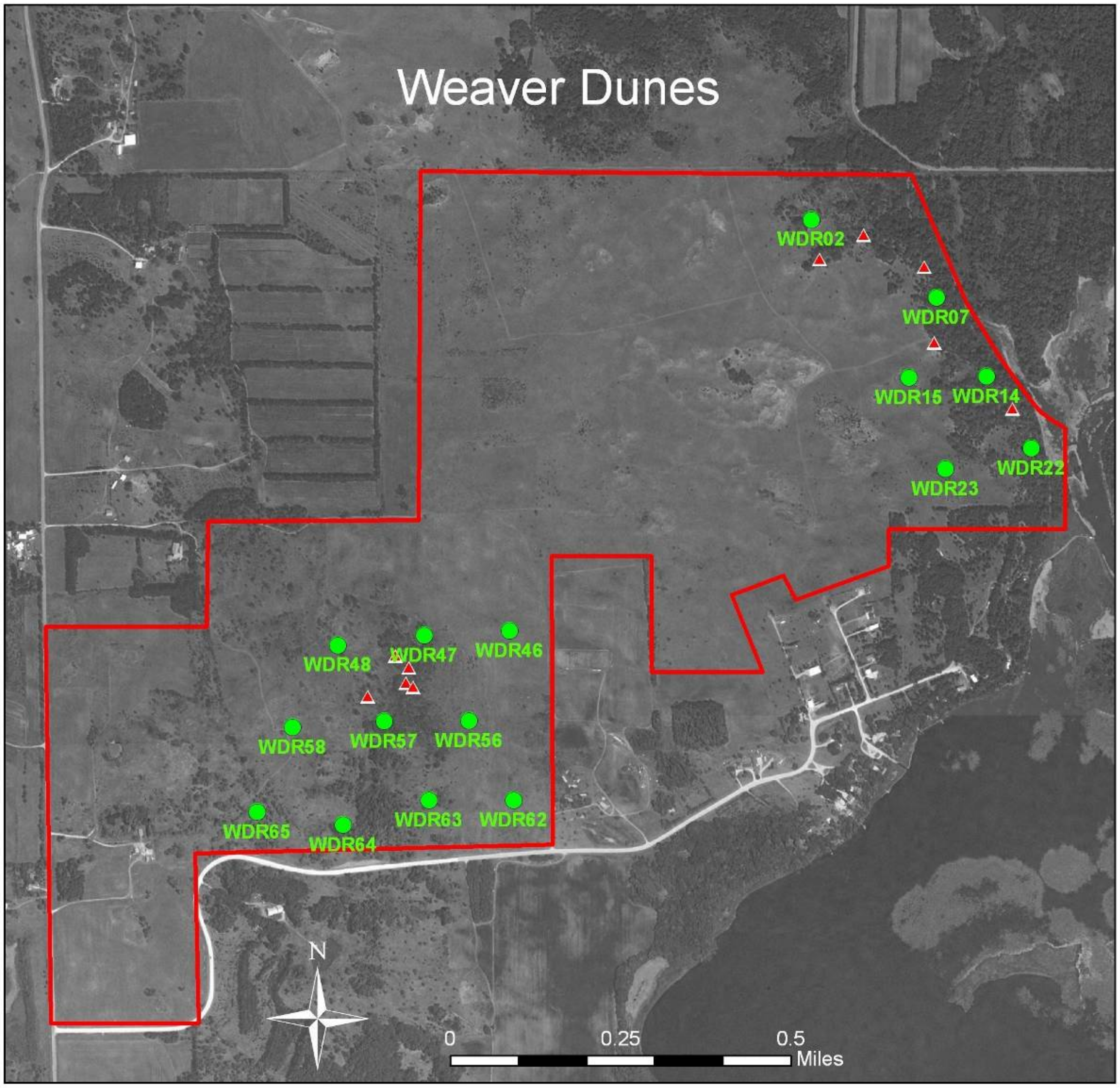


Figure 10: Aerial map of Weaver Dunes in Wabasha County. Red boundary line marks borders of Weaver Dunes owned by TNC. Green circles indicate plot locations and red triangles indicate location of trees sampled for fire scars. Source of photo: The Nature Conservancy.

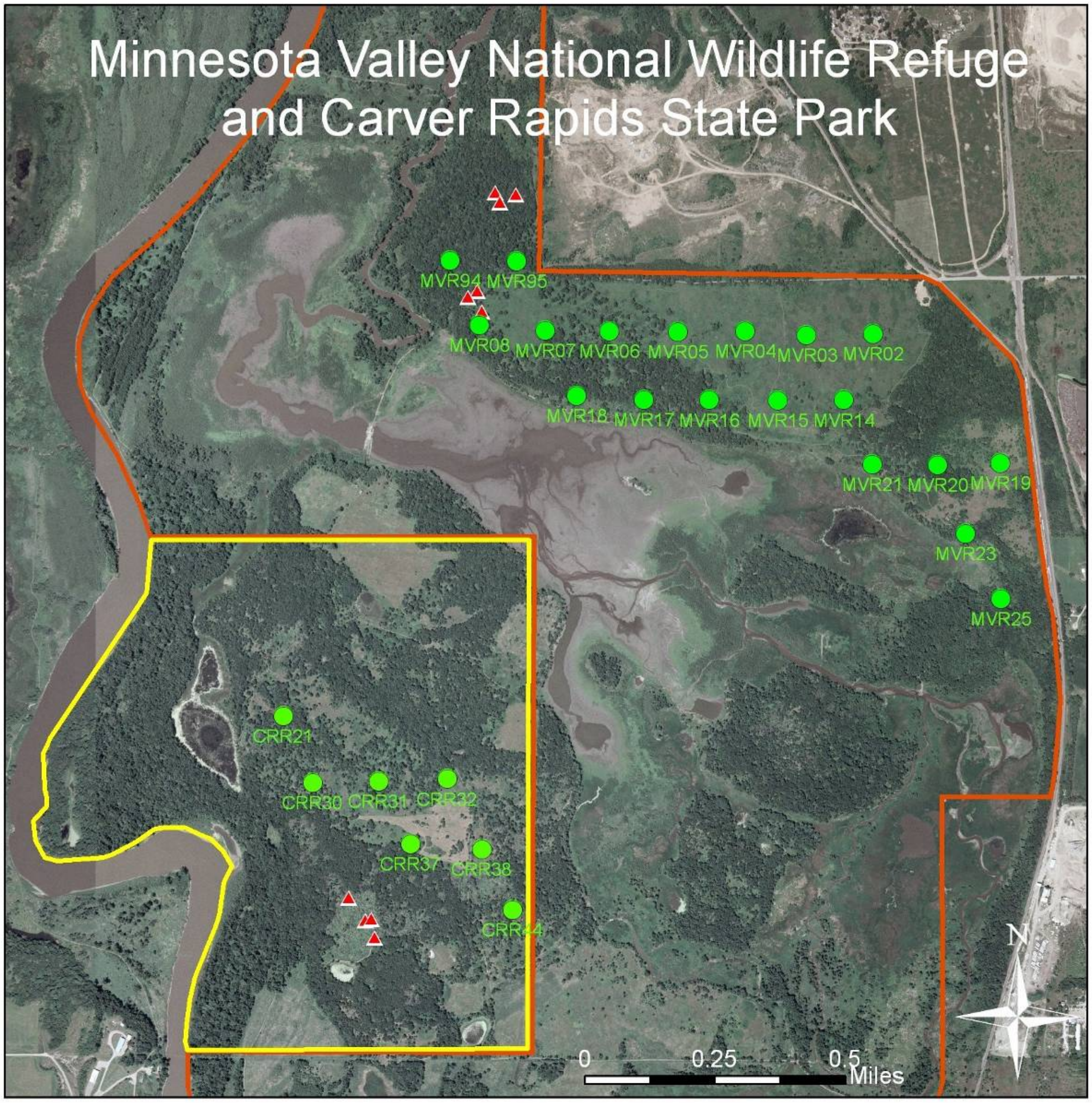


Figure 11: Aerial map of Minnesota Valley NWR and Carver Rapids SP in Scott County. Red boundary line marks borders of Minnesota Valley NWR (owned by the US Fish and Wildlife Service) and the yellow boundary line marks borders of Carver Rapids SP (owned by the MN Dept. of Natural Resources). Green circles indicate plot locations and red triangles indicate location of trees sampled for fire scars. Source of photo: Minnesota Valley National Wildlife Refuge.

All herbaceous species were recorded in three 1m x 1m-squares located at the north, center and south end of each plot. Within each square, absolute percent cover was recorded for each herbaceous species. Additionally, environmental conditions including canopy height, light penetration and canopy cover were assessed at each square. Although these environmental variables were measured solely using ocular estimate techniques, the author performed the ranking each time for consistency. Each variable was divided into three categories: Canopy height: (<3m, 3m-6m, >6m); light penetration: (<15%, 15-60%, >60%); canopy cover: (0-10%, 10-50%, over 50%). In all, 200 1m x 1m square plots were assessed for herbaceous species composition – 42 at Ordway, 27 at Helen Allison, 48 at Weaver Dunes and 83 at Minnesota Valley NWR/Carver Rapids State Park. Additional plots were occasionally added in areas with no trees for the purpose of comparing species composition with growing conditions.

Public Land Survey (PLS) data were also collected from the Minnesota Historical Society with help from Dr. Rod Squires from the University of Minnesota. Public Land Surveys were performed prior to European settlement in western territories to aid in the sale of public lands. Surveyors noted specific characteristics regarding potential land-use in each area: land surface, land type, timber, soil, roads, trails, etc. (see Almendinger 1996 for more detailed information on the surveyor's instructions). Fortunately, survey records and notes from these surveys are available to the general public and can provide us with valuable ecological information (Bourdo 1956, Almendinger 1996).

Age-structure analysis:

To reconstruct the age structure of each plot, increment cores (pencil-sized samples displaying the rings of a tree's radius) were extracted. In many plots, all trees were cored. However, in dense plots (usually over 40 trees per 0.1 hectare plot) we constructed a smaller circular mini-plot with a radius of 12 m (as opposed to the original radius of 17.8 m). In most cases, only one core was extracted from each tree. However, if it was clear that the visible ring curvature in the core could not be used to estimate the center of the tree, a second core was taken. Cores were taken at 30 cm height. Trees were often rotten at the base and, in those cases, the sample was taken higher on the trees' bole, and the coring height was recorded. To correct for the number of rings missed by coring above the root collar (Gutsell and Johnson 2002), 20-30 saplings of different species at each site were cut and brought back to the lab for further analysis of age at the base versus age at coring height.

Fire history analysis:

To assess fire history, 57 samples were collected from both living and dead oak trees (16 from Ordway, 18 from Helen Allison, 13 from Weaver Dunes and 10 from Minnesota Valley NWR/Carver Rapids SP). Oaks were the only trees used for the fire history analysis because they are long-lived and widely distributed throughout the study areas. Fire history trees were purposefully selected to minimize the number of samples required and maximize the usefulness of information (Baker and Ehle 2001). We first and foremost targeted oaks that exhibited "old tree" characteristics (long, gnarled, low branches) that potentially had fire scars extending as far back in time as possible.

Secondly, we selected trees with visible fire scars. Trees that have scarred once tend to scar again in the same place (these trees are often called "recorders") (Romme 1980). However, as oaks increase in age and bark thickness, they are less likely to scar from a fire (Guyette and Stambaugh 2004). Oaks have thick, fire-resistant bark, as well as the ability to compartmentalize their wounds and heal quickly (Shigo 1984, Smith and Sutherland 1999). For these reasons, it is unlikely to find old oak trees with visible fire scars. Therefore, we sampled both apparently old oaks with *no* visible fire scars, and younger trees with visible scars to increase the odds of finding inner fire scars. Also, sampling both young and old trees helps minimize possible age-related scarring biases (Guyette and Cutter 1991, Guyette et al. 2003)

In cases where the oak showed external fire scar evidence (aka "catface"), a pie-shaped wedge was removed from the side of the tree displaying the scar (Figure 12). The pie-shaped wedges ranged in thickness from 1 to 3 inches and removed approximately one-quarter of the basal area of the tree. One study has shown that wedge-removal does not significantly shorten a tree's lifespan (Heyerdahl and McKay 2002).

Figure 12: Charred bur oak at MN Valley with a fire scar wedge removed from its base.

In cases for which the tree displayed characteristics of an older tree, but no fire scar was visible, it was necessary to cut the entire tree because the location of the potential scar(s) inside the tree could not be accurately predicted. Studies in post oak savannas in Missouri (Paulsell 1957, Guyette and Cutter 1991) as well as an in-depth study on fire scar formation (Gutsell and Johnson 1996) found that trees tend to scar on the uphill or leeward side of the tree. Of the few studies looking at scarring in oak-dominated systems however, one found that oaks actually tend to scar on the downhill side of the tree (Smith and Sutherland 1999). Additionally, my study sites have relatively gentle topography, making the direction of fire and scarring even more unpredictable.

To locate fire scars on older but apparently sound trees, many cuts were made at different levels on the trunk. On some occasions, two cross-sections taken at different levels on the tree bole were brought back to the lab for analysis. In most cases, the cross-sections were taken at approximately 10 cm from the ground, or if scars were visible, the cut always bisected the scar. In all cases, wedges and cross-sections were wrapped in plastic-wrap in the field to ensure that all pieces arrived back at the lab intact.

Laboratory Processing

All cores were air-dried for 1 month before being mounted onto small blocks of wood and then sanded in the woodshop. All cores were sanded with progressively finer grits (100, 200 and 400 ANSI as well as microfinishing film) to ensure ring visibility. Each core was crossdated, a process by which growth patterns from many trees are matched and each ring is assigned exact calendar date (Stokes and Smiley 1996). Ten of the oldest cores at each site were skeleton plotted and a master chronology was created for each site. In addition to skeleton plotting, I kept tallies of narrow ring years for each site to further verify narrow years and accurate tree dating.

All saplings collected for the age-to-coring height correction were marked at 0cm, 30cm, 50cm and 100cm, and 1-inch thick cross-sections at these heights were sanded. I then dated each small cross-section to determine how long the sapling took to reach that height.

Similar to the tree cores and sapling cross-sections, all cross-sections sampled for fire scar analysys were sanded with progressively finer grits (100, 200 and 400 ANSI) to ensure not only ring visibility, but also for finding small, inner fire scars and assigning accurate calendar dates to them. A tree can scar for many reasons (e.g., another tree falling on it, frost cracks, animals' antlers), so to ensure that the inner scars I was finding were actually caused by fire and not from other factors, I compared them to known fire scars caused by prescribed burns. Wedges and cross-sections were analyzed under a microscope, and crossdated (Stokes and Smiley 1996). Due to excessive rot in some of the cross-sections, only 42 of the 57 fire scar samples were used in the analysis (16 from Ordway, 11 from Helen Allison, 8 from Weaver Dunes and 7 from Minnesota Valley NWR/Carver Rapids State Park). Determining scar seasonality was difficult. To calibrate my assessment of fire seasonality, I tried to determine the season that scars from known prescribed fires occurred before reading the records to find out the actual season the burns occurred in.

Unknown herbaceous species were brought to the University of Minnesota Herbarium for correct identification.

Data Analysis

No age-to-coring height corrections were made to tree ages because results from sapling cross-sections revealed no significant difference between the age at the root collar and the age at 30 cm (Appendix V-1). Tree ages were binned to decades for the purposes of visually analyzing age distributions.

Age of establishment of each oak tree (separated by species) was plotted against the dbh to examine the age-size relationship. Only trees that established before 1980 were used for correlation calculations because extremely young (and small) trees would skew results. I used Pearson's correlation coefficient in Excel to calculate r and the student's t-test to calculate a t-value and test for significance.

Determining the seasonality of fire scars in my samples was unreliable and inaccurate. I tested myself by trying to determine the seasonality of known prescribed burn scars and determined that the data were not accurate enough to report.

I used FHX2 software (Grissino-Mayer 1995), to develop a fire chronology for my four sites based on fire scars found in my fire samples. Herbaceous species were compiled and data were partially analyzed. However, no results are presented in this paper. The herbaceous species recorded are listed in Appendix V-1 and this data will be used in future studies.

Results

Table 2: Summary of sample sizes at each site.

	Ordway Prairie	Helen Allison	Weaver Dunes	MN Valley/ C. Rapids	Total
Size of preserve	**581 acres**	**86 acres**	**592 acres**	**2,600/300 acres**	**4159 acres**
# of plots	**12**	**9**	**16**	**26**	**63**
# trees cored	**165**	**175**	**168**	**338**	**846**
# samples used in fire history	**16**	**11**	**8**	**7**	**42**

Forest Structure

Ordway Prairie

In 12 plots, Ordway Prairie contained 12 different tree species, but overall was dominated by bur oak (QUMA), the only species of oak at the site (Figure 13). Green ash (*Fraxinus pennsylvanica* - FRPE) and box elder (*Acer negundo* - ACNE) occurred frequently at five plots and at six plots respectively. Quaking aspen grew in only two plots, but had a total stem density, basal area and importance value far exceeding all other species except bur oak (Appendix I-1). The total basal area (in m^2/ 0.1 hectare) of each forest structure plot ranged from 7.9 at OR36 to 35.1 at OR34 (Appendix I-2). Plots clearly dominated by bur oak (OR26, OR34, OR35, OR36, OR43, OR56 and OR63) had the lowest canopy species richness (Figure 13) and the largest basal areas (Figure 14).

A high richness of seedlings and saplings occurred throughout the site (Figures 15 and 16), very few of which were bur oak. In fact, we detected only two oak seedlings (at OR36 and OR55) and 26 oak saplings (at OR35 and OR36) in the entire area sampled. Plot OR36 contained over 2,500 sumac seedlings but, comparatively few sumac saplings while OR64 contained over 130 sumac saplings compared to relatively few sumac seedlings (Figures 15 and 16). OR26 is the only site with a considerable amount of hazel seedlings or saplings. Hazel grew at only two plots, OR25 and OR26, and in both sites there was a large number of hazel seedlings relative to hazel saplings (Figures 15 and 16). Plot OR34 had a notable number of prickly ash seedlings and saplings.

In 35 years of prescribed burning, all sites have been burned at least twice and at most eight times with the majority (approximately 70%) of fires set in the spring (Appendix I-4). The average mean fire return interval (MFI) was 6.9 years with a few sites experiencing an MFI as low as 3.75 years and one site as high as 29 years (Appendix I-4). The percentage of fire-scarred trees (visibly open scars only) ranged from zero (OR35, OR63 and OR64) to 70% (OR56) with an average of 11.5% (Appendix I-3). Mean number of scarred trees did not increase with tree density. Counter-intuitively, the number of trees with charred bark was often negatively associated with the number of trees scarred at each plot (Appendix I-3). So, the more charred bark in the plot, the fewer open fire scars found in the plot (Appendix I-3).

Plots with a predominant scarring direction had no discernible pattern. Scars were on the uphill side of the majority of trees for four plots, the downhill side for one plot, and the side-slope side for two plots (Appendix I-3). The plots with the highest percentage of "oak multiples" (a.k.a "grubs" or multiple stems caused by repeated killing and resprouting) were OR63 with 78%, OR34 with 58%, OR35 with 52% and OR43 with 48% of its bur oak trees as part of a multiple tree (Appendix I-3).

Table 3: Code and color/pattern identification table for trees and shrubs used in graphs.

Color/Pattern	Code	Scientific name	Common Name
	ACNE	*Acer negundo*	Boxelder
	ACSA3	*Acer saccharum*	Sugar maple
	AMELA	*Amelanchier sp*	Juneberry / Serviceberry
	BENI	*Betula nigra*	River birch
	CACO	*Carya cordiformis*	Bitternut hickory
	CEOC	*Celtis occidentalis*	Hackberry
	COAM	*Corylus americana*	American hazel
	COXX	*Cornus sp*	Dogwood
	FRPE	*Fraxinus pennsylvanica*	Green ash
	JUVI	*Juniperus virginiana*	Eastern red cedar
	LOTA	*Lonicera tatarica*	Tartarian honeysuckle
	OSVI	*Ostrya virginiana*	Ironwood
	PODE	*Populus deltoides*	Eastern Cottonwood
	POTR	*Populus tremuloides*	Quaking aspen
	PRAM	*Prunus americana*	American plum
	PRPE	*Prunus pensylvanica*	Pin cherry
	PRSE	*Prunus serotina*	Black cherry
Orange/white waves	PRVE	*Prunus virginiana*	Chokecherry
	QUEL	*Quercus ellipsoidalis*	Northern pin oak
	QUMA	*Quercus macrocarpa*	Bur oak
	RHCA	*Rhamnus cathartica*	Buckthorn
	RHGL	*Rhus glabra*	Smooth sumac
	TIAM	*Tilia americana*	Basswood
	ULAM	*Ulmus americana*	American elm
	ULRU	*Ulmus rubra*	Slippery elm
	ZAAM	*Zanthoxylum americanum*	Prickly ash

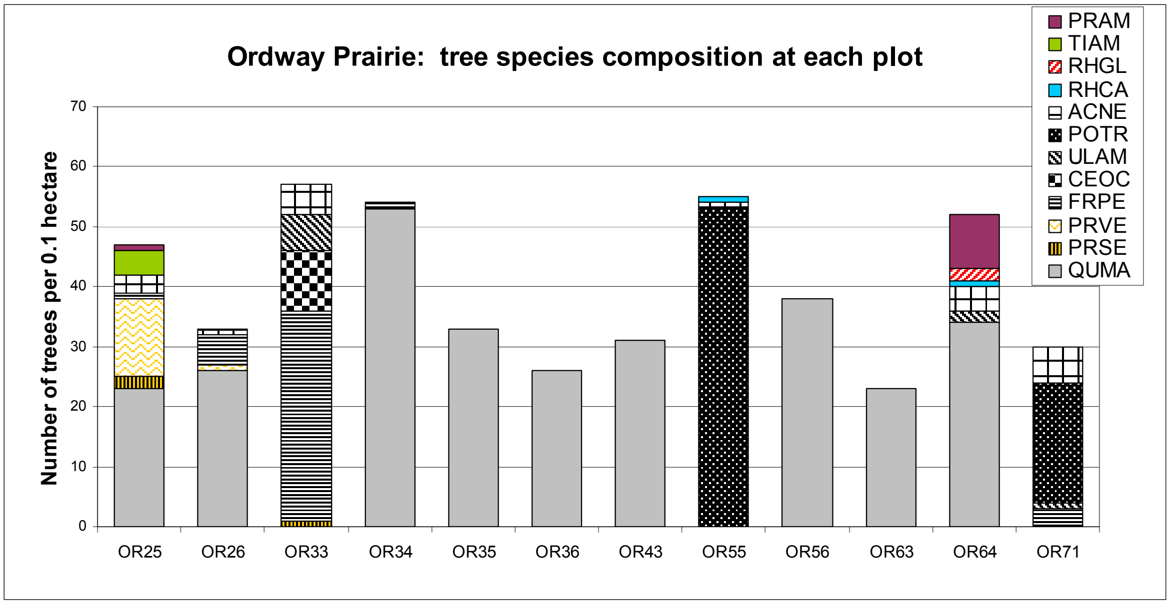


Figure 13: Ordway Prairie species composition (and number of each species present) at each plot. See key to species abbreviations in Table 3.

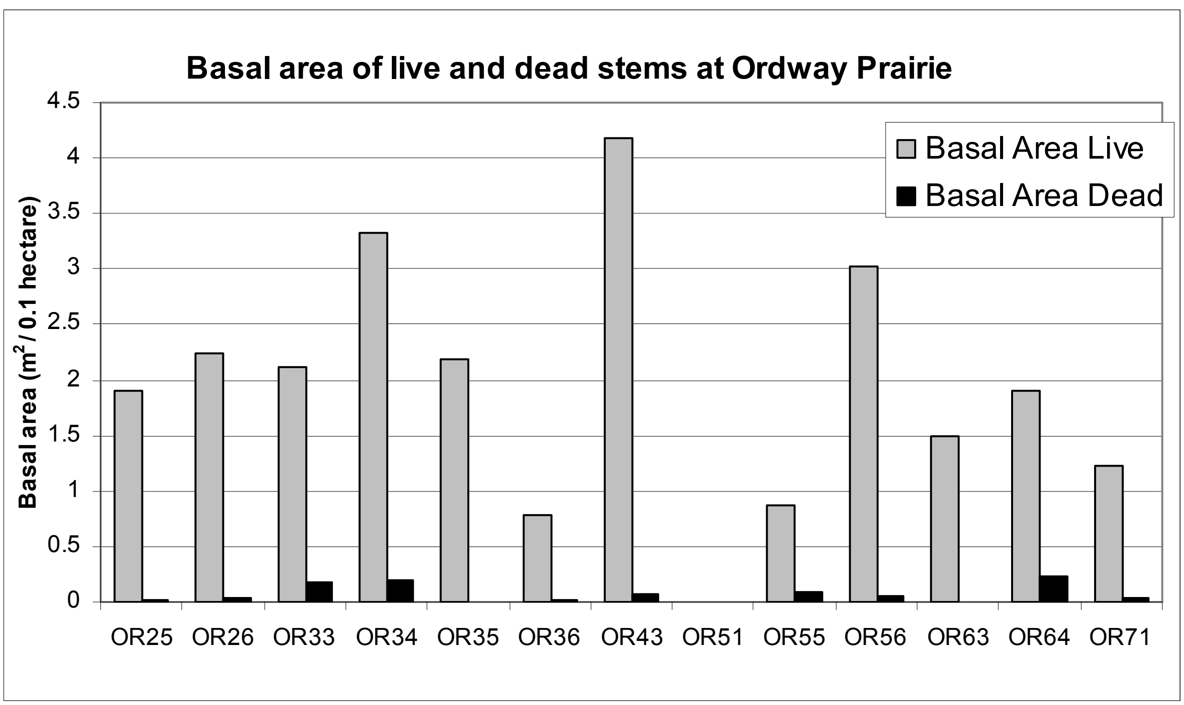


Figure 14: Basal area of live and dead stems at Ordway Prairie.

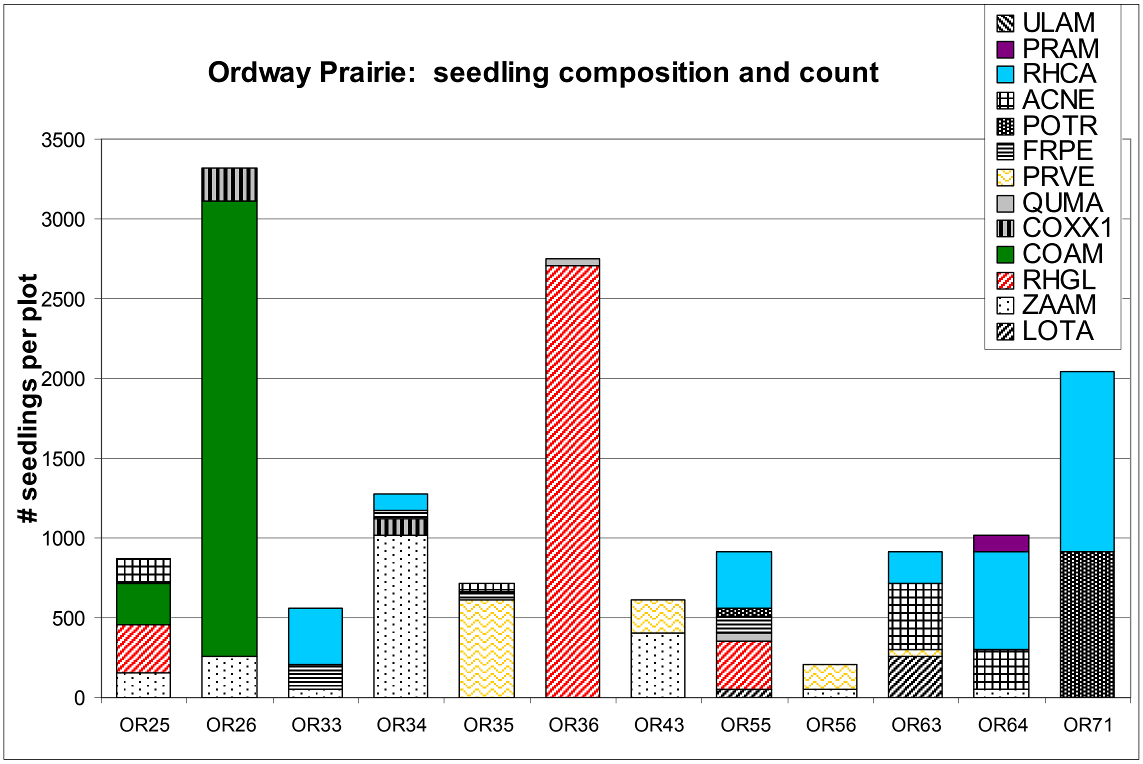


Figure 15: Number of seedlings by species at each plot at Ordway Prairie.

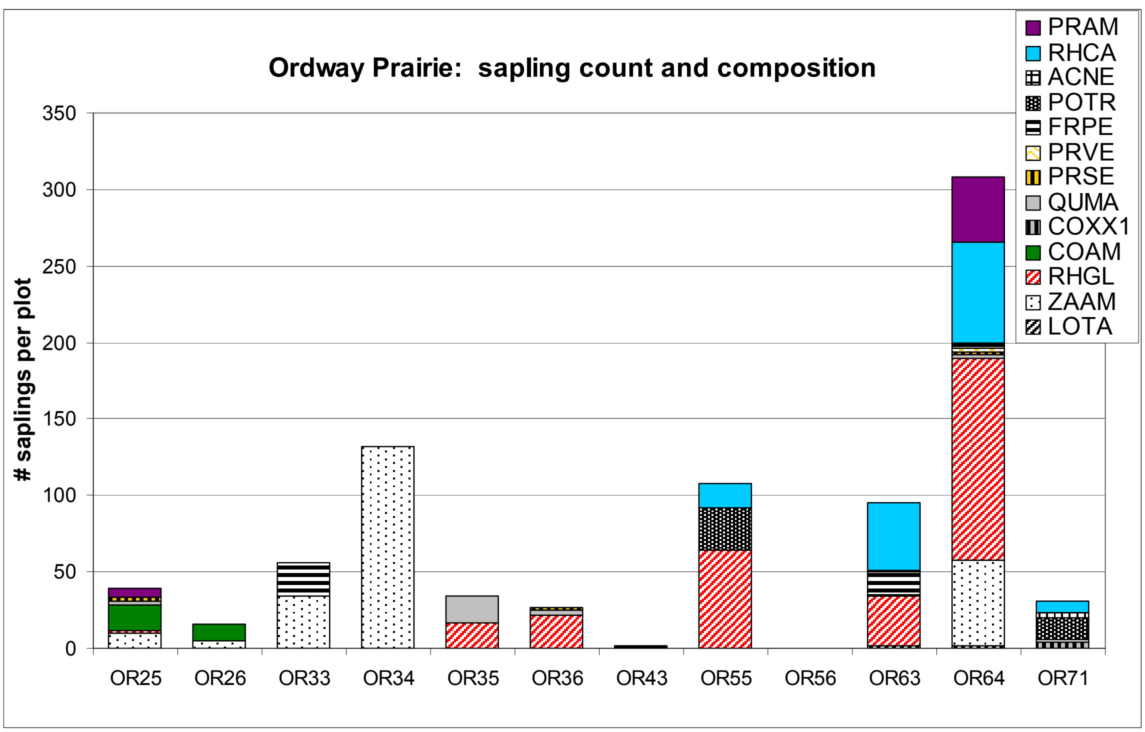


Figure 16: Number of saplings by species at each plot at Ordway Prairie.

Helen Allison

In contrast to Ordway Prairie, only four tree species occurred at Helen Allison (Figure 17). Bur oak and northern pin oak were co-dominants. Four plots contained green ash, but in relatively low numbers. Black cherry (*Prunus serotina*) and choke cherry (*Prunus virginiana*, which is a shrub but grew large enough to be cored and, therefore, was considered in the tree category) were present at some sites. Plots were dominated by either bur or northern pin oak but the two species were co-dominant at HA05 and HA06. The remainder of species (all fire-intolerant) appeared in low numbers and very low importance values (Appendix II-3). Northern pin oak always occurred with bur oak.

Live basal area measurements ranged from 0.1 m^2/ 0.1 hectare at HA11 to 2.4 in m^2/ 0.1 hectare at HA33 (Figure 18). Compared to Ordway Prairie, Helen Allison had a large amount of oak regeneration. Oak seedlings were present at all plots and oak saplings were present at all but one (HA04) of the plots (Figures 19 and 20). Plots HA06 and HA31 contained dense sumac and northern pin oak saplings. Plot HA04 had an abundance of hazel saplings but few seedlings while plot HA32 contained ample hazel seedlings, but few saplings. At the site level, Helen Allison displays a large quantity of bur oak seedlings, but little to no bur oak saplings (Figures 19 and 20). There are more northern pin oak saplings relative to northern pin oak seedlings than there are bur oak saplings relative to bur oak seedlings (Figure 21).

In 45 years of prescribed fire, all sites were prescribed burned at least 5 times and as many as 19 times in the case of HA06. The majority of these burns occurred during the springtime. The only fall burning occurred in 1987 and 1990 when 6 of 9 plots

(HA04, HA05, HA10, HA11, HA32, and HA33) were burned. In fact, the three plots that were not fall burned (and have never experienced a fall burn under the managed fire regime), HA06, HA12 and HA31, have the longest burning record as well as the highest burn frequencies of all the plots (Appendix II-5). The MFI ranges from 1.94 years at HA06 to 4 years at several plots.

The plots with the highest percentage of "oak multiples" (a.k.a "grubs" or multiple stems caused by repeated killing and resprouting) were HA10 with 100% (all QUMA) and HA12 with 100% (all QUEL). HA11 has no oak multiples and the average percentage of QUMA and QUEL found as part of a multiple was 29% and 28% respectively (Appendix II-3).

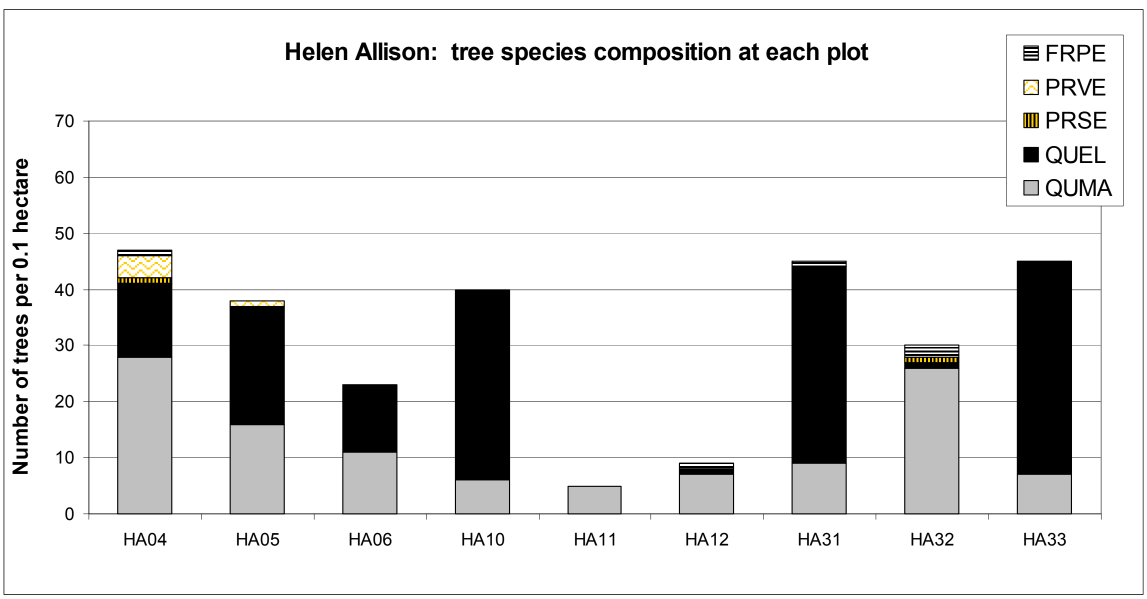


Figure 17: Species composition and number of trees present at each plot at Helen Allison. See key to species abbreviations in Table 3.

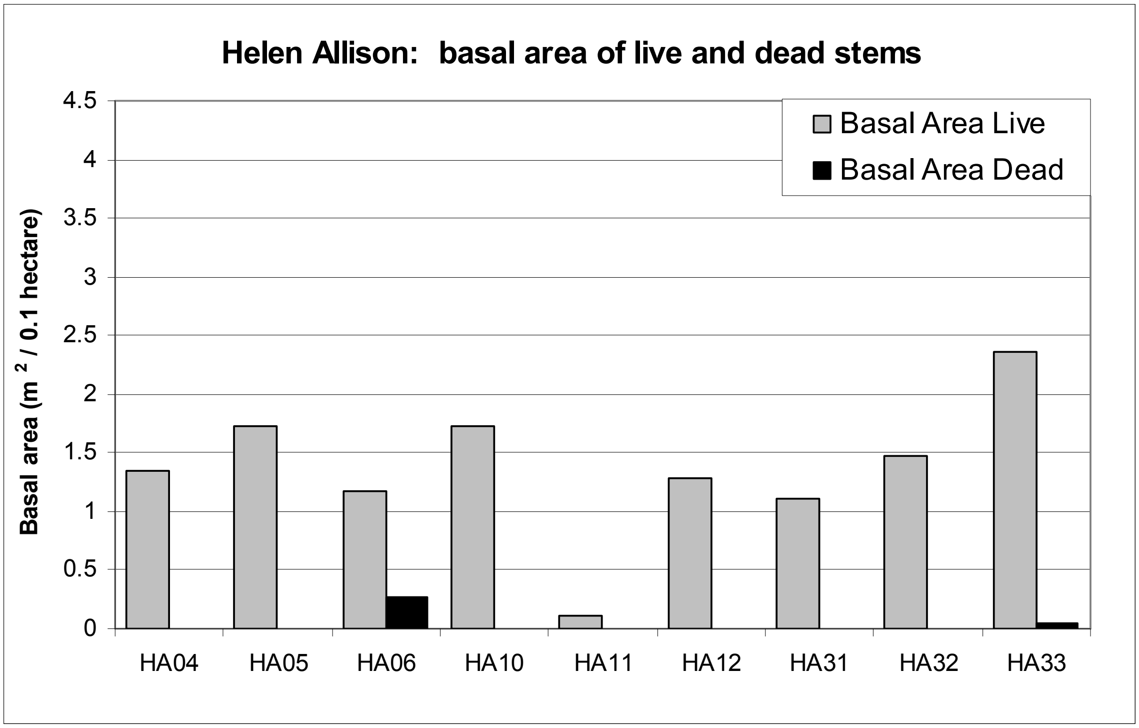


Figure 18: Basal area of live and dead stems at each plot at Helen Allison.

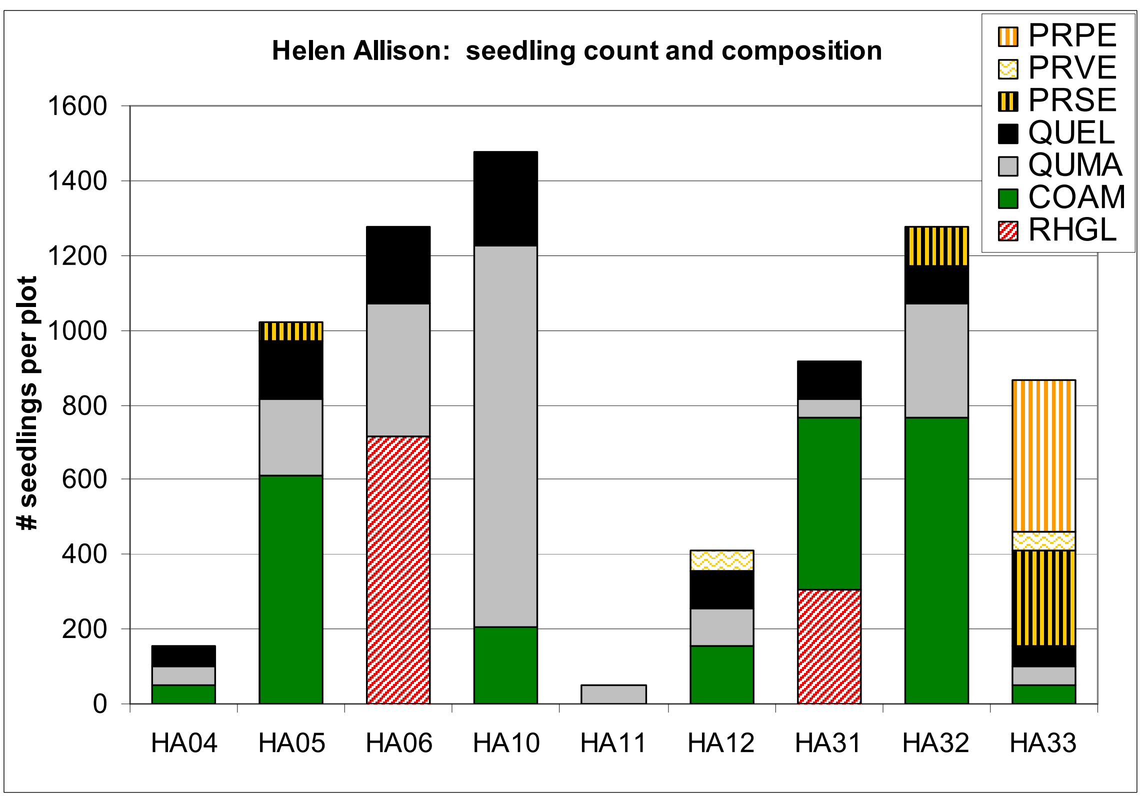


Figure 19: Number of seedlings and seedling composition at each plot at Helen Allison.

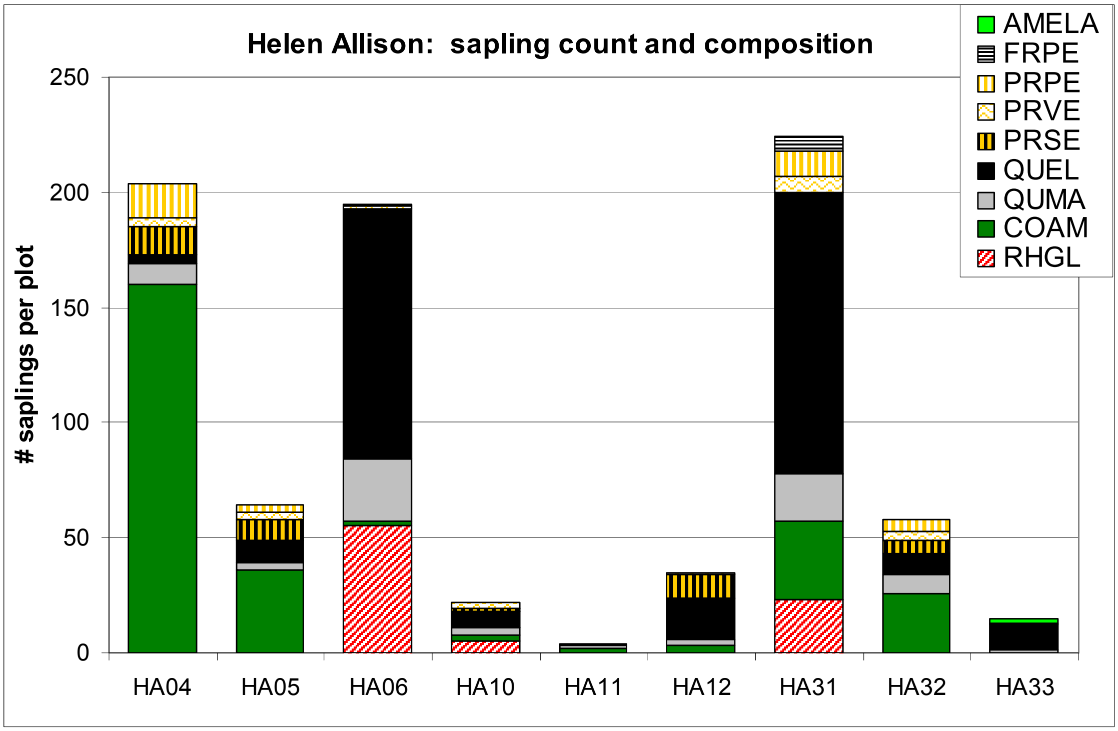


Figure 20: Number of saplings and sapling composition at each plot at Helen Allison.

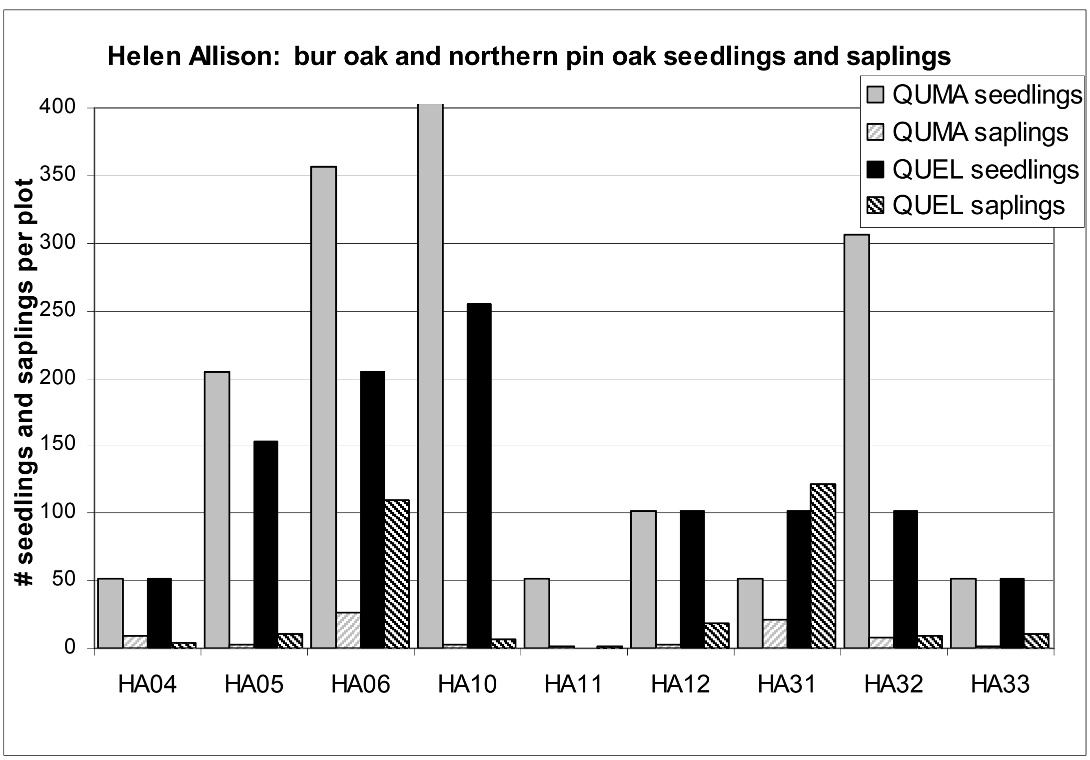


Figure 21: Number of bur oak (QUMA) and northern pin oak (QUEL) seedlings and saplings at each plot within Helen Allison. QUMA seedling count at HA10 extends over 1100.

Weaver Dunes

In 16 plots, Weaver Dunes contained 12 different tree species (Figure 23). Of those 12 tree species, northern pin oak dominated. Two sites were composed solely of northern pin oak (WD07 and WD15) (Figure 22), and seven plots had northern pin oak importance values over 115 (Appendix III-3). Green ash had the second highest total stem density (Appendix III-1) for all sites, grew at seven plots (Figure 22) and had high importance values (Appendix III-3). American plum had the third highest total stem density (Appendix III-1), but only appeared at two plots (Figure 22) and had very low importance values (Appendix III-3). Red cedar (*Juniperus virginiana*) was present at seven plots (Figure 22). Bur oak occurred in only one plot, WD57. Basal areas at all plots were relatively low, ranging from >0.1 m^2/0.1 hectare at WD62 to 2.6 m^2/0.1 hectare at WD07 (Figure 23). Plots dominated by northern pin oak had the highest basal areas (Figure 23).

Although northern pin oak seedlings dominated at many plots, for the most part, the seedling compositions at Weaver Dunes varied from plot to plot. Plot WD07 had 27 northern pin oak seedlings, far more than any other plot. The sapling layer was slightly more diverse than the seedling layer (19 species in the sapling class vs. 13 species in the seedlings class) within and among plots. Again, northern pin oak dominated, but green ash and prickly ash (*Zanthoxylum americanum*) were both abundant, especially at WD47.

Only one bur oak tree was recorded for the entire site, but, interestingly, we found seven bur oak saplings (but no seedlings). One bur oak sapling occurred at plot WD48 (though no bur oak trees were tallied there) and six saplings were recorded at WD57 (where the one bur oak tree with a dbh of 12.5 cm was found).

In 25 years of prescribed burning, all plots have experienced fire at least twice and at most four times (Appendix III-4). The majority of the burns occurred in the spring, although over the past decade, man plots experienced at least one fall burn. For example, three fall burns have affected WD46 in the past 8 years (Appendix III-4). The average MFI over the prescribed burning era was 6.6 years, with MFI's ranging from 4 to 9 years. The percentage of oak grubs (multiples) at plots ranged from 0% at WD22, WD23, WD56, WD58 and WD65 to 100% at WD62, with a site average of 28% (all QUEL) (Appendix III-3).

Percentage of scarred trees ranged from 0% at WD62 and WD63 to 33% at WD15 (Appendix III-3), with no predominant scarring direction apparent. Only one tree at one plot (WD14) throughout the entire site showed evidence of char (Appendix III-3). Tree density was not associated with number of open fire scars (Appendix III-3)).

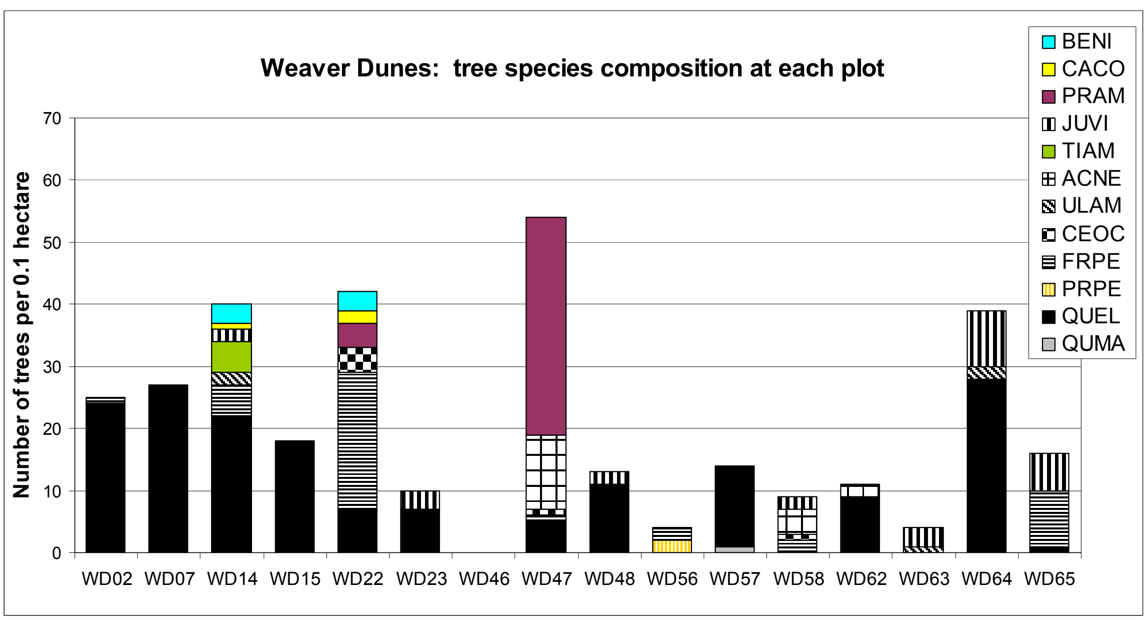


Figure 22: Species composition and number of trees at each plot at Weaver Dunes. See key to species abbreviations in Table 3.

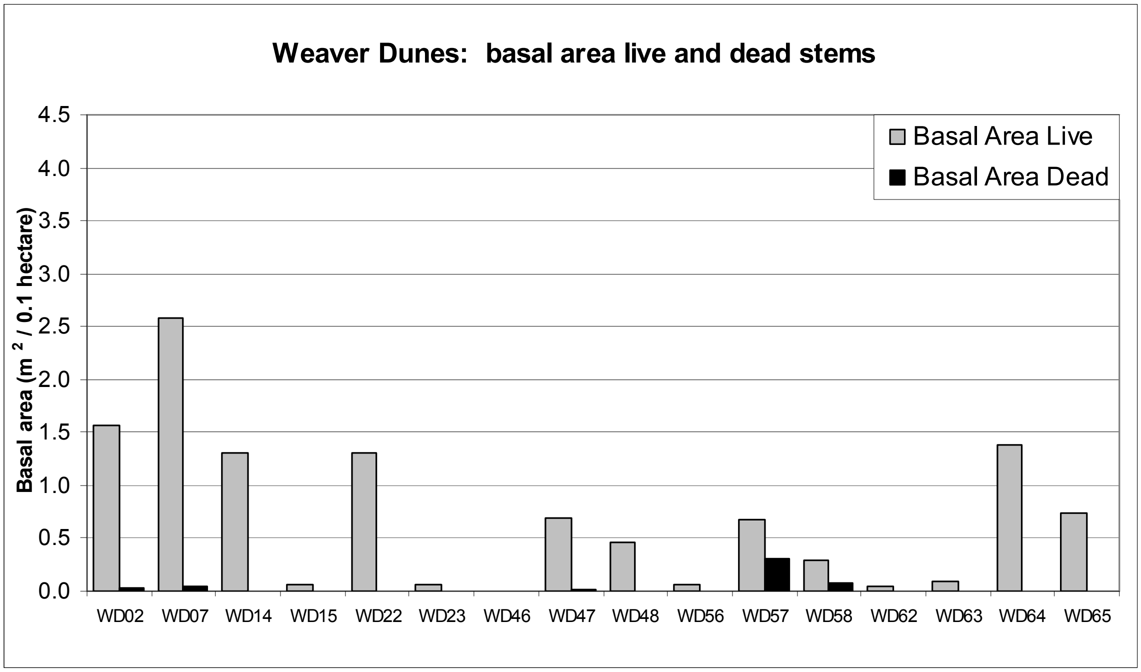


Figure 23: Basal area of live and dead stems at each plot at Weaver Dunes.

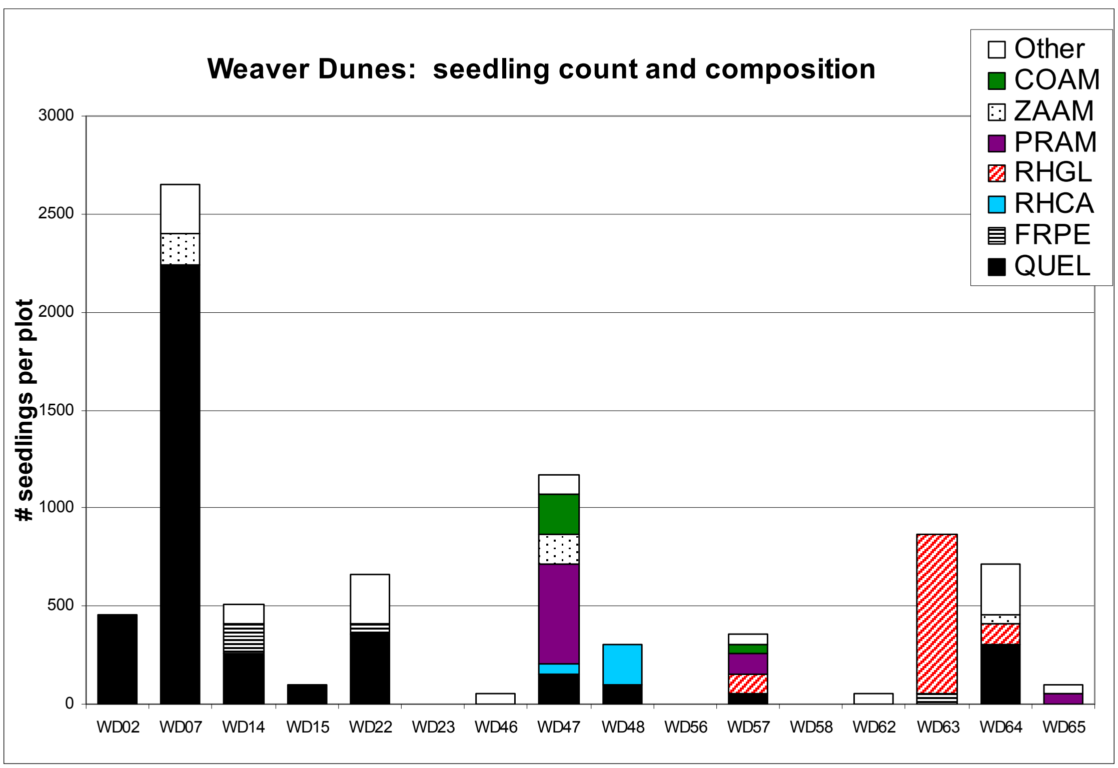


Figure 24: Seedling count and species composition at each plot at Weaver Dunes. “Other” category includes the following species: CACO, ACNE, PRPE, PRVE and PRSE.

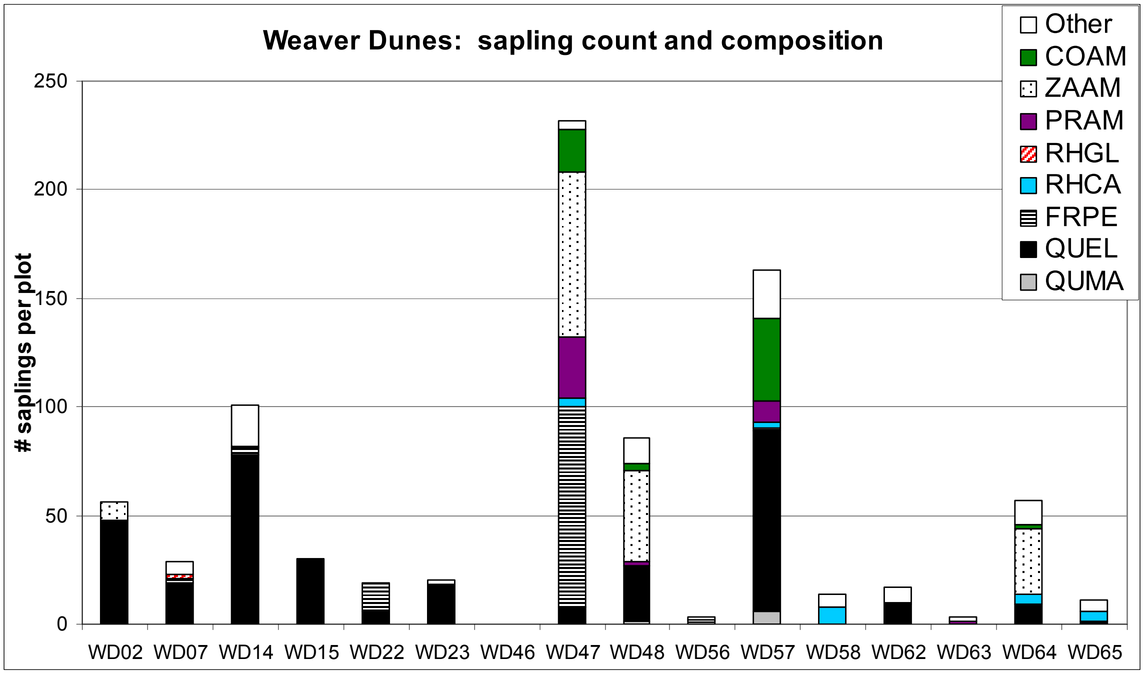


Figure 25: Sapling count and species composition at each plot at Weaver Dunes. "Other" category includes the following species: PRSE, PRVE, PRPE, ULAM, ACNE, TIAM, PIRE, CACO, COXX1, LOTA and JUVI.

Minnesota Valley NWR and Carver Rapids SP

In 26 plots throughout the NWR and the SP, 15 different tree species were recorded (Figure 26). Both bur and pin oak were found in high numbers, though bur oak (with a total live stem density of 148 trees/0.1 hectare) occurred more frequently than northern pin oak (with a total live stem density of 63 trees/0.1 hectare). However, interestingly, northern pin oak dead stem density was over three times higher than that of bur oak (Appendix IV-1).

Thirteen of the 26 plots were clearly dominated by oak species. American elm had the second highest total stem density (at 128 trees/0.1 hectare), surpassed only by bur oak. In fact, American elm appears in more plots than northern pin oak (eleven vs.

seven) and has a total stem density more than double that of northern pin oak (128 vs. 63 trees/0.1 hectare). However, when looking at total basal area, bur oak is by far the largest – American elm had a mere 1.4 m^2/0.1 hectare compared to bur oak's 14.1 m^2/0.1 hectare (Appendix IV-2). In general, oak dominated plots had higher basal areas than non-oak dominated plots (Figure 27).

Mesic species at Minnesota Valley/Carver Rapids clearly have a prominent presence. American elm was abundant at three plots in particular – MV20, MV23 and MV25 (Figure 26). Green ash occurred in four plots, but only twice with a stem density over 3 trees/0.1 hectare (plots MV19 and MV23). Box elder appears in two plots (MV23 and MV25), but with high stem densities both times (18 and 23 trees/0.1 hectare) in heavy abundances both times (Appendix IV-1).

In general, the largest numbers of seedlings were present at plots with the fewest trees (Figure 28). The seedling layer was dominated by sumac (Figure 28). In fact, at many sites, the only seedlings found were sumac. Buckthorn (*Rhamnus cathartica*, an invasive Eurasian species) seedlings were also widespread, occurring in eleven of the 26 plots, sometimes in large numbers (as in MV06, MV07, MV17, MV18, MV20 and MV95). Bur oak seedlings occurred in six plots and were more common than northern pin oak seedlings, which occurred at only three plots and in much lower numbers (Appendix IV-5). Green ash and hazel and dogwood appeared frequently in plots with high seedling species richness (Figure 28).

The sapling count looks quite different from the seedling count. Sumac did not dominate the sapling layer as it did the seedling layer (Figure 29). In fact, the sapling layer at these plots was not dominated by any particular species! Most sites had a large diversity of sapling species. The only plot predominantly composed of only one species was CR32 (with sumac). Plots with abundant sumac seedlings had few sumac saplings. Tree stem density of bur oaks was higher than that of northern pin oaks (Appendix IV-1), thus, it was surprising to see that the number of northern pin oak saplings is three times greater than the number of bur oak saplings (Appendix IV-5). But, despite the low numbers of bur oak saplings, there is a large number bur oak seedlings (Figure 28 and 29).

Although MN Valley NWR and Carver Rapids SP are neighboring preserves, they are managed by different agencies (USFWS and MN DNR). The prescribed burn records were successfully located for MN Valley NWR, but, unfortunately, cannot be found for Carver Rapids SP. Fortunately, some of the burns performed on Carver Rapids SP are listed in MN Valley records, but not all. Without a written prescribed burn record, I needed some idea as to how often (and where) Carver Rapids was burned. Mark Cleveland (MN Valley State Recreation Manager) graciously compiled information from current and previous DNR burn bosses and preserve managers, but the data may not be complete.

In 24 years of burning at the MN Valley Louisville swamp unit, some plots never saw fire and some were burned as many as 16 times (Appendix IV-4). Plots MV19, MV20, MV23, MV25, MV94 and MV95 have not been burned at least since 1984, but probably a lot longer. Most other sites have seen fire incredibly frequently, with MFIs around 1.5 years. In fact, plots MV02, MV03, MV04, MV05, MV06, MV07, MV08, MV14, MV15, MV16, MV17 and MV18 have been burned every single year for the past five years! Virtually all burns were done in the spring with the exception of burning in 2005, which took place in the fall.

The following information was acquired from Mark Cleveland. From 1979 to 1982, three prescribed fires were conducted at Carver Rapids as well as an extensive 24D spot application to treat staghorn sumac. Between 1982 and 1999 there were two additional prescribed burns. All burns at this time were conducted on the 75 acre Johnson Slough Loop. In 1998 and 1999, Minnesota State Parks and the USFWS mechanically dropped a large number of mature northern pin oaks using a hydro axe. In 2000, the Johnson Slough Loop as well as an additional area south of the loop in the recently hydro axed zone were burned. The fire was more intense than anticipated due to drought conditions, sandy soils and heavy fuel loading, including slash, which resulted in high mortality of bur oaks. Only a few of the bur oaks that were in the hydro axed area survived (Mark Cleveland, pers. comm.).

Many plots in both MN Valley and Carver Rapids have experienced mechanical thinning using a hydroaxe. Often, the hydroaxe removes virtually all non-oaks from the area. This disturbance is labeled as “MECH” in Appendix IV-4.

There was not a predominant scarring direction on the trees nor was there a predominant scarring direction relative to the slope of the land (Appendix IV-3). Denser plots do not necessarily contain more fire scars (Figure 34). The percentage of oak grubs (QUMA and QUEL multiples) at plots ranged from 0% at MV06, MV08, MV16, MV19, MV20, CR30 and CR32 to 79% at MV21 with a site average of 24% for QUMA and 30% for QUEL (Appendix IV-3).

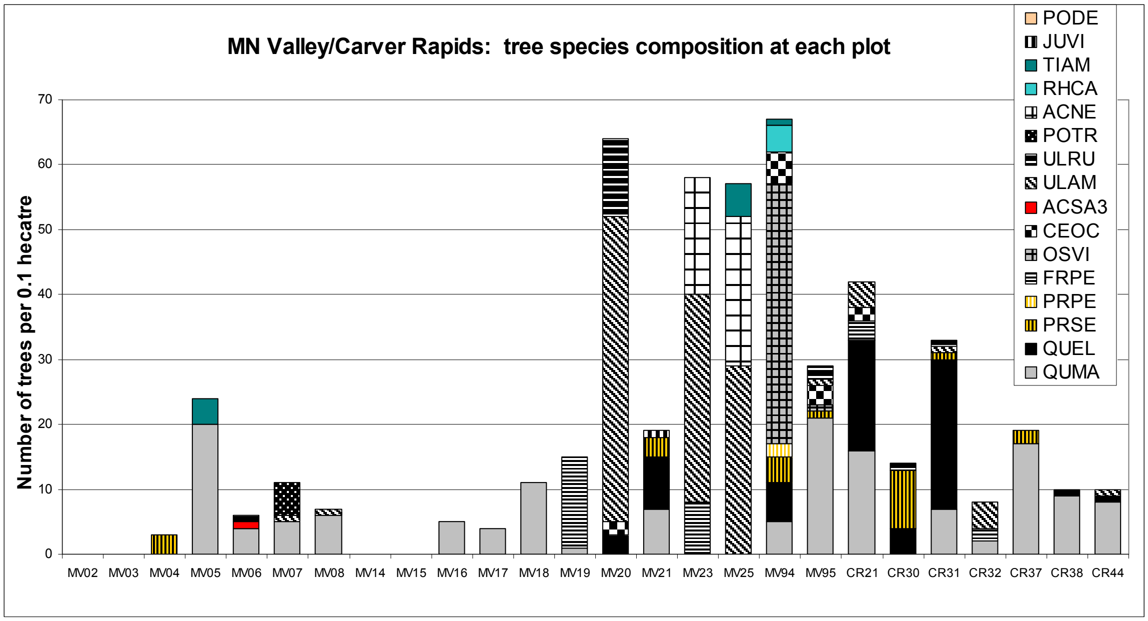


Figure 26: Species composition and number of trees at each plot in MN Valley/Carver Rapids. See key to species abbreviations in Table 3.

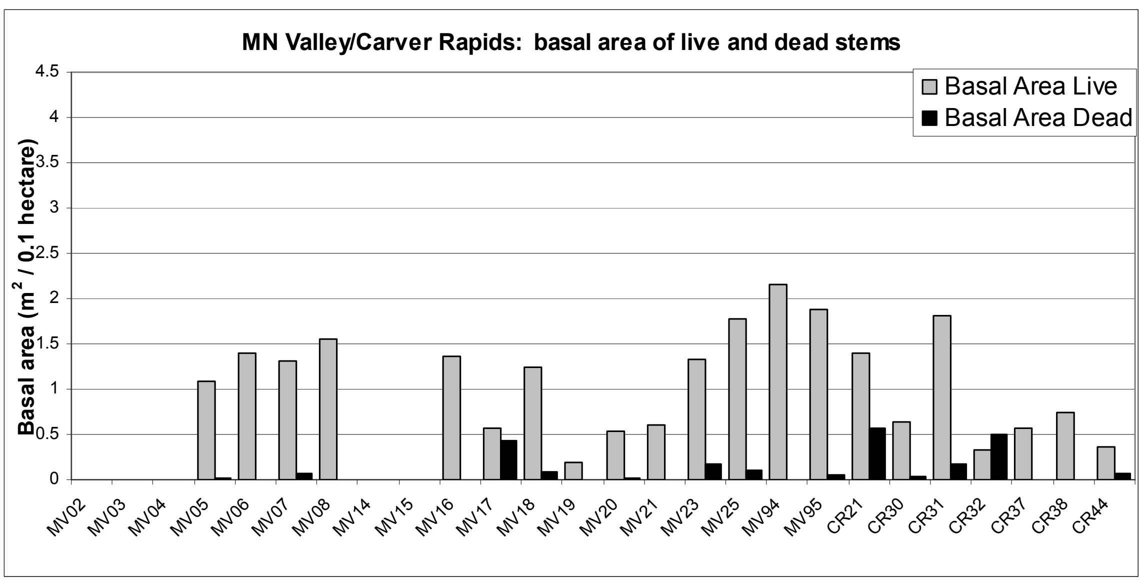


Figure 27: Basal area of live and dead stems at each plot in MN Valley/Carver Rapids.

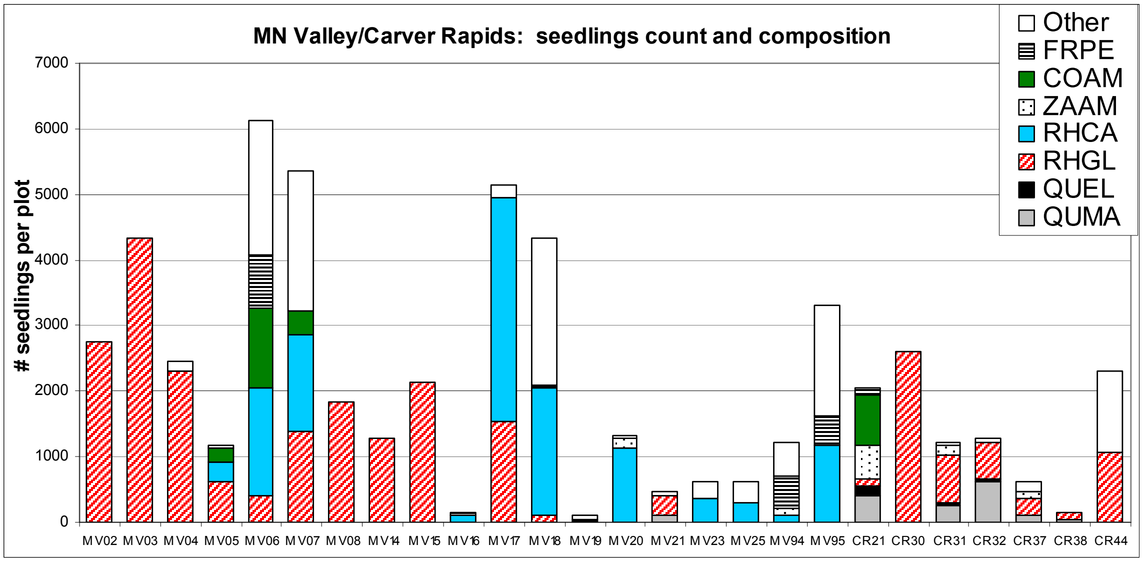


Figure 28: Number of seedlings and species composition of seedlings at each plot in MN Valley/Carver Rapids. "Other" category includes the following species: PRAM, ULRU, ULAM, JUVI, ACNE, TIAM, POTR, COXX1, CEOC, OSVI, PRSE, PRVE and PRPE.

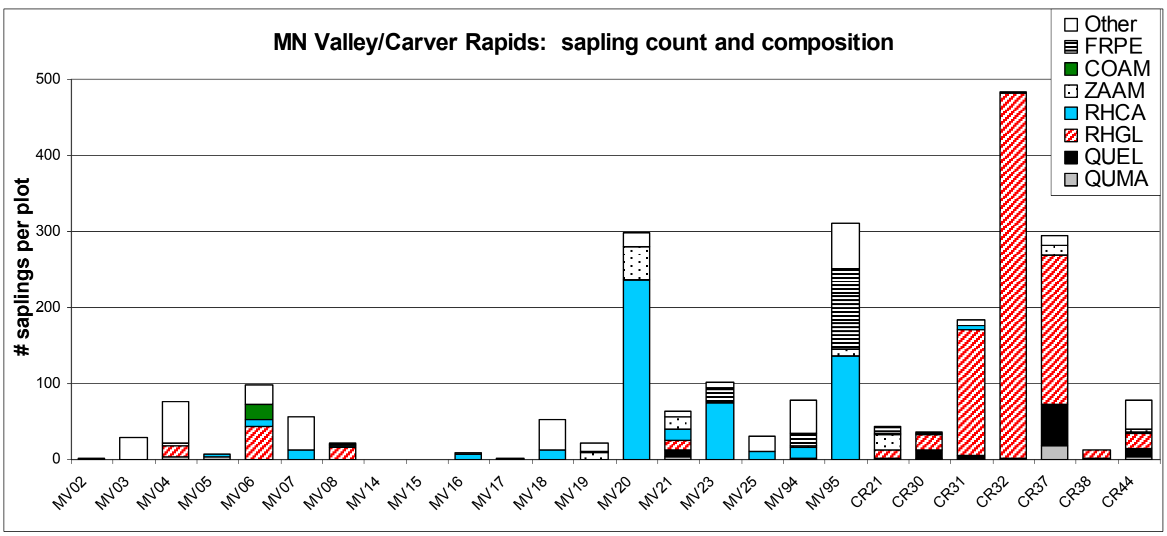


Figure 29: Number of saplings and species composition of saplings at each plot in MN Valley/Carver Rapids. "Other" category includes the following species: PRAM, ULRU, ULAM, ACNE, LOTA, TIAM, POTR, COXX1, CEOC, OSVI, PRSE, PRVE and PRPE.

Forest structure of oak savannas at a landscape scale

Throughout four oak savanna sites across Minnesota, only two species of oak were found: *Q. macrocarpa* (bur oak) and *Q. ellipsoidallis* (northern pin oak). The presence of these two oak species, however, was not ubiquitous; Ordway Prairie had 100% bur oak, Helen Allison had 43% bur oak and 57% northern pin oak, Minnesota Valley/Carver Rapids had 70% bur oak and 30% northern pin oak and Weaver Dunes had 0.005% bur oak and nearly 100% pin oak (Figure 30). There is a clear gradient in oak composition at sites, going from complete bur oak dominance in the northwest to near complete northern pin oak dominance in the southeast.

Mean stem density per plot varied slightly among sites. Ordway had the largest mean stem density per plot with 34 trees per 0.1 hectare, Helen Allison was second with 31 trees per 0.1 hectare, and Weaver Dunes and Minnesota Valley/Carver Rapids both had approximately 20 trees per 0.1 hectare (Figure 30). With the exception of Helen Allison, which had the majority of its stem density composed of oak species, non-oak mesic species composed a rather large proportion of each site's mean stem density. In fact, on average, at MN Valley, more than half its plot's stems were non-oak species.

Across the four sites, mean basal area per plot displays a clear gradient with the largest mean basal area in the Northwest region and the smallest in the Southeast. Ordway Prairie had the largest mean live basal area per plot with an average of 1.7 m^2/0.1 hectare, Helen Allison was second with 1.4 m^2/0.1 hectare, Minnesota Valley/Carver Rapids had 0.88 m^2/0.1 hectare and Weaver Dunes with 0.66 m^2/0.1 hectare (Figure 30). Basal area appears to be highest at sites dominated by bur oak.

Non-oak species display relatively high importance values (Ordway – 55, Minnesota Valley/Carver Rapids– 64, Weaver Dunes – 83) at all sites except Helen Allison, where non-oak species hold an average importance value as low as 6 (Figure 30). Non-oak species importance does not appear to be related to oak species composition at sites.

Sumac and hazel were present at all sites, although densities varied greatly. Minnesota Valley/Carver Rapids had a high number of sumac seedlings and saplings at each plot, but comparatively smaller amounts of hazel (Figure 31). Ordway Prairie also had a high density of sumac seedlings and saplings, a high density of hazel seedlings (but not saplings) and a large amount of prickly ash. Helen Allison has comparatively lower amounts of sumac, but high hazel densities. Weaver Dunes had few shrubs except prickly ash saplings.

At sites containing both oak species, a proportionately larger number of bur oak seedlings were found than northern pin oak seedlings (Figure 32). Similarly, at these two sites, proportionately more northern pin oak saplings were found than bur oak saplings. Ordway Prairie had relatively few seedlings or saplings while Weaver Dunes had a large amount of both.

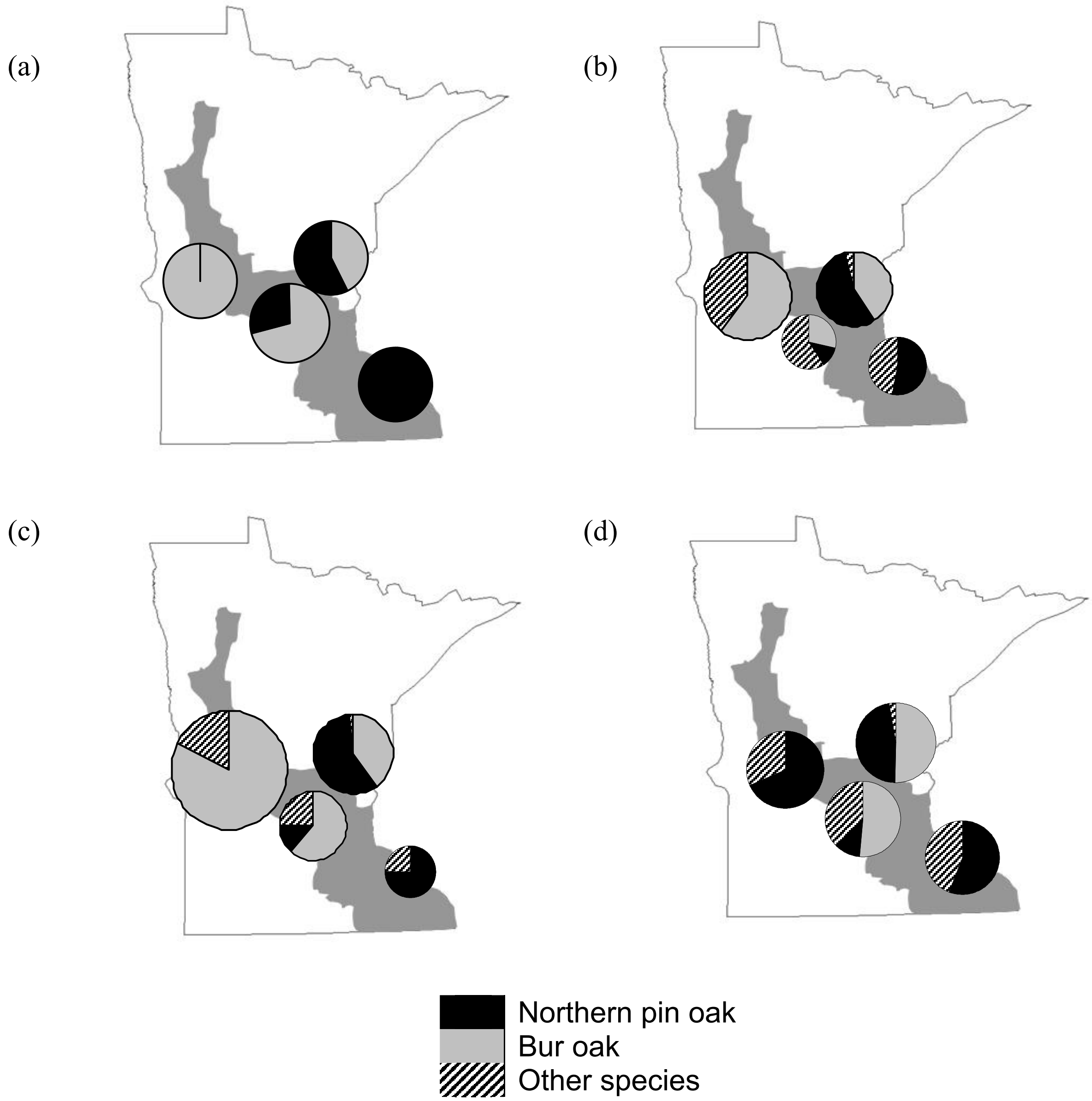
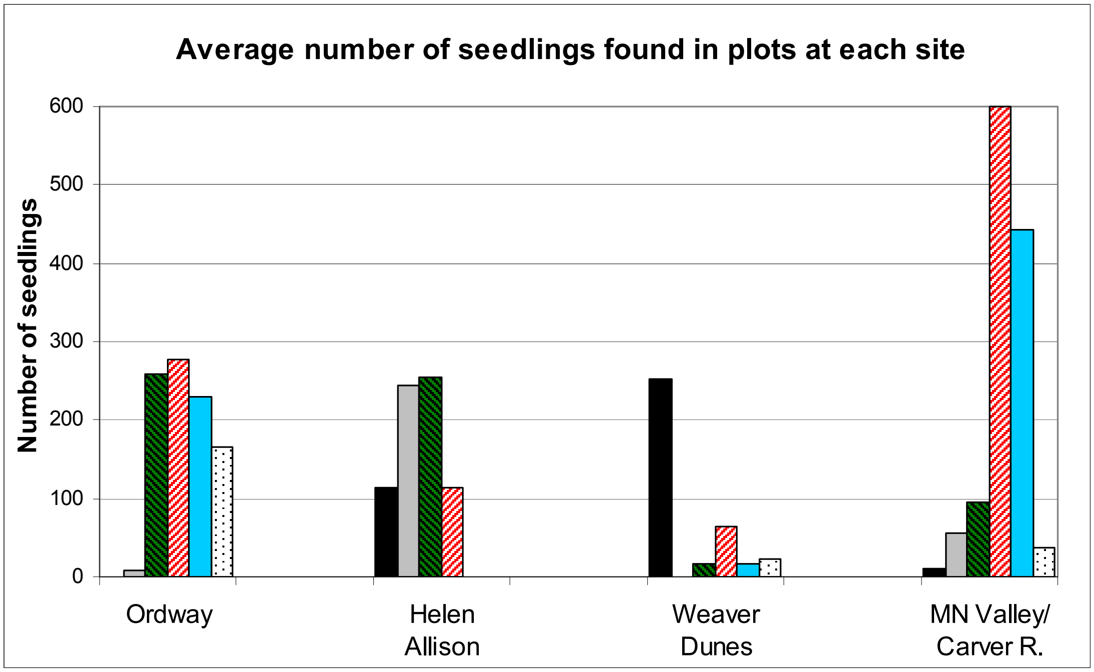
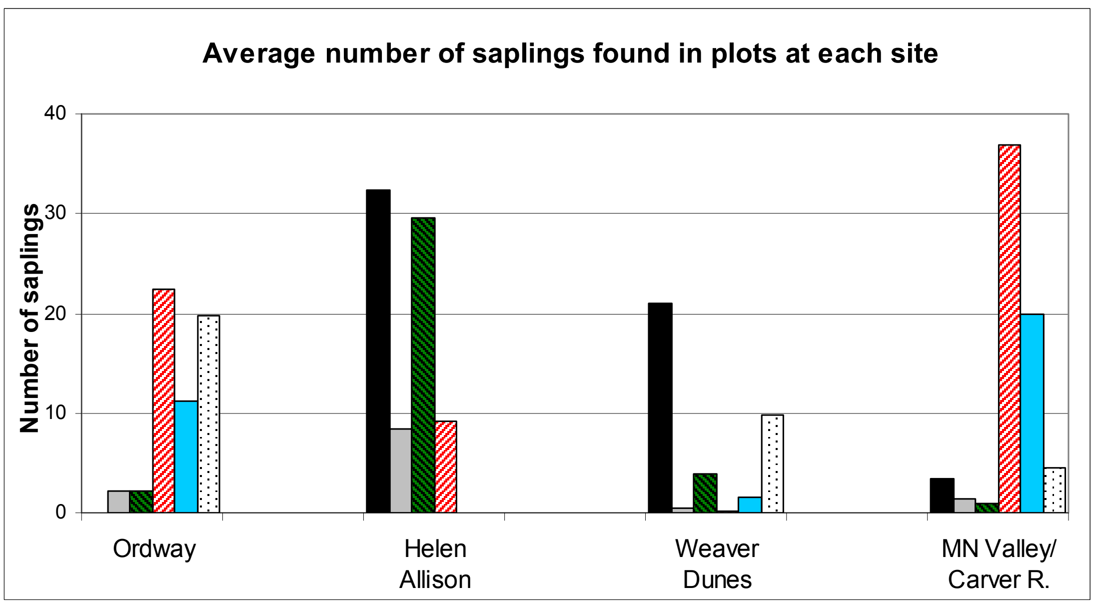


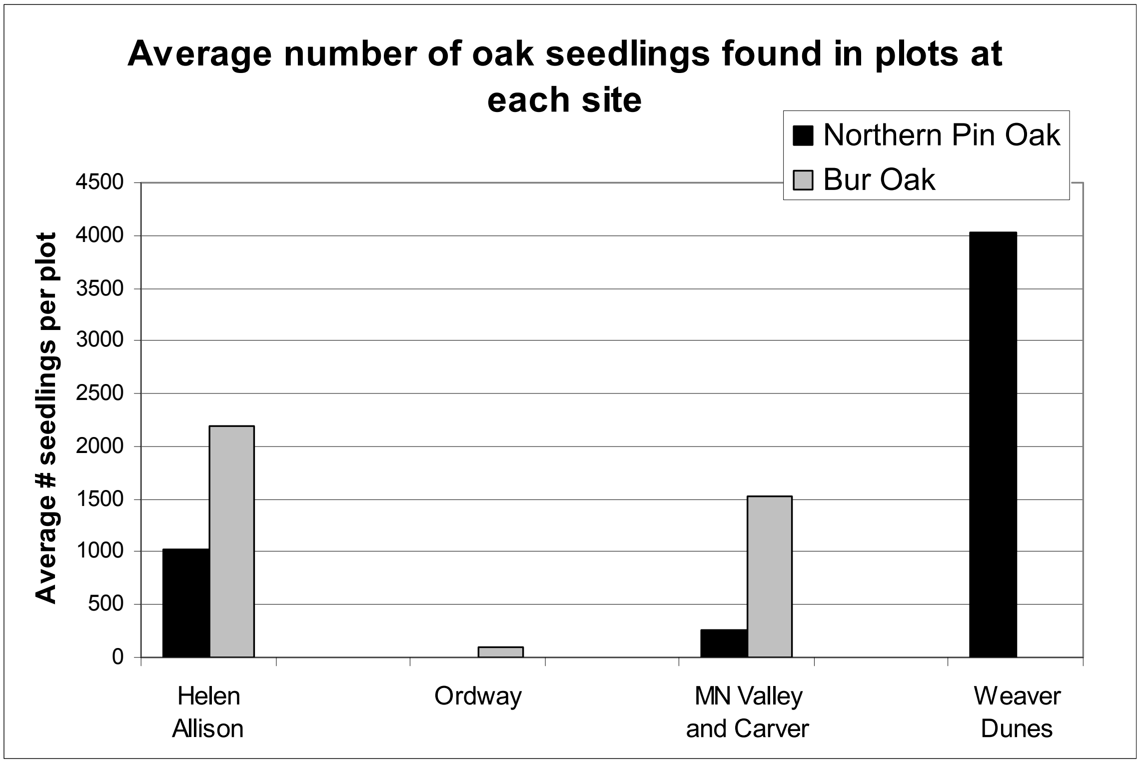
Figure 30: (a) Percent composition of tree species at each site displaying a gradient from complete bur oak dominance in the northwest to near complete northern pin oak dominance in the southeast. (b) Average stem density per plot (size of pie charts corresponds to number of trees and color wedges designate percentages of specific tree species). Stem density is highest at northern sites and sites with more bur oak. (c) Average live basal area per plot at each site (size of pie chart corresponds to basal area). There is a gradient in mean basal area per plot, from highest in the northwest to lowest in the southeast. (d) Average importance values at plots. Non-oak species display rather high importance values at all sites except Helen Allison.





Color/Pattern	Code	Scientific name	Common Name
	QUEL	*Quercus ellipsoidalis*	Northern pin oak
	QUMA	*Quercus macrocarpa*	Bur oak
	COAM	*Corylus americana*	American hazel
	RHGL	*Rhus glabra*	Smooth sumac
	RHCA	*Rhamnus cathartica*	Buckthorn
	ZAAM	*Zanthoxylum americanum*	Prickly ash

Figure 31: Average number of seedlings and saplings found at plots at each site. Minnesota Valley/Carver Rapids' sumac count actually extends to 902 seedlings.



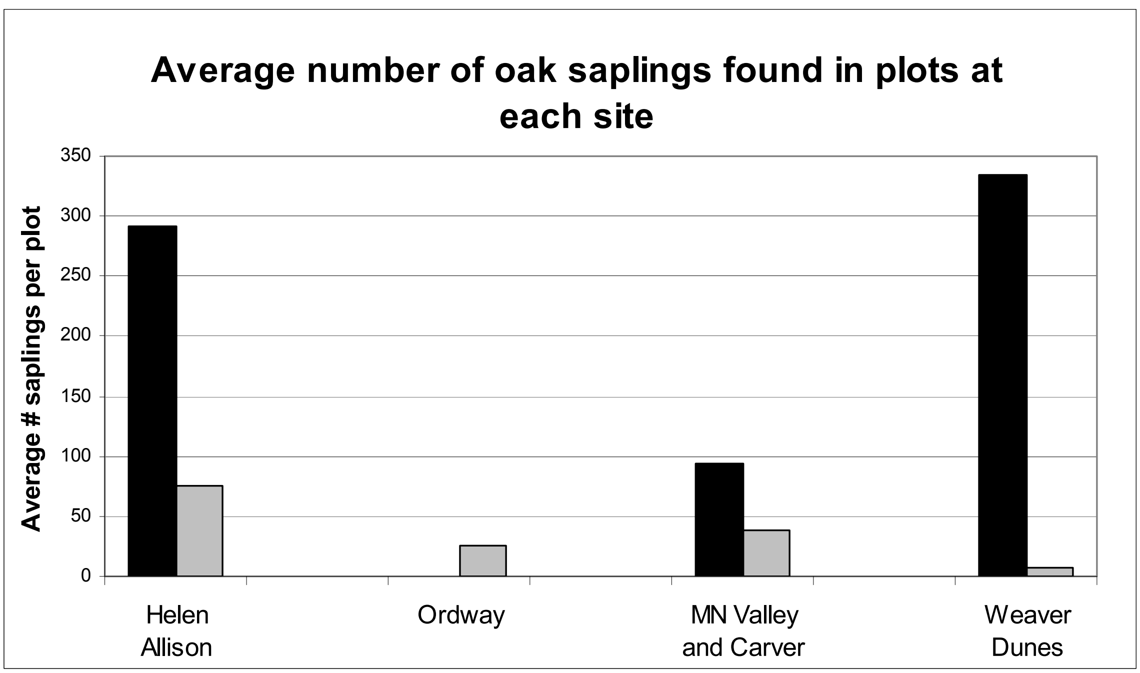


Figure 32: Number of bur oak and northern pin oak seedlings and saplings found in total at each site. Ordway Prairie has low numbers of bur oak seedlings and saplings. Weaver Dunes has high numbers of northern pin oak seedlings and saplings. In both Helen Allison and Minnesota Valley/Carver Rapids, there were more bur oak seedlings compared to northern pin oak seedlings and more northern pin oak saplings relative to the number of bur oak saplings.

Age Structure

Ordway

A total of 165 trees were cored at Ordway. The ages of the trees ranged from 148 years old (a bur oak established in 1859 at OR56) to 10 years old (an American elm established in 1997 at OR64). The correlation between the size (dbh) and the age of bur oaks (Figure 33) was significant at 0.001, rejecting the null hypothesis that there is no relationship between the age and the size of a bur oak ($r = -0.55$, $p < 0.001$, $n = 56$).

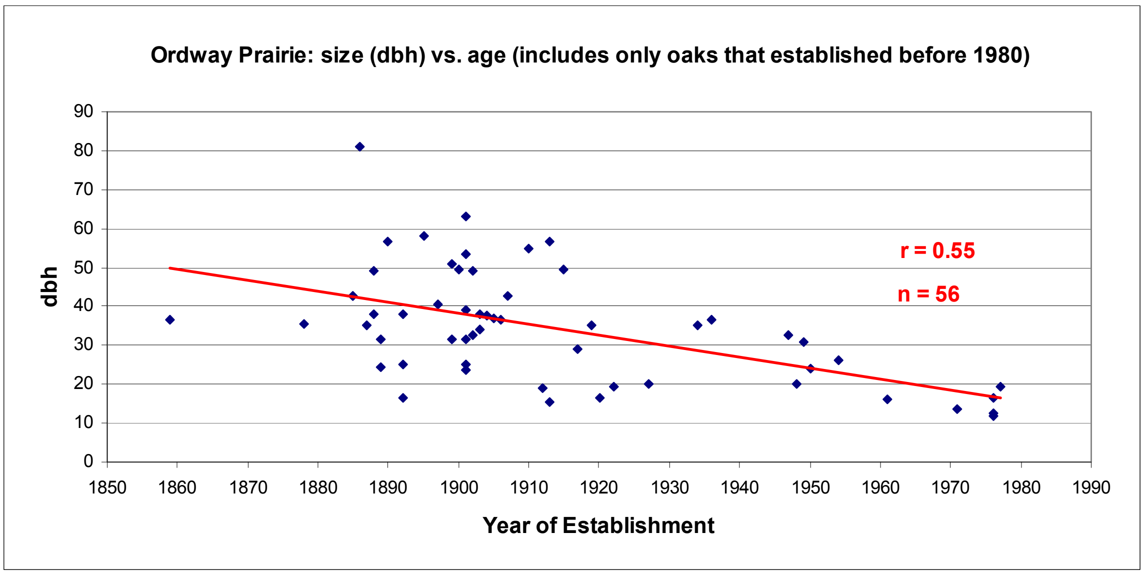


Figure 33: Significant relationship between the age and the size of bur oaks at Ordway Prairie.

Several clear trends emerged from the pattern of establishment dates from Ordway (Figure 34). There was a surge of bur oak establishment in the late 1800s and early 1900s. Bur oak establishment decreased substantially in the 1930s and stayed low throughout the mid 1900s. The oldest non-oak species found was a green ash dating back to the 1930s. The first box elder and hackberry appeared in the 1940s. Bur oak establishment increased again in the 1970s and 1980s, but to a level <50% of the 1900s surge, and non-oak species establishment during this time exceeded oak establishment. Non-oak species (fire-intolerant species) establishment seems to have decreased in the 1990s, although this is likely an artifact of only coring trees over 5cm dbh. Green ash has established at a relatively consistent rate since the 1930s.

Table 4: Color/pattern identification for species used in age-structure charts. “Min” indicates that I was unable to estimate to the center ring and thus, provides a minimum estimate of establishment date.

Color/Pattern	Code	Scientific name	Common Name
	ACNE	*Acer negundo*	Boxelder
	ACNE (MIN)	*Acer negundo*	Boxelder
	FRPE	*Fraxinus pennsylvanica*	Green ash
	FRPE (MIN)	*Fraxinus pennsylvanica*	Green ash
	QUEL	*Quercus ellipsoidalis*	Northern pin oak
	QUEL (MIN)	*Quercus ellipsoidalis*	Northern pin oak
	QUMA	*Quercus macrocarpa*	Bur oak
	QUMA (MIN)	*Quercus macrocarpa*	Bur oak
	ULAM	*Ulmus Americana*	American elm
	ULAM (MIN)	*Ulmus Americana*	American elm
	Other	----------------------	-------------------
	Other (MIN)	----------------------	-------------------

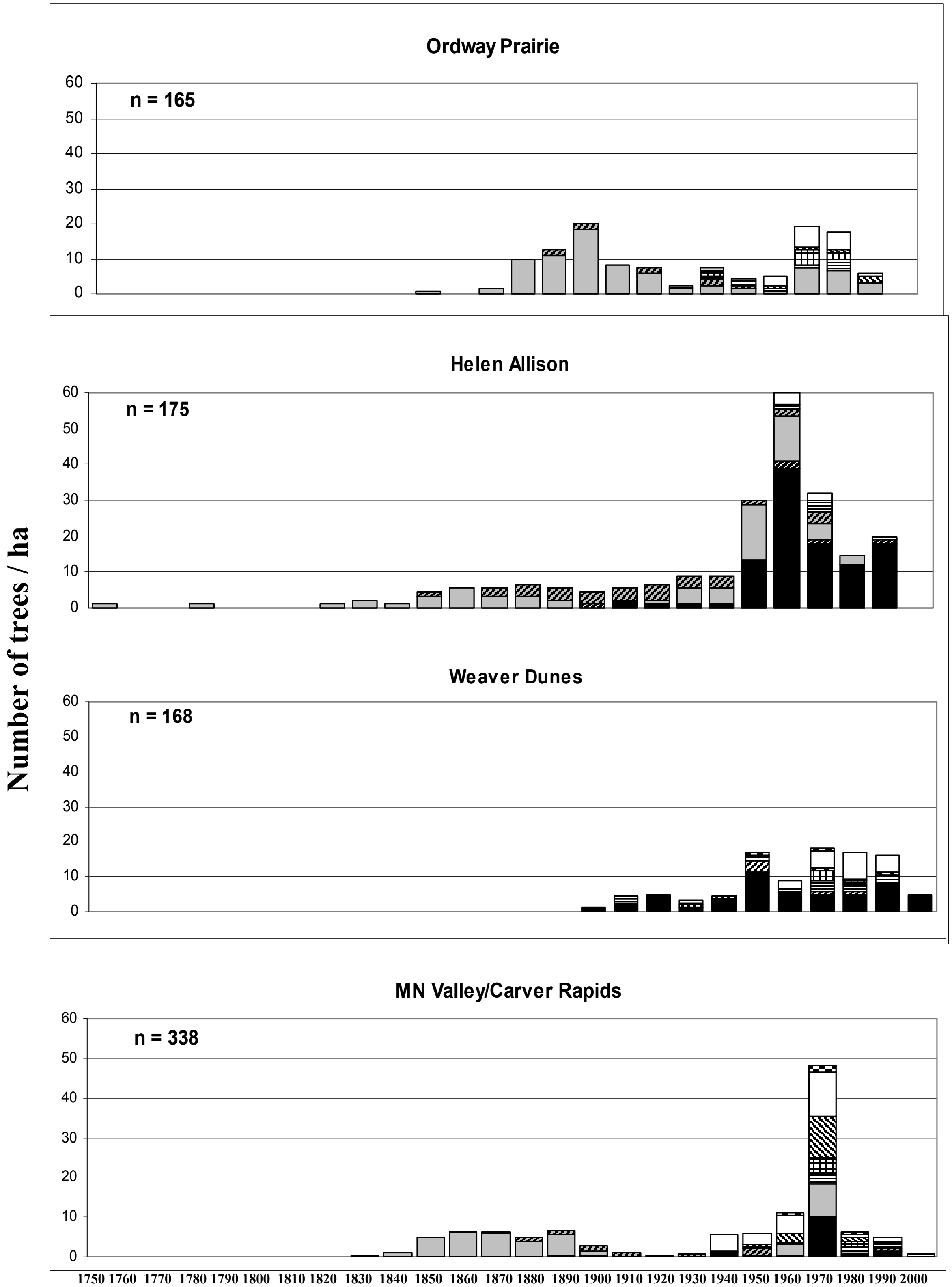


Figure 34: Age structure of sites illustrating the decade in which trees established (reached coring height) on the x-axis and the number of trees on the y-axis. Table 5 on previous page provides color/pattern identification.

Helen Allison

The oldest trees at any of my sites were found at Helen Allison. In all, 175 trees were cored at Helen Allison. Trees ranged in age from 9 years (a northern pin oak established in 1998 at HA31) to 255 years (a bur oak established in 1752 at HA06). Age of establishment of each oak tree (separated by species) was plotted against the dbh, but only for trees established after 1980 (Figure 35). Age and size were significantly correlated for both northern pin oak ($r = .53$, $p < 0.001$, $n = 68$) and bur oak ($r = .89$, $p < 0.001$, $n = 56$).

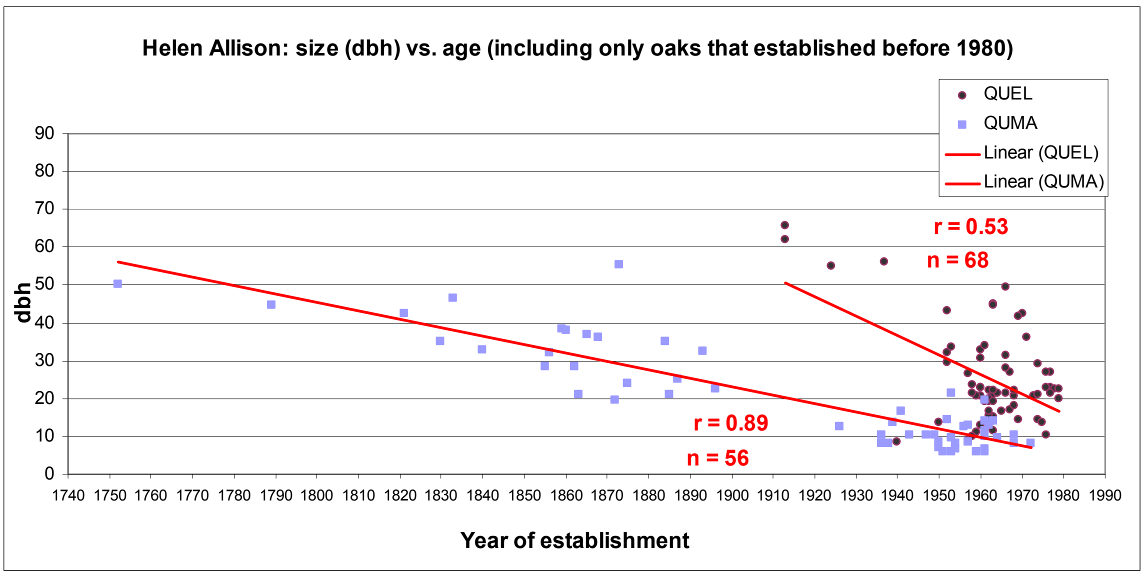


Figure 35: Significant correlations between age and size for both northern pin oaks and bur oaks.

Several clear trends emerged when we view all tree ages for the entire site (Figure 34). The oldest trees are all bur oaks, which seem to have relatively large cohorts from the mid and late 1800s still intact. Northern pin oaks emerged in the early 1900s, but maintained low establishment rates until the 1950s. The mid 1900s had a surge of northern pin oak establishment, but no similar increase in bur oak establishment relative to past decades. Thus, the ratio between the two oak species shifted, with bur oak dominating until 1950, and northern pin oak dominating thereafter. In fact, no bur oaks established in the 1990s, but several pin oaks established. No non-oak species established prior to the 1960s (or if they did, they died and were not present to be sampled). In the 1960s and 1970s, choke cherry, black cherry and green ash established at some plots. However, after those two decades, few non-oak, fire intolerant species established (though perhaps they did but were smaller than the 5 cm dbh trees we cored.

Weaver Dunes

In all, 168 trees were cored at Weaver Dunes. Trees ranged from 107 years old (a northern pin oak that established in 1900 at WD14) to 7 years old (several pin oaks and a box elder established in 2000 at WD62). Tree age and dbh were not significantly correlated (r = 0.17, n = 56) for individuals that established before 1980 (Figure 36).

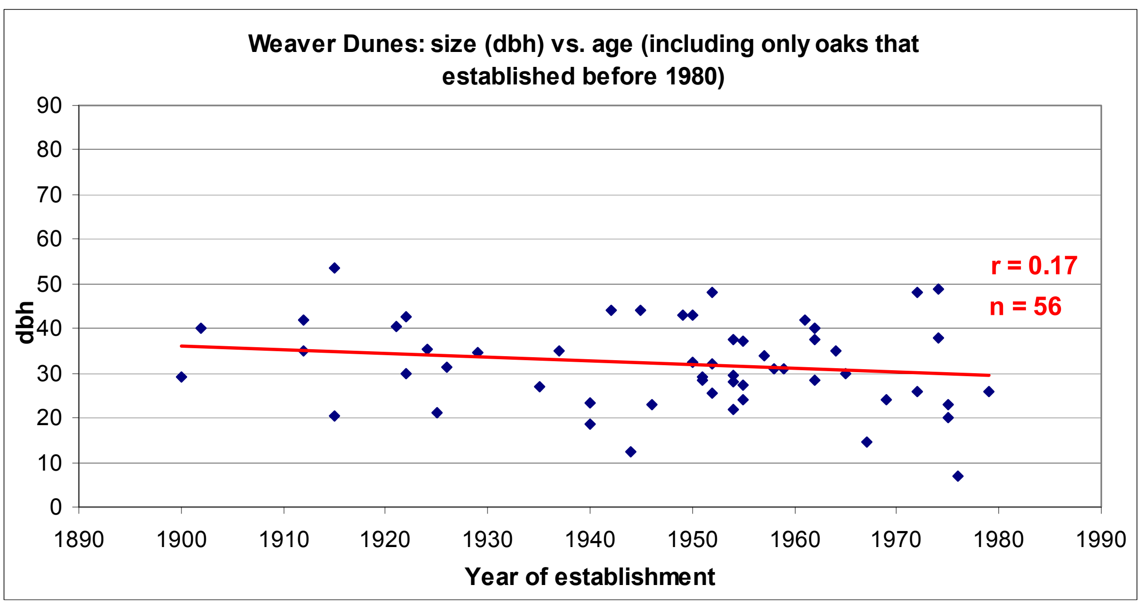


Figure 36: No significant relationship was found between size and age of northern pin oaks established before 1980.

When all tree ages at Weaver Dunes were compiled, the first thing noticed is the lack of old trees at the site (Figure 34). As noted before, the oldest tree at the site dates back only to 1900. Northern pin oak establishment rates were relatively low throughout the early 1900s, and green ash and river birch (*Betula nigra*) established as early as the 1910s. Hickory established in the 1930s and American elm established in the 1940s. In the 1950s, northern pin oak experienced a surge of regeneration, which dropped off in the 1960s and remained low throughout the early 2000s. At the time that northern pin oak establishment declined, a multitude of non-oak (fire-intolerant) species began to invade. Establishment of non-oak species lasted throughout the 1990s and probably the 2000s also, but because we only sampled trees over 5cm dbh, we may have missed many of these recently established trees.

Minnesota Valley/Carver Rapids

In all, 338 trees were cored in Minnesota Valley NWR and Carver Rapids SP. The trees ranged in age from 5 years old (a black cherry establishing in 2002 at MV04) to 169 years old (a bur oak establishing in 1838 at MV06). Age and dbh were significantly correlated for both bur oak, ($r = 0.69$, $p < 0.001$, $n = 102$) and northern pin oak ($r = 0.73$, $p < 0.001$, $n = 32$). Pooled together, age and size were not significantly correlated for the fire-intolerant species ($r = 0.08$, $n = 136$) (Figure 37).

Many bur oaks established at MN Valley/Carver Rapids in the late 1800s (Figure 34). The oldest pin oak established in the 1890s. Very few sampled oaks established in the early 1900s, in fact, none of the sampled oaks of either species established in the 1920s. Only a few sampled bur oaks dated back to the 1930s (no northern pin oaks) and only a few sampled northern pin oaks (no bur oaks) dated back to the 1940s. Establishment increased slightly in the 1960s, both for oak and non-oak species. The 1970s was a high-establishment, including 14 fire intolerant species, most notably basswood and box elder. Tree establishment has decreased significantly relative to the 1970s. Oaks still establish, but the majority of the regeneration is northern pin oak, not bur oak.

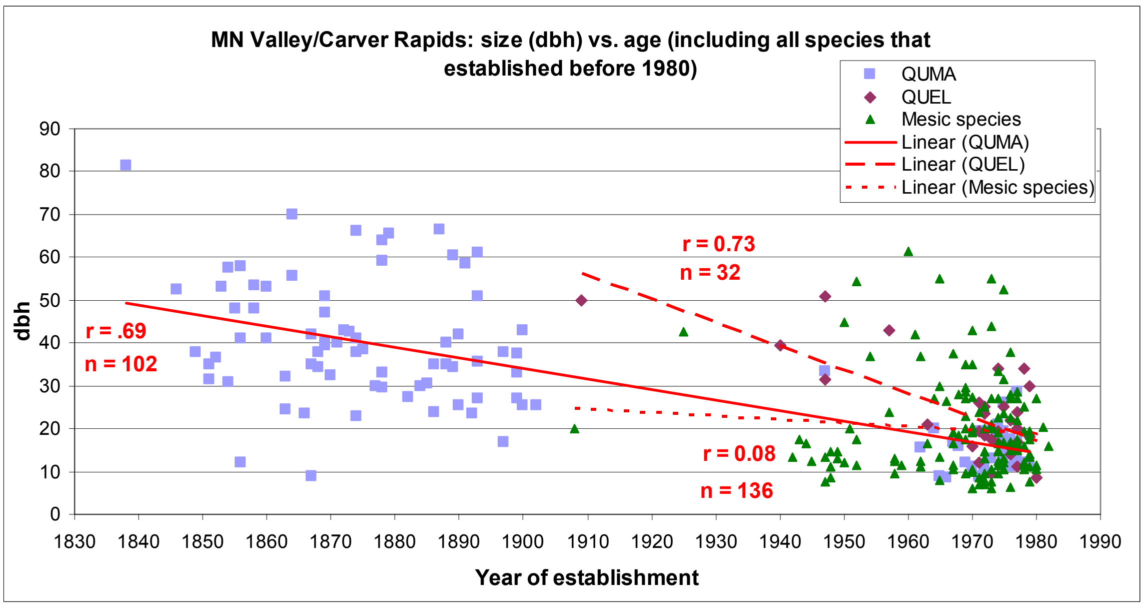


Figure 37: Age and dbh were significantly correlated for both bur oak, and northern pin oak, but not significantly correlated for the mesic species.

All sites' age-structure compared

Across Minnesota, there was high bur oak establishment in the mid to late 1800s and into the first two decades of the 1900s. Low overall oak establishment during the 1930s and 1940s is followed by increasing oak establishment as well as non-oak species establishment in the mid-1900s. Northern pin oak establishment increases rapidly in the mid-1900s, while bur oak establishment appears to decrease, displaying a shift from bur oak dominated establishment to pin oak dominated establishment over the past 200 years (Figure 38).

Table 5: Comparison of dominant species establishment over time and ages of oldest species found at each site.

Dominant species establishment	**Ordway P.**	**H. Allison**	**Weaver D.**	**MN V./C. Rap.**
pre-settlement	QUMA	QUMA	--------	QUMA
settlement to beg of fire suppression	QUMA	QUMA	QUEL	QUMA
fire suppression	QUMA/mesic	QUMA	QUEL	none dominant
management	mesic/QUMA	QUEL	QUEL/mesic	mesic
present	Mesic	QUEL	QUEL/mesic	mesic
Years of establishment				
oldest QUMA	1859	1752	1944	1838
oldest QUEL	-------	1900	1900	1898
oldest FRPE	1931	1965	1912	1964
oldest ACNE	1940	------	1953	1950
oldest ULAM	1969	-------	1947	1947
oldest CEOC	1949	------	1983	1959

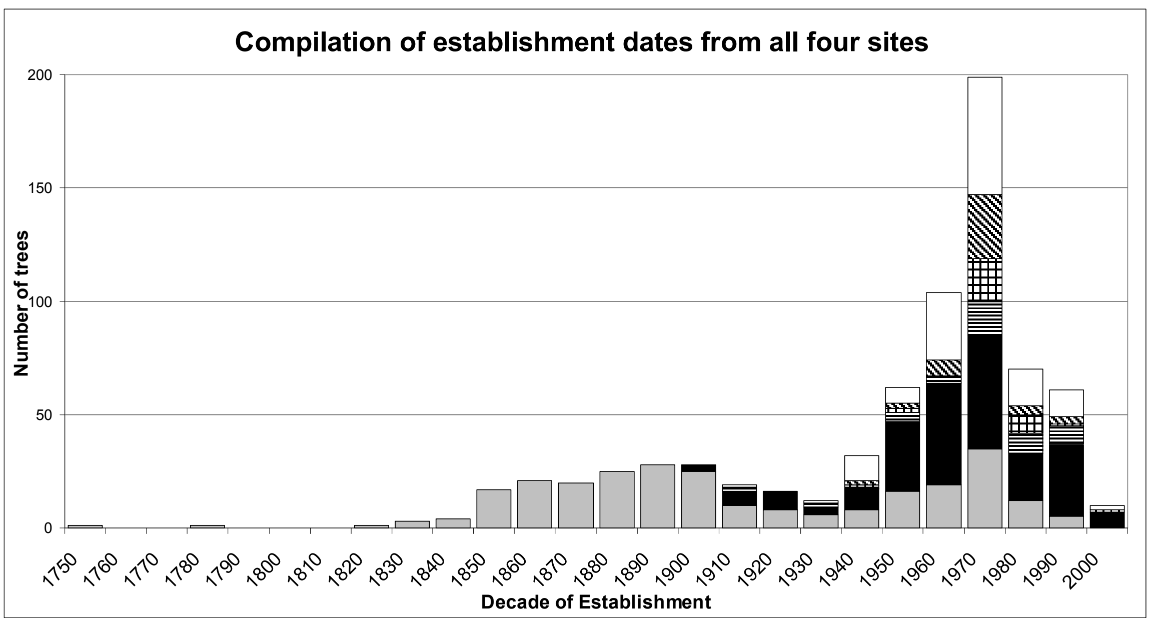


Figure 38: Results of establishment dates compiled from all four sites showing the patterns of decadal establishment throughout the four sites. Only cores where I was successfully able to estimate to the center ring were used.

Fire History

A total of 57 samples were collected from the four sites to analyze the fire history: 16 from Ordway, 18 from Helen Allison, 13 from Weaver Dunes and 10 from Minnesota Valley/Carver Rapids. Due to rot, only 42 samples were used in the study: 16 from Ordway Prairie, 11 from Helen Allison, 8 from Weaver Dunes and 7 from Minnesota Valley/Carver Rapids (Table 2 and Figure 39).

Ordway

All trees sampled for fire scars at Ordway Prairie were bur oak. Of the 16 samples, three were full cross-sections of the tree and 13 were wedges taken from the base. Although the two oldest trees dated back to 1887, the earliest fire was recorded in 1976, thus the fire scar record extends from 1976 to 2007 and all but one sample (dating back only to 1946) pre-date fire suppression. In 16 samples, 17 scars were found and dated. Of the 17 identified fire scars, none of them were from fires predating fire suppression and all of them matched the dates of prescribed burns. Fire scars were found at heights ranging from 16 cm to 60 cm and the average size of trees that were scarred was 46.5 cm in dbh. Based on the scars found (which, again, were all from prescribed burns), the mean fire interval (MFI) for the site is 6.5 years. From the prescribed burn records, the average MFI at sampled plots in the site is 6.2 years.

Helen Allison

All trees sampled for fire scars at Helen Allison were bur oak. All eleven samples were full cross-sections of the tree. Although the oldest tree sampled dated back to 1857, the earliest fire was recorded in 1868, thus the fire scar record extends from 1868 to 2006 and all but two samples pre-date fire suppression. In 11 samples, 18 scars were found and dated. Of the 18 identified fire scars, none were from a fire that pre-dated settlement, seven were from fires predating fire suppression, two were from wildfires that occurred before the prescribed burning program began in 1962 (during fire suppression) and nine of them were from prescribed burns. The MFI for the site from pre-European settlement through the present is 10.4 years; 8.6 years for the pre-fire suppression era and 11.9 years for the post-fire suppression era. The recorded prescribed burn average MFI for sampled plots in the site is 3.6 years.

Weaver Dunes

Of the eight usable fire scar samples at Weaver Dunes, six were pin oak and two were bur oak. Six samples were full cross-sections and two samples were wedges. The oldest tree sampled was a bur oak that dated back to 1861 and the earliest fire was recorded in 1967, thus, the fire scar record extends from 1967 to 2007. Only four of the eight samples pre-date fire suppression. In eight samples, 10 scars were found and dated. Of the 10 identified fire scars, none originated prior to fire suppression, one likely arose from a wildfire in 1967 and nine of them were likely caused by prescribed burns. Fire scars occurred at heights ranging from 5 cm to 40 cm and the average size of trees that were scarred was 32.8 cm dbh. Based on the scars found, the MFI for the site is 7.6 years (based entirely on post fire suppression era samples). From the written prescribed burn records, the average MFI for sampled plots at the site is 6.6 years.

Minnesota Valley/Carver Rapids

All seven fire scar samples collected from Minnesota Valley/Carver Rapids were bur oak. Three of the samples were full cross-sections of the tree and four were wedges. The oldest tree sampled dated back to 1851 and the earliest fire was recorded in 1977. Thus, the fire scar record only extends from 1977 to 2007, and all seven samples pre-date fire suppression. No samples pre-date European settlement. In seven samples, 10 fire scars were detected. None of the fire scars pre-date fire suppression and all of them were from prescribed burns. Fire scars were found at heights ranging from 21 cm to 50 cm and the average size of trees scarred was 47 cm in dbh. The MFI for the site is 4.5 years (based entirely on post fire suppression, prescribed burns). From the prescribed burn records, the average MFI for sampled plots at the site is 3.2 years.

Table 6: Comparison of fire scar sampling results from all four sites

Fire History	**Ordway P.**	**H. Allison**	**Weaver D.**	**MN V./C. R.**
Oldest scar	1976	1868	1967	1977
# samples that pre-date settlement	0	1	0	0
# samples that pre-date fire-suppression	15	9	4	7
# samples total	16	11	8	7
# pre-settlement scars found	0	0	0	0
# pre-fire suppression scars found	0	5	0	0
# prescribed burn scars found	17	9	10	10
Pre-fire suppression MFI (years)	------	8.6 years	--------	---------
Post-fire suppression MFI (from scars)	6.5 years	11.85 years	7.6 years	4.5 years
MFI (entire time period)	6.5 years	10.38 years	7.6 years	4.5 years
Recorded prescribed burn MFI (years)	6.15 years	3.56 years	6.6 years	3.2 years

All sites

The composite fire history record for the four sites spanned the period of 1868 to 2007 (Table 6). Overall, 55 fire scars from 42 trees were dated. Of the 42 trees, only one pre-dates Euro-American settlement and 35 pre-date fire suppression. Of the 55 scars, none pre-date Euro-American settlement, seven of them were from fires predating fire suppression (all from Helen Allison), three were from wildfires during fire suppression times and 45 were from prescribed burns. Therefore, the calculated pre-fire suppression MFI for all four sites is what we found at Helen Allison (8.6 years). The calculated prescribed burn MFI for the landscape from the fire scar data is 7.5 years whereas the actual recorded MFI for prescribed burns is 5 years. Compiling all sites' fire scars together, fire scars were found at heights ranging from 5 cm to 60 cm.

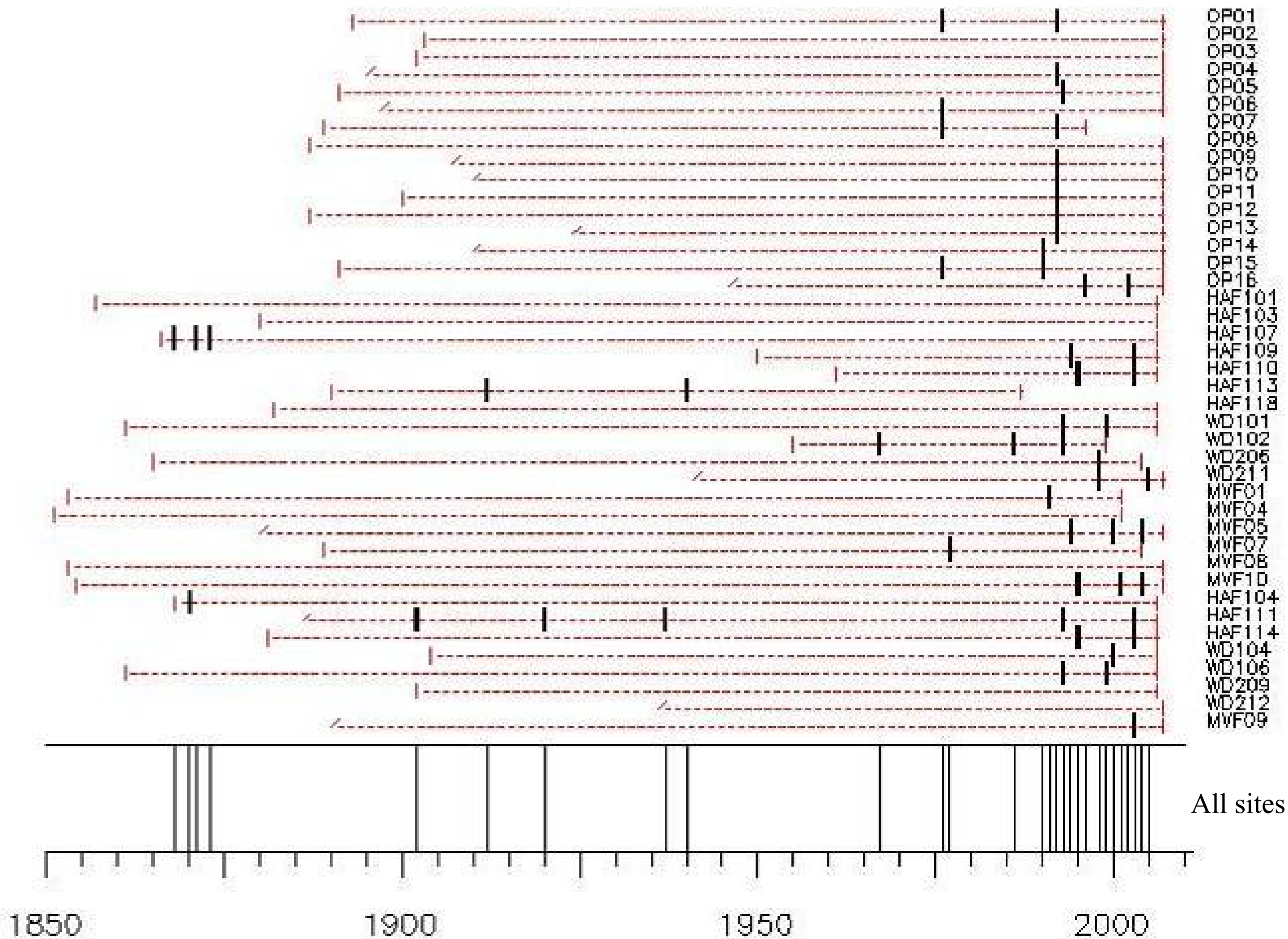


Figure 39: Fire chart displaying all fire samples taken (horizontal dashed lines) and all fire scars found in those samples (vertical, thick black lines). This chart was created using the computer program, FHX2 (Grissino-Mayer 1996).

Public Land Survey Records

During public land surveys in the mid 1800s, bearing trees were marked and measured by surveyors to facilitate the relocation of survey corners (Almendinger 1996). Though it is not specified in any of the survey instructions, bearing trees were likely measured below breast height, towards the base of the tree (Bourdo 1954). Therefore, tree measurements are probably overestimates of the actual dbh of the trees, but likely not by much.

Table 7: Year each site was surveyed and location in Land Survey Field Notes. Field Notes were obtained from the Minnesota Historical Society.

	Yr. surveyed	Location in Land Survey Field Notes
Ordway Prairie	1856	Volume 498, pp. 27-32, 35-40, 46, 47, 80-83
Helen Allison	1857	Volume 181, pp. 11, 12, 22-26
Weaver Dunes	1855	Volume 270, pp. 27-30, 48, 49, 68-70, 75-79
MN Valley/Carver Rapids	1855	Volume 307, pp. 64-77, 86-99

Ordway Prairie

Surveyors used the following phrases in their field notes to describe the Ordway Prairie area: "oak openings", "scattering oak", "grove of oak", "timber oak and aspen", "prairie and timber oak", "prairie" and "wet marsh" (Land Survey Field Notes, Volume 498, pp. 27-32, 35-40, 46, 47, 80-83). Bur oak was the only oak species reported in the area and was the predominant marker tree used by the surveyors as well as the predominant tree reported in observational notes. The average size of a bur oak bearing tree was 9.25 inches (23.5 cm) in diameter. Aspen was occasionally used as a bearing marker tree and was often reported in observational notes. Ironwood, elm (probably

American, but species unknown) and birch were reported to have been growing together near lakes. In these more species diverse areas, an “undergrowth of prickly ash and hazel” was reported. “Deposited charcoal” was frequently noted. Much of the surrounding land is labeled as “prairie” and, often, no trees in the immediate vicinity could be located as markers, so an Osage orange tree was planted as a marker (Almendinger 1996).

Helen Allison Savanna

The following descriptive phrases were used: “Timber scattering, black and burr oak and oak brush”, “Black oak openings”, “Timber black oak” and “wet marshes”. Of the 12 bearing trees marked in this area, three were bur oak and nine were “black oak” (Land Survey Field Notes, Volume 181, pp. 11, 12, 22-26). “Black oak” likely refers to northern pin oak because Helen Allison is north of the range of black oak (Burns and Honkala 1990, Almendinger 1996). The average size of a marked bur oak tree was 11 inches (28 cm) and the average size of a marked northern pin oak was 9.5 inches (24 cm).

Weaver Dunes

The following descriptive phrases were used for the area: “prairie”, “sandy prairie”, “dry sandy bottom”, “timber oak”, “scattering oak”, timber oak ash”, “timber oak, elm, ash, maple, lind etc.” “oak, ash, elm and cottonwood” and “marshes” (Land Survey Field Notes, Volume 270, pp. 27-30, 48, 49, 68-70, 75-79). “Lind” probably refers to basswood (Almendinger 1996). Much of the area was labeled “prairie” and lacked any trees for marking, thus, mounds were created and Machua seeds were planted to mark corners. Of the few bearing trees marked in this area, six were black oak, one was elm and one was maple. "Black oak" likely refers to northern pin oak because Weaver Dunes is north of the range of black oak (Burns and Honkala 1990, Almendinger 1996). The average size of a marked northern pin oak tree was 14 inches (36 cm), the elm was 12 inches (31 cm) and the maple was 20 inches (51 cm).

Minnesota Valley/Carver Rapids

Surveyors described the area as: "Timber bur black and white oak", "Timber sugar bur white and red oak", "Timber very scattering bur black and white oak", "Timber oak aspen and elm", "Timber oak sugar elm lind and butternut", "Timber sugar elm oak lind and ash" as well as "prairie" and "marshy" (Land Survey Field Notes, Volume 307, pp. 64-77, 86-99). On the western side of the river, where scattering bur oak was observed and only bur oak trees were marked, surveyors noted that it was "impossible to make trench", implying that the bedrock was very near the surface (similar to what we saw at Minnesota Valley/Carver Rapids). "Black oak" likely refers to northern pin oak because Minnesota Valley/Carver Rapids is north of the range of black oak (Burns and Honkala 1990, Almendinger 1996). "Sugar" refers to sugar maple and "lind" refers to basswood. Often *Q. ellipsoidalis* (northern pin oak) was called "red oak" and often *Q. macrocarpa* was referred to as "white oak" (Almendinger 1996). Of the bearing trees marked in the extended area surrounding Minnesota Valley/Carver Rapids, the surveyors identified 28 bur oak, 19 northern pin oak, 16 sugar maple, 16 elm, 8 white oak, 2 ash, 2 basswood, 2 aspen, 2 maple, and one each of bitternut, hickory, ironwood and box elder. Ironwood was noted only once in the field notes and used once as a marker tree. In a list of surveyors "preferred" marker trees, ironwood is listed high on the list, meaning that if it was available, it would have likely have been used as a marker tree (Almendinger 1996). The average size of a marked bur oak was 10 inches (25.5 cm), northern pin oak 12.8 inches (32.5 cm), elm 13.5 inches (34.5 cm), white oak and sugar maple 12 inches (30.5 cm).

Discussion

Filtering out various anthropogenic disturbances at work in these four oak savanna sites is challenging. The following description pieces together the relationship between the forest structure, age structure and fire patterns of each preserve with the known landscape history since European settlement and the elimination of large ungulates and fire. In essence, this analysis assesses the effects of anthropogenic factors on the landscape. These deductions and conclusions in conjunction with surveyor notes, allow inferences as to what pre-settlement conditions were like at each site.

Oak species found during sampling

As stated before, two species of oak were encountered across my four sites: *Q. macrocarpa* and *Q. ellipsiodallis*. These oaks' distinctly different life history characteristics are displayed in the table below:

Table 8: Life history characteristics of bur oak and northern pin oak.

	Bur oak (*Q. marcrocarpa*)	**Northern pin oak (*Q. ellipsoidalis*)**
Shade tolerance	Intolerant[1]	Intolerant[1]
Bark thickness	Thick[2,3]	Thick (but not as thick as b. oak)[4]
Growth rate	slow[2,10,11]	Moderately fast growing[11]
Longevity (years)	200-400 [2,5]	100-200[6]
Minimum seed-bearing age (yrs)	35[2]	15-20[4]
Acorn size	Large[5]	Small
Acorn palatability	Palatable	Relatively un-palatable
Germination (time of year)	Fall[2,3,7]	Spring[9]
Soil preferences	Clay, loam and sand[10]	Very sandy soils[4]
Climatic preferences	Drought tolerant[8]	Less drought tolerant than bur oak[8]

Data sources: [1]Abrams and Kubiske (1990); [2]Tirmenstein (1988); [3]Burns and Honkala (1990); [4]USDA/NRCS "northern pin oak"; [5]Guyette et al. (2004); [6]Peterson and Reich (2001); [7]Fox (1882); [8]Faber-Langendoen and Tester (1993); [9]Illinois DNR ; [10]USDA/NRCS "bur oak"; [11]Minnesota DNR.

Historical ecological records

Dendroecological records pre-dated Euro-American settlement at two sites: Helen Allison and Minnesota Valley/Carver Rapids. Although the pre-settlement tree-ring records are not extensive, I am nevertheless able to provide a rough pre-settlement historical reference through tree rings and inner fire scars at these two sites. Public Land Survey (PLS) accounts combined with known landscape changes and a dendroecological record extending back prior to European settlement of the area enable me to provide a relatively accurate assessment of conditions prior to European settlement.

Ordway Prairie's dendroecological record does pre-date settlement, but is far too short to provide a reliable pre-settlement historical reference through tree rings. None of the dendroecological record at Weaver Dunes pre-dated settlement of the area, and thus, I am unable to provide a pre-settlement historical reference through tree rings and inner fire scars. However, the data collected in this study combined and compared with known landscape changes as well as vegetation notes provided by PLS records can elucidate historical vegetation patterns at Ordway Prairie and Weaver Dunes (Asbjornsen et al. 2005).

Early settlement era (mid-1800s to early 1900s)

Fate of old bur oaks

Bur oaks can live 200 to 400 years (Burns and Honkala 1990) and they had a notable presence in PLS reports at Ordway Prairie, Helen Allison and Minnesota Valley/Carver Rapids. However, only Helen Allison contained bur oaks dating older than 200 years. Dendroecological records at Ordway Prairie and Minnesota

Valley/Carver Rapids barely pre-date settlement, although their age structures display heavy bur oak establishment in the late 1800s. In fact, while over 40 bur oaks were found to have established in the late 1800s at Ordway Prairie, only one bur oak, which reached coring height around 1870, pre-dated Euro-American settlement. Why were no older bur oaks present in my sampling at Ordway Prairie and Minnesota Valley/Carver Rapids?

Karnitz and Asbjornson (2006) found similar results in an Iowa oak savanna and concluded that early settlers logged and/or cleared the timber for grazing or farming, thus accounting for the lack of old oaks at the site. However, my age structure data shows that bur oak establishment surged *during* the period of early Euro-American settlement (late 1800s-early 1900s). Therefore, there must have been bur oaks on the preserve just prior to this surge as well as during the surge to provide an acorn seed bank sufficient enough to foster establishment. It is extremely unlikely that viable bur oak acorns would remain in the seed bank for more than a year or so due to heavy predation (McShea and Schwede 1993, Fox 1982) and life history characteristics. Immediately after falling from the tree in autumn, bur oak acorns sprout and quickly establish a long taproot. The acorns that do not sprout are highly susceptible to freezing and burial by squirrels (who remove the germinating part of the acorn before burying it) (Fox 1982). Therefore, some larger bur oaks must have been present in the area during the early settlement period to effectively replenish the seed bank. I propose five possible scenarios as explanations for the lack of old bur oaks in my tree ring records at these two sites:

1) Similar to other oaks, bur oaks often have shorter life expectancies when growing on poorer soils (Burns and Honkala 1990). Thus, bur oaks of pre-Euro-American

settlement may have experienced shorter life spans on Ordway Prairie's sandy soil and Minnesota Valley/Carver Rapids shallow, stony soil. However, older bur oaks are present at Helen Allison, which also has sandy soil. Moreover, if early senescence is the explanation, I would likely be seeing some signs of weakening or canopy death in the oldest oaks - which I did not observe. Remnant and fallen snags (standing dead trees) were absent from sample plots. However, it is likely that oaks that died in the mid to late 1800s would be in such later stages of decay by 2007, that they would be unrecognizable or completely decayed (Berry and Beaton 1972). It is also possible that these old oaks did senesce and die and the early settlers removed all of the dead wood, but, again, if this was the case, and bur oaks do not live longer than 150 years in these growing conditions, the oldest oaks would have shown signs of degradation. At Minnesota Valley/Carver Rapids, it is equally probable that many of these dead and downed logs have been pilfered through the years for firewood.

2) Old bur oaks were simply not detected by my sampling grid. If this is the case, it is possible that only a few parent individuals combined with a few successful mast years may have been sufficient for successful recruitment of new oak seedlings (Karnitz and Asbjornson 2006). However, these would have to be relatively impressive, large canopied trees to provide enough acorns and, given the relatively small size of areas sampled, I would likely have come across them and/or have been informed of their presence by land managers.

3) Older oaks died due to extreme drought. Faber-Langendoen and Tester (1993) found that drought may have been a primary factor responsible for oak mortality in CCNHA. Furthermore, Engle (1997) found that tree mortality in drought is greater for

older trees. Therefore, a severe drought, such as the drought of 1910 or the drought of the 1930s (see Figure 40) might have been enough to kill many of the remaining old oaks. Another study on oak mortality showed that there was a time lag (approximately one decade) between the drought that caused the oak death and the actual death of the oak (Drobyshev et al. 2007). These remnant standing or fallen snags from the mid-1900s would likely still persist to this day and, further, no remnant snags or logs were noted. These dead snags may have since been logged, accelerating the decay process, rendering their stumps unrecognizable.

4) The oldest trees were not logged until later in the early 1900s (perhaps around the 1930s or 40s) and, thus, were able to provide a seed bank for the earlier surge, but would be absent now. If the trees were logged in the 1930s or 40s, it is possible that chainsaws (which were mass-produced beginning in the 1930s) were used, and therefore, remnant stumps are lower and more likely to be missed in this study's sampling grid and by land managers.

In reality, the fate of these old parent oaks is probably a combination of the four scenarios stated above. Given that much of the land surrounding Ordway was treeless prairie (PLS field notes), the bur oaks there were probably logged early on to build Fort Johanna (around 1865). Similarly, much of the MN Valley/Carver Rapids area was either cleared for cultivation or selectively logged for firewood and lumber in the mid-late 1800s. The old oaks that *were* spared in this early settlement period (perhaps because they were too small) grew vigorously with less competition and provided the acorn seed bank for the surge in the early settlement period. Some of these older oaks have likely died and rotted away, some died due to droughty conditions and some were not logged until the mid-1900s.

Fate of old northern pin oaks

In contrast to Ordway and Minnesota Valley/Carver Rapids, bur oaks at Helen Allison dated to 1752, confirming that this area did, indeed, contain old, gnarled bur oaks characteristic of idyllic oak savannas. PLS observation notes at Helen Allison indicate that northern pin oak had an equal presence (if not more of a presence based on the number of times it was mentioned in records) on the savanna as bur oak. However, my age structure data suggests that Helen Allison was composed of solely bur oak until the early 1900s when northern pin oak establishment increased and ultimately dominated. Similarly, not a single northern pin oak from any of my forest structure plots pre-dated European settlement of the Weaver Dunes or the Minnesota Valley/Carver Rapids area. PLS records indicate the presence (and dominance) of northern pin oak in the Weaver Dunes area and the presence and (likely co-dominance) of northern pin oak at Minnesota Valley/Carver Rapids. Why are we not seeing more old northern pin oaks at these three sites? There are four possible explanations for this:

1) In soils with low water holding capacity and low fertility, northern pin oak is relatively short-lived (Peterson and Reich 2001), often living only 100-120 years old. Thus, it is possible that many of the northern pin oaks that established in the 1700s and 1800s have died already. However, in agreement with Ziegler et al. (2008), I saw no evidence of old northern pin oak stumps, snags or remnants. Northern pin oaks, which are relatively susceptible to decay (especially considering the amount of burning in this

preserve), may be in such late stages of decay as to render them unrecognizable by now. In fact, I encountered more heart rot (more incomplete tree cores) at Helen Allison than any of the other sites.

2) The northern pin oaks are actually older than tree rings indicate. Northern pin oak, more so than bur oak, tends to get setback from fire and forms grubs (sometimes called scrub oak) (Bowles and McBride 1998). In some instances, the bases of trees are much older than the tree rings at coring height suggest (Gutsell and Johnson 2002, Niklasson 2002). Unfortunately, without digging up the roots, I am unable to assess the full age of these grubs.

3) The first settlers that arrived in the mid-1800s selectively logged the area to provide lumber for houses. Although bur oak is known to be better lumber than northern pin oaks (Abrams 2003), and choice bur oaks were probably logged first, perhaps bur oaks were sufficiently gnarled and low-limbed to preclude cutting them with a cross-cut saw. Settlers may have selectively logged the northern pin oak because it often grows faster, straighter and taller. This explanation, however, is unlikely considering the fact that much of the northern pin oak in the area was probably small-diameter scrub oak. No history of logging is reported for the Weaver Dunes area; however, settlers most likely harvested some northern pin oaks for lumber and firewood, and to clear the ground for cultivation.

4) I simply missed the old northern pin oaks in my sampling grid. However, in the case of Helen Allison, this study combined with data from Ziegler et al. (2008) creates a thorough dendrochronological assessment of the small preserve, so this is unlikely.

The fate of these older northern pin oaks is probably a mixture of scenarios 1 and 2. While selective logging likely occurred in these areas, it probably did not contribute to the absence of old northern pin oaks in the tree ring records at Helen Allison and Minnesota Valley/Carver Rapids. Northern pin oak is considered poor quality lumber (Cassens 2007) and is not even mentioned in the *Silvics of North America*, a manual which represents most commercially important trees of North America (Burns and Honkala 1990). However, because Weaver Dunes is virtually completely composed of northern pin oak, the likelihood that selective logging did contribute to the lack of old northern pin oak in the area is relatively high.

Surge of oak establishment or lull in oak establishment?

Oak regeneration at all four sites has fluctuated through time. In all instances, heavy oak establishment in the late 1800s (and sometimes early 1900s) is followed by a low establishment period in the early-mid 1900s. In many cases, it is hard to determine whether we're seeing heavy establishment in the late 1800s, or if we're simply seeing low establishment in the early-mid 1900s (or both).

A number of factors could have contributed to increased oak establishment in the late 1800s and early 1900s: 1) a decrease in ungulate herbivory and 2) cattle grazing and the subsequent reduction in fine fuels.

Hunting by early settlers effectively reduced deer and elk populations and completely extirpated bison from the area by the late 1800s (Coffin and Pfannmuller 1988). These ungulates fed on acorns and trampled and browsed woody seedlings, thus representing a disturbance capable of having major effects on woody shrubs and seedlings (Vera 2000, Danell et al. 2006, Ripple and Beschta 2007). Studies have shown that oak successfully regenerates and survives and is even favored in areas grazed by bison and other large ungulates (Vera 2000, Briggs et al. 2002). However, bison were transient, allowing periods of growth for herbaceous species (the main competition for woody seedlings) to recover from grazed conditions. Therefore, elimination of transient ungulate populations (and the subsequent implementation of continuous cattle grazing (see below)) would remove competition from herbaceous plants, increasing bur oak seedling establishment.

Light to moderate cattle grazing weakens the herbaceous layer, allowing woody species, like oak, to establish (Scholes and Archer 1997, Jackson 1999). Cattle feed on the herbaceous layer first, avoiding the woody seedlings. A study in South Dakota found a similar surge of bur oak establishment in the late 1800s when open-range cattle ranching (light grazing) was practiced (Ripple and Beschta 2007). In addition, grazing also reduced the amount of fine fuels, decreasing not only the likelihood of fire, but also the intensities and spatial extents of fires that may have passed though the site. Fire samples at Ordway Prairie and Minnesota Valley/Carver Rapids reveal approximately four decades of post-settlement, pre-fire suppression tree-ring history. No fire scars were found for this post-settlement, pre-fire suppression time period. Even though bur oaks have thick, fire-resistant bark, it is nevertheless surprising that this study failed to find even one fire scar during these four decades. This lack of fire scars indicates that fires were either less intense during this period or much less frequent (or both) than recent prescribed fires have been. This period of light grazing and slightly reduced fire intensities would have fostered oak establishment. Further, the frequent scarring from prescribed burns indicates that these pre-fire suppression fires (if they occurred at all) were most likely less intense than the prescribed burns of today.

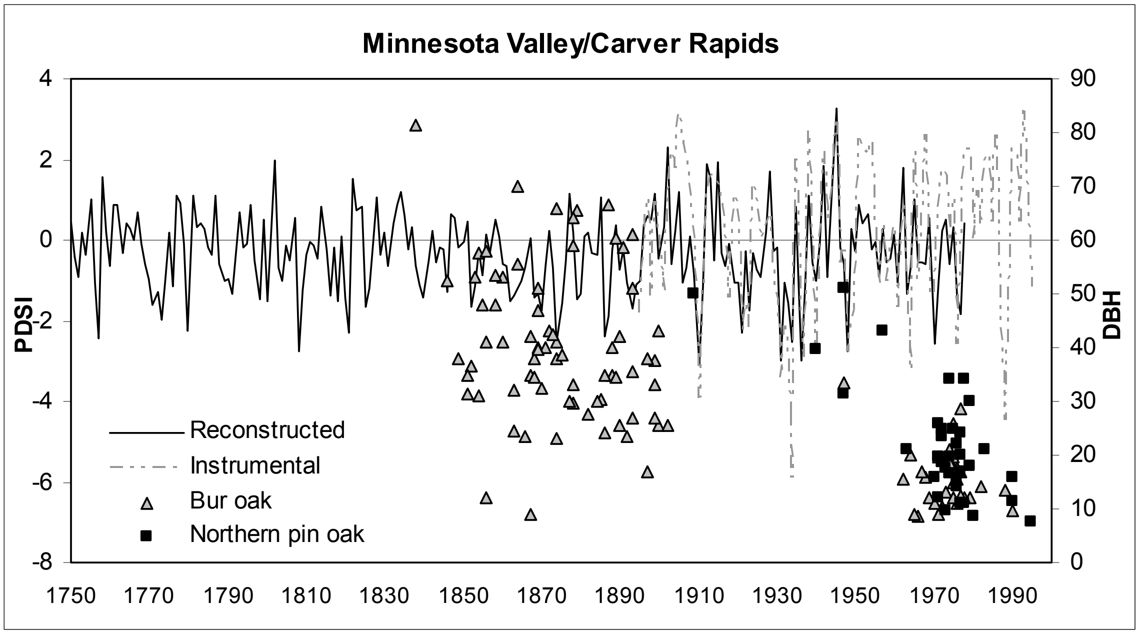
Similarly, a number of factors likely contributed to low oak establishment in the early-mid 1900s: 1) drought and 2) increased grazing intensities and the onset of farming.

Severe drought in the 1930s may have created harsh enough conditions to kill many young oak saplings that established in the first two decades of the 1900s and decrease further oak establishment during the dry spell. Although northern pin oaks are often found on the sandiest and nutrient deficient soils, they are not as drought resistant as bur oak and often fare worse during droughty periods (Faber-Langendoen and Tester 1993). Studies in the Missouri Ozarks found similar results, showing a higher abundance of red oaks compared to white oaks on drought-prone and nutrient-deficient sites (Kabrick et al. 2008), but significantly greater red oak mortality during droughty conditions (Law and Gott 1987, Starkey et al. 1989). This study found mixed results regarding oak species establishment during droughty conditions (Figure 40).

Compared to bur oaks, northern pin oaks established less frequently during droughts at Helen Allison and Minnesota Valley/Carver Rapids (Figure 40). Bur oaks at Ordway Prairie appear to establish more often during wet periods, but do show establishment during droughty periods (Figure 40). Northern pin oaks at Weaver Dunes appear to fare better during droughts than at any other site (Figure 40). Thus, it appears that, in competition with bur oak, northern pin oak is the less drought resistant and less competitive species, but when growing without competition from bur oak, northern pin oak is able to successfully establish during droughts.

The soil at Minnesota Valley/Carver Rapids is relatively thin (6 inches or less of soil material) and the bedrock is close to the surface. Not only would these soil conditions make it difficult for oaks to establish in harsh, droughty conditions, but they would also make it difficult for young oak saplings without established root systems to survive, perhaps accounting for the lack of establishment in the 1920s, when there were wetter conditions.

Although bur oaks establishment appears to have occurred during droughts, my results are not convincing enough to state that bur oaks establish during droughts. Ziegler (2008) found that oaks established at Helen Allison during droughts. They hypothesized that "dry conditions limited plant productivity, which in turn decreased competition between grasses and tree seedlings and reduced rates of accumulation of fine fuels, enabling seedlings to grow tall to resist subsequent fires" (Ziegler et al. 2008, p. 47). As seen in Figure 40, in general, establishment dates from my study do not match as well with dry periods as establishment dates documented by Ziegler et al. (2008). This poor match/establishment during the dry spell of the 1930s is likely due to heterogeneity across the site. The effects of horse grazing during the first half of the century were, perhaps, not consistent across the site and, during these dry conditions, when Ziegler et al. (2008) hypothesized that oak seedlings would be most likely to establish and survive, herbaceous plant densities were already stressed, forcing grazers to eat the oak seedlings as well (Vera 2000). Further analysis of the relationship between oak establishment and climate is needed to more accurately determine when and why oaks establish.



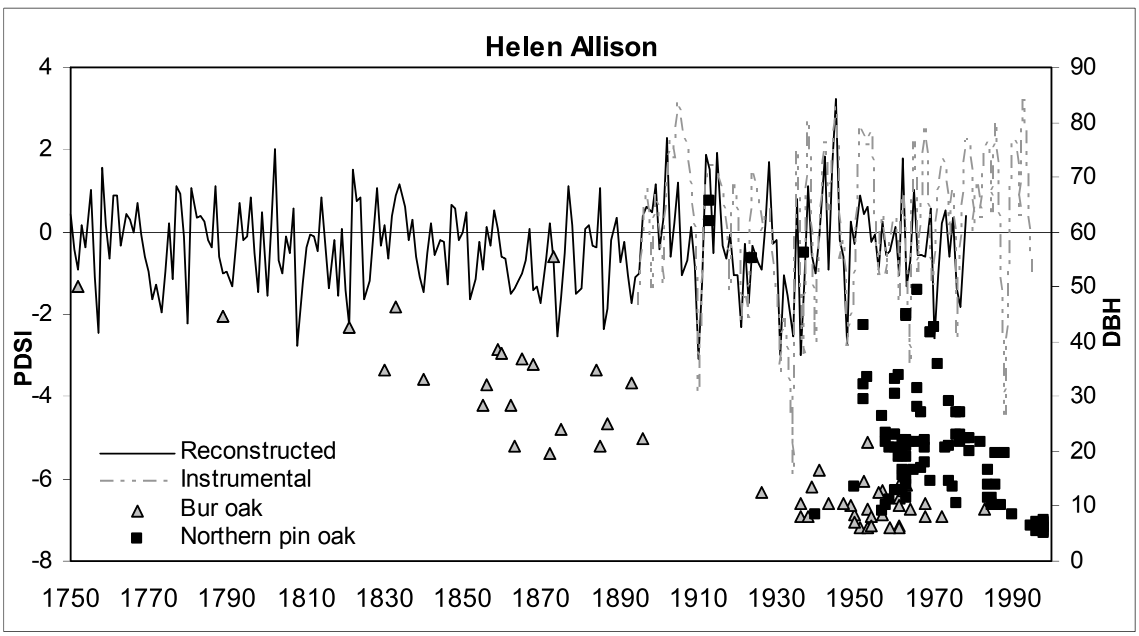
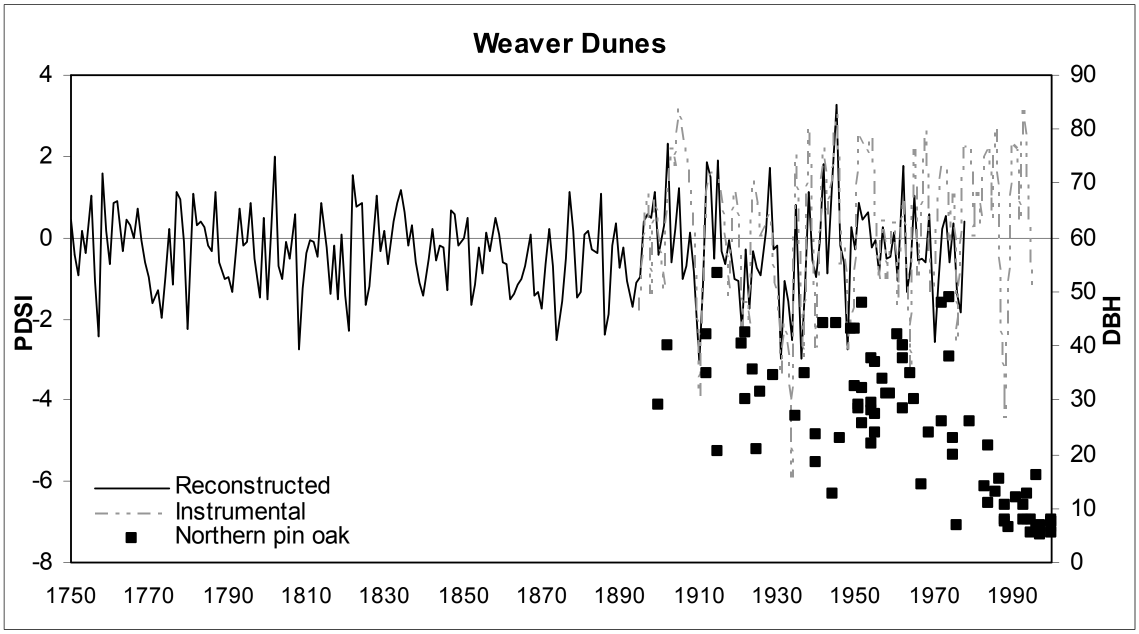


Figure 40: Tree-ring reconstructed Palmer Drought Severity Index (PDSI) and instrumental PDSI record for each site, with oak establishment dates and size of tree (dbh) plotted on graph. Graph illustrates low oak establishment during droughts of 1910 and 1930s at MN Valley/Carver Rapids and Helen Allison. PDSI data were downloaded from the National Climatic Data Center, www.ncdc.noaa.gov/paleo/pdsidata.html.



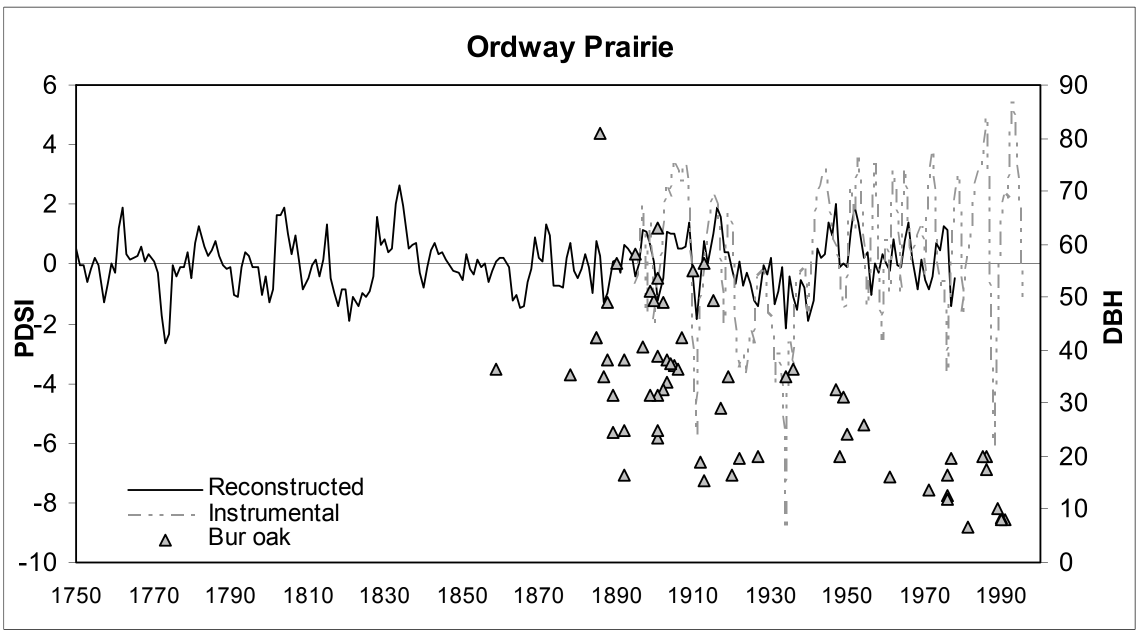


Figure 40 (continued): Tree-ring reconstructed Palmer Drought Severity Index (PDSI) and instrumental PDSI record for each site, with oak establishment dates and size of tree (dbh) plotted on graph. Graph illustrates low oak establishment during droughts of 1910 and 1930s at MN Valley/Carver Rapids and Helen Allison. PDSI data were downloaded from the National Climatic Data Center, www.ncdc.noaa.gov/paleo/pdsidata.html.

The onset of farming and increased grazing intensities at Weaver Dunes

Minnesota Valley/Carver Rapids impeded woody establishment. Increases in farming activity involved extensive clearing and cultivation, resulting in the death of young and old oaks. Studies in abandoned agriculture fields display limited tree establishment due to resource limitation, dispersal limitation, herbaceous competition and lack of mycorrizal symbionts (Dickie et al. 2007). At Weaver Dunes, plots that underwent intensive farming during the early half of the 1900s (see Galatowitsch 1984 for complete land-use history) show inhibited oak establishment for decades, even after farming ceased.

Intensive grazing has been shown to decrease oak establishment because grazers, in efforts to find food, are forced to feed on woody seedlings and saplings (Vera 2000). Plots at Weaver Dunes that had been previously under intensive grazing show little to no oak establishment during that time period. Much of the Minnesota Valley/Carver Rapids site was thought to have been grazed beginning in the late 1880s or early 1890s (the majority of the Louisville swamp unit was unsuitable for cultivation because of the stony soil (Harms 1959)). While the grazing intensities began as rather light, cattle densities increased quickly and, by the early 1900s, intensive grazing was likely the dominant land-use type at Minnesota Valley/Carver Rapids. Alternatively, the lack of oak establishment at Minnesota Valley/Carver Rapids during the early 1900s could be solely an artifact of anthropogenic forest thinning. It is possible that in an effort to restore the savanna to an open-canopy structure, the hydroaxe removed many of the average/mid-size oaks that established in the early 1900s.

Alternatively, the fluctuating oak establishment patterns seen in the establishment dates at the four sites may be due to successional changes rather than (or in addition to) environmental gradients or anthropogenic alterations (Whipple and Dix 1979). Perhaps the area we currently designate as oak savanna was once dense deciduous-oak forest and, for centuries, frequent Native American fire successfully maintained open canopies and encouraged and facilitated oak recruitment and survival across the Minnesota landscape. The absence of this anthropogenic-ignited fire triggered the start of successional processes working their way from savanna conditions back to forested conditions. It is possible that successional processes began with a flush of oak establishment (as seen in the late 1800 and early 1900s), transitioning into a period of stem exclusion (as seen in the lack of oak regeneration in the mid-1900s) and, finally, increasing the establishment of more shade-tolerant species (as seen in the late 1900s). This hypothesis challenges not only the presence and role of fire in the area designated as oak savanna, but also the succesional status of oaks in these systems. Nowacki and Abrams (1992) question whether oak in central Pennsylvania are a stable component of area forests, or are transitional to more shade–tolerant species. While this hypothesis is interesting and exciting to contemplate, it is questionable whether frequent Native American fire would be sufficient to transform a denser forest into an oak savanna. While frequent fire has been shown to be successful in maintaining open canopies, numerous studies have illustrated the inability of fire to transform denser forest into open savanna conditions (White 1983, White 1986, Brudvig and Asbjornsen 2005, Brudvig and Asbjornsen 2008).

Fire Suppression era (mid-1900s – start of management)

Fire suppression began at different times at different sites. At Minnesota Valley/Carver Rapids, fire suppression probably began around the 1920s, while further from urban centers, fire suppression likely started later in the 1940s. The suppression of fire has undoubtedly had an effect on the ecology of each site; however, it is important not to underestimate the effect of the concurrent land-use that was occurring at each site during the mid-1900s. Teasing out the effects of fire suppression when combined with a myriad of land-use histories is difficult. However, in general, fire suppression has caused a proliferation of woody shrubs and brush, decreased bur oak establishment and increased northern pin oak establishment.

Illustrated in this study as well as other studies throughout the prairie-forest border, the suppression of fire in the mid-1900s caused a proliferation of woody shrubs and brush in the latter half of the century (Gleason 1913, Nuzzo 1986, Packard 1988, Peterson and Reich 2001). Without fire, shrubby and woody brush growth was not suppressed and therefore, increased in height (though not necessarily in density). Similar to other studies' findings, more mesic and fire-intolerant tree species such as green ash, box elder and American elm were able to establish and survive, increasing the amount of shading in the understory (Henderson and Long 1984).

As a result, the relatively slower growing, shade intolerant bur oaks were outcompeted by shrubs and woody brush. The onset of fire suppression coincides with a decline in bur oak establishment at Ordway Prairie (around the 1930s), Helen Allison (around the 1930s) and Minnesota Valley/Carver Rapids (around the 1920s). Increased shading has been shown to impede white oak (*Quercus alba*, a relatively shade-intolerant species similar to bur oak) establishment (Abrams and Kubiske 1990, Karnitz and Asbjornsen 2006). Similarly, in this scenario, the quick growing mesic species shaded the forest floor and young bur oaks were shaded and out-competed. In comparison, northern pin oak is a moderately fast grower and was likely able to compete with the flush of woody, shrubby growth. An increase in northern pin oak establishment during the 1940s, 1950s and 1960s is seen at Helen Allison, Minnesota Valley/Carver Rapids and Weaver Dunes.

The establishment dates at sites with both oak species (Helen Allison and Minnesota Valley/Carver Rapids) illustrate the decrease in bur oak establishment and increase in northern pin oak establishment during this time period. Until the start of fire suppression, bur oak dominated the overstory at Helen Allison and Minnesota Valley/Carver Rapids. In the latter half of the century, northern pin oak became the dominant oak species. This shift in ratio began in the 1970s due to fire suppression and intensified in subsequent decades (Figure 41).

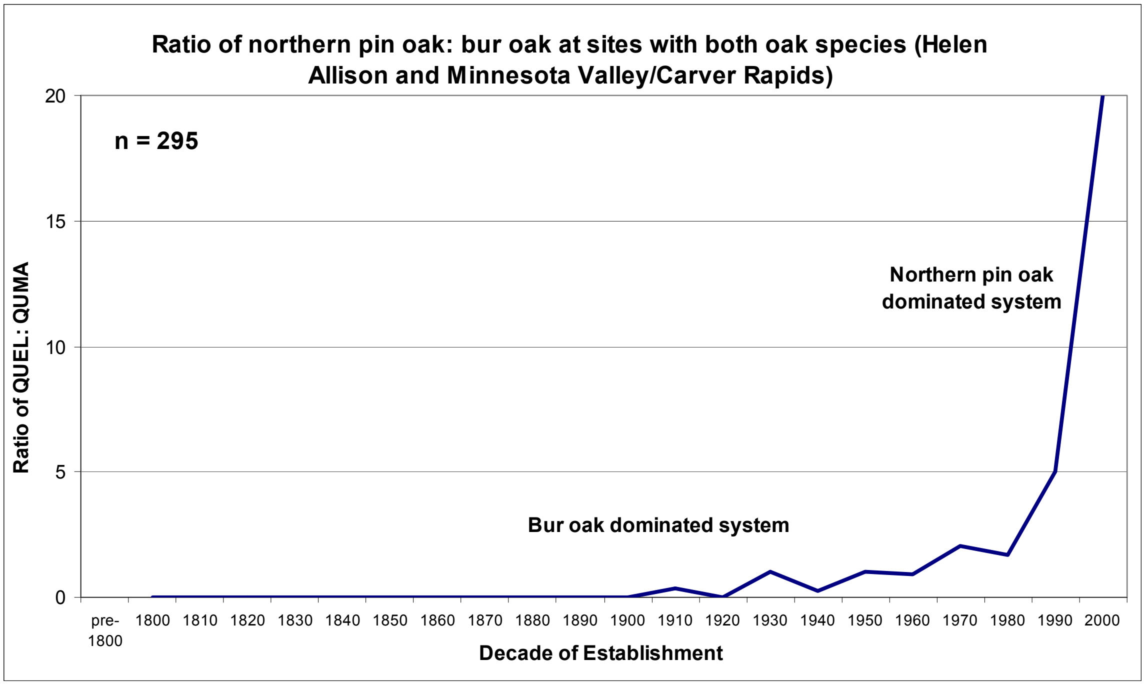


Figure 41: The shift from bur oak dominated systems to northern pin oak dominated systems. Only Helen Allison and Minnesota Valley/Carver Rapids were used in the analyses so as to look only at systems where bur oak and northern pin oak compete with one another.

However, increases in oak establishment at Minnesota Valley/Carver Rapids in the 1950s is not due solely to fire suppression, it is also likely due to the cessation in land-use practices in the 1950s. Release from intense grazing or farming pressure probably initiated oak establishment. This release coupled with continued fire suppression for the next three decades enabled many oaks and mesic species to establish successfully and thrive.

My initial glance at Weaver Dunes' age-structure led me to conclude that this was a classic example of an oak savanna increasing in oak establishment due to the absence of fire. However, if you examine the plots one at a time, you can see that certain plots are clearly skewing the compilation. Plots WD02 and WD64 both have huge surges of oak establishment in the 1950s, however, none of the other plots have much establishment in the 1950s. Similarly, the oak establishment of the early 1900s in the compilation is almost solely from one plot, WD07. Galatowitsch (1984) noted that the Weaver Dunes area saw a myriad of grazing intensities and farming. Thus, in contrast to other sites which had more homogenous land-use histories, at Weaver Dunes, land-use history and current forest and age structure at individual plots appear to be closely linked.

Some areas of Weaver Dunes were heavily grazed while others were only lightly grazed. The eastern oak savanna strip was moderately grazed while the western oak savanna cluster was lightly grazed and parts of it farmed for corn. In both sections, grazing ceased in 1981 and farming ceased in 1982. The areas that were previously farmed (WD47, WD56, WD62 and WD58) had virtually no oak establishment (except for the 2000 decade in WD62). The only plot in the heavily grazed area of Weaver Dunes is WD02, where there is virtually no oak establishment in the early half of the century presumably because in heavily grazed areas the cows eat everything, including oak seedlings (Vera 2000). That area of the preserve was heavily grazed until 1981; however, a wildfire in 1954 burned the entire eastern half of Weaver Dunes and most likely initiated a flush of prairie grasses and forbs (Vogl 1970 cited in Haney and Apfelbaum 1993). A few years of plentiful herbaceous vegetation, enough to satisfy the herds, allowed many northern pin oak seedlings to survive to sapling height. A northern pin oak from the heavily grazed area that was sampled for fire scars (WD206) dated back to 1865, thus confirming that there were, indeed, oaks in this specific area prior to grazing.

The areas of the preserve that were under more moderate and light grazing (WD07, WD57, and WD64) show evidence of oak establishment during grazing times. In these areas, low cattle densities enabled oak seedling survival (Vera 2000).

Management era (start of management – present)

The onset of management programs at Ordway Prairie (1970), Helen Allison (1960s), Weaver Dunes (1980s) and Minnesota Valley/Carver Rapids (1980s) coincided with a flush of tree establishment. Comparatively, this latest incoming cohort displays high numbers of oak establishment as well as high levels of more mesic, fire intolerant species. Are current rates of oak establishment similar to pre-settlement rates? Is current management creating conditions where rates of mesic species establishment in these oak savannas are far higher than in pre-settlement times?

Presence of mesic species

The lack of mesic and fire-intolerant species dating back to the early settlement period does not necessarily imply that there were only oaks at the site when settlers first arrived. In fact, we know that some mesic species were present based on PLS reports at each site. Since many of these fire-intolerant species have shorter life expectancies than oaks, it is likely that those present during the mid-1800s would have senesced already.

For example, at Ordway Prairie, green ash, box elder and American elm all show high establishment numbers around the start of the management programs. Both green ash and box elder have life expectancies around 60 years (Burns and Honkala 1990), so it is likely that they may have senesced by now. However, some mesic trees such as

American elm can live to be 200 years old and, logically, if they had been present pre-fire-suppression, individuals that established before 1930 should still be living (American elm did not reach coring height until 1960). It is possible that many of the older elms have been hit by Dutch elm disease, a fungus that has ravaged much of the elm population around Minnesota. However, if this is the case, we would likely have seen dead elm snags in the area, which we did not. Therefore, even though elms are present in the PLS records at Ordway Prairie, it is likely that they have increased in abundance since 1960.

At Helen Allison, the establishment of more mesic, fire-intolerant species (green ash, black cherry and choke cherry) is also concurrent with the initiation of the prescribed burning program in the 1960s. In general, these species can live up to 60 years (Burns and Honkala 1990), so these species may have been a part of the pre-settlement savanna, or they may not have. Neither ash nor any cherry species are mentioned in the PLS records for this study area, which does not mean that they were not present, it just means that they were not present in large amounts along the surveyed lines. In fact, it is noted that ash was "somewhat avoided" as a bearing tree marker (Almendinger 1996). So, perhaps they were underrepresented in the PLS reports. Ziegler et al. (2008) found several green ash at Helen Allison that pre-dated fire suppression. It is highly possible that small cohorts of green ash (and probably cherry species as well) were present in the pre-settlement savanna, but their populations were kept in check by frequent surface fires. Fire suppression allowed these trees to reach a height at which they are now somewhat fire resistant. Therefore, we have small clumps of green ash, black cherry and choke cherry that have reached their largest sizes (perhaps ever) in Helen Allison Savanna.

PLS reports confirm the presence of mesic species during pre-settlement times at Weaver Dunes and Minnesota Valley/Carver Rapids. Therefore, the current presence of mesic species is no surprise finding. However, there is a definite increase in mesic species establishment as well as oak establishment in the 1970s at both sites.

Continued shift in ratio from bur oak to northern pin oak dominated system

Despite the beginning of prescribed burning and, therefore, the end of fire suppression, the shift in ratio from bur oak dominated systems to northern pin oak dominated systems appears to still be occurring, and is best seen in the seedling/sapling data. Throughout the plots at Helen Allison and Minnesota Valley/Carver Rapids, there was no shortage of oak regeneration. However, although there were a significant number of bur oak seedlings, few of them appear to be surviving to the sapling stage, compared to the northern pin oaks, which were more commonly surviving to the sapling stage. At Helen Allison, the three plots in areas that have been burned (mostly in spring) since 1962 have very little to no bur oak establishment since the initiation of burning in 1962, but have higher amounts northern pin oak establishment during the 1970s and 1980s. The other six plots seem to have slightly more bur oak establishment than the first three plots during that intermediate time (1962-1987) before they were burned for the first time but after those first three plots were burned.

Minnesota Valley/Carver Rapids had only a few plots with bur oak regeneration in the past three decades since the onset of management. Of the nine plots that have undergone excessive spring burning, only one plot (MV05) contains any bur oak regeneration. Granted, many of these younger oaks may have been removed when the hydroaxe came through but even so, many of the sites that were not hydroaxed, but did experience spring burns have no bur oak regeneration. Overall, in spite of the number of old bur oaks at each plot, there is a deficiency of young bur oaks. The lack of bur oak saplings and, consequently, the shift in ratio from bur oak to northern pin oak over time is most likely due to three factors: 1) spring burning, 2) increased canopy cover due to fire suppression and, 3) likely increases in deer and squirrel populations.

Unlike northern pin oak acorns, which sprout in the spring, bur oak acorns sprout immediately after falling from the tree in autumn. I hypothesize that spring burns (mid-April to mid-May) are killing the young, recently sprouted bur oak seedlings, and the northern pin oak seedlings, which haven't sprouted yet, remain unharmed. Henderson and Long (1984) mentioned that fall germination makes white oak (which is very similar in life history traits to bur oak) seedlings vulnerable to spring fires. At Ordway Prairie, plots with extended time between fires, or extended time between spring burns tended to have more bur oak seedlings and saplings. One bur oak tree and six bur oak saplings (more saplings than were tallied at all but one of the plots at Ordway) were found at plot WD57 at Weaver Dunes. Interestingly, this density of bur oak saplings supports the idea that spring burns are killing bur oaks seedlings because plot WD57 was fall burned in 2000 and hasn't seen a spring burn since 1993 – plenty of time for bur oak seedlings to reach sapling size.

In addition to spring burns, increased woody encroachment from mesic species and an increase in the oak canopy cover itself (both due mainly to fire suppression) also hinder bur oak establishment. Mesic species have reached a size where their bark can now resist fires, and so burning without thinning will not only spare the mesic species, but it will also create bare ground ideal for opportunistic mesic species to establish. Unlike oaks, the seeds of some mesic species can remain in the soil for years, waiting for the ideal moment (e.g. after a burn) to sprout (Burns and Honkala 1990). By the late 1900s, oaks that established during the surge in the late 1800s and early 1900s have grown to maturity and their canopies now create a dense cover, shading the forest floor. One would expect that as the number of mature oaks at the site increases, so would the number of acorns produced and thus, more seedlings would establish. Several studies in white oak systems have illustrated that although white oak seedlings were more abundant beneath white oak trees, the white oak seedlings establishing in inter-canopy gaps had greater survival rates, height, diameter and number of leaves (Brudvig and Asbjornsen 2005, Brudvig and Asbjornson 2008). This is probably what we are detecting at several sites, especially Ordway Prairie; the increased number of mature oaks is filling canopy gaps, reducing the number and size of gaps where bur oaks are more likely to establish and thrive.

Additionally, increases in deer populations due to land fragmentation and a lack of predators in the area would likely decrease bur oak seedling establishment and survival because deer prefer white oak over red oak acorns (Dougherty 2003), thus, shifting the ratio. All sites have experienced increases in deer populations since 1993 (MN Dept. of Natural Resources, Deer Population Statistics 1993-2008). Increases in squirrel populations would also likely favor northern pin oak seedling establishment over bur oak seedling establishment. Squirrels remove the germinating part of the bur oak acorn before burying it in the fall, preventing it from quickly establishing a long taproot (which would make unearthing the acorns very difficult). In contrast, the northern pin oak acorns, which do not sprout until spring, are buried intact. It is not uncommon for squirrels to forget about buried acorns, and in that case, only the northern pin oak acorns would sprout. Unfortunately squirrel population records do not exist and squirrel harvest data records only extend back to 1995 and show very little alterations in annual mean harvest (MN Department of Natural Resources, Hunting Harvest Statistics 2008).

Many of the plots with older bur oaks have a surprising lack of younger bur oak saplings. Again, this may be a result of selective mechanical thinning (thinning younger trees and leaving older oaks), but more likely it is a result of spring burns. Similar to the previous sites analyzed, there is a disproportionate number of bur oak saplings compared to northern pin oak saplings and this is likely due to spring fires killing the already-sprouted bur oaks.

Weaver Dunes is certainly not suffering from a lack of oak (or any other tree species for that matter) regeneration. Compared to other sites, Weaver Dunes appears to have a proliferation of saplings. Therefore, management at Weaver Dunes must be conducive to northern pin oak as well as more mesic species regeneration. It should be noted that the high number of northern pin oak saplings may, in part, be because many of the "oak grubs" of this savanna fell into the sapling category.

Compared to other oak savanna sites, Weaver Dunes has been prescribed burned relatively infrequently, and many sites have not seen fire for a decade. These long fire return intervals combined with a large quantity of mature trees due to fire suppression, enables high levels of tree survival and establishment. More frequent fires would have likely decreased woody plant survival and enabled a flush of new, vigorous herbaceous growth. These high sapling levels are probably higher than usual.

Management and mesic species

At all sites, decades of fire suppression enabled mesic tree species to reach a size where they are now able to resist fires and produce offspring. These opportunistic and fast growing species can (and have) quickly taken advantage of bare ground produced by prescribed burns (Kathol and Harrington 2002).

At Ordway Prairie, prescribed burns have cleared away woody brush, increasing light penetration and allowing some bur oaks and mesic species to establish once again. However, it is difficult to say whether oak establishment has returned to the levels it was pre-European settlement because, due to grazing during the late 1800s, the early periods of oak establishment at Ordway Prairie were unusually high, skewing our reference period.

At Helen Allison, increased establishment of more mesic, fire-intolerant species (green ash, black cherry and choke cherry) is concurrent with the initiation of the prescribed burning program in the 1960s. Though all three of these species are likely members of the pre-settlement savanna vegetation, my data seem to show that the prescribed burning program is, in fact, aiding in the establishment of these mesic species, possibly because fire enables these opportunistic mesic seeds a chance to germinate. Years of fire suppression have enabled these more mesic trees to reach not only a size where their bark can withstand the prescribed fires, but also an age in which they can produce a large number of seeds to effectively load the seed bank.

At Weaver Dunes, fire suppression caused the northern pin oak grubs to attain heights they have likely seldom attained in earlier decades, increasing shading on the savanna floor and encouraging a proliferation of shrubs and shade-intolerant tree species.

Similar to Helen Allison, by the 1970s, the absence of fire enabled these fire-intolerant, mesic species to attain sizes they ordinarily would not reach in what is thought to be a fire-prone environment (Minnesota Department of Natural Resources 2005). These now-mature mesic species not only produced more offspring than usual, but were establishing under a denser canopy, thus, heavily shaded environment – conducive to the establishment and survival of mesic species.

Fire suppression at Minnesota Valley/Carver Rapids has increased shading and allowed many mesic species to establish and reproduce. A large proportion of the tree establishment during the management era at Minnesota Valley/Carver Rapids has been mesic species. However, the largest surge of mesic species appears to be in the 1970s, just before the start of management. This result is probably a factor of the recent mechanical removal of mature non-oak trees that did establish in the 1980s, 1990s and early 2000s.

Shrubs

Sumac proliferation is currently a primary concern for TNC prairie–forest border land managers as well as DNR and USFWS managers. TNC management objectives currently target sumac in an attempt to deter further sumac in-growth and decrease current density. Thus, it is in their primary interests to know how much sumac was present in pre-settlement oak savannas. A concrete answer to that problem is virtually impossible; however, some conclusions about sumac density can be inferred. In general, sumac is not palatable to cattle and, in response to grazing in tallgrass prairies, sumac is a so-called increaser (Hetzer and McGregor 1951). Cattle are selective but not necessarily picky eaters. They feed on certain plants first, but under pressure, will graze indiscriminately (Robert Self, pers. comm. 2008). While often the intensity, timing and frequency of the grazing that took place at these four sites during the late 1800s and early 1900s is relatively unknown, but some conclusions about vegetation structure and composition prior to grazing can be made based on known grazers' preferences and patterns.

At Ordway Prairie and Minnesota Valley/Carver Rapids, during the light grazing of the late 1800s – early 1900s, sumac is likely to have increased in abundance and vigor. Without fire, sumac cover has been known to increase (Haney and Apfelbaum 1990, Tester 1996), implying that during the fire suppression period, sumac cover further increased. Additionally, spring burns (which are the majority of prescribed burns) have been shown to increase sprouting and sumac densities (Smith and Owensby 1973, Hutchinson 1992). Therefore, overall, at Ordway Prairie and Minnesota Valley/Carver Rapids, sumac abundance and distribution has likely increased considerably since pre-settlement times, and current management techniques do not appear to be decreasing current cover.

Hazel is a key component of Midwestern oak savannas (Haney and Apfelbaum 1993), but was only mentioned in PLS reports at Ordway Prairie, and was only listed in association with more mesic tree species. In response to grazing, hazel density increases in some cases (Vera 2000) and decreases in others (Kathol and Harrington 2002). In response to fire suppression, hazel has also been shown to be an increaser (Paulson 1968, Clark 1990). Several studies have shown that hazel has been able to sprout vigorously after spring fires, increasing densities (Buckman 1964, Axelrod and Irving 1978, White

1983). At Ordway Prairie and Helen Allison, hazel abundance and densities have likely increased considerably since pre-settlement times.

Prickly ash has been found to be a decreaser in response to grazing and an increaser in response to fire suppression (Kathol and Harrington 2002). Stan et al. (2006) did not find a difference in prickly ash densities between prescribed burned and unburned plots. With this limited knowledge, it is difficult to speculate as to what pre-settlement prickly ash densities were like.

Fire in oak savannas

Only Helen Alison had samples with fire scars that pre-dated fire suppression. The other three sites had samples that pre-dated fire suppression, but none of these samples contained fire scars, and virtually all contained one (if not multiple) fire scars from prescribed burns. These findings beg the question: are trees scarring more frequently now than they were during pre-fire suppression times? If so, are prescribed fires more intense or, perhaps, too infrequent?

Excessive woody growth due to fire suppression has increased fuel loads, inevitably altering fire behavior (Shang et al. 2004). An increase in live fuel loads could possibly increase the intensity of prescribed burns (He et al. 2004) and, consequently, increase the amount of scarring. Anderson and Brown (1986) found heavier mortality in denser area than in more open savannas, suggesting that more forested areas are more likely to scar. Or, perhaps current prescribed burning frequencies are too infrequent. Studies have shown that frequent burns often lead to fewer fire scars (Paulsell 1957, Dey et al. 2004). Therefore, relatively infrequent burning may have contributed to higher scarring rates.

Perhaps an increase in fuel loads or fire frequency has, indeed, altered the nature of current fires and increased the amount of scarring in present-day oak savannas. However, the question of why we're not finding any pre-fire suppression fire scars at Ordway Prairie, Weaver Dunes or Minnesota Valley/Carver Rapids still remains. All three sites experienced grazing during the late 1800s and early-mid 1900s. A probable explanation is that grazing sufficiently reduced the amount of fuel on the ground to either reduce the intensity of fires that swept through the area or reduce the number of fires altogether (or both) (Jensen and McPherson 2008). This would explain reduced scarring during that period of time.

The MFI's found through fire scar analysis are close to the calculated prescribed burn intervals (based on agency records) at all sites except Helen Allison. The fact that these two numbers are close at three of my four sites lends support to the accuracy and reliability of fire scar dating and dendroecological methods of fire history research. At Helen Allison, the use of dendroecology to reconstruct fire history underestimated the frequency of fire. This underestimate is likely due to frequent prescribed burning. Paulsell (1957) and Dey et al. (2004) note that more frequently burned plots had less fuels and fewer scars. Therefore, frequent prescribed burns could have led to fewer scars, producing an underestimate of fire frequency. This underestimate could possibly be overcome by more sampling, which, given the size and the scarcity of old trees in these savannas, was not desirable. In this situation and at this site, the calculated MFI from prescribed burn fire scars is an underestimate of the actual number of fires that the site experienced; we can assume that the MFI calculated for the pre-settlement era is also an underestimate of the actual number of fires that occurred. Additionally, fire scars have been found to be the most important entry for decay fungi, accelerating the decay process (Berry and Beaton 1972). Therefore, it is possible that many of the most severely and frequently fire-scarred trees from the pre-settlement era have senesced and died.

Increases in the frequency of scarring may ultimately have deleterious (or unintended) effects. Because fire scarring lowers a tree's fitness and life expectancy, Mickley (unpublished data) hypothesized that areas with higher tree densities would have more scarring and, thus, higher mortality, putting these areas on a trajectory towards prairie (assuming the burns continually suppress establishment of oak seedlings). I did not find any significant correlation between the amount of scarring in a plot and the density (number of trees) of the plot at Ordway Prairie ($r = 0.285$, $n = 14$), Weaver Dunes ($r = 0.38$, $n = 16$) or Minnesota Valley/Carver Rapids ($r = 0.25$, $n = 26$) (no scarring calculations can be made for Helen Allison because scarring was not noted for every plot). However, a more long term study is needed to accurately detect a relationship. Nevertheless, the abundance of scarring could possibly lead to increased oak mortality in the future.

Though studies have shown that spring burning increases sumac cover (Smith and Owensby 1973, Hutchison 1992), I found no increases in sumac seedlings or saplings at plots that were recently burned in the spring. Seedlings and saplings of hazel and prickly ash, on the other hand, were found in highest abundances in plots that last experienced a spring burn. In response to spring burns, hazel has been known to increase (Buckman 1964), while prickly ash decreases (Kathol and Harrington 2002).

Age vs. dbh

The estimated age of a tree (which is used in decisions regarding forest health and management), is most often based solely on its size. The correlation between the size and age of a bur oak was significant at Ordway Prairie, Helen Allison and Minnesota Valley/Carver Rapids; however, there are definite exceptions at each site. In fact, the oaks that established during early settlement at Ordway Prairie ranged in size from as small as 18 cm dbh to as large as 81 cm. This finding implies that growing conditions around the preserve were highly variable. Although size may be a relatively good indicator of age in some cases, this study supports the idea that many dendrochronologists have been touting for decades: you cannot immediately judge the age of a tree based on its size (LaMarche 1969).

At Weaver Dunes, no significant correlation was found between the age and the size of a northern pin oak. This lends support to the idea that many areas in Weaver Dunes were scrub savanna (composed almost solely of northern pin oak brush). Additionally, the average percentage of oaks that were part of a multiple (a.k.a "grubs" or multiple stems caused by repeated killing and resprouting) was 39.5%. Bowles and McBride concluded that oak grubs were a strong component of a savanna in Illinois when they found that 40.6% of the trees had multiple stems.

At Helen Allison, bur oaks have a notably higher correlation between age and size than northern pin oaks, indicating that with their fire-resistant bark, bur oaks are less likely to be set-back by fire and probably less likely to grow scrubby. In this scenario, larger single standing, gnarly bur oaks are growing amongst the more grubby, multiple stemmed northern pin oaks. However, examination of my forest structure data (where I noted whether or not the tree I cored was a part of a multiple tree or not) indicated differently. At Helen Allison, I found that 37% of the bur oaks I cored were members of a multi-trunked tree, while only 28% of the northern pin oaks I cored were a part of a multiple.

Interestingly, at Ordway Prairie, the average size of bur oaks marked as bearing trees in the PLS records were relatively small (23.5 cm) compared with many of the bur oaks currently on the site. Although this PLS data cannot be used to say that all (or even most) bur oaks on the site were that small, it can be used to suggest that perhaps current conditions are enabling bur oaks to grow to larger sizes than previous conditions might have allowed. No bearing trees were encountered during sampling.

Minnesota's oak savannas at a landscape level

In accordance with several studies noting the patchy matrix-like landscape of the prairie-forest border region (Leitner et al. 1991, Leach and Givnish 1999), this research demonstrates the incredible heterogeneity within and among the dynamic oak savanna transition zone in Minnesota between the prairies and the deciduous forests. A variety of environmental and anthropogenic variables such as previous land use, climate characteristics, soils, current and previous management and historical legacies are responsible for several distinct differences as noted below.

Tree species composition

One of the most apparent and striking differences among the four savannas was in the oak species composition. Weaver Dunes was dominated by northern pin oak, Ordway Prairie was dominated by bur oak and Helen Allison and Minnesota Valley/Carver Rapids contained both species. A few bur oaks occur at Weaver Dunes, but conditions clearly favor northern pin oak. At Ordway, no northern pin oaks occur, nor were they noted in PLS notes. I postulate that these compositional differences are attributable to a combination of climatic and edaphic conditions.

Episodic climatic events affecting moisture (droughts) have differential effects on oak species. In agreement with other studies (e.g. Faber-Langendoen and Tester 1993), this study found that although northern pin oaks are often found on less favorable, more nutrient deficient, sites, they are not as drought resistant as bur oak and often fare worse during droughty periods. Thus, it appears that in areas where northern pin oak would be more edaphically competitive with bur oak (less-favorable, nutrient-deficient sites), it is less competitive in regards to drought. Moreover, this study shows that, when in direct competition with bur oak, northern pin oak is the less drought resistant and less competitive species, but when growing without competition from bur oak, northern pin oak is able to successfully establish during droughts. Therefore, droughty periods in conjunction with edaphic conditions can have significant effects on the oak species composition.

Another noteworthy compositional difference is the variation in tree species richness between sites. Minnesota Valley/Carver Rapids and Weaver Dunes had higher tree species richness than Ordway Prairie or Helen Allison. This is most likely due to MN Valley/Carver Rapids and Weaver Dunes' proximity to rivers. These bodies of water not only provide nearby riparian habitats that encourage the establishment of non-oaks, supplying a substantial and diverse seedbank, but also provide an added mode of seed dispersal, increasing the likelihood and number of species present in the local area.

Tree ages

Helen Allison Savanna had considerably older trees (and more of them) than did any of the other sites due to anthropogenic land-use practices, species specific life history characteristics, and sampling design. Many of the old oaks at Ordway and Minnesota Valley/Carver Rapids were logged early on or removed for agricultural purposes. Lack of old oaks at Weaver Dunes is likely due to the fact that northern pin oaks do not live much older than 150 years, especially in such sandy soil conditions. It is also very likely that I missed many of the older oaks at Ordway and Minnesota Valley/Carver Rapids. Helen Allison is the smallest of my four sites, hence the sampling grid covered a larger percentage of the total preserve area, increasing the likelihood of detecting older trees.

Fire scars

Fire scar sampling of oaks in Ordway Prairie, Weaver Dunes and Minnesota Valley/Carver Rapids revealed an MFI similar to the recorded prescribed burn records, indicating that dendroecology research is relatively accurate in determining fire frequency. However, the MFI derived from fire scar sampling at Helen Allison revealed that dendroecological techniques produced an underestimate of fire frequency. This underestimate is probably not due solely to under-sampling. In fact, of all four sites, Helen Allison had by far the most samples per unit area. This underestimate could likely be the product of more frequent burning. Paulsell (1957) and Dey et al. (2004) note that more frequently burned plots had less fuels and fewer scars. Therefore, frequent prescribed burns could have led to fewer scars, producing an underestimate of fire frequency. This underestimate could possibly be overcome by more sampling, which, given the size and the scarcity of old trees in these savannas, was undesirable.

Shrub composition

Shrub composition varied from site to site for a number of different reasons. MN Valley has a higher number of sumac seedlings and saplings than any other sites. This abundance is likely due to frequent burning, and low average plot basal area and stem density. These factors allow sumac to thrive in its ideal conditions - unshaded and frequently burned. However, it should also be noted that Ordway Prairie, with the highest average plot basal area and stem density of all sites, also has a notable presence of sumac. This result is attributable to a couple sites with comparatively lower basal areas and stem densities, providing an unshaded forest floor (experiencing a relatively high fire frequency as well). Lighter sumac densities at Helen Allison are likely due to the heavy hazel densities, utilizing the ground surface space and out-competing the sumac.

Average hazel densities vary among sites and are heavily associated with oak importance values (with the highest hazel densities at Helen Allison and the lowest at Weaver Dunes). This association is likely due forest floor shading.

Common patterns among the four savannas

As seen above, depending on slight variations in site characteristics and disturbance regimes, this transition zone can manifest itself in many different forms. Each of my four sites was previously characterized/labeled as "oak savannas" by their respective agencies. So, after analysis of each site's stand structure, age structure and fire history, the following patterns about "oak savanna" forest and age structure have been extracted:

1) *Many refuges and preserves that we currently designate as "oak savannas" may not have many (or any) oaks predating European settlement of the area due to previous land-use, climatic conditions, or species specific life history characteristics. Nevertheless, the scarcity or absence of these older oaks does not imply that these areas were not of oak savanna origin.* The most common indicator of a historic oak savanna is the presence of gnarly, open-grown oak trees and all of my sites were probably designated as "oak savannas" for that reason. Several studies have also shown that the oldest trees in Midwestern oak savannas originated after settlement (Henderson and Long 1984, Karnitz and Asbjornson 2006). Similar to this study, they concluded that although the large, open-grown oak trees at their site did not predate settlement, the area was likely oak savanna before land use changed. Several other studies in oak dominated systems in eastern forests also noted the absence of oaks predating settlement of the area, attributing the absence to anthropogenic manipulations such as logging/farming etc. (Abrams and Nowacki 1992, McClenahen and Houston 1998).

2) *Northern pin oak is a relatively short-lived species and thus, may be absent from older age classes. Therefore, the absence of northern pin oak from older age classes should not be interpreted as a complete absence of northern pin oak from historic oak savannas. For that reason, it is important to have some knowledge of savanna structure, land-use history and, perhaps, PLS records before asserting that current northern pin oak densities have significantly increased from historic densities.* Faber-Langendoen and Tester (1993) found that although northern pin oak more often occurs on well-drained sites, it is not as drought resistant as bur oak, and thus is not likely to live as long. Peterson and Reich (2001) found that northern pin oaks have shorter life spans than bur oaks.

3) *This study* <u>*has*</u> *revealed a recent shift from bur oak dominated savannas to northern pin oak dominated savannas.* The ratio of bur oak to northern pin oak is lower for saplings than it is for trees. Compared to bur oak saplings, northern pin oak saplings increased in response to fire suppression, preserve management and increases in deer populations. Faber-Langendoen and Tester (1993) noted high survival numbers of northern pin oak saplings relative to bur oak saplings. Others have noted the general decrease in importance values of white oak species from pre-settlement forests to the present (Pallardy et al. 1988, Fralish et al 1991, Abrams and Ruffner 1995, Abrams 2003). This study illustrates several reasons for the decline in bur oak saplings:

   a. *Prescribed burns performed in the spring are probably killing recently sprouted bur oak seedlings, preventing them from attaining sapling status* (bur oak acorns, unlike northern pin oak acorns, sprout in the fall, leaving the bur oak seedlings vulnerable to spring burns). Henderson and Long (1984) mentioned that fall germination makes white oak seedlings vulnerable to spring fires.

b. *Fire suppression has caused a proliferation of woody shrubs and brush, hindering the establishment of more shade-intolerant and slower growing bur oak more than the establishment of northern pin oak.*

c. *Increases in deer populations (which preferentially feed on bur oak acorns) are likely contributing to the shift in ratio*.

d. *Possible increases in squirrel populations may be contributing to the shift toward northern pin oak dominance because squirrels eat the germinating part out of bur oak acorns.* Fox (1982) noted that squirrels immediately remove the germinating part of bur oak acorns in the fall (not northern pin oak because they germinate in spring) before burying it.

This trend towards northern pin oak dominance could put Minnesota oak savannas on a trajectory towards a more prairie-like system. Northern pin oak scars more readily than does bur oak. Therefore, if prescribed fires continue to scar trees in these Minnesota oak savannas at high rates, a savanna of northern pin oak dominance would be more heavily scarred and, these northern pin oaks more susceptible to death. Under this scenario, current Minnesota oak savannas might look more like prairies in the future.

4) *There was a surge of bur oak establishment in the late 1800s – early 1900s across the Minnesota oak savanna landscape*. In the late 1800s, the cessation of transient large ungulate browsing and trampling and the implementation of cattle grazing increased bur oak establishment and survival. Transient large ungulate browsing kept

woody establishment in check, forcing oaks to establish in pulses. In comparison, light continuous cattle grazing favored continuous woody establishment.

5) *Historic land-use, more than any other factor (fire suppression, climate, etc.), has shaped the savanna community composition and structure since European settlement.* Thus, knowledge of land-use patterns is important before determining land management objectives.

   a. Excessive hunting caused reductions in ungulate (bison, deer, elk, etc.) browsing, which led to increased survival of woody species.
   b. Logging has reduced the presence of old oaks.
   c. Light grazing has increased the survival and establishment of oak seedlings and heavy grazing has reduced the survival and establishment of oak seedlings. Light grazing both reduces the vigor of herbaceous species and reduced the intensities and/or frequency of fire increasing the likelihood of woody seedling survival.
   d. Heavy grazing forces grazers to feed on woody seedlings as well (Vera 2000).
   e. Crop farming has eliminated and fragmented habitat and decreased the establishment and survival of oak seedlings.

6) *Canopy cover has increased due to fire suppression and the maturation of early surges (late 1800s) of oak establishment*. This increase in canopy cover has altered savanna understory conditions.

7) *Green ash is a prominent member of the pre-settlement and modern oak savanna community.* Green ash was found at all four sites and was commonly mentioned in

PLS reports. Watt (1924 cited in Vera 2000) noted that oak and ash are constantly being established on the outer edge of the scrub extending into the grassland.

8) *Fire suppression, land-use practices and current management techniques have increased sumac and hazel densities.* Increased shading, grazing and spring burns are increasing vigor and sprouting of these two species.

9) *The size of an oak tree is not necessarily indicative of its age.* Although size may be a relatively good indicator of age in some cases, this study supports the idea that many dendrochronologists have been touting for decades: you cannot immediately judge the age of a tree based on its size (LaMarche 1969). McClaran (1986) found that the blue oak (*Quercus douglasii*) size poorly predicted tree age and is of little value in describing stand age structure. These findings have important implications for land managers when selecting which trees to thin, and for conservation planners in the selection of future refuges and preserves. If possible, land managers should core trees before thinning to determine approximate ages.

The sample size in this study's fire history analysis is comparable to, if not larger than, sample sizes used in other fire history studies (Wolf 2004, Guyette and Stambaugh 2004). However, due to an insufficient number of old oaks, a generalized pre-Euro-American settlement average fire return interval for Minnesota oak savannas could not be deduced from the fire history aspect of this study, however, the fire scars (or lack thereof) nevertheless reveal several patterns:

10) *Prescribed burning programs are not reducing the number of mesic, fire-intolerant species*. In fact, these fire intolerant species have increased in importance and density since the onset of prescribed burns. In many cases, these fire-intolerant mesic species have reached a size at which they are resilient to low intensity fires.

11) *Prescribed burns are scarring trees more frequently than pre-fire suppression fires did.* Virtually all of the oaks that pre-dated fire suppression contained no pre-fire suppression scars, but did contain one if not multiple fire scars from prescribed burns. Thus, prescribed burns are not doing a good job at mimicking historical fires. This increase in scarring is likely due to increased forest densities.

12) *Spring fires are likely killing recently sprouted bur oak saplings and increasing shrub densities.* Therefore, perhaps pre-settlement fires most likely occurred during the summer and/or fall season.

13) *Grazing during the late 1800s and early 1900s most likely reduced the intensities of fire for decades*. Grazing reduces the amount of available fuels, effectively decreasing the chance and/or intensities of fire. However, during pre-settlement times when ungulate browsing represented an additional disturbance regime capable of having major effects on woody seedling survival, fires were probably more intense.

14) *This research supports the accuracy of fire history research in general.* My reconstructed prescribed burn intervals from fire scars closely correspond to the actual burn intervals recorded.

15) *Determining the seasonality of a fire based on the location of a fire scar in the tree ring is not always accurate*. I tested this by trying to determine the seasonality of scars on cross-sections and then verifying with land managers' records.

16) *Compiling all sites' fire scars together, the average height that a scar was found at was 25 cm above the ground (range: 5cm to 60cm)*. This finding is supported by another fire scar study in an oak dominated system in the Missouri Ozarks where they found that different oaks species (*Quercus velutina*, *Q. coccinea*, *Q. shumardii, Q. stellata,*and *Q. alba*) were scarring at varying heights ranging from 55 cm to 100 cm from the ground (Stevenson, Muzika and Guyette 2008). This supports the idea that scarring height differs depending on the species and the environmental conditions. This finding stresses the importance of making multiple cuts at varying heights on the tree in future fire scar studies in oak dominated ecosystems of the upper Midwest.

Management Implications

Restoring remnant oak savanna sites will depend on what specific agencies want their oak savannas to look like. At all four of my sites, proliferation of woody growth due to fire suppression has increased canopy cover and forest density. PLS reports conveyed an image of less dense, more "scattered" oak-dominated landscapes. Increased forest density is hindering bur oak establishment, allowing more mesic species to establish and survive, further promoting a proliferation of woody shrub growth and altering fire behavior. Therefore, a reduction in forest density is needed and this study recommends mechanically thinning dense oak stands as well as mesic species. Use caution when selecting which oaks to thin, because this study has shown that although most sites showed a significant relationship between the age and the size of a tree, there are definite exceptions and the size of the oak is not necessarily indicative of its age. It is important to protect these old trees that have survived numerous anthropogenic manipulations. These individuals contain valuable historical ecological information, genetic diversity, and provide a seed source for future generations. So, cutting smaller oaks and leaving the larger ones does not mean the youngest oaks are removed. Look for characteristics of old trees (gnarly, low-lying limbs, twisted trunk) as seen in Figure 42.

Figure 42: Picture of old, gnarly bur oak at Helen Allison Savanna

While prescribed burning has been shown to reduce smaller diameter oak stems (Peterson and Reich 2001, White 1986) numerous studies have illustrated the additional need for structural manipulation (White 1983, White 1986, Brudvig and Asbjornsen 2005, Brudvig and Asbjornsen 2008). Brudvig and Asbjornsen (2005) found that white oak seedlings grew best in canopy gaps and, therefore, without canopy thinning, white oak seedlings did not persist to the sapling stage. Unfortunately, low oak regeneration during the past century is a chronic finding (Abrams 1992, Abrams 2003, Brudvig and Asbjornson 2008) and the consensus has been that woody encroachment removal is the best management tool for promoting oak regeneration.

At all four of my sites, fire suppression has allowed mesic species to attain sizes they have likely rarely attained at these sites, sizes at which these fire-intolerant species are now rather fire tolerant. Blake and Schuette (2000) showed that *Ulmus* and *Acer* individuals >10 cm dbh were little affected by fires. Thinning many of these larger mesic species may be necessary to reduce canopy cover.

At sites where either the ratio between oak species has shifted toward northern pin oak dominance and/or bur oak regeneration is low, ensuring bur oak seedling survival and establishment should be of primary concern. Therefore, summer or fall burns (not spring) are recommended.

Hazel, sumac and prickly ash were certainly permanent fixtures in the Minnesota oak savanna landscape. However, through various anthropogenic land-use changes and fire suppression, shrub densities have increased. To effectively control and, hopefully, reduce shrub densities a bit, this study recommends summer or fall burns.

Numerous studies have assessed the effects of prescribed burn frequencies and intensities on Midwestern oak savanna vegetation, however, rarely in conjunction with dendroecological analyses. Most recommended fire frequencies are in the range of three fires/decade (MFI of 2-4 years) (Guyette and Cutter 1991, Peterson and Reich 2001). Due to a lack of old trees and fire scars, I am unable to recommend a concrete historical fire frequency, however I can say that current burning regimes are scarring oaks at high rates. This higher scarring rate is likely due to higher forest density (Henderson and

Long 1984). Therefore, in opposition to some who stress the importance of high intensity burns (Haney et al. 2008), I do not recommend higher intensity burns at my sites. Instead, mechanical thinning (as stated above) before performing low-intensity burns is suggested to prevent excessive scarring which may lead to increased tree mortality. Pollet and Omi (2002) illustrate that sites with thinning had more dramatically reduces fire severity compared to sites with prescribed fire only. Other studies report that fuel reduction is needed to reduce the intensity of wildfire (Shang et al. 2004) and that reducing ladder fuels can reduce fire intensity (Agee and Skinner 2005). Additionally, if spring burns are necessary, allow several years between fires for bur oak regeneration to become more resistant to subsequent fires.

Specific management recommendations for each site:

Ordway

Mechanical thinning of mesic species as well as some denser oak areas is needed to create more inter-canopy gaps and reduce live fuels. To ensure bur oak regeneration and decrease hazel and sumac growth, a burning regime with fewer spring burns and more summer or fall burns is recommended (occasionally, long fire intervals (time between fires) may be needed if fall burns are not possible because of weather or fuel conditions).

Helen Allison

To ensure bur oak regeneration and keep hazel densities in check, this study recommends summer or fall burns. Some thinning and removal of downed wood may be necessary to reduce forest densities and, possibly, reduce scarring. Mesic species densities are relatively low and thinning them is probably not needed.

Weaver Dunes

Mechanically thin dense stands of oak and thin some of the larger mesic species before prescribed burning to effectively reduce forest density and tree scarring. Weaver Dunes may also benefit from a more frequent burning regime. Peterson, Reich and Wrage (2007) suggest that on sandy soils (where trees have less competition from grasses for water), high frequency fire regimes are important for controlling shrubs and trees.

Minnesota Valley/ Carver Rapids

Extensive mechanical thinning has already been performed at Minnesota Valley/Carver Rapids. To maintain a healthy oak savanna age structure and composition and ensure young oak survival in the future, further thinning right now is not recommended. To ensure bur oak regeneration, summer or fall burns are recommended and an annual burning regime is not advised. While annual burning may be used to keep woody shrubs constantly in check, it is preventing bur oak establishment and could possibly reduce overall species diversity in the future (Denslow 1980). Although this thinning produces the idyllic savanna structure, this is probably not what "pre-settlement" conditions were like. Bur oaks presently dominating the area are likely larger than historical sizes. Bur oaks in PLS records had an average dbh of 25.5 cm while bur oaks presently in the area have an average dbh of 33 cm with numerous bur oaks surpassing 60 cm dbh.

Conclusion

This study demonstrates the variation between and heterogeneity within Minnesota oak savannas, exemplifying the problems inherent in extrapolating patterns and management implications from site-specific case studies. Through a dendroecological analysis of four Minnesota oak savannas, this study examined not only the dynamics of four very different savannas, but more importantly, extracted landscape-scale patterns to better understand these dynamics.

Many areas we currently designate as "oak savanna" may not have many (or any) oaks predating European settlement of the area due to previous land-use, climatic conditions, or species specific life history characteristics. Nevertheless, the scarcity or absence of older oaks in these areas (regardless of oak species) does not directly imply that these areas were not pre-settlement oak savanna. Anthropogenic land-use has heavily shaped the savanna community composition and structure since European settlement. Throughout Minnesota in the late 1800s, the cessation of transient large ungulate grazing and the implementation of continuous cattle grazing increased bur oak establishment and survival. Periods of logging and heavy grazing have reduced the presence of old oaks. Canopy cover has increased at all sites due to fire suppression and the maturation of earlier surges of oak establishment. Above all, the most apparent trend throughout my sites and, perhaps, the most threatening to savanna structure and composition is the recent shift from bur oak dominated savannas to northern pin oak dominated savannas due to a combination of springtime prescribed burns, fire suppression, increasing deer populations and squirrels.

A conclusive pre-settlement average fire return interval for Minnesota oak savannas could not be deduced from the fire history aspect of this study due to an insufficient number of pre-settlement fire scars. Verification of recent fire scars with prescribed burn records illustrate the accuracy in using dendroecology and fire scar sampling to determine fire frequency. At the same time, this study highlights the difficulty of performing dendroecological fire history studies in oak-dominated ecosystems where trees may be highly resistant to scarring. Prescribed burns probably scar trees more frequently than historical fires did and fail to reduce the number of mesic, fire-intolerant trees. Heavier scarring could potentially put Minnesota oak savannas on a trajectory towards prairie.

Future oak savanna management in Minnesota should focus on thinning areas before prescribed burning as well as performing fall burns to decrease the intensities of prescribed fires and increase bur oak seedling survival and establishment. Knowledge of land-use patterns is important before determining land management objectives. Additionally, this study found that the size of an oak tree is not necessarily indicative of its age, necessitating that land managers take precautions when performing mechanical thinning to preserve the few old oaks remaining.

Dendroecological analyses, such as this, can illustrate important relationships between historical disturbance patterns, land-use patterns and current stand structure and composition. However, further research on the effects of increasing deer populations, invasion of non-native earthworms and the possible effects of climate change is crucial to future management decisions. Compounding perturbations can often cloud our ecological analyses and make it difficult to reconstruct pre-settlement conditions.

Nevertheless, there is inherent value in furthering our understanding of historical ecology and disturbance variability. More importantly, there is value in attempting to base management decisions off of sound, research-based results as opposed to generalized notions of what oak savannas should look like. In that respect, this study provides a sturdy framework for future oak savanna management and research in Minnesota.

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Stem Density (trees per 0.1 hectare) – Ordway

	OR25	OR26	OR28	OR33	OR34	OR35	OR36	OR43	OR51	OR55	OR56	OR63	OR64	OR71	Total
LIVE															
QUMA	23	26	0	0	53	33	26	31	0	0	38	23	34	0	287
PRSE	2	0	0	1	0	0	0	0	0	0	0	0	0	0	3
PRVI	13	1	0	0	0	0	0	0	0	0	0	0	0	0	14
FRPE	1	5	0	35	1	0	0	0	0	0	0	0	0	3	45
CEOC	0	0	0	10	0	0	0	0	0	0	0	0	0	0	10
ULAM	0	0	0	6	0	0	0	0	0	0	0	0	2	1	9
POTR	0	0	0	0	0	0	0	0	0	53	0	0	0	20	73
ACNE	3	1	0	5	0	0	0	0	0	1	0	0	4	6	20
RHCA	0	0	0	0	0	0	0	0	0	1	0	0	1	0	2
RHGL	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
TIAM	4	0	0	0	0	0	0	0	0	0	0	0	0	0	4
PRAM	1	0	0	0	0	0	0	0	0	0	0	0	9	0	10
Total live	47	33	0	57	54	33	26	31	0	55	38	23	52	30	479
DEAD															
QUMA	1	2	0	0	9	1	1	3	0	0	2	1	1	0	21
PRSE	0	0	0	0	0	0	4	0	0	0	0	0	0	0	4
PRVI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FRPE	0	0	0	6	0	0	0	0	0	0	0	0	0	0	6
CEOC	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
ULAM	0	0	0	3	0	0	0	0	0	0	0	0	0	0	3
POTR	0	0	0	0	0	0	0	0	0	8	0	0	0	3	11
ACNE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RHCA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RHGL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TIAM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRAM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total dead	1	2	0	10	9	1	5	3	0	8	2	1	1	3	46
TOTAL (Live and Dead)	48	35	0	67	63	34	31	34	0	63	40	24	53	33	525

Basal Area (m^2 per 0.1 hectare) - Ordway Prairie

	OR25	OR26	OR28	OR33	OR34	OR35	OR36	OR43	OR51	OR55	OR56	OR63	OR64	OR71	Total
LIVE															
QUMA	1.55	2.03	0	0	3.32	2.19	0.78	4.17	0	0	3.03	1.49	1.49	0	20.04
PRSE	0.01	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0.03
PRVI	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05
FRPE	0	0.09	0	0.59	0	0	0	0	0	0	0	0	0	0.02	0.71
CEOC	0	0	0	0.17	0	0	0	0	0	0	0	0	0	0	0.17
ULAM	0	0	0	0.2	0	0	0	0	0	0	0	0	0.32	0.02	0.53
POTR	0	0	0	0	0	0	0	0	0	0.87	0	0	0	1.04	1.91
ACNE	0.04	0.01	0	0.41	0	0	0	0	0	0	0	0	0.04	0.14	0.65
RHCA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01
RHGL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TIAM	0.26	0	0	0	0	0	0	0	0	0	0	0	0	0	0.26
PRAM	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0.05
Total live	1.91	2.14	0	1.38	3.32	2.19	0.78	4.17	0	0.88	3.03	1.49	1.9	1.22	24.4
DEAD															
QUMA	0.02	0.03	0	0	0.19	0	0	0.07	0	0	0.05	0.01	0.24	0	0.61
PRSE	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0.01
PRVI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FRPE	0	0	0	0.04	0	0	0	0	0	0	0	0	0	0	0.04
CEOC	0	0	0	0.04	0	0	0	0	0	0	0	0	0	0	0.04
ULAM	0	0	0	0.03	0	0	0	0	0	0	0	0	0	0	0.03
POTR	0	0	0	0	0	0	0	0	0	0.09	0	0	0	0.03	0.12
ACNE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RHCA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RHGL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TIAM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRAM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total dead	0.02	0.03	0	0.11	0.19	0	0.01	0.07	0	0.09	0.05	0.01	0.24	0.03	0.84
TOTAL (live and dead)	1.93	2.27	0	2.3	3.51	2.19	0.8	4.24	0	0.97	3.07	1.49	2.14	1.25	26.2

Importance Values – Ordway

	OR25	OR26	OR28	OR33	OR34	OR35	OR36	OR43	OR51	OR55	OR56	OR63	OR64	OR71
QUMA	131.3	175.0	0.0	0.0	198.4	200.0	193.1	200.0	0.0	0.0	200.0	200.0	146.9	0.0
PRSE	4.8	0.0	0.0	2.6	0.0	0.0	14.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PRVI	29.4	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FRPE	2.2	18.6	0.0	103.1	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.5
CEOC	0.0	0.0	0.0	30.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ULAM	0.0	0.0	0.0	28.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.5	4.7
POTR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	196.3	0.0	0.0	0.0	155.1
ACNE	8.2	3.5	0.0	35.1	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	9.6	29.7
RHCA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	2.0	0.0
RHGL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0
TIAM	22.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PRAM	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.1	0.0

Various Environmental Conditions and Forest Structure Results – Ordway

	OR25	OR26	OR28	OR33	OR34	OR35	OR36	OR43	OR51	OR55	OR56	OR63	OR64	OR71
Slope	5	11	1	12	18	10	7	4	10	14	15	19	20	20
Aspect	S	SW	N	E	SW	SW	S	S	N	NW	N	S	S	S
% QUMA multiples	34.783	26.923	0	100	58.491	51.515	26.923	48.387	0	0	31.579	78.261	32.353	0
Scarring														
# OFS	7	4	0	5	5	0	2	1	0	7	28	0	0	2
# HS	1	4	0	0	2	1	0	5	0	2	4	0	1	0
# trees with CB	0	0	0	0	3	24	21	18	0	0	1	0	0	1
% scarred in plot	14.583	11.429	0	7.4627	7.9365	0	6.4516	2.9412	0	11.111	70	0	0	6.0606
Predominant scarring dir.	W	none	--------	N/NW	N/NW	-------	N/NW	NW	-------	NE	SE	-------	--------	N
Scarring relative to slope	side	none	--------	side/uphill	uphill	------	uphill	uphill	--------	downhill	uphill	-------	-------	uphill

OFS = open face fire scar
HS = healed fire scar
CB = charred base
TH = top of hill, no aspect could be determined

Prescribed Burning History – Ordway

	OR25	OR26	OR28	OR33	OR34	OR35	OR36	OR43	OR51	OR55	OR56	OR63	OR64	OR71
1973										sp	sp	sp	sp	
1974														
1975			sp			sp	sp	sp	Sp	sp	sp	sp	sp	sp
1976	sp	sp	sp	sp	sp	sp	sp	sp	Sp	sp	sp	sp	sp	
1977														
1978														
1979														
1980														
1981														
1982												sp	sp	
1983														
1984														
1985											fa	fa	fa	
1986	sp	sp		sp	sp						fa	fa	fa	
1987														
1988	fa	fa		fa	fa									
1989														
1990			sp			sp	sp	sp	Sp					
1991														
1992	sp	sp		sp	sp					sp	sp	sp	sp	
1993														
1994														
1995														
1996														
1997			fa			fa	fa							
1998														
1999	sp*	sp*		sp	sp					sp	sp	sp	sp	
2000														
2001														
2002			sp			sp	sp	sp	Sp					
2003	sp	sp		sp	sp					sp	sp	sp	sp	
2004	sp	sp	sp	sp	sp									sp
2005														
2006			fa			fa	fa	fa	Fa					
2007														

	OR25	OR26	OR28	OR33	OR34	OR35	OR36	OR43	OR51	OR55	OR56	OR63	OR64	OR71
# burns	7	7	7	7	7	6	6	5	5	6	8	9	9	2
Total years	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Freq.	5	5	5	5	5	5.83	5.83	7	7	5.83	4.38	3.89	3.89	17.5
MFI	4.5	4.5	5.16	4.5	4.5	6.2	6.2	7.75	7.75	5	4.28	3.75	3.75	29
Time since fire	3	3	1	3	3	1	1	1	1	4	4	4	4	3
T.S. spring burn	3	3	3	3	3	5	5	5	5	4	4	4	4	3

* Didn't burn under canopy

sp = spring burn, su = summer burn, fa = fall burn.

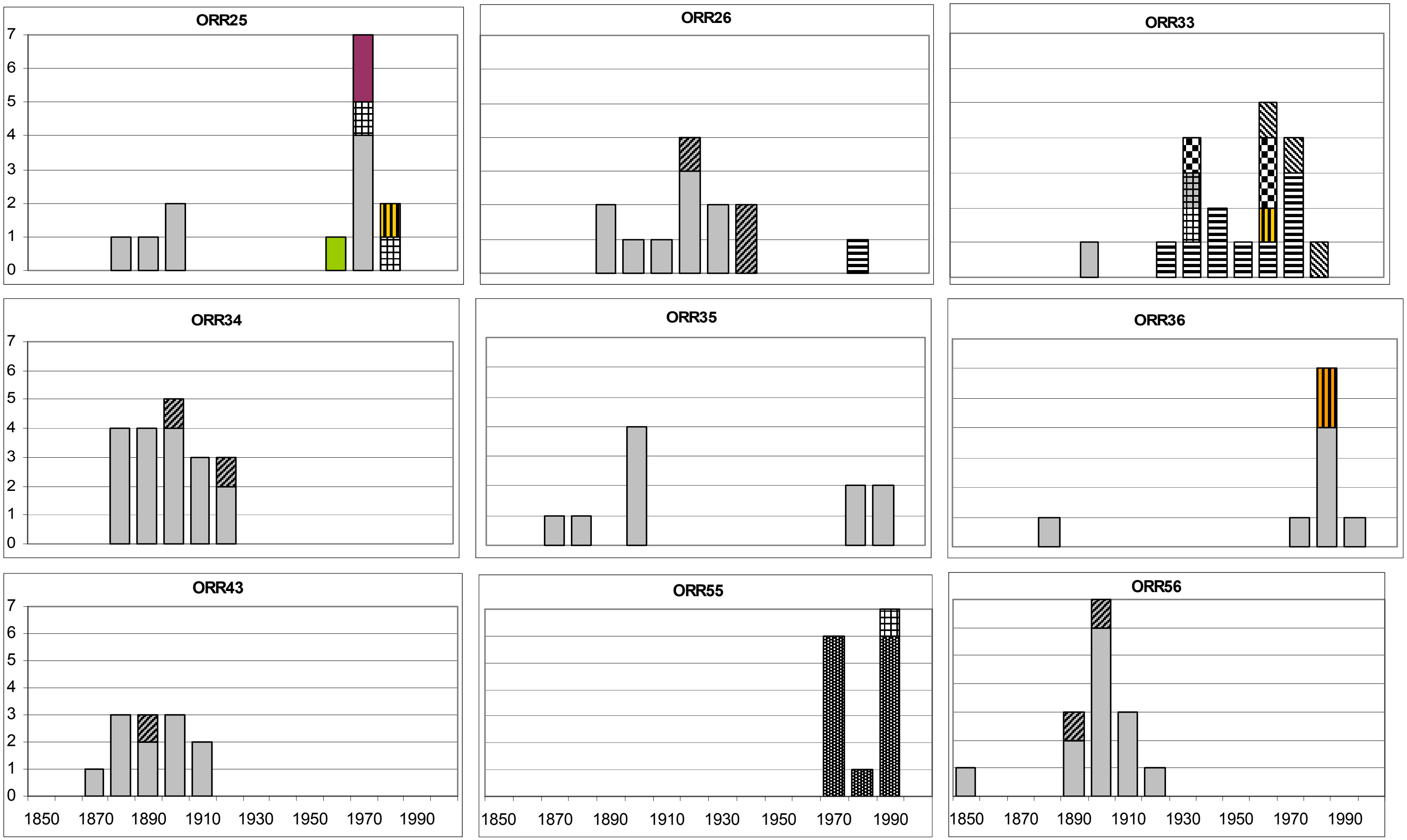
Appendix I - 4

Seedlings per 0.1 hectare (original numbers multiplied by 51 for extrapolation to entire plot) - Ordway

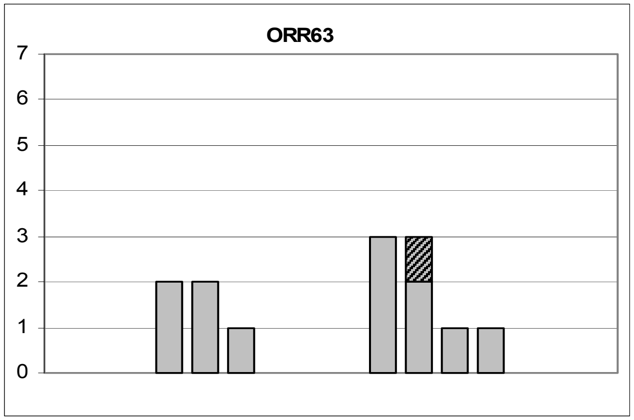
	OR25	OR26	OR28	OR33	OR34	OR35	OR36	OR43	OR51	OR55	OR56	OR63	OR64	OR71	Total
QUMA	0	0	0	0	0	0	51	0	0	51	0	0	0	0	102
RHGL	306	0	0	0	0	0	2703	0	0	306	0	0	0	0	3315
COAM	255	2856	0	0	0	0	0	0	0	0	0	0	0	0	3111
FRPE	0	0	0	153	51	51	0	0	0	102	0	0	0	0	357
PRSE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRVI	0	0	0	0	0	612	0	204	0	0	153	51	0	0	1020
LOTA	0	0	0	0	0	0	0	0	0	51	0	255	0	0	306
ZAAM	153	255	0	51	1020	0	0	408	0	0	51	0	51	0	1989
COXX1	0	204	0	0	102	0	0	0	0	0	0	0	0	0	306
ULAM	0	0	0	102	0	0	0	0	0	0	0	0	0	0	102
POTR	0	0	0	0	0	0	0	0	0	51	0	0	0	918	969
ACNE	153	0	0	0	0	51	0	0	0	0	0	408	255	0	867
RHCA	0	0	0	357	102	0	0	0	0	357	0	204	612	1122	2754
PRAM	0	0	0	0	0	0	0	0	0	0	0	0	102	0	102
Total	867	3315	0	663	1275	714	2754	612	0	918	204	918	1020	2040	15300

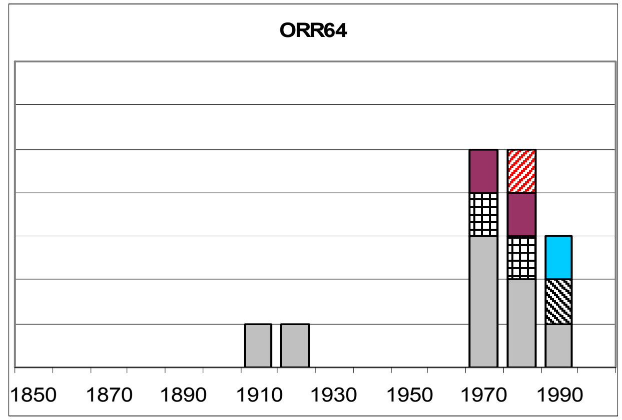
Saplings per 0.1 hectare – Ordway

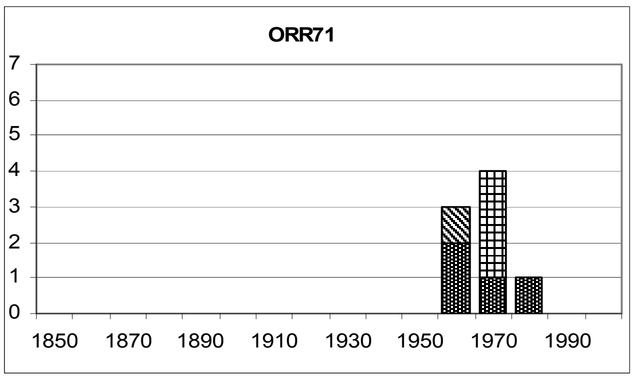
	OR25	OR26	OR28	OR33	OR34	OR35	OR36	OR43	OR51	OR55	OR56	OR63	OR64	OR71	Total
QUMA	3	0	0	0	0	17	3	0	0	0	0	1	2	0	26
RHGL	2	0	0	0	0	17	22	0	0	64	0	32	132	0	269
COAM	16	11	0	0	0	0	0	0	0	0	0	0	0	0	27
FRPE	0	0	0	22	0	0	0	0	0	0	0	15	2	2	41
PRSE	2	0	0	0	0	0	2	1	0	0	0	0	2	0	7
PRVI	0	0	0	0	0	0	0	1	0	0	0	0	2	0	3
LOTA	0	0	0	0	0	0	0	0	0	0	0	2	2	0	4
ZAAM	10	5	0	34	132	0	0	0	0	0	0	0	56	0	237
COXX1	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4
ULAM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POTR	0	0	0	0	0	0	0	0	0	28	0	0	0	14	42
ACNE	0	0	0	0	0	0	0	0	0	0	0	1	2	3	6
RHCA	0	0	0	0	0	0	0	0	0	16	0	44	66	8	134
PRAM	6	0	0	0	0	0	0	0	0	0	0	0	42	0	48
Total	39	16	0	56	132	34	27	2	0	108	0	95	308	31	848



Appendix I – 6: Age-structure of individual plots at Ordway Prairie. Tree species legend is on following page. X-axis represents decade of establishment while the y-axis represents the number of trees found.







Color/Pattern	Code	Scientific name	Common Name
	ACNE	*Acer negundo*	Boxelder
	ACNE (MIN)	*Acer negundo*	Boxelder
	CEOC	*Celtis occidentalis*	Hackberry
	FRPE	*Fraxinus pennsylvanica*	Green ash
	POTR	*Populus tremuloides*	Quaking aspen
	PRAM	*Prunus americana*	American plum
	PRSE	*Prunus serotina*	Black cherry
	QUMA	*Quercus macrocarpa*	Bur oak
	QUMA (MIN)	*Quercus macrocarpa*	Bur oak
	RHCA	*Rhamnus cathartica*	Buckthorn
	RHGL	*Rhus glabra*	Smooth sumac
	TIAM	*Tilia americana*	Basswood
	ULAM	*Ulmus americana*	American elm

Appendix I – 6 continued: Age-structure of individual plots at Ordway Prairie. X-axis represents decade of establishment while the y-axis represents the number of trees found.

Stem Density (trees per 0.1 hectare) - Helen Allison

	HA04	HA05	HA06	HA10	HA11	HA12	HA31	HA32	HA33	Total
QUMA	28	16	11	6	5	7	9	26	7	115
QUEL	13	21	12	34	0	1	35	1	38	155
PRSE	1	0	0	0	0	0	0	1	0	2
PRVI	4	1	0	0	0	0	0	0	0	5
FRPE	1	0	0	0	0	1	1	2	0	5
Total live	47	38	23	40	5	9	45	30	45	282
DEAD										
QUMA	0	1	1	0	0	0	0	0	2	4
QUEL	0	0	1	0	0	0	2	0	3	6
PRSE	0	0	0	0	0	0	0	0	0	0
PRVI	0	0	0	0	0	0	0	0	0	0
FRPE	0	0	0	0	0	0	0	0	0	0
Total dead	0	1	2	0	0	0	2	0	5	10
TOTAL (Live and Dead)	47	39	25	40	5	9	47	30	50	292

Basal Area (m^2 per 0.1 hectare) - Helen Allison

	HA04	HA05	HA06	HA10	HA11	HA12	HA31	HA32	HA33	Total
LIVE										
QUMA	0.50	0.48	0.47	0.16	0.12	0.81	0.74	1.22	0.42	4.92
QUEL	0.79	1.24	0.70	1.56	0	0.47	0.37	0.15	1.94	7.22
PRSE	0.01	0	0	0	0	0	0	0.07	0	0.07
PRVI	0.03	0.01	0	0	0	0	0	0	0	0.04
FRPE	0.02	0	0	0	0	0.01	0.002	0.04	0	0.07
Total live	1.34	1.73	1.17	1.72	0.12	1.29	1.11	1.47	2.36	12.31
DEAD										
QUMA	0	0.01	0.03	0	0	0	0	0	0.02	0.05
QUEL	0	0	0.24	0	0	0	0.01	0	0.02	0.26
PRSE	0	0	0	0	0	0	0	0	0	0
PRVI	0	0	0	0	0	0	0	0	0	0
FRPE	0	0	0	0	0	0	0	0	0	0
Total dead	0	0.01	0.26	0	0	0	0.01	0	0.04	0.32
TOTAL (live and dead)	1.34	1.73	1.44	1.72	0.12	1.29	1.12	1.47	2.40	12.62

Importance Values - Helen Allison

	HA04	HA05	HA06	HA10	HA11	HA12	HA31	HA32	HA33
QUMA	96.839	71.684	82.463	24.413	200	141.03	84.887	169.79	36.263
QUEL	86.206	125.25	117.54	175.59	0	47.31	112.81	13.44	163.74
PRSE	2.7129	0	0	0	0	0	0	7.5207	0
PRVI	10.521	3.0638	0	0	0	0	0	0	0
FRPE	3.721	0	0	0	0	11.662	2.3031	9.2531	0

Various Env. Conditions and Forest Structure Results - Helen Allison

	HA04	HA05	HA06	HA10	HA11	HA12	HA31	HA32	HA33
Slope	2	10	2	1	7	3	1	8	3
Aspect	N	NE	S	S	S	N	S	N	E
% QUMA multiples	14.286	56.25	18.182	100	0	0	11.111	34.615	28.571
% QUEL multiples	23.077	23.81	33.333	0	-------	100	54.286	0	7.8947

Prescribed Burn History - Helen Allison

	HA04	HA05	HA06	HA10	HA11	HA12	HA31	HA32	HA33
1962			sp			Sp	Sp		
1963			sp			Su	Sp		
1964			sp						
1965			sp						
1966									
1967									
1968			sp				sp		
1969						Su			
1970									
1971									
1972			sp				sp		
1973									
1974			sp			Su	sp		
1975			sp				sp		
1976			sp						
1977			sp						
1978			sp			Sp	sp		
1979			sp			Sp	sp		
1980			sp						
1981			sp						
1982									
1983			sp			Sp	sp		
1984			sp			Sp	sp		
1985									
1986			sp			Sp	sp		
1987	fa	fa		fa	fa			fa	fa
1988									
1989									
1990	fa	fa		fa	fa			fa	fa
1991			sp			Sp	sp		
1992	sp	sp		Sp	sp			sp	sp
1993									
1994									
1995	sp	sp		Sp	sp			sp	sp
1996									
1997			sp			Sp	sp		
1998									
1999									
2000									
2001									
2002									
2003	sp	sp		sp	sp			sp	sp
2004						Sp			
2005									
2006									
2007									

# burns	5	5	19	5	5	12	13	5	5
total years	20	20	46	20	20	46	46	20	20
freq.	4	4	2.4	4	4	3.8	3.5	4	4
MFI	4	4	1.9	4	4	3.5	2.6	4	4
Time since fire	4	4	10	4	4	3	10	4	4

sp = spring burn, su = summer burn, fa = fall burn.

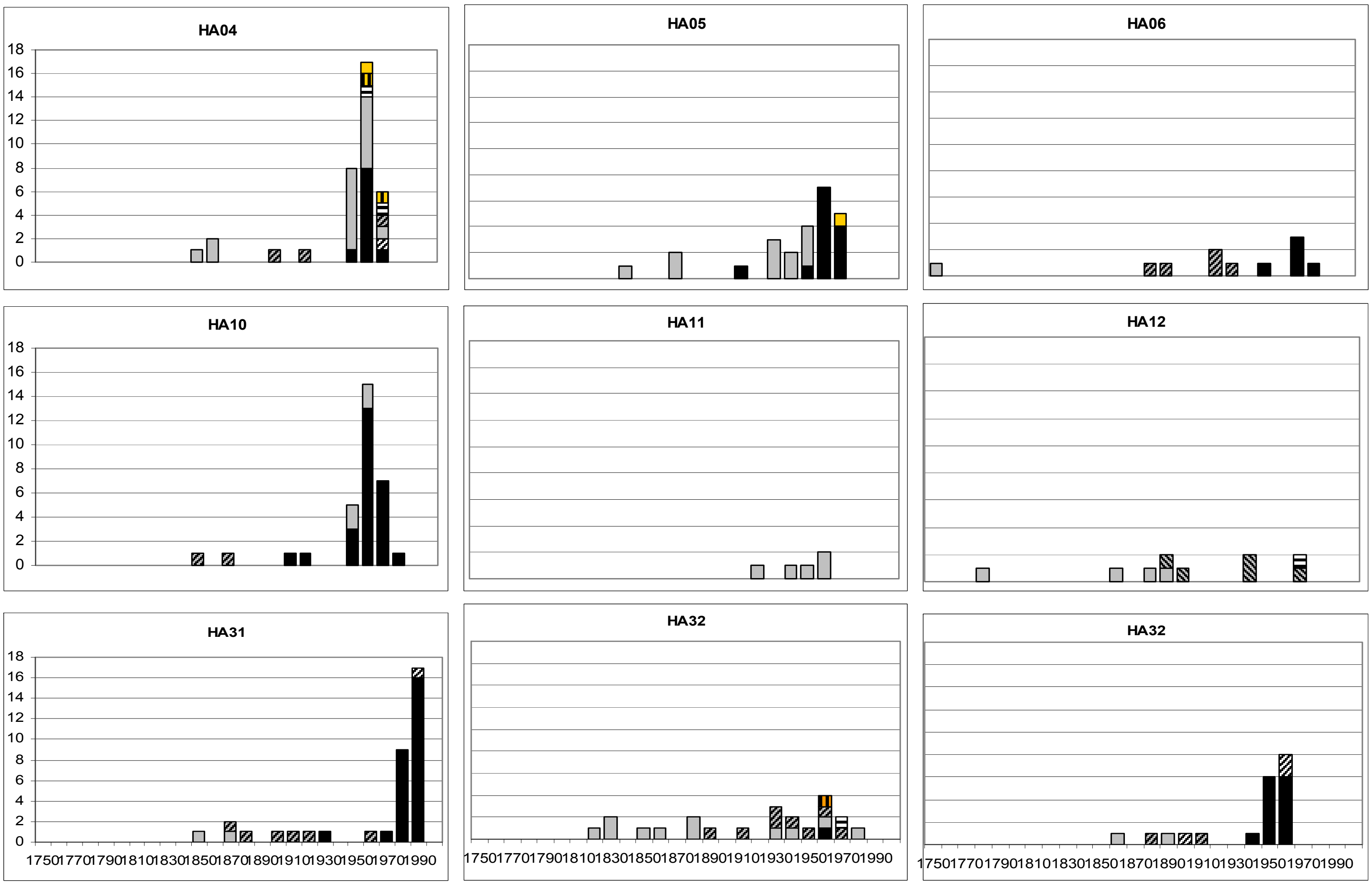
Appendix II - 4

Seedlings per 0.1 hectare (orig. #'s multiplied by 51 for extrap. to entire plot) - Helen Allison

	HA04	HA05	HA06	HA10	HA11	HA12	HA31	HA32	HA33	Total
QUMA	51	204	357	1020	51	102	51	306	51	2193
QUEL	51	153	204	255	0	102	102	102	51	1020
RHGL	0	0	714	0	0	0	306	0	0	1020
COAM	51	612	0	204	0	153	459	765	51	2295
FRPE	0	0	0	0	0	0	0	0	0	0
PRSE	0	51	0	0	0	0	0	102	255	408
PRVI	0	0	0	0	0	51	0	0	51	102
PRPE	0	0	0	0	0	0	0	0	408	408
Total	153	1020	1275	1479	51	408	918	1275	867	7446

Saplings per 0.1 hectare - Helen Allison

	HA04	HA05	HA06	HA10	HA11	HA12	HA31	HA32	HA33	Total
QUMA	9	3	27	3	1	3	21	8	1	76
QUEL	4	10	109	7	1	18	122	9	11	291
RHGL	0	0	55	5	0	0	23	0	0	83
COAM	160	36	2	3	2	3	34	26	0	266
FRPE	0	0	1	0	0	0	6	0	0	7
PRSE	12	9	0	1	0	10	0	6	1	39
PRVI	4	3	1	3	0	1	7	4	0	23
PRPE	15	3	0	0	0	0	11	5	0	34
Total	204	64	195	22	4	35	224	58	15	821



Appendix II – 6: Age-structure of individual plots at Helen Allison. X-axis represents decade of establishment while the y-axis represents the number of trees found. Key to colors is on following page.

Color/Pattern	Code	Scientific name	Common Name
	FRPE	*Fraxinus pennsylvanica*	Green ash
	PRPE	*Prunus pensylvanica*	Pin cherry
	PRSE	*Prunus serotina*	Black cherry
	PRVE	*Prunus virginiana*	Chokecherry
	QUEL	*Quercus ellipsoidalis*	Northern pin oak
	QUEL (MIN)	*Quercus ellipsoidalis*	Northern pin oak
	QUMA	*Quercus macrocarpa*	Bur oak
	QUMA (MIN)	*Quercus macrocarpa*	Bur oak

Appendix II – 6 continued

Stem Density (trees per 0.1 hectare) - Weaver Dunes

	WD02	WD07	WD14	WD15	WD22	WD23	WD46	WD47	WD48	WD56	WD57	WD58	WD62	WD63	WD64	WD65	Total
LIVE																	
QUMA	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
QUEL	24	27	22	18	7	7	0	5	11	0	13	0	9	0	28	1	172
PRPE	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2
FRPE	1	0	5	0	22	0	0	1	0	2	0	2	0	0	0	9	42
CEOC	0	0	0	0	4	0	0	1	0	0	0	1	0	0	0	0	6
ULAM	0	0	2	0	0	0	0	0	0	0	0	0	0	1	2	0	5
ACNE	0	0	0	0	0	0	0	12	0	0	0	4	2	0	0	0	18
TIAM	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	5
JUVI	0	0	2	0	0	3	0	0	2	0	0	2	0	3	9	6	27
PRAM	0	0	0	0	4	0	0	35	0	0	0	0	0	0	0	0	39
CACO	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	3
BENI	0	0	3	0	3	0	0	0	0	0	0	0	0	0	0	0	6
Total live	25	27	40	18	42	10	0	54	13	4	14	9	11	4	39	16	326
DEAD																	
QUMA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
QUEL	2	2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	6
PRPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FRPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CEOC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ULAM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ACNE	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
TIAM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUVI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRAM	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	6
CACO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BENI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total dead	2	2	0	0	0	0	0	6	0	0	2	1	0	0	0	0	13
TOTAL (Live and Dead)	27	29	40	18	42	10	0	60	13	4	16	10	11	4	39	16	339

Basal Area (m^2 per 0.1 hectare) - Weaver Dunes

	WD02	WD07	WD14	WD15	WD22	WD23	WD46	WD47	WD48	WD56	WD57	WD58	WD62	WD63	WD64	WD65	Total
LIVE																	
QUMA	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0.01
QUEL	1.52	2.58	0.89	0.06	0.64	0.03	0	0.38	0.44	0	0.66	0	0.04	0	1.27	0	8.49
PRPE	0	0	0	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0.02
FRPE	0.05	0	0.13	0	0.4	0	0	0	0	0.04	0	0.1	0	0	0	0.62	1.33
CEOC	0	0	0	0	0.04	0	0	0.02	0	0	0	0.01	0	0	0	0	0.07
ULAM	0	0	0.03	0	0	0	0	0	0	0	0	0	0	0.04	0.04	0	0.11
ACNE	0	0	0	0	0	0	0	0.13	0	0	0	0.13	0.01	0	0	0	0.26
TIAM	0	0	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04
JUVI	0	0	0.03	0	0	0.03	0	0	0.02	0	0	0.06	0	0.06	0.07	0.11	0.38
PRAM	0	0	0	0	0.02	0	0	0.16	0	0	0	0	0	0	0	0	0.18
CACO	0	0	0.01	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0.03
BENI	0	0	0.17	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0.37
Total live	1.57	2.58	1.3	0.06	1.31	0.06	0	0.69	0.46	0.06	0.67	0.3	0.04	0.1	1.38	0.74	11.28
DEAD																	
QUMA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
QUEL	0.02	0.05	0	0	0	0	0	0	0	0	0.31	0	0	0	0	0	0.39
PRPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FRPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CEOC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ULAM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ACNE	0	0	0	0	0	0	0	0	0	0	0	0.07	0	0	0	0	0.07
TIAM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUVI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRAM	0	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0	0	0.02
CACO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BENI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total dead	0.02	0.05	0	0	0	0	0	0.02	0	0	0.31	0.07	0	0	0	0	0.48
TOTAL (live and dead)	1.59	2.63	1.3	0.06	1.31	0.06	0	0.71	0.46	0.06	0.98	0.37	0.04	0.1	1.38	0.74	11.76

Importance Values - Weaver Dunes

	WD02	WD07	WD14	WD15	WD22	WD23	WD46	WD47	WD48	WD56	WD57	WD58	WD62	WD63	WD64	WD65
QUMA	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0
QUEL	193	200	124	200	65	117	0	62	180	0	192	0	166	0	164	7
PRPE	0	0	0	0	0	0	0	0	0	84	0	0	0	0	0	0
FRPE	7	0	22	0	83	0	0	2	0	116	0	47	0	0	0	140
CEOC	0	0	0	0	13	0	0	4	0	0	0	13	0	0	0	0
ULAM	0	0	7	0	0	0	0	0	0	0	0	0	0	67	8	0
ACNE	0	0	0	0	0	0	0	38	0	0	0	105	34	0	0	0
TIAM	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0
JUVI	0	0	7	0	0	83	0	0	20	0	0	36	0	133	28	53
PRAM	0	0	0	0	11	0	0	94	0	0	0	0	0	0	0	0
CACO	0	0	3	0	6	0	0	0	0	0	0	0	0	0	0	0
BENI	0	0	21	0	22	0	0	0	0	0	0	0	0	0	0	0

Various Environmental Conditions and Forest Structure Results - Weaver Dunes

	WD02	WD07	WD14	WD15	WD22	WD23	WD46	WD47	WD48	WD56	WD57	WD58	WD62	WD63	WD64	WD65
Slope	15°	0°	15	12	0°	20	0	10	2	2	5	3-10°	1	7	12°	5
Aspect	**TH**	TH	N	S	TH	N	none	E	SE	W	SW	TH	S	W	TH	W
% QUEL multiples	29.2	7.4	9.1	77.8	0.0	0.0	0.0	40.0	18.2	0.0	92.3	0.0	100.0	0.0	21.4	0.0
Scarring																
# OFS	6	2	2	6	3	2	0	2	2	1	2	4	0	0	10	4
# HS	4	7	1	0	1	0	0	1	4	1	4	0	0	0	7	0
# trees with CB	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
% scarred in plot	22.2	6.9	5	33.3	7.2	20	0	3.3	15.4	25	12.5	40	0	0	25.6	25
Pred. scarring dir.	S	none	none	E/SE	none	none	---------	--------	none	W	S	none	---------	--------	S/SE	none
Scarring rel. to slope	--------	none	none	si/down	none	none	---------	--------	none	downhill	downhill	none	---------	--------	----------	none

OFS = open face fire scar
HS = healed fire scar
CB = charred base
TH = top of hill, no aspect could be determined

Prescribed Burn History - Weaver Dunes

	WD02	WD07	WD14	WD15	WD22	WD23	WD46	WD47	WD48	WD56	WD57	WD58	WD62	WD63	WD64	WD65
1983																
1984																
1985																
1986								sp	sp							
1987		Sp	sp	sp	sp	sp										
1988	sp															
1989																
1990																
1991																
1992																
1993							sp	sp	sp	sp	sp	sp	sp	sp	sp	sp
1994																
1995																
1996																
1997			sp	sp	sp	sp										
1998	sp	sp														
1999							fa	fa	fa	fa	fa	fa	fa	fa	fa	fa
2000																
2001																
2002							fa			fa			fa			
2003			sp	sp	sp	sp										
2004																
2005	sp	Sp														
2006							fa									
2007																
# burns	3	3	3	3	3	3	4	3	3	3	2	2	3	2	2	2
total years	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
freq.	8.3	8.3	8.3	8.3	8.3	8.3	6.3	8.3	8.3	8.3	12.5	12.5	8.3	12.5	12.5	12.5
MFI	8.5	9	8	8	8	8	4	6.5	6.5	4.5	6	6	4.5	6	6	6
Time since fire	2	2	4	4	4	4	1	8	8	5	8	8	5	8	8	8

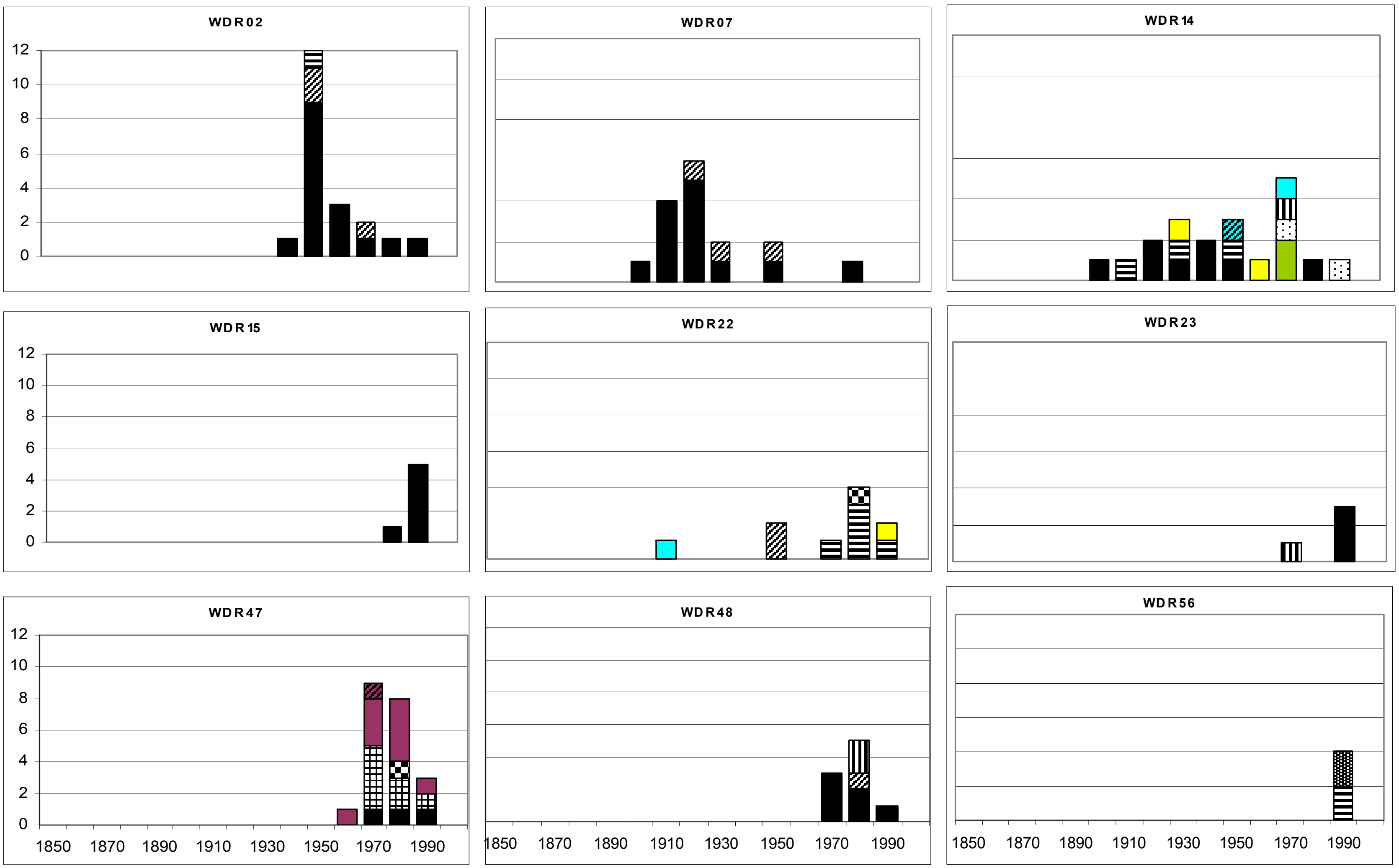
sp = spring burns, fa = fall burns

Seedlings per 0.1 hectare (original numbers multiplied by 51 for extrapolation to entire plot) - Weaver Dunes

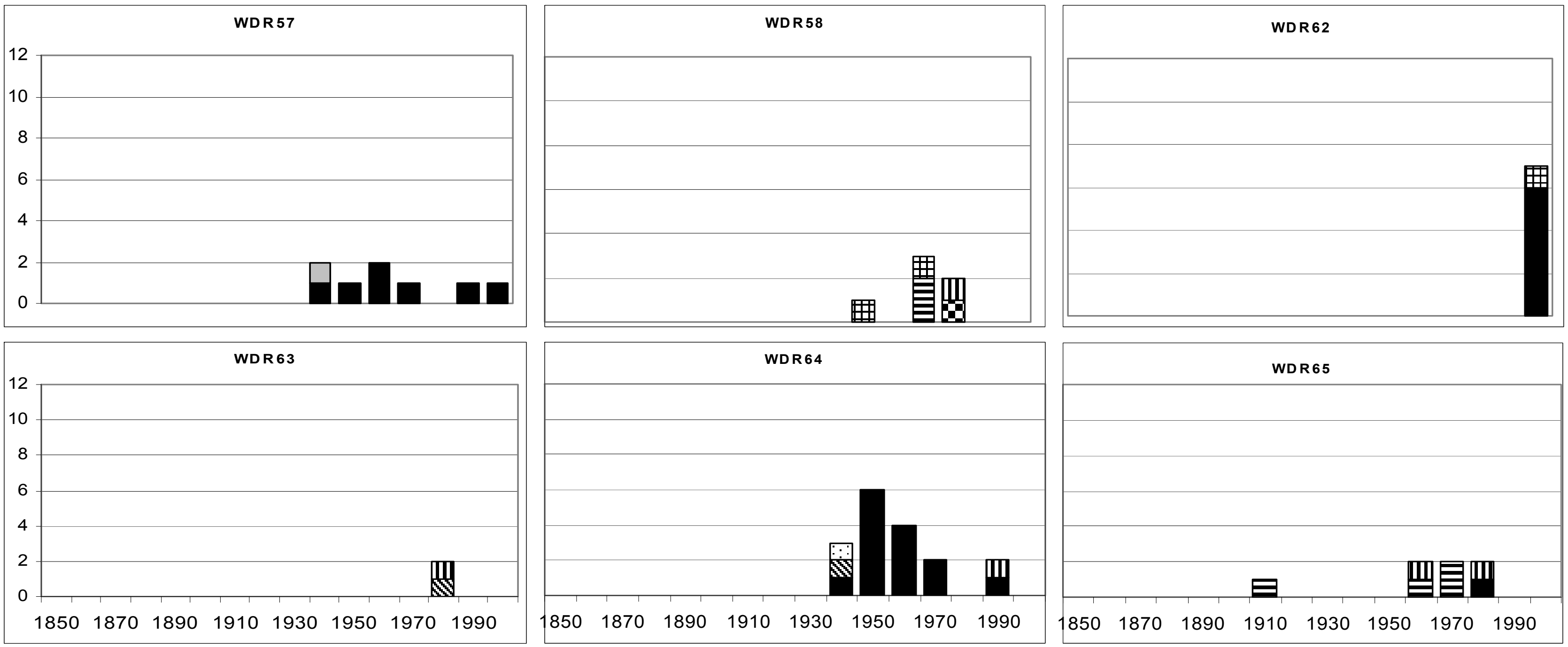
	WD02	WD07	WD14	WD15	WD22	WD23	WD46	WD47	WD48	WD56	WD57	WD58	WD62	WD63	WD64	WD65	Total
QUMA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
QUEL	459	2244	255	102	357	0	0	153	102	0	51	0	0	0	306	0	4029
RHGL	0	0	0	0	0	0	0	0	0	0	102	0	0	816	102	0	1020
COAM	0	0	0	0	0	0	0	204	0	0	51	0	0	0	0	0	255
FRPE	0	0	153	0	51	0	0	0	0	0	0	0	0	51	0	0	255
PRSE	0	0	0	0	255	0	0	0	0	0	0	0	0	0	0	0	255
PRVI	0	0	51	0	0	0	0	0	0	0	0	0	0	0	0	0	51
PRPE	0	0	51	0	0	0	0	0	0	0	51	0	0	0	255	51	408
LOTA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ZAAM	0	153	0	0	0	0	0	153	0	0	0	0	0	0	51	0	357
Currant sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COXX1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ULAM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ACNE	0	0	0	0	0	0	51	102	0	0	0	0	51	0	0	0	204
RHCA	0	0	0	0	0	0	0	51	204	0	0	0	0	0	0	0	255
TIAM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUVI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRAM	0	0	0	0	0	0	0	510	0	0	102	0	0	0	0	51	663
CACO	0	255	0	0	0	0	0	0	0	0	0	0	0	0	0	0	255
PIRE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	459	2652	510	102	663	0	51	1173	306	0	357	0	51	867	714	102	8007

Saplings per 0.1 hectare - Weaver Dunes

	WD02	WD07	WD14	WD15	WD22	WD23	WD46	WD47	WD48	WD56	WD57	WD58	WD62	WD63	WD64	WD65	Total
QUMA	0	0	0	0	0	0	0	0	1	0	6	0	0	0	0	0	7
QUEL	48	19	78	30	6	18	0	8	26	0	83	0	9	0	9	1	335
RHGL	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3
COAM	0	0	0	0	0	0	0	20	3	0	38	0	0	0	2	0	63
FRPE	0	2	3	0	13	0	0	92	0	2	1	0	0	0	0	0	113
PRSE	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2
PRVI	0	2	2	0	0	0	0	0	0	0	0	0	0	0	1	0	5
PRPE	0	2	3	0	0	0	0	0	10	0	19	0	3	0	5	0	42
LOTA	0	0	5	0	0	0	0	0	0	0	3	2	0	0	4	0	14
ZAAM	8	0	1	0	0	0	0	76	42	0	0	0	0	0	30	0	157
Currant sp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
COXX1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2
ULAM	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
ACNE	0	0	1	0	0	0	0	4	0	0	0	4	3	1	0	1	14
RHCA	0	0	0	0	0	0	0	4	0	0	3	8	0	0	5	5	25
TIAM	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
JUVI	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	4	6
PRAM	0	0	0	0	0	0	0	28	2	0	10	0	0	1	0	0	41
CACO	0	1	6	0	0	0	0	0	0	0	0	0	0	0	0	0	7
PIRE	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2
Total	56	29	101	30	19	20	0	232	86	3	163	14	17	3	57	11	841



Appendix III – 6: Age-structure of individual plots at Weaver Dunes. Tree species in legend follow four letter codes listed on page 158. X-axis represents decade of establishment while the y-axis represents the number of trees found.



Appendix III – 6 continued: Age-structure of individual plots at Weaver Dunes. Tree species in legend follow four letter codes listed on following page. X-axis represents decade of establishment while the y-axis represents the number of trees

Color/Pattern	Code	Scientific name	Common Name
	ACNE	*Acer negundo*	Boxelder
	BENI	*Betula nigra*	River birch
	BENI (MIN)	*Betula nigra*	River birch
	CACO	*Carya cordiformis*	Bitternut hickory
	CEOC	*Celtis occidentalis*	Hackberry
	FRPE	*Fraxinus pennsylvanica*	Green ash
	JUVI	*Juniperus virginiana*	Eastern red cedar
	POTR	*Populus tremuloides*	Quaking aspen
	PRAM	*Prunus americana*	American plum
	PRAM (MIN)	*Prunus americana*	American plum
	QUEL	*Quercus ellipsoidalis*	Northern pin oak
	QUEL (MIN)	*Quercus ellipsoidalis*	Northern pin oak
	QUMA	*Quercus macrocarpa*	Bur oak
	TIAM	*Tilia americana*	Basswood
	ULAM	*Ulmus americana*	American elm
	ULAM (MIN)	*Ulmus americana*	American elm

Appendix III – 6 continued

Stem Density (trees per 0.1 hectare) - Minnesota Valley NWR and Carver Rapids SP

	MV02	MV03	MV04	MV05	MV06	MV07	MV08	MV14	MV15	MV16	MV17	MV18	MV19	MV20	MV21	MV23	MV25	MV94	MV95	CR21	CR30	CR31	CR32	CR37	CR38	CR44	Total
LIVE																											
QUMA	0	0	0	20	4	5	6	0	0	5	4	11	1	0	7	0	0	5	21	16	0	7	2	17	9	8	148
QUEL	0	0	0	0	0	0	0	0	0	0	0	0	0	3	8	0	0	6	0	17	4	23	0	0	1	1	63
PRSE	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	0	0	4	1	0	9	1	0	2	0	0	23
PRPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2
FRPE	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	8	0	0	0	3	0	0	2	0	0	0	27
OSVI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	1	0	0	0	0	0	0	0	41
CEOC	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	5	3	2	0	0	0	0	0	0	12
ACSA1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
ULAM	0	0	0	0	0	1	1	0	0	0	0	0	0	47	0	32	29	0	1	4	0	1	4	0	0	1	121
ULRU	0	0	0	0	1	0	0	0	0	0	0	0	0	12	0	0	0	0	2	0	1	1	0	0	0	0	17
POTR	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
ACNE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	23	0	0	0	0	0	0	0	0	0	41
RHCA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	4
TIAM	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	5	1	0	0	0	0	0	0	0	0	10
JUVI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Total live	0	0	3	24	6	11	7	0	0	5	4	11	15	64	19	58	57	67	29	42	14	33	8	19	10	10	516
DEAD																											
QUMA	0	0	0	2	0	0	0	0	0	0	4	1	0	0	0	0	0	0	1	0	0	1	0	0	0	2	11
QUEL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	7	0	0	0	0	31
PRSE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	10	0	0	0	0	12
PRPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FRPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	3
OSVI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CEOC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ACSA1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ULAM	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	6	3	0	0	0	0	0	0	0	0	0	12
ULRU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POTR	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
ACNE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0	0	0	0	0	5
RHCA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TIAM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUVI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total dead	0	0	0	2	0	2	0	0	0	0	4	1	0	3	0	8	6	0	1	25	2	18	2	0	0	2	76
TOT. (L and D)	0	0	3	26	6	13	7	0	0	5	8	12	15	67	19	66	63	67	30	67	16	51	10	19	10	12	592

Appendix IV - 1

Basal Area (m^2 per 0.1 hectare) - Minnesota Valley NWR/Carver Rapids SP

	MV02	MV03	MV04	MV05	MV06	MV07	MV08	MV14	MV15	MV16	MV17	MV18	MV19	MV20	MV21	MV23	MV25	MV94	MV95	CR21	CR30	CR31	CR32	CR37	CR38	CR44	Tot.
LIVE																											
QUMA	0.0	0.0	0.0	0.9	1.2	1.2	1.6	0.0	0.0	1.4	0.6	1.2	0.1	0.0	0.4	0.0	0.0	0.2	1.8	1.0	0.0	0.9	0.1	0.5	0.7	0.3	14.1
QUEL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	1.4	0.0	0.3	0.3	0.9	0.0	0.0	0.1	0.0	3.2
PRSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.1	0.0	0.0	0.5
PRPE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FRPE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.3
OSVI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
CEOC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
ACSA1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
ULAM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.7	0.4	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	1.6
ULRU	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
POTR	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
ACNE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4
RHCA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
TIAM	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
JUVI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total live	0.0	0.0	0.0	1.1	1.4	1.3	1.6	0.0	0.0	1.4	0.6	1.2	0.2	0.5	0.6	1.3	1.8	2.2	1.9	1.4	0.6	1.8	0.3	0.6	0.7	0.4	22.8
DEAD																											
QUMA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.7
QUEL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.1	0.0	0.0	0.0	0.0	0.7
PRSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1
PRPE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FRPE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.5
OSVI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CEOC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ACSA1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ULAM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
ULRU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
POTR	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
ACNE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
RHCA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TIAM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JUVI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total dead	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.6	0.0	0.2	0.5	0.0	0.0	0.1	2.3
TOTAL (Live and Dead)	0.0	0.0	0.0	1.1	1.4	1.4	1.6	0.0	0.0	1.4	1.0	1.3	0.2	0.6	0.6	1.5	1.9	2.2	1.9	2.0	0.7	2.0	0.8	0.6	0.7	0.4	25.1

Importance Values - Minnesota Valley NWR and Carver Rapids SP

	MV02	MV03	MV04	MV05	MV06	MV07	MV08	MV14	MV15	MV16	MV17	MV18	MV19	MV20	MV21	MV23	MV25	MV94	MV95	CR21	CR30	CR31	CR32	CR37	CR38	CR44
QUMA	0	0	0	172	152	123	186	0	0	200	200	200	55	0	107	0	0	19	170	75	0	62	38	178	180	158
QUEL	0	0	0	0	0	0	0	0	0	0	0	0	0	16	62	0	0	73	0	106	65	107	0	0	33	20
PRSE	0	0	200	0	0	0	0	0	0	0	0	0	0	0	21	0	0	7	4	2	118	26	0	22	0	0
PRPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
FRPE	0	0	0	0	0	0	0	0	0	0	0	0	145	0	0	19	0	0	0	6	7	0	112	0	0	0
OSVI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	76	4	0	0	0	0	0	0	0
CEOC	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	11	12	4	0	0	0	0	0	0
ACSA1	0	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ACSA2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ULAM	0	0	0	0	0	8	14	0	0	0	0	0	0	143	0	115	74	0	3	7	0	3	51	0	0	22
ULRU	0	0	0	0	27	0	0	0	0	0	0	0	0	31	0	0	0	0	7	0	9	2	0	0	0	0
POTR	0	0	0	0	0	69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ACNE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	66	92	0	0	0	0	0	0	0	0	0
RHCA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0
TIAM	0	0	0	28	0	0	0	0	0	0	0	0	0	0	0	0	34	2	0	0	0	0	0	0	0	0
JUVI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0
PODE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Check	0	0	200	200	200	200	200	0	0	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200

Various Environmental Conditions and Forest Structure Results - Minnesota Valley NWR and Carver Rapids SP

	MV02	MV03	MV04	MV05	MV06	MV07	MV08	MV14	MV15	MV16	MV17	MV18	MV19	MV20	MV21	MV23	MV25	MV94	MV95	CR21	CR30	CR31	CR32	CR37	CR38	CR44
Slope	0	1	0	0	2	1	0	1	0	0	30	21	0	1	5	1	3	15	2	0	0	1	0	0	0	1
Aspect	none	N	none	none	S	S	none	S	none	none	S	S	none	S	S	S	W	S	S	none	none	N	none	none	none	NW
% QUMA multiples	-------	-------	-------	10	0	40	0	-------	-------	0	50	18.18	0	-------	71.43	------	------	0	52.38	31.25	-------	0	0	35.29	44.44	50
% QUEL multiples	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	0	87.5	------	------	33.33	-------	47.06	0	69.57	--------	--------	0	0

Scarring

	MV02	MV03	MV04	MV05	MV06	MV07	MV08	MV14	MV15	MV16	MV17	MV18	MV19	MV20	MV21	MV23	MV25	MV94	MV95	CR21	CR30	CR31	CR32	CR37	CR38	CR44
# OFS	0	0	1	7	3	5	4	0	0	1	0	1	0	0	5	5	1	0	0	5	5	10	3	6	1	3
# HS	0	0	0	3	3	0	0	0	0	0	0	0	1	0	0	4	1	0	0	4	2	7	1	1	2	0
# trees with CB	0	0	1	1	0	2	1	0	0	1	0	5	0	1	0	0	0	0	0	0	3	5	1	1	0	5
% scarred in plot	------	------	33.3	26.9	50.0	38.5	57.1	-------	-------	20.0	0.0	8.3	0.0	0.0	26.3	7.6	1.6	0.0	0.0	7.5	31.3	19.6	30.0	31.6	10.0	25.0
Pred. scarring Direction	------	------	W	S	W	E	none	---------	--------	none	--------	N	--------	--------	E/SE	E	W	----------	--------	SW	none	none	none	none	E	none
Scarring rel. to slope	--------	--------	------	------	side	side	-------	----	----	----	----	uphill	--------	--------	s/down	side	downhill	---------	---------	---------	---------	-------	-------	-------	-------	-------

OFS = open face fire scar, HS = healed fire scar, CB = charred bark

Prescribed Burn History - Minnesota Valley NWR and Carver Rapids SP

	MV02	MV03	MV04	MV05	MV06	MV07	MV08	MV14	MV15	MV16	MV17	MV18	MV19	MV20	MV21	MV23	MV25	MV94	MV95	CR21	CR30	CR31	CR32	CR37	CR38	CR44
1979																				burn*	burn*	burn*	burn*			
1980																										
1981																				burn*	burn*	burn*	burn*			
1982																				burn*	burn*	burn*	burn*			
1983																										
1984	sp	sp	sp	sp	sp		sp	sp	sp						sp											
1985																										
1986	sp	sp						sp							sp											
1987																				burn*	burn*	burn*	burn*			
1988																										
1989	sp	sp	sp	sp	sp		sp	sp	sp						sp											
1990																										
1991			sp	sp	sp		sp		sp											burn**	burn**	burn**	burn**			
1992	sp	sp	sp	sp	sp		sp	sp	sp						sp											
1993																										
1994	sp	sp	sp	sp	sp		sp	sp	sp						sp											
1995			sp	sp	sp		sp		sp																	
1996			sp	sp	sp		sp		sp																	
1997																										
1998	sp	sp	sp	sp	sp		sp	sp	sp						sp					MEC	MEC	MEC	MEC			
1999			sp	sp	sp/MEC		sp/MEC		sp											MEC	MEC	MEC	MEC			
2000	sp	sp	sp	sp	sp		sp	sp	sp						sp					fa	fa	fa	fa	fa	fa	fa
2001	sp	sp	sp/MEC	sp	sp/MEC		sp/MEC	spMEC	sp/MEC		MEC	MEC			sp/MEC											
2002															MEC											
2003	sp	sp	sp	sp	sp	sp	sp	sp	sp	sp	sp	sp			sp											
2004	sp	sp	sp	sp	sp	sp	sp	sp	sp	sp	sp	sp														
2005	fa	fa	fa	fa	fa	fa	fa	fa	fa	fa	fa	fa			fa											
2006	sp	sp	sp	sp	sp	sp	sp	sp	sp	sp	sp	sp			sp											
2007	sp	sp	sp	sp	sp	sp	sp	sp	sp	sp	sp	sp			sp											
# burns	13	13	16	16	16	5	16	13	16	5	5	5	0	0	12	0	0	0	0	6	6	6	6	1	1	1
total years	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	29	29	29	29	29	29	29
freq.	1.8	1.8	1.5	1.5	1.5	4.8	1.5	1.8	1.5	4.8	4.8	4.8	-------	------	2	-------	------	------	-------	21	21	21	21	21	21	21
MFI	1.9	1.9	1.5	1.5	1.5	1	1.5	1.9	1.5	1	1	1	------	------	2.1	------	------	------	------	5	5	5	5	8	8	8
yrs since fire	0	0	0	0	0	0	0	0	0	0	0	0	24	24	0	24	24	24	24	6	6	6	6	6	6	6

sp = spring burn, fa = fall burn, MEC = mechanical thinning using hydroaxe

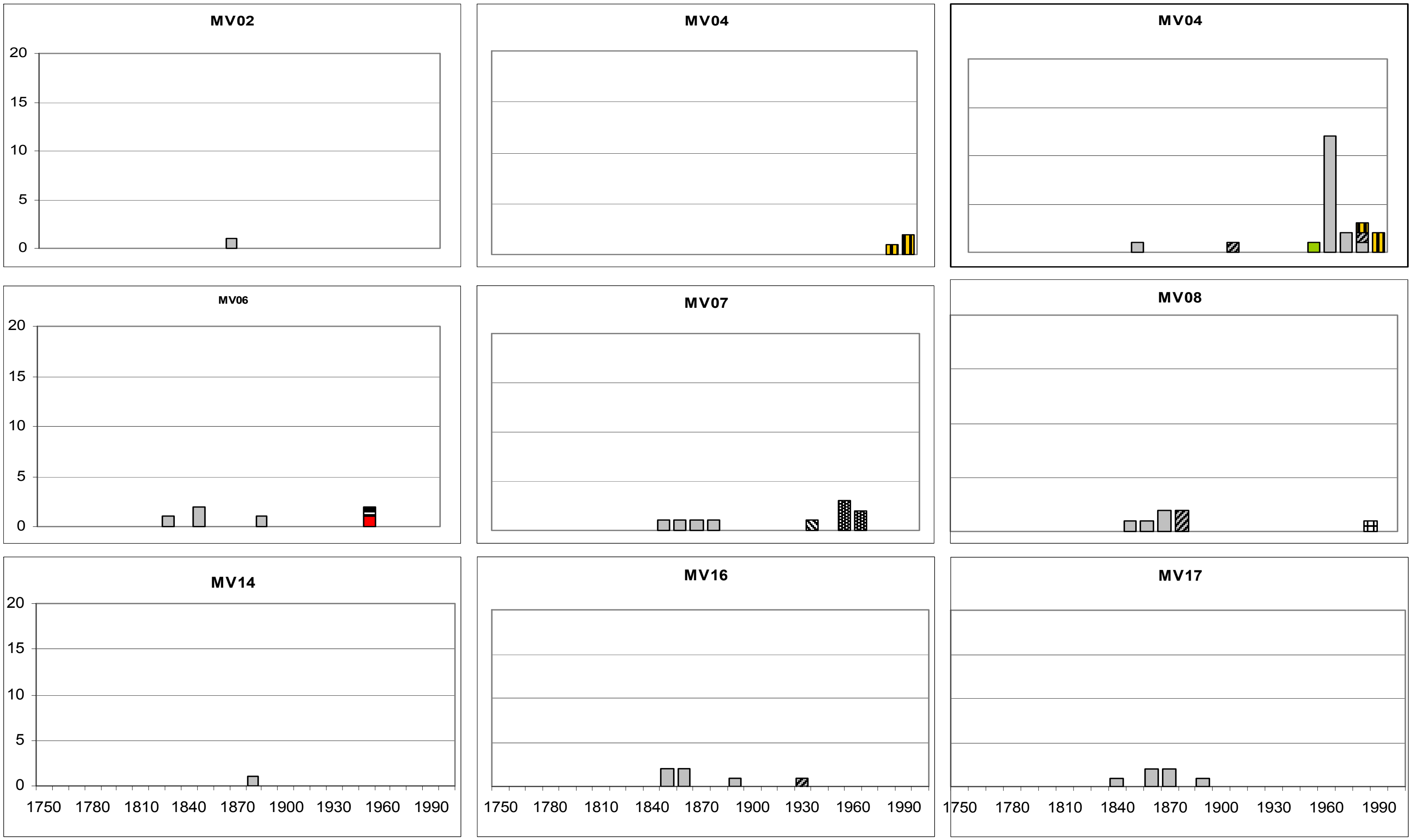
* The burn year may be off by one or two years in either direction because written burn record could not be located.
** The exact year that this burn occurred is known, but the seasonality is unknown

Seedlings per 0.1 hectare (original numbers multiplied by 51 for extrapolation to entire plot) - Minnesota Valley NWR/Carver Rap. SP

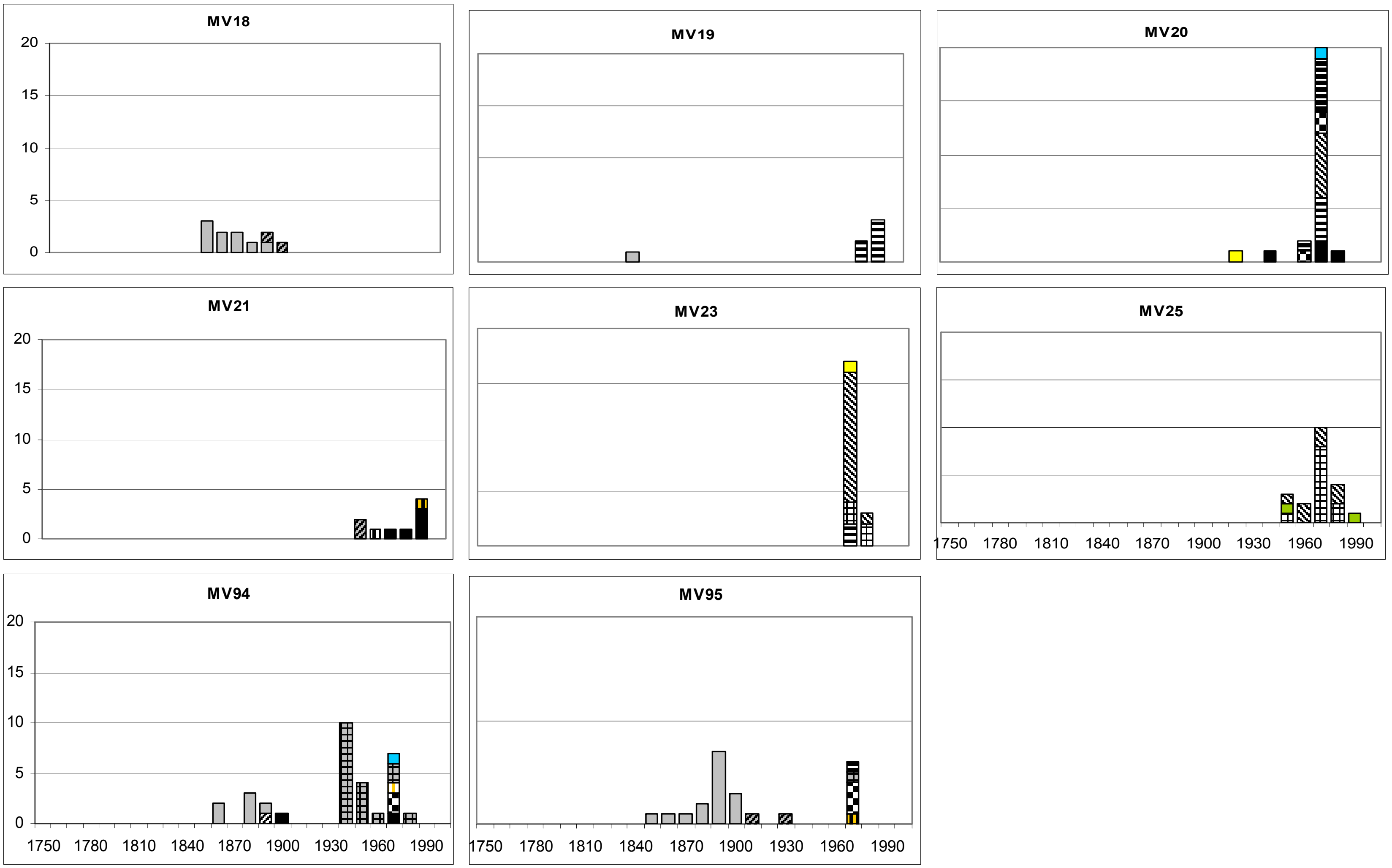
	MV02	MV03	MV04	MV05	MV06	MV07	MV08	MV14	MV15	MV16	MV17	MV18	MV19	MV20	MV21	MV23	MV25	MV94	MV95	CR21	CR30	CR31	CR32	CR37	CR38	CR44	Total
QUMA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	102	0	0	0	0	408	0	255	612	102	51	0	1530
QUEL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	153	0	51	51	0	0	0	255
RHGL	2754	4335	2295	612	408	1377	1836	1275	2142	0	1530	102	0	0	306	0	0	0	0	102	2601	714	561	255	102	1071	24378
COAM	0	0	0	204	1224	357	0	0	0	0	0	0	0	0	0	0	0	0	0	765	0	0	0	0	0	0	2550
FRPE	0	0	0	0	816	0	0	0	0	51	0	51	51	0	0	0	0	510	459	102	0	0	0	0	0	0	2040
PRSE	0	0	153	0	408	102	0	0	0	0	0	102	0	0	0	51	0	0	51	0	0	0	0	0	0	0	867
PRVI	0	0	0	0	816	51	0	0	0	0	0	0	0	0	0	153	0	0	255	0	0	0	0	0	0	0	1275
PRPE	0	0	0	0	0	510	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	510
LOTA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ZAAM	0	0	0	0	0	0	0	0	0	0	0	0	0	153	0	0	0	102	0	510	0	153	0	102	0	0	1020
COXX1	0	0	0	51	204	1275	0	0	0	0	204	1530	0	51	0	0	0	0	0	0	0	51	51	0	0	0	3417
OSVI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51	561	0	0	0	0	0	0	0	612
CEOC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51	0	0	0	0	0	0	0	0	0	0	51
ULAM	0	0	0	0	612	0	0	0	0	0	0	357	51	0	0	0	0	408	102	0	0	0	0	0	0	0	1530
ULRU	0	0	0	0	0	0	0	0	0	0	0	255	0	0	0	0	0	0	612	0	0	0	0	0	0	0	867
POTR	0	0	0	0	0	204	0	0	0	0	0	0	0	0	0	0	0	51	0	0	0	0	0	0	0	0	255
ACNE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	306	0	0	0	0	0	0	0	0	0	306
RHCA	0	0	0	306	1632	1479	0	0	0	102	3417	1938	0	1122	0	357	306	102	1173	0	0	0	0	0	0	0	11934
TIAM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	102	0	0	0	0	0	0	0	102
JUVI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51	0	0	0	0	0	0	0	0	0	0	0	51
PRAM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	153	0	1224	1377
APAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	2754	4335	2448	1173	6120	5355	1836	1275	2142	153	5151	4335	102	1326	459	612	612	1224	3315	2040	2601	1224	1275	612	153	2295	54927

Saplings per 0.1 hectare - Minnesota Valley NWR and Carver Rapids SP

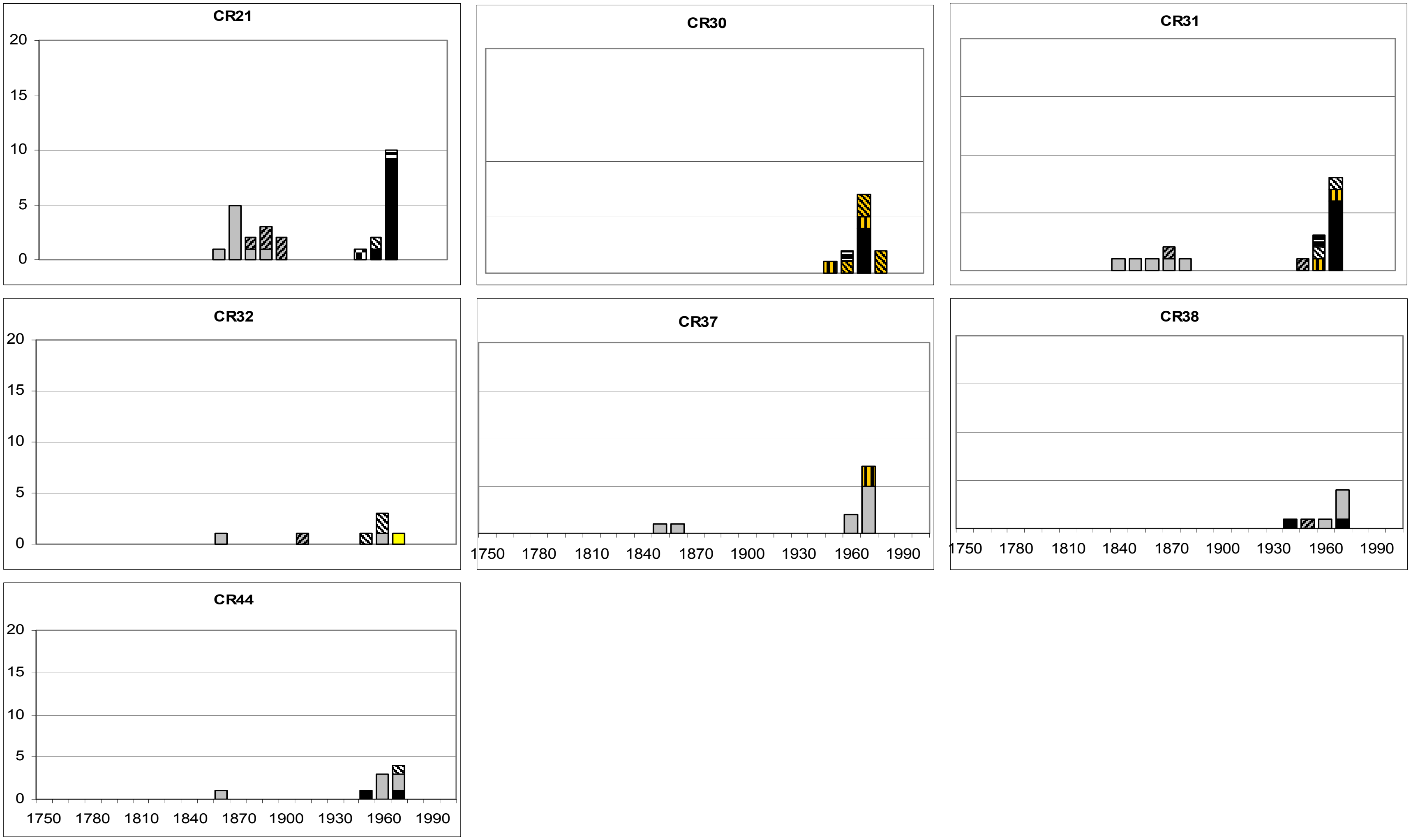
	MV02	MV03	MV04	MV05	MV06	MV07	MV08	MV14	MV15	MV16	MV17	MV18	MV19	MV20	MV21	MV23	MV25	MV94	MV95	CR21	CR30	CR31	CR32	CR37	CR38	CR44	Total
QUMA	0	0	3	4	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	2	2	0	2	18	0	4	39
QUEL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	2	0	0	10	6	0	54	2	11	94
RHGL	1	0	15	0	44	0	17	0	0	0	0	0	0	0	13	0	0	0	0	11	20	165	480	198	10	20	994
COAM	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	24
FRPE	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	18	0	16	105	8	2	0	2	0	0	0	155
PRSE	0	0	13	0	16	28	0	0	0	1	1	40	0	0	3	0	0	0	6	0	2	4	0	12	0	3	129
PRVI	0	0	38	0	0	4	0	0	0	1	0	0	0	0	1	0	0	5	14	0	0	0	0	0	0	0	63
PRPE	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	10	6	1	0	0	0	0	0	0	21
LOTA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
ZAAM	0	0	4	0	0	0	0	0	0	0	0	0	9	44	16	1	0	1	10	19	1	0	0	12	1	3	121
COXX1	0	0	0	0	3	0	0	0	0	0	0	0	10	2	0	0	0	2	6	0	0	1	0	0	0	0	24
OSVI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	16	0	0	0	0	0	0	0	32
CEOC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	6	0	0	0	0	0	0	0	15
ULAM	0	0	1	0	0	4	0	0	0	0	0	0	0	4	4	5	16	0	6	0	0	0	0	0	0	0	40
ULRU	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	1	0	0	0	0	0	0	0	0	13
POTR	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
ACNE	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	11
RHCA	0	0	0	3	8	12	1	0	0	7	0	12	0	236	14	75	11	15	136	0	0	5	0	0	0	2	537
TIAM	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	4
JUVI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRAM	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	66
APAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2
Total	1	30	76	7	99	56	22	0	0	9	1	52	21	298	64	101	31	79	311	44	37	184	484	294	13	79	2393



Appendix IV – 6: Age-structure of individual plots at Minnesota Valley NWR. Tree species in legend follow four letter codes listed on page 167. X-axis represents decade of establishment while the y-axis represents the number of trees found.



Appendix IV – 6 continued: Age-structure of individual plots at Minnesota Valley NWR. Tree species in legend follow four letter codes listed on page 167. X-axis represents decade of establishment while the y-axis represents the number of trees found.



Appendix IV – 6: Age-structure of individual plots at Carver Rapids State Park. Tree species in legend follow four letter codes listed on page 167. X-axis represents decade of establishment while the y-axis represents the number of trees found.

Color/Pattern	Code	Scientific name	Common Name
	ACNE	*Acer negundo*	Boxelder
	ACSA3	*Acer saccharum*	Sugar maple
	CACO	*Carya cordiformis*	Bitternut hickory
	CEOC	*Celtis occidentalis*	Hackberry
	FRPE	*Fraxinus pennsylvanica*	Green ash
	JUVI	*Juniperus virginiana*	Eastern red cedar
	OSVI	*Ostrya virginiana*	Ironwood
	POTR	*Populus tremuloides*	Quaking aspen
	PRPE	*Prunus pensylvanica*	Pin cherry
	PRSE	*Prunus serotina*	Black cherry
	PRSE (MIN)	*Prunus serotina*	Black cherry
	QUEL	*Quercus ellipsoidalis*	Northern pin oak
	QUEL (MIN)	*Quercus ellipsoidalis*	Northern pin oak
	QUMA	*Quercus macrocarpa*	Bur oak
	QUMA (MIN)	*Quercus macrocarpa*	Bur oak
	RHCA	*Rhamnus cathartica*	Buckthorn
	TIAM	*Tilia americana*	Basswood
	ULAM	*Ulmus americana*	American elm
	ULRU	*Ulmus rubra*	Slippery elm

Appendix IV – 6 continued

Average # of years to coring height (0.3m)

	OR	HA	WD	MV/CR	Average
QUMA	0.6	3.1	-----	0.3	1.3
QUEL	-----	0.3	1.0	0.0	0.4
PRSE	0.0	1.0	-----	1.0	0.7
COAM	-----	1.0	-----	-----	1.0
FRPE	-----	-----	2.0	7.0	4.5
PRAM	-----	-----	0.5	-----	0.5
JUVI	-----	-----	7.0	-----	7.0
TIAM	-----	-----	0.0	-----	0.0
ACNE	-----	-----	0.0	0.0	0.0
ULAM	-----	-----	-----	0.5	0.5
RHGL	-----	-----	-----	0.0	0.0
OSVI	-----	-----	-----	0.0	0.0
RHCA	------	-----	-----	4.0	4.0
CEOC	------	-----	-----	3.0	3.0

Average # years to coring height (0.3m)

	OR	HA	WD	MV/CR	Average
Shady:	0.4	0.7	0.0	-----	0.4
Partial Shade:	0.5	3.0	4.0	-----	2.5
Sunny:	0.8	0.3	0.6	0.1	0.5

Average # years to coring height (0.3m)

	OR	HA	WD	MV/CR	Average
QUMA Shady	0.4	1.0	------	none	0.7
QUMA partial shade	0.5	3.8	------	none	2.2
QUMA Sunny	0.8	1.0	------	0.3	0.7
QUEL Shady	------	0.5	0.0	------	0.3
QUEL partial shade	------	0.5	4.0	------	2.3
QUEL Sunny	------	0.0	0.6	0.0	0.2

List of herbaceous species

Scientific name	Common Name	Code
Acer negundo	boxelder	ACNE1
Acer rubrum	red maple	ACRU
Acer saccharinum	silver maple	ACSA2
Acer saccharum	sugar maple	ACSA3
Achillea millefolium	common yarrow	ACMI2
Adiantum pedatum	maiden hair fern	ADPE
Ageratina altissima	white snakeroot	AGAL1
Allium cernuum	nodding wild onion	ALCE2
Allium stellatum	prairie wild onion	ALST
Ambrosia artemisiifolia	common ragweed	AMAR2
Ambrosia psilostachya	western ragweed	AMPS
Amelanchier sp.	juneberry / serviceberry	AMXX1
Amorpha canescens	leadplant	AMCA1
Amphicarpaea bracteata	hog peanut	AMBR1
Andropogon gerardii	big bluestem	ANGE1
Anemone canadensis	meadow anemone	ANCA8
Anemone cylindrica	thimbleweed	ANCY1
Anemone quinqefolia	wood anemone	ANQU1
Apocynum androsaemifolium	spreading dogbane	APAN1
Aquilegia canadensis	columbine	AQCA1
Aralia nudicaulis L.	wild sarsaparilla	ARNU2
Arctium minus	burdock	AMRI1
Arisaema triphyllum	jack in the pulpit	ARTR1
Artemesia campestris	tall wormwood	ARCA1
Artemisia ludoviciana	white sage	ARLU1
Asclepias exaltata	poke milkweed	ASEX1
Asclepias syriaca	common milkweed	ASSY1
Asparagus officinalis	wild asparagus	ASOF
Aster macrophyllus	large-leaved aster	ASMA1
Aster novae-angliae L.	New England aster	ASNO1
Betula nigra	river birch	BENI
Bouteloua curtipendula	side oats grama	BOCU1
Bouteloua hirsuta	hairy grama	BOHIH
Bromus inermis	smooth brome	BRIN1
Calamovilfa longifolia (Hook.) Scribn.	prairie sand reed	CALO
Callirhoe involucrata	purple poppy mallow	CAIN2
Carex spp.	sedge spp.	CAXX1
Carya cordiformis	bitternut hickory	CACO
Celtis occidentalis	hackberry	CEOC1
Chamaecrista fasciculata	partridge pea	CHFA2
Chenopodium album	lambsquarter	CHAL1
Cicuta maculata	water hemlock	CIMA1
Circaea lutentiana	enchanters nightshade	CILU1
Cirsium discolor	field thistle	CIDI
Convolvulus arvensis	bindweed	COAR4
Coreopsis palmata Nutt.	stiff tickseed	COPA10
Cornus sp	dogwood	COXX1
Corylus americana	american hazel	COAM1
Cuscuta L.	dodder	CUSCU
Desmodium glutinosum	tick trefoil	DEGL
Dichanthelium acuminatum	hairy panic grass	DIAC2
Dichanthelium oligosanthes	Scribners panic grass	DIOL1
Dichanthelium wilcoxianum	Wilcox's panic grass	DIWI5
Echinocystis lobata	wild cucumber	ECLO1
Elymus canadensis	Canada wild rye	ELCA4

Elymus trachycaulus	slender wheatgrass	ELTR7
Equisetum hyemale	horsetail	EQHY
Eragrostis spectabilis	purple love grass	ERSP1
Erigeron philadelphicus	fleabane	ERPH1
Euphorbia corollata L.	flowering spurge	EUCO10
Fragaria sp.	wild strawberry	FRXX1
Fraxinus pennsylvanica	green ash	FRPE1
Galium sp.	bedstraw	GAXX1
Geranium maculatum	wild geranium	GEMA1
Gnaphalium obtusifolium	sweet everlasting	GNOB1
Helianthus pauciflorus Nutt.	stiff sunflower	HEPA19
Heracleum maximum	cow parsnip	HEMA80
Hesperostipa spartea	porcupine grass	HESP11
Impatiens capensis	jewelweed	IMCA
Juniperus virginiana	eastern red cedar	JUVI1
Koeleria macrantha	june grass	KOMA1
Lactuca seriola	prickly lettuce	LASE
Leonurus cardiaca	motherwort	LECA2
Lepidium virginicum L.	Virginia pepperweed	LEVI3
Liatris aspera Michx.	blazing star	LIAS
Lithospermum canescens (Michx.) Lehm.	hoary puccoon	LICA12
Lithospermum caroliniense	Carolina hoary puccoon	LICA13
Lonicera tatarica	tartarian honeysuckle	LOTA1
Maianthemum canadense	Canada mayflower	MACA
Maianthemum stellatum	starry false solomon's seal	MAST1
Malus pumila x baccata	crabapple spp.	MAPU2
Mollugo verticillata	carpetweed	MOVE1
Monarda fistula	wild bergamot	MOFI1
Monarda punctata	spotted bee-balm	MOPU
Muhlenbergia cuspidata	marsh mully/plains mully	MUCU3
Nepeta cataria	catnip	NECA1
Oligoneuron rigidum	stiff goldenrod	OLRI
Osmorhiza claytonii	sweet cicely	OSCL
Ostrya virginiana	ironwood	OSVI1
Panicum capillare	witch grass	PACA1
Panicum virgatum	switch grass	PAVI1
Parthenocissus quiquefolia	Virginia Creeper	PAQU2
Paspalum setaceum Michx.	hairy bead	PASE5
Phalaris aundinacea	reed canary grass	PHAR1
Physalis heterophylla	clammy ground cherry	PHHE5
Physalis virginiana	virginia ground cherry	PHVI5
Plantago major	plantain	PLMA1
Poa pratensis	kentucky bluegrass	POPR1
Polygonatum biflorum	solomon's seal	POBI1
Populus deltoides	eastern cottonwood	PODE
Populus tremuloides	quaking aspen	POTR1
Potentilla arguta	prairie cinquefoil	POAR7
Prunus americana	American plum	PRAM1
Prunus pensylvanica	pin cherry	PRPE1
Prunus serotina	black cherry	PRSE1
Prunus virginiana	chokecherry	PRVE1
Psoralea argophylla	silver scurf pea	PEAR6
Quercus ellipsoidalis	northern pin oak	QUEL1
Quercus macrocarpa	bur oak	QUMA1
Rhamnus cathartica	buckthorn	RHCA1
Rhus glabra	smooth sumac	RHGL1
Rhus hirta	staghorn sumac	RHHI1
Ribes sp	currant	RIXX1

Appendix VI – 1 continued

Rosa sp	wild rose	ROXX1
Rubus sp	raspberry	RUXX1
Salix humilis	prairie willow	SAHU1
Sanicula marildica	black snakeroot	SAMA1
Saponaria officinalis L.	bouncingbet	SAOF4
Schizachyrium scoparuim	little bluestem	SCSC1
Solanum dulcamara	bittersweet nightshade	SODU1
Solidago canadensis L.	Canada goldenrod	SOCA6
Solidago flexicaulis L.	zig-zag goldenrod	SOFL2
Solidago gigantea	giant/late goldenrod	SOGI
Solidago missouriensis Nutt.	Missourri goldenrod	SOMI2
Solidago nemoralis	grey/old-field goldenrod	SONE
Solidago speciosa Nutt.	showy goldenrod	SOSP2
Sorghastrum nutans	indian grass	SONU1
Sphagnum girgensohnii	sphagnum moss	SPGI1
Strophostyles helvola (L.) Elliott	wild bean	STHE9
Symphyotrichum cordifolium	heart-leaved aster	SYCO4
Symphyotrichum ericoides	heath aster	SYER
Symphyotrichum oblongifolium	aromatic aster	SYOB
Symphyotrichum oolentangiense	skyblue aster	SYOOO
Taraxacum officinale	common dandelion	TAOF
Thelypteris palustris	marsh fern	THPA1
Tilia americana	basswood	TIAM
Toxicodendron rydbergii	poison ivy	TORY1
Tradescantia occidentalis	prairie spiderwort	TROC1
Trifolium spp.	clover	TRIFO
Trogopogon dubius	yellow goats beard	TRDU
Ulmus americana	American elm	ULAM1
Ulmus rubra	slippery elm	ULRU1
Urtica dioica	stinging nettle	URDI1
Verbascum thapsus	mullein	VETH
Viola canadensis L.	Canada white violet	VICA4
Viola pedata	birds foot violet	VIPE1
Viola pedatifida	prairie violet	VIPE2
Viola sagittata	arrowleaf violet	VISA2
Vitis riparia	wild grape	VIRI1
Zanthoxylum americanum	prickly ash	ZAAM1

Appendix VI – 1 continued