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THE PROLOGUE TO MANAGEMENT: THE EFFECTS OF HISTORICAL ANTHROPOGENIC ACTIVITIES ON FOREST ECOSYSTEMS AND CURRENT MANAGEMENT OPPORTUNITIES IN SOUTHWESTERN ILLINOIS

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by

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Forest disturbance occurs on a wide gradient of selectiveness and creates new growth opportunities for adapted species. Across the spectrum of disturbance, anthropogenic disturbance influences community assembly in the Midwest more than other mechanisms but is its role in shaping and maintaining ecosystems is inadequately considered in most discussions on the historic range of variability (HRV). Forest resiliency is threatened by unprecedented agents of ecosystem change such as invasive species and reduced regeneration potential of native species. Historic anthropogenic disturbance largely resulted in forest conditions which commonly contained high value attributes like heterogeneity across habitat types and landscape diversity, yet also produced forests of undesirable traits due to high grading for timber and overgrazing by domesticated stock. In order to maintain historical representative forests and improve the degraded forests, active forest management is necessary to continue historic disturbance patterns and combat new threats. Forest transition theory is used here to describe the impacts of human settlement and development activities on forest ecosystems across the Middle Mississippi River Valley. To date, researchers have identified the need for information related to changes of forest attributes such as species composition and stand structure, improved descriptions of short- and medium-term dynamics within the context of the long-term transition, and the integration of biophysical drivers of forest change through time. In Midwestern U.S.A., forest dynamics were influenced by frequent, low intensity disturbance events that mediate forest composition and stand structure by selecting for disturbance regimes that create oak woodland and interspersed prairies and meadows. The onset of Euro-American settlement was accompanied by detailed land-use records with information related to forest attributes, agricultural activities, and parcel ownership patterns. We aggregated multiple sources of historic forest conditions into a geodatabase in order to document changes over the past 200 years in Elsah Township, Illinois, where the pre-settlement (1820) forest, once dominated by oak and hickory species, has largely shifted to a maple dominated system with a declining oak-hickory component, heavily influenced by an invasive shrub species, bush honeysuckle. Using on ordinary kriging interpolation, forest density was estimated at 8.7 stems per acre on average with a mean basal area of 14.6 square feet per acre prior to settlement. Conservation practices of the early 1900s, including fire suppression and erosion control resulted in changes to forest structure with density increases to 127 trees per acre with a basal area of 175.8 square feet per acre. The high degree of topographic variability near the Mississippi River influenced forest cover changes as slopes with low angles were the first to be converted from forest cover to other land uses (circa 1850). Forest re-initiation occurred in areas with steeper slope due to a lack of human activities. Forest cover declined to the lowest point in 1927 and has been rebounding steadily throughout this century. Of the original 15,252 forested acres, 11.6% remained covered throughout the past 200 years and coincided with slopes with an average of 39.1 degrees. These data can provide a spatially explicit and historically accurate tool to guide land management decisions including restoration treatment, disturbance regime management, and land use preservation activities in similarly heterogeneous environments. Forest communities along the bluffs of the Mississippi River differ in species composition and stand structure associated with specific topographic positions of floodplain, transition talus slope, bluff top, and upland. In order to assess current stand characteristics and ecosystem trajectory, we measured all woody stems in 316 fixed radius plots (79 plots per topographic position) with a plot area of 25 m^2. Alpha (defined as within system diversity) and Beta (defined as between system diversity) diversity and diameter distributions were determined for seedling, shrub layer, and overstory stems. Stem density increased from 21.4 stems ha^{-1} in 1820 to 613 stems ha^{-1} in 1936 followed by reduction to 314 stems ha^{-1} in 2017. Average stand diameter decreased from 40.9 cm in 1820 to 25.3 cm in 2017 (for upland stems greater than 7.5 cm) while basal area increased from 3.3 m^2 ha^{-1} in 1820 to 40.4 m^2 ha^{-1} in 2017. Alpha diversity was highest in the upland overstory and in the river island shrub layer. Beta diversity in the overstory was highest (0.67) between the bluff and the upland while lowest (0.08) between the bluff and the river island. Importantly, mesophytic species are no longer restricted to watercourses and valleys as reported in historical accounts and confirmed by the spatial analysis of original witness tree records. Currently, bush honeysuckle, an invasive species, dominates the shrub layer on most non-hydric sites of the talus slope, upland, and particularly across the bluff top where it is an indicator. Across all forest sites in the study, we found evidence of a community shift to less diversity and more mesophytic species over the past 80 years. Hill prairie vegetation on the limestone bluffs of the central Mississippi River Valley represents a significant portion of the remaining prairie, savanna, and woodland systems of the Midwest and should be appropriately managed with prescribed fire and woody stem reduction efforts. We examined the structure, composition, and temporal community patterns of the forest-prairie gradient by employing hierarchical cluster analysis and non-metric multi-dimensional scaling in combination with indicator species analysis and dendrochronological methods. Results suggest that four general community types exist across the forest-prairie gradient: Group 1

consists of the woodland community structure with significant indicator values for the density of *Juniperus virginiana* (indicator value 58.4, p = 0.0002), *Carya glabra* (45, 0.0022), *Quercus stellata* (23.7, 0.0424), and *Lonicera maackii* (74.2, 0.0002) and a high basal area (BA) of *J. virgniana* (21.4, 0.0276) and *L. maackii* (47.9, 0.0054). The first year of *L. maackii* presence was 1964 with the primary wave of invasion beginning around 1990. Group 2 contains bare soil coverage in the subplot (40.4, 0.0002) as the one indicator at a significant level. The species with the highest BA in Group 2 include *Acer saccharum* (9.08 m^2 ha^{-1}), *Q. velutina* (5.89 m^2 ha^{-1}), and *Q. muehlenbergii* (5.32 m^2 ha^{-1}). Group 3 typifies the hill prairie community with the sole indicator of grass coverage in the subplots (39.7, 0.0196). Group 4 represents the stage of forest development following the cessation of disturbance events and the trajectory advancing towards a mesophytic forest and contains 14 significant indicators. This descriptive research was used to plan forest management activities at the landscape level in Chapter 5.

DEDICATION

To my loving family, for their support and understanding, I dedicate this dissertation to Stephanie, Jackson, and Maya.

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FOREWORD

Forestry has always tried to balance the multiple needs and desires of society at large and landowners in particular. Integrating historical ecological conditions and processes into current management strategies, all while understanding that major changes are occurring to the entire system, is becoming easier as abundant scientific and technical information accumulates. Meanwhile, the new manager must be able to synthesize vast amounts of this information and parse out the relevant implications for each management unit and the ecosystem overall. As I began managing 2,600 acres of oak-hickory forest, prairies, and farmland at Principia College in 2010, I knew that the past contained vital information about how to treat our current vegetation stands and management units, set goals, prioritize, and manage, since after all, as in the immortal words of the great bard William Shakespeare, “What’s the past is prologue.” But I was initially at a loss as to where to start. In part, this dissertation is a start. By synthesizing historical ecology observations, forest management patterns, and current ecological dynamics, the trajectories of ecological development emerged from the data and management solutions became fairly evident. These historically anchored solutions are not the answer for every acre of every stand, but the contiguity of historical conditions on most portions of the landscape as we move into an uncertain future will provide the greatest amount of options for the development of a healthy and resilient forest. Now, when I look out my office window and consider how the forest came to be, a long chronology of events can be visualized, and current trends are brought into focus.

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THE INFLUENCE OF ANTHROPOGENIC DISTURBANCE PATTERNS ACROSS ECOSYSTEMS OF THE AMERICAN BOTTOMS AND THE MIDDLE MISSISSIPPI RIVER VALLEY: HISTORIC LAND-USE IMPLICATIONS FOR CURRENT FOREST MANAGEMENT

Abstract

Forest disturbance occurs on a wide gradient of lethal selectiveness and creates new growth opportunities for adapted species. Across the spectrum of disturbance, anthropogenic disturbance influences community assembly in the Midwest more than other mechanisms but is sadly often discounted or overlooked in many discussions on the historic range of variability (HRV). In most ecosystems of the Midwest, current forest conditions are influenced by human activity which served as a major impact over the last few centuries of vegetation development. Anthropogenic disturbance can be correlated with natural analogs and viewed as a mechanism that both enhances and mimics natural disturbance regimes. In addition, anthropogenic disturbance has led to the creation of novel regimes as observed with the effects of human applied fire, which accounts for much of the forest resiliency following disturbance, particularly in the Midwest as seen in historical analysis of these prairie-forest ecotones. Forest resiliency is threatened by unprecedented agents of ecosystem change such as invasive species and reduced regeneration potential of native species. Historic anthropogenic disturbance largely resulted in forest conditions which commonly contained high value attributes like heterogeneity across habitat types and landscape diversity, yet also produced forests of low value due to high grading for timber and overgrazing by domesticated stock. In order to maintain the high value forests and improve the low value forest, active forest management is necessary to continue historic disturbance patterns and combat new threats.

Introduction

Momentum for the current conservation movement can be attributed to a coalition of diverse stakeholder groups and is reflected in the publications, guidelines, and laws of natural resource management and environmental protection agencies (Western, 2018). Implicit within some of these campaigns is the desire to implement and maintain the historic or natural functioning of ecosystems as seen in some ideal undisturbed natural areas. In reality, an undisturbed system in the Midwest is a simulacrum of wilderness when considering that the ecological role of anthropogenic disturbance served as a fundamental driver of ecosystem formation (Guyette, Muzika, & Dey, 2002; Pyne, 2017). In these cases, human caused disturbance is often discounted and categorized as an exception to the foundational forces that shaped current conditions that are valued today. In the spectrum of natural resource management ranging from unkempt wilderness to manicured cityscapes, managers must often craft compelling cases for intervention, and tie each reason directly to shifting, contradictory, and sometimes undefined societal values in order to proceed with management activities.

When managers articulate how management activities are consistent with the processes that create specific and valued ecosystem states and functions, then the sources of obstruction splinter and lose strength. An implicit assumption in natural resource management claims that the processes in natural systems are fundamentally superior to those in human systems (Foster, Fluet, & Boose, 1999). Managers are compelled to research and describe patterns of ecological development and incorporate these processes into management activities by mimicking natural processes (Toivanen & Kotiaho, 2007). The central pillar in defining disturbance regimes for the sake of understanding the origin, frequency, intensity, and size of disturbances lies with the much pondered question related to the parameters that are considered natural (Covington &

Moore, 1994). That is, what were the mechanisms of community assembly that lead the forest ecosystem to this current set of conditions that are highly valued? If the events are repeated, will the forest reliably return to a predictable state? Is anthropogenic disturbance natural? Finally, can anthropogenic disturbance enhance resiliency and achieve predictable outcomes in changing systems?

The historical mechanisms of natural disturbances in forest ecosystems interest managers who attempt to mimic natural disturbances through silvicultural activities in order to preserve ecosystem processes. Increasingly focused attention on managing forests from an ecological perspective and valuing forests as complex systems has amplified the need for historical ecology information (Fahey et al., 2018; Puettmann, Coates, & Messier, 2012; Sample, 2018). A knowledge of past disturbance patterns allows managers to understand which management activities are within or outside of the realm of historic ecosystem disturbances, often called the historic range of variability (Frelich, Jõgiste, Stanturf, Parro, & Baders, 2018). The events that shaped current forest conditions prove central to the question of management planning, despite the vast uncertainties of the future. Forest disturbance in the Midwest existed as a unique regime, ubiquitous at varying levels of intensity and diverse in spatial scales. Stochastic and deterministic events, both endogenous and exogenous, shape the physiognomy of the landscape by damaging susceptible species and releasing resistant and resilient species. As a forest ages, the probability of a stand replacing disturbance event increases (Oliver, 1980). Furthermore, as the time between disturbance events increases, the probability of a high severity disturbance increases. Forests in the Midwest exhibit the effects of frequent disturbance when compared to most other North American forest types which have longer time periods between disturbance events. For example, the mean fire return interval in central Midwest upland hardwoods is 0 to 5 years on ridges and southern exposures, and 11 to 15 years for valley bottoms and northern slopes (LANDFIRE, 2010). Evidence is emerging that Midwestern forests were significantly shaped by a combination of anthropogenic activities and natural events that created a pattern of significant disturbance affecting both species composition and structural changes (Guyette et al., 2002). Forest ecosystems are sensitive to human disturbance and respond in enduring ways to human impacts (Foster, Orwig, & McLachlan, 1996; Guyette et al., 2002). Direct human involvement in the formation of forest communities, stretching back millennia, suggests that there is an important role for managers to consider when planning management activities.

The relevancy of historical information in ecological restoration has been questioned by researchers who view the trajectories of novel systems as original and without analog (Alagona, Sandlos, & Wiersma, 2012; Jackson & Hobbs, 2009; Hobbs et al, 2006; Swetnam, Allen, & Betancourt, 1999). The objections can be categorized into three primary topics: 1) Historical restoration targets are impractical when the shifting climate patterns, presence of invasive species, and disruptions to ecological processes have fundamentally changed the conditions and governing processes off an ecosystem (Jackson & Hobbs, 2009). 2) The accuracy of historical information is often problematic in identifying specific targets for the size and other attributes of target populations (Alagona, Sandlos, & Wiersma, 2012). 3) Selecting a reference timeframe for restoration is plagued by uncertainty in determining an appropriate range for ecological restoration goals since ecosystems are dynamic and responsive to internal and external forces (Jackson & Hobbs, 2009). Although these critiques of using historical information in ecological restoration are valid, managers have addressed the claims by presenting a nuanced interpretation of historical reference conditions. This view focuses less on comparing pre- and post-disturbance conditions and instead seeks to maintain continuity of historic ecological trajectories by reestablishing or enhancing fundamental ecological processes (Balaguer, Escudero, Martin-Duque, Mola, & Aronson, 2014). Carefully setting restoration targets with the full acknowledgement of anthropogenic drivers of ecosystem development permits the manger to achieve a range of conditions that develop towards desired states.

In the field of forestry, the management of a stand is directly informed by historical events and trends. In the elements of a silvicultural prescription, the section on the description of a site contains a unit on the potential vegetation wherein information is required for the previous and present plan cover, pioneer, seral, and climax species, and the seral state (Wenger, 1984). Sections on wildlife, range resources, visual resources, and even protection from disturbance are completed using the findings of local historical ecology. Because silviculturalists contemplate the implications of management decisions on stand development on a daily basis, their understanding of the significance of prior ecological conditions and trends is highly developed.

To the casual observer, forest ecosystems that are identified with the term "recovered" from a previous disturbance may mislead one into believing that the system has returned to the previous state, which serves to minimize the importance of anthropogenic activity during cohort recruitment. Recovery of generic forested conditions and biomass volumes serve as basic indicators of the ecological context, but species composition and forest structure are greatly influenced by the individual attributes of the disturbance event. On one hand, human activity is appropriately recognized as a significant cause of significant and sometimes deleterious ecological effects. However, on the other hand, cohort establishment and perpetual composition adjustment created by humans are often overlooked drivers of community assembly when identifying the nature of ecological filters that created desirable stand conditions (Balaguer et al., 2014). In the Midwest, ecosystems with high ecological, social, and economic value were the product of interweaving anthropogenic disturbances and ecological processes (McEwan & McCarthy, 2008). The mechanisms of anthropogenic disturbance related to fire, clearing, hydrological modification, and grazing were superimposed on the background disturbance regimes of aeolian, hydraulic, zoogenic, and geologic events to create a novel set of conditions in which a particular disturbance-adapted cohort established. The anthropogenic events leading up to and including the period of Euro-American settlement resulted in an ecological legacy of mixed forest quality. In order to perpetuate high value forests and restore degraded forests, an understanding of the mechanisms of stand initiation and development is required.

The ecological history of a site is governed by ecological filters that are conditions or events that restrain or enhance select species. For example, a species that is fire tolerant has the ability to grow, re-sprout, or reproduce post-fire. Such a species is able to take advantage of recently released growing space formally occupied by a fire intolerant species. Not all species considered to be fire intolerant may be affected by fire due to a variety of variables such as timing, intensity, duration, frequency, and size of a fire. In other words, most ecological filters are comparatively coarse and fail to filter all target species for a variety of reasons such as slight differences in micro-topography or chance association. Some individuals may persist in a microsite of favorable conditions and proliferate when the surrounding conditions become suitable (Oliver & Larson, 1990).

Originally considered an aberration to normal ecological development by early ecologists (Clements, 1929), disturbance, at some level, is now largely considered a critical component in ecosystem formation and function (Frelich et al., 2018). Tantamount to the shifts in ecological thinking regarding disturbance, the significant anthropogenic role in historic disturbance regimes is gaining acknowledgement in the fields of ecology and management science (Abrams, 1992;

Abrams & Nowacki, 2015; Guyette et al., 2002). In some cases, disturbance dependent systems experiencing a lack of disturbance are considered negatively impacted and the non-disturbance is changing the functioning of some ecosystems (Flatley, Lafon, Grissino-Mayer, & LaForest, 2015; Nowacki & Abrams, 2008; Stambaugh, Marschall, & Guyette, 2014). Successional pathways are the patterns of vegetation changes following disturbance and can be heavily influenced by the type, duration, size, and intensity of the disturbance. Therefore, a comprehensive understanding of the historical disturbance record will inform the study of community assembly and provide managers with a context for predicting how the system will respond to various disturbance events.

The focus of the scientific literature concerning the characterization of ecological disturbances trends towards describing the effects of a discrete disturbance event on existing plant communities and the community assembly processes that occur post-disturbance (Knapp, Stephan, & Hubbart, 2015). Notable exceptions include studies that examine the effects of land-use history in conjunction with compound disturbance events (Nelson, Groninger, Ruffner, & Battaglia, 2009). In reality, forests often experience a gradient of overlapping disturbance events such as a drought induced insect outbreak, then windthrow followed by prescribed fire that span natural and anthropogenic, stochastic and deliberate disturbances. Temporal variation in disturbance frequency plays a critical role in forest community assemblages and these variations have been documented extensively in recent times with remote sensing methods (Hirschmugl, Deutscher, Gutjahr, Sobe, & Schardt, 2017) and, further back through dendrochronological and paleoecological studies (Roy, Bhiry, Woollett, & Delwaide, 2017). By viewing the chronology of historic disturbance regimes, managers will have a more complete understanding of the ecological filters that have shaped current stand conditions and be more knowledgeable regarding how silvicultural treatments will mimic historic regional disturbance patterns. The purpose of this review is to characterize the broad scale mechanisms of anthropogenic and natural disturbance as these relate to forest management impacts in Midwestern forests.

Late Pleistocene Events

Current topoedaphic site conditions for stands were most directly influenced in the late Pleistocene epoch of maximum glacier extent of the Late Wisconsin 20,000 YBP. At this point, the northern Midwest was covered by an ice sheet and the southern Midwest was composed of a periglacial tundra, an open boreal forest type of spruces, firs, and pines, and expansive grasslands inhabited by megaherbivores (Johnson, 2009). Humans were becoming more active in North America as glaciers began to retreat 15,000 BYP (Goebel, Waters, & O'Rourke, 2008) and their effects on the environment through hunting and burning soon initiated changes in ecological development. Of the theories that explain the mass extinction of megafauna during the end of the Pleistocene, including the megaherbivores such as mammoths, declines due to Clovis culture hunting remains probable as a significant source of population depletion (Ripple & Valkenburgh, 2010; Robinson, Burney, & Burney, 2005), though disputed by some who attribute declines to changes in climate (Grayson, 1991; Grayson & Alroy, 2001). Charcoal records suggest that fire was used extensively by early human inhabitants thereby explaining the dominance of pyrophytic species and communities (Abrams & Nowacki, 2015; Bowman et al., 2009). The dramatic modification to the vegetation communities as a result of reduced herbivory and changes to seed dispersal patterns 14,800 to 13,700 YBP altered the trophic system to allow the advancement of hardwood species, thereby initiating the first anthropogenic induced novel plant communities in North America (Gill, Williams, Jackson, Lininger, & Robinson, 2009). The changes in faunal and anthropogenic activities were reflected in shifts to the ecological communities and the associated ecological filters.

Forest Development in the Holocene

The specific mechanisms of northward migration of tree species post-glaciation remains unidentified (MacDougall, 2003). However, the principles of post-disturbance invasion recognized in large infrequent disturbance events would apply to migration and colonization of new growing space (Turner, Baker, Peterson, & Peet, 1998). Palynology studies provide broad insight into the plant communities that developed post-glaciation and into the origins of current forest composition and structure, which developed concomitantly with Paleoindian cultures and anthropogenic fire. As the Wisconsin Glacial Episode concluded, the areas under ice cover underwent primary succession and unglaciated areas transitioned to new plant communities. The loss and accumulation of ice during the changing seasons created a dynamic environment south of the glacier in which soil was deposited by aeolian processes, glacier lakes formed and drained, outwashes were scoured with flood pulses, and landforms were deposited and shaped. By 10,000 to 11,000 YBP, the vegetation changed from *Pinus*-dominated to *Quercus* as far north as Comstock Lake, Wisconsin according to a study examining pollen records in a lacustrine sediment core (Morris, Mueller, Nurse, Long, & McLauchlan, 2014). A palynology study in south-central Minnesota found that boreal forests existed 12,500 to 10,000 YBP, transitioning to *Ulmus-Ostrya* forest 10,000 to 9,000 YBP, followed by prairie and deciduous forests 8,000 to 4,250 YBP, and finally *Quercus* dominated forests began 4,250 to 3,000 YBP, all while demonstrating an increase in fire severity with each progressive forest type (Camill et al., 2003). In the Cliff Palace Pond of Kentucky, fossilized pollen evidence revealed spruce and northern white cedar dominated 9,500 to 7,300 YBP, succeeded by a mixed mesophytic forest from 7,300 to 4,800 YBP, hemlock and eastern red cedar were found 4,800 to 3,000 YBP, and oak-chestnut and pine dominated for the past 3,000 years. The authors suggest that the charcoal record found in the pond provides evidence that Late Archaic and Woodland peoples enhanced culturally important oak, chestnuts, and pines with widespread use of fire (Delcourt, Delcourt, Ison, Sharp, & Gremillion, 1998). At the Kolarik Mastodon Site in northwest Indiana, pollen and plant fossils provided evidence that open spruce forest dominated with elements of aspen, fir, and tamarack 12,000 to 11,0000 YBP followed by pine, spruce, oak, ash, hickory, and hornbeam between 11,000 and 9,500 YBP, after which point the pollen and fossil record becomes obscured (Jackson, Whitehead, & Ellis, 1986).

Table 1

Palynology results of historic forest communities in the Midwest

Location	YBP	Type
Comstock Lake, Wisconsin	Before 11000	Pinus
	After 11000 to 10000	Quercus
South Central Minnesota	12500 to 10000	Boreal
	10000 to 9000	Ulmus-Ostrya
	8000 to 4250	Prairie and deciduous
	4205 to 3000	Quercus
Cliff Palace, Kentucky	9500 to 7300	White Cedar
	7300 to 4800	Mixed mesophytic
	4800 to 3000	Hemlock and eastern red cedar
	3000 to present	Oak-chestnut and pine
Kolarik Mastodon Site, Indiana	12000 to 11000	Open spruce with aspen, fir, tamarack
	11000 to 9500	pine, spruce, oak, ash, hickory, Hornbeam

Table 2

Reference table for periods and correlating timeframe

Period	YBP		
Altonian	70000	to	28000
Farmdalian	28000	to	22000
Woodfordian	22000	to	12500
Twocreekan	12500	to	11000
Valderan	11000	to	5000

Late Archaic and Woodland Ecological Management

Evidence for Native American modification to ecological systems of the Midwest suggests that their influence was ubiquitous and significant. Throughout pre-Columbian history, Native Americans used fire, hunted predators and herbivores, cultivated and dispersed plants, and cut trees (Abrams & Nowacki, 2008). Human population figures during this time are contentiously debated but have been estimated at over half a million in the eastern US (Kroeber, 1934) until Columbian contact when the population declined fifty percent due to rampant disease transmission (Shumway & Jackson, 1995).

The effects of human activities cast enduring legacies on forest composition. On the Allegheny Plateau of northwest Pennsylvania, areas with a high intensity of Native American use were found as the most accurate variables at predicting where oak, hickory, and chestnut ranges were dominant over beech, maple, and hemlock when compared to other topoedaphic and bioclimatic predictor variables (Black, Ruffner, & Abrams, 2006). Evidence of landscape scale fire in the southern Appalachian forests has been identified going back 10,570 years before present with regular fire beginning 4,000 years ago, and increasing in frequency 1,000 years ago when Woodland Traditional Native American culture established, but tapering off 250 years ago in coincidence with post-Columbian contact (Delcourt et al., 1998: Fesenmyer & Christensen, 2010). Little evidence exists for the northward migration of plants due to the assistance by Native American during the glacial retreat, despite the cultivation and widespread usage of tree species (Munson, 1989; Abrams & Nowacki, 2008; MacDougall, 2003).

Euro-American Settlement of the Midwest

Pre-settlement surveys in the Midwest of the early 1800s provide insight into the forest composition and structure during a time of transition between low intensity Native American management and before the land was burned at higher frequencies, cut for timber production, grazed by livestock, and cleared for agriculture and home construction by Euro-Americans. The process of forest clearing involved the felling of trees, which varied in density and size, followed by burning the slash and grubbing out the stumps with a team of oxen after cutting the roots with an axe. In order to transition a forest into a tillable farm, an average of 32 man hours per acre was required, compared with 1 to 1.5 days to till prairie sod (Williams, 1989). Each farm required a steady supply of fuelwood to heat the farm houses, a source of which could not be less than 20 acres, though often heavy clearing near the settlement created high demands on the productivity of the local woodlot (Williams, 1989). Species with high levels of energy such as hickory, oak, and black locust were selected for fuelwood while species that did not make good firewood such as elm remained in the forest. As fertility in forest-cleared fields diminished, settlers advanced into the prairie peninsula of the Midwest in which a gradient between grasslands and forests varied with each site. The most desirable land existed on the ecotone boundary between forest and prairie, combining the benefits of open ground for grazing and hay with the fuelwood and timber resources of the adjacent forest (Williams, 1989).

Pre-settlement forest conditions were influenced by Native American activities such as burning and agricultural clearing. However, directly preceding settlement in the Midwest, low

Native American population levels diminished the frequency of forest vegetation modification resulting in widespread stand initiation and developing into closed canopy conditions with high stem densities. The occurrence of savanna systems in central Kentucky circa 1800 have been associated with the era of settlement when forests were thinned in part to increase forage opportunities for livestock (McEwan & McCarthy, 2008). The re-initiation of human activities during settlement restored stand conditions that existed historically due to active Native American forest utilization and burning cycles.

The relationship between human activities and forest physiognomy has been analyzed in the Missouri Ozarks by several previous studies. The cycle of fire in oak-forests identified that fire frequency, nearly all sourced from human ignitions, was largely dependent on human population levels, as well as the availability of surface fuels, fuel fragmentation due to land use changes which limited the spatial extent of fires, and cultural behavior that emphasized fire control and limitation (Guyette et al., 2002). Vegetation in the early 1800s on the Current River watershed of the Ozarks in south-central Missouri was analyzed in a study that found anthropogenic fire regimes produced significant effects on species assemblages, with a fire return interval of 6.1 years in lower regions of the watershed and 12 years in the upper reaches between 1701 and 1821 (Batek et al., 1999). In the Illinois Ozark Hills, disturbance regimes over a 300 year time period were analyzed based on topographic variables and the authors found a fire return interval of 30-45 years on mid to upper slopes and ridgetops during pre-settlement followed by a period of stand damaging severe earthquakes and frequent fire, grazing, and timber cutting during settlement years between 1880-1925 (Fralish & McArdle, 2009).

Rhemtulla et al. (2007) found that the period between 1850 and 1935 saw the upper Midwest experience forest cover decline by a third, agricultural lands increase to 24%, mixed forest and savannas transition to deciduous closed forests, while the central Midwest saw 75% of the land area in savannas and prairies converted to cropland and pasture.

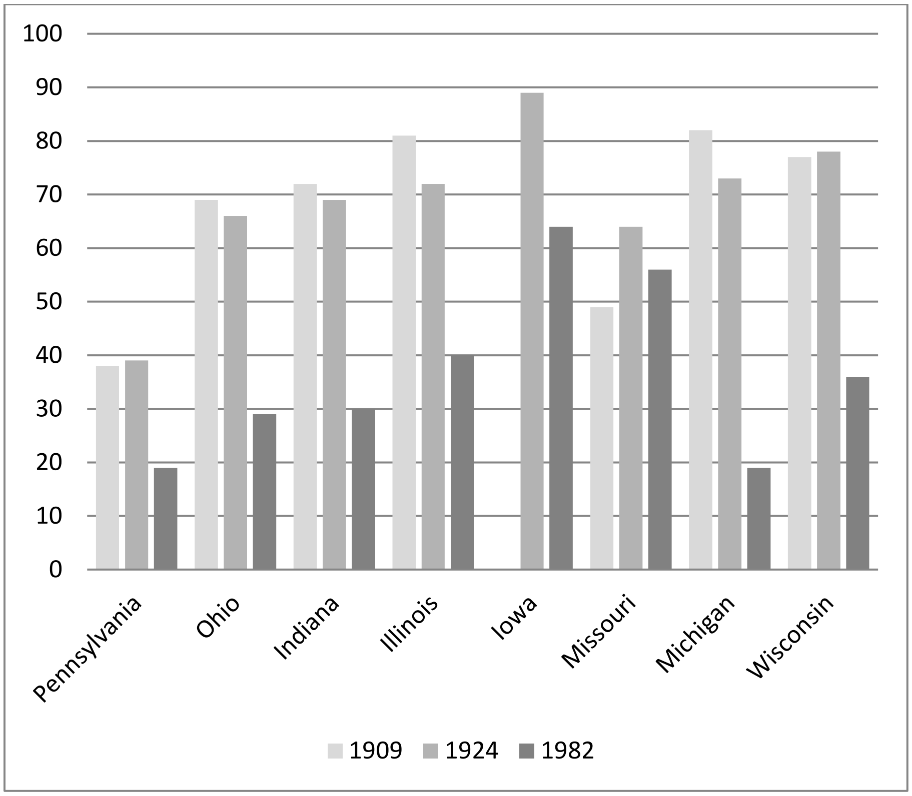

Figure 1: Percentage of woodland grazed. Adapted from Whitney (1994). Original data sources Goldenweiser and Ball (1918) and US Census Bureau (1932 and 1984). Note that 1909 data for Iowa are absent.

As European settlement advanced westward from the East, game species were displaced by livestock. Woodland bison and elk ceased to inhabit the Midwest and turkey and white-tailed deer populations were isolated to small areas. Swine, cattle, goats, and sheep were allowed to forage throughout forested areas and impacted the soil and biota in ecologically significant ways compared to the displaced game species. The characteristics of livestock disturbance produced irreversible ecological legacies evident in forest composition and structure, and should be considered as an anthropogenically induced modification since humans introduced livestock to the region (Whitney, 1994).

The use and frequency of fire for multiple benefits as employed by the Native Americans were limited by population density (Guyette et al., 2002). As European settlers advanced, the frequency of fires spiked by comparison to previous eras and was only limited by the availability of fuels and, later, fuel fragmentation (Guyette et al., 2002). The burning frequency increases in concert with clearing fields for agriculture and selectively thinning woodlots for fuelwood and building supplies created ecological conditions which favored fire adapted and shade intolerant or intermediate species.

As forests regenerated in the Northeast due to farm abandonment, early and mid-seral species were represented in higher abundance and the composition was more homogeneous (Thompson, Carpenter, Cogbill, & Foster, 2013). Due to a higher frequency of disturbance, primarily attributable to anthropogenic fire, in the Midwest, early- and mid-seral species remained stable as settlement transitioned to a developed state. The lack of historic disturbance has been considered a new type of disturbance that favors fire-intolerant mesophytic species and results in a shift in dominant tree species (Fralish & McArdle, 2009).

Ecological Descriptions of the Confluence Region of the Middle Mississippi River

John White (2000) compiled ecological accounts of the Big Rivers Area, a large area around the confluence region of the Mississippi, Illinois, and Missouri rivers. The following accounts provide a historical reference of ecological composition and structure prior to and during Euro-American settlement. Descriptions of the ecology were excerpted from White's volume and divided into the following sections: Historical Descriptions from the Elsah Township Area; Descriptions of the Landscapes within the Big River Area; and Accounts of Fire. These accounts support the results from analysis of witness tree data as well as provide a rich narrative of the ecological impacts of settlement activities. Characterizing the ecosystems around the beginning of Euro-American influences serves to establish the historic range of variability and provide a spatiotemporal reference condition for ecological restoration activities that seek to preserve diversity and complexity.

Historical Descriptions from Elsah Township Area

Each description of the area in the Elsah Township region varies slightly in emphasis, but each observer noted the general topography and the vegetation type that existed on the site. In 1823, Lewis C. Beck described the topography of the area and the amount of prairie and forest of the area thus,

> The face of the country is in general [sic] level, or gently undulating with the exception of those under the bluffs of the Illinois. Although this county contains a large proportion of timbered land, it is diversified with prairies, some of which are beautiful beyond description. The banks of the Mississippi in the southerly part of this county are generally composed of perpendicular cliffs, varying in height from 80 to 150 feet. This bluff continues along the Mississippi and Illinois to the northern part of the county, sometimes, however, receding several miles east, leaving a low but fertile alluvion [sic], which in general is heavily timbered.

In 1868, A.H. Worthen, the State Geologist, described the Elsah area and a typical community of mature trees along steep slopes near the river,

> Adjacent to the bluffs of the great rivers which form the southern and western boundaries of the county, and extending back for a distance of from three to six miles, the surface is broken into steep ridges, which are separated by deep ravines. This portion of

the county was originally covered with a heavy growth of timber, consisting of the usual varieties of oak, hickory, wild cherry, etc.

In 1882, W.R. Brink wrote of the area around Elsah,

The surface of the country presents a pleasing variety, gently rolling prairies predominating. The majestic bluffs of the Mississippi present a rocky wall along its shore from the mouth of the Illinois to Alton and then tending inland around the great American bottom, round their fronts into grassy sloped hills that go down more gently to the fertile fields of the garden spot of Illinois. These bluffs, like adamantine walls checking the course of destruction of raging floods, are from eighty to one hundred and fifty feet in height. From their crest a lovely panorama spreads out to view, comprehending as it does a view of the valley of the great Missouri which commingles its muddy waters with those of the Mississippi in their onrushing to the sea, and the intervening landscape of cultivated fields, here and there marred by stretches of sand or sloughs waiting to be made to bloom and blossom as the rose before the hand of industry when once redeemed by drainage. Eastward from the bluffs are far-reaching prairies relieved by grove-crowned eminences, beautiful valleys and inviting hillsides. On many of the prairies are stretches of young and vigorous timber, where once was an open space consequent upon annual fires sweeping everything before them. The timber tracts, in the main, follow the meanderings of the various streams or crown the bluffs that hem in the valleys. The largest bodies of timber skirt the streams. Oak in great variety abounds, embracing black, white, overcup, post. There are also white, black and shellbark hickory, soft and sugar maple, ash, sassafras, black and white, or English walnut, wild cherry, elm, pecan, sycamore, honey locust, box alder, paw-paw, buckeye, redbud, persimmon, hackberry and other woods indigenous to south and central Illinois. Of shade trees there are black locust, elm, maple, and representatives of the numerous family of evergreens.

In 1919, Judge Oscar B. Hamilton described the landscape along the Mississippi and Illinois Rivers in Jersey County,

> The bluffs on the west and south sides of Jersey County form the most magnificent and picturesque scenery of the entire 2,000 miles of the course of the Mississippi River. For twenty miles east from the mouth· of the Illinois River, the bluffs rise from the river bank to a height of three or four hundred feet, with hollows or valleys between, in which are found numerous springs of cool and refreshing water. The valleys and the tops of these bluffs are covered with original forest trees of great height and size, which at the time that Marquette was viewing this wonderful landscape had been unseen and untouched by civilized man.

From these descriptions, the good timber resources that observers noted were found within areas where fire severity would be limited by moist conditions, topographic roughness, and fuel breaks. These elements are found near large and small water courses which are abundant in the southern and western portions of Jersey County where the limestone bluffs exist. In particular, forests were extremely variable in density with thick groves near water and sparse stems within the grassland dominated areas of ridges. Mesophytic species were observed near water sources, particularly the sugar maple, while pyrophylic species were found further up the slopes.

Descriptions of Landscapes within the Big Rivers Area

In the general area, landscape descriptions are useful for providing context for large scale trends in ecological development. In 1698, Jean Fransçois Busson de St. Cosme recorded that the land “is bordered by a belt of very fine timber which is not very Wide so that one soon reaches beautiful prairies containing numbers of Deer.” Later in 1773, Patrick Kennedy remarked that “the land is well timbered, and covered with high weeds. There are fine meadows at a little distance from the River… The timber in general very tall Oaks.” These “high weeds” would be consistent with the growth form of big bluestem (*Andropogon gerardii*), common to the tallgrass prairies of Illinois. At the beginning of the Lewis and Clark expedition in 1803-04, William Clark wrote of the mix of prairie vegetation and forest along banks and bluffs of the Mississippi River upstream of St. Louis,

> The Country about the Mouth of Missouri is pleasant [sic] rich and partially Settled On the East Side of the Mississippi a leavel [sic] rich bottom extends back about 3 miles, and rises by several elevations to the high Country, which is thinly timbered with Oakes & On the lower Side of the Missouri, at about 2 miles back the Country rises gradually [sic], to a high plesent [sic] thinly timberd [sic] Country, the lands are generally fine on the River bottoms and well calculating for farming on the upper Country in the point' the Bottom is extensive and emensly [sic] rich for 15 or 20 miles up each river, and about two thirds of which is open leavel [sic] plains in which the inhabtents [sic] of st Charles & portage de Scioux thad ther [sic] crops of corn & wheat.

As a member of a surveying crew in 1816, Henry Allyn noted the patches of forest within the prairie and their proximity to water courses,

> The country all prarie [sic] except here & there an island of timber of from 100 to 500 acres, & a narrow list of timber along the margins of the largest streams. We arrived at the Illinois bluff, at a place where the bottom was wide & timbered; & after advancing some distance, came to a body of water, but were in doubt whether it was the river.

Also in 1816, Reverend Timothy Flint described his experience from a keelboat floating on the Mississippi River through the American Bottom. He observed that forest existed within a wide buffer near the river and prairie extending farther away. The river, he wrote,

> [The river] has a skirt of wood two or three miles in width. Still farther from the river, and beyond the timbered land, is a most beautiful prairie of the richest land, from two to four miles in width. Beyond this are lofty and perpendicular stone bluffs, the bases of which appear evidently to have been once worn with running water. This charming skirt, partly timbered, partly prairie, and every where limited by this kind of bluff, extends from this point to a considerable distance above St. Louis.

Flint's observation that the "skirt" of vegetation along the bluffs consisted of a mix of prairie and forest demonstrates the flux of the ecological gradient that is mediated by fire disturbance.

A U.S. General Land Office surveyor, William Rector, wrote of Calhoun County in 1816 regarding the density of forest as low, but with clusters of dense forest in select locations, "The greatest objection to that part of the Country seems to be the scarcity of timber there is however in many places considerable bodies of exellent [sic] timber." In 1817-53, Gershom Flagg described the area of his new property,

> The prairies are very large while the timbered land is confined almost wholly to the intervales [sic] and low rounds. The land is generally good but there is a great quantity of Prairie and some whole townships destitute of timber. We consider the land generally that lies from 4 to ten miles from the large rivers to be the best for farming & for health. The land near the water courses is richer but not considered heathy [sic] and after you get some distance from water courses the Prairies are much too large. A belt of

timber accompanies all water courses but between the head waters of streams it is generally open level Prairie. The Bounty tract is setling [sic] very fast and the Imigration [sic] to the state is more now than it has been since I came here.

In the1820s, Daniel Harmon Brush wrote,

A prairie of richest soil stretched out about 4 miles in length and one mile wide, extending to the timber growing next the river. The strip of timber-pecan, hickory, black walnut, oak, persimmon, ash, hackberry, etc.-being some three miles in width to the Bluffs that were bare of timber with walls of rock in places standing perpendicular from the prairie's edge, one hundred or more feet in height. Grass covered the summits, which loomed up above the rock in rounded cones of varied heights, kept denuded of other growth than grass by annual fires that overswept[sic] the hills and the prairie ground below. At intervals of half to three fourths of a mile small spring-fed creeks of living water came through passes in the Bluffs and took their winding way down through the prairie until lost by spreading out in the bottomland towards the river. At many points along the Bluffs ever-living and unchanging springs of cold water, clear and pure, burst forth beneath the solid walls of rock, non-freezing in winter and refreshingly cold in summer, from which little rivulets sang their way over pebbly beds towards the setting sun. East of the Bluffs a short distance, a fine growth of choicest timber set in and covered the broken ground, as also the valleys, from which ample supplies were obtained for building and fencing purposes. Great groves of sugar maples were common along the little streams that came down through the hills, from which came most of the sugar used by the settlers for many years.

Author James Hall wrote in the November 1830 issue of the Illinois Monthly Magazine,

> The prairies are not flat, but composed of a succession of swells. The timber is scattered in groves and strips, the whole country being one vast illimitable prairie, ornamented by small collections of trees. Sometimes the woodland extends along the river for several miles continuously-sometimes it is seen stretching in a wide belt far off into the country, and marking the course of some tributary stream and sometimes in vast groves, of several miles in extent, standing alone like islands, in this wilderness of grass and flowers. But more often we see the single tree without a companion near, or the little clump composed of a few dozen oaks or elms; and not unfrequently, hundreds of acres embellished with a kind of open woodland, and exhibiting the appearance of a splendid park, decorated with skill and care by the hand of taste. Here we behold the beautiful lawn enriched with flowers, and studded with trees, which are so dispersed about as not to intercept the prospect-standing singly, so as not to shade the ground, and occasionally collected in clusters, while now and then the shade deepens into the gloom of the forest, or opens into long vistas and spacious plains, destitute of tree or shrub.

English immigrants, Rebecca Burlend and her son Edward, settled on 80 acres in Big Blue Creek of Pike County in 1831 and provided an excellent description of the variability of forest density and the state of maturity,

> The strong timber trees grow at various distances from each other, sometimes being as near to each other as they can possibly grow, at others twenty or thirty yards apart. They not only vary considerably in this respect, but also in magnitude and age. Not a few are to be found in the last stage of decay, their patriarchal dignity gradually submitting to the all-subduing influence of time. Numbers more are quite hollow, in which bees, owls, and rabbits severally find shelter and propagate their species.

In 1868, A.H. Worthen, the State Geologist, wrote of Jersey County in Volume III of the *Geological Survey of Illinois*, and corroborated other accounts that describe forest as primarily found in the steep terrain adjacent to the river along the bluffs,

> The central and eastern portions are mostly prairie, and are comparatively level or gently rolling; while the western portion becomes more broken as we approach the river bluffs, which are intersected by deep ravines, separated by narrow ridges, many of which are from one hundred and fifty to two hundred feet in hight [sic]. This portion of the county is heavily timbered.

Remembering back from 1919, Oscar B. Hamilton wrote of the importance of sugar maples in the area,

> Then there was the maple sugar camp... The main camps in this county were those of Col. Josiah Askew in 6-11, and Henry Noble in Sugar Hollow southwest of Otterville, 7-12. Sixty years ago maple sugar was a staple article of trade at the stores, as were also three and four-foot oak clapboards and pickets, staves and heading, hoop-poles and ten-foot rails.

Accounts of Fires

In 1817-53, Gershom Flagg described fire behavior and the seasonality of fires in forest and prairie systems. He observed significant mortality in the new seedling growth following a fires that were ignited by farmhands to clear fields that resulted the lack of quality timber but with an abundance of prairie vegetation.

> There has been a great *fue* [fire] in M Paddocks fields this afternoon a [and] all the Men and part of the women in the neighborhood turned out to fight it. it was the worst fire to manage that I ever saw in the Prairie we could not put it out even when the wind

was in our favor and we had to let it run tluough [through] the fences and then tear them down to prevent the rails from being burnt They have lost a good many Rails I do not know how many They have hired a wild Irishman lately and he undertook to burn over the stubble ground and the fire spread as it had a right to do all over the fields.

In 1879, Clement L. Clapp remembered the effects of fires during a prolonged drought,

The winter of 1819 and '20 proved to be an unusually severe one. The long grass of the prairies had been destroyed by fires lighted by the Indians or hunters, and much of the undergrowth in the woods was killed by the same element. Before the close of the winter, the provisions gathered by them for their stock, from places where it had escaped the ravages of the fire, gave out and they were compelled to cut down trees, from the boughs of which the cattle and horses could procure a scanty supply of food. Many of these wandered away and were lost, while some of them died from the effects of cold and hunger.

Charles C. Chapman wrote of the efforts to minimize the damage from human ignited fires in 1880,

In pioneer times, when there were scarcely any fences, and not land enough under cultivation to stop the great prairie fires which occurred in the fall for the year, they proved very disastrous to those living on the prairie. The township consists, for the most part, of Mississippi river bottom land, a large portion of which is prairie. The grass on this bottom land grew to an enormous height, was very thick, and as high as a man's head while on horseback. This grass was so heavy and thick that when the settlers went a-fishing in the Sny [sic] they would hitch the team to a large brush or tree and drag it through the grass and mash it down, to make a road for them to pass over. In the fall of the year this luxuriant growth of grass would be set on fire by the Indians or hunters, and especially when the wind was high, would sweep resistlessly [sic] over the whole country, high and low, destroying a great deal of property. The pioneers early learned to guard against this destructive element by plowing wide strips of land around their premises and around their grain and hay. As soon as the alarm of fire was given, each settler would immediately begin to 'back fire.' This was done by setting the grass on fire next outside the plowed strip, which would burn slowly and meet the rapidly advancing flames that came rolling in majestic grandeur, from 20 to 30 feet in the air.

In 1911, soon after fire suppression was adopted at a national level, Charles A. Walker wrote,

Before the busy hand of man changed the face of nature by reducing it to his uses and purposes, the timber lines stood out in bold relief like promontories extending far out into the ocean, and they served the weary traveler as landmarks to guide him to his goal. In those old days, the hunters, rangers and Indians burned the prairies in the fall of the year, but the permanent settlers soon put a stop to that. It appears that the channels of the larger streams checked the progress of the fires and protected the forests along their courses, so that the timber along the creeks was good, there being white oak, black oak, red oak, post oak, hickory, ehn [elm], ash and some walnut. One of the attractions to the first settlers in this region was the abundance of limestone which cropped out in the streams in five places, first in the Piasa creek on the Jersey county line, one and a fourth miles west of Piasa, thence appearing on four branches nearly on a line south by west for a distance of about two and one-half miles in the same direction.

In 1919, Judge Oscar B. Hamilton wrote of fires,

> Then there was also danger from the forest fires, started by hunters, campers or other careless persons, among the forest leaves, and in case of a heavy wind, or even a strong breeze, the fire would spread, and be as dangerous as the prairie fires. Whole neighborhoods of settlers, men, women and children of sufficient size, would be called out to fight the fire, and continue the contest day and night until it was headed off, usually by clearing the ground of its coat of leaves, and backfiring, and then watching for flying branches or burning leaves which would be carried by the wind beyond this backfire barrier. These would be attacked with wet sacks, or other means would be taken to extinguish the fire before it could get another start. These were strenuous and dangerous emergencies, taxing the courage and physical endurance of the early settlers, whose farms were along the skirt of timber, and extending out into the prairie, where this was possible. Many of the pioneers went into the timber because they had to get wood for their buildings, all of their other improvements, and for their fires. Many were born and bred woodsmen, and found security and safety in the timber, and were afraid of the open prairie with its aunual [sic] fires, insecurity from attacks from the Indians, and supposed hardships and impossibility of hauling sufficient timber to improve and maintain the rude appliances then possessed by them. There in the timberland, which skirted the streams, springs were to be found which supplied them with cool water for both the family and livestock.

These early ecological observations provide a useful reference for assessing the long-term development of floristic patterns in the Big Rivers Area. Based on palynological studies, many of the above descriptions could apply to the ecology of the area for the previous 10,000 years with much historic variability attributed to human population density effets on the land as well as dramatic shifts in climatic cycles. This largely fire mediated system, and the interaction of topography and hydrology in influencing fire severity, has endured 10,000 years of relative stability until the activities of Euro-American settlement divided fuel contiguity and imposed a conservation ethic which promoted fire suppression to protect the establishment and growth of forest resources for society's conservation and use.

Following settlement, artist and poet, Fredrick Oakes Sylvester moved to a cabin on the bluffs and captured the dramatic landscape in several artistic works (Sylvester, 1911). The paintings depict many of the features written about in the early written accounts of the area with dense forest near the river valleys and upland bluff and prairies with scattered trees along the ridgelines (Figures 2 and 3).

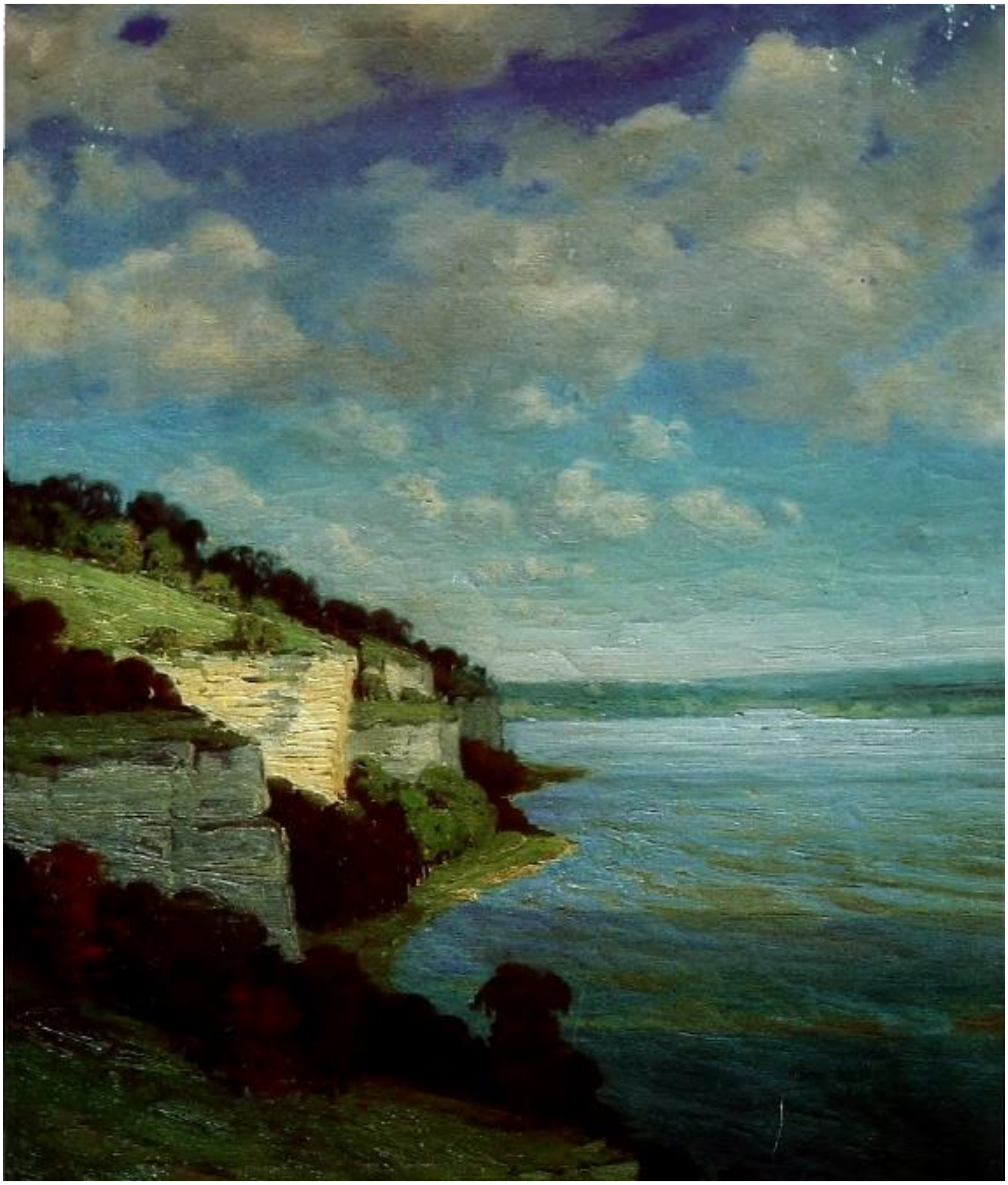

Figure 2. The bluff region near West Farm at Principia College as painted by F.O. Sylvester circa 1906.

Figure 3. “Soft Twilight Lingers”, circa 1906, depicting the Mississippi River and limestone bluffs at Grassy Hollow on West Farm, Principia College by F.O. Sylvester.

Figure 4. Current photograph along the Mississippi River bluffs shows closed-canopy forest with small prairie openings perched on the edge of the bluff.

Disturbance Regimes of the Midwest Forest

Natural and anthropogenic disturbance in the Middle Mississippi River Bluffs Region greatly altered forest structure and composition thereby creating unique plant assemblages. The scope of modern disturbance has been recorded in detail when the events caused significant damage to property (Table 3). However, the occurrence of low intensity disturbances (e.g. prescribed fires) has largely escaped systematic record keeping.

Table 3

Frequency of atmospheric disturbance events in the central Midwest.

Disturbance Type	Number of Events since 1955
Wind	104,161
Tornados	12,695
Hail	66,059

Data from NOAA Storm Events Database (https://www.ncdc.noaa.gov/stormevents/ftp.jsp)

Wind disturbance events exert the greatest impact on tall trees with large crowns and weak trees with compromised root systems and lethality is proportional to wind speed. Wind can damage vegetation by causing the tattering leaves which leads to accelerated desiccation, upbraiding limbs and stems with other plant parts, snapping stems, or uprooting. If the stand contains multiple cohorts of varying heights and sizes, wind disturbance often removes the overstory while releasing the understory individuals who escape lethal damage by falling dominants. Hail typically occurs during the growing season and can batter leaves resulting in reduced photosynthetic capabilities which may result in decreasing tree vigor and the ability of a tree to defend itself against pathogens. Wind events associated with groups of thunderstorms and include downbursts, micro- and macrobursts, and mesoscale convective systems such as supercells, bow echoes, squall lines, and derechos. Destructive wind events occur on a gradient including tattering leaves, removing leaves, breaking twigs and limbs, and snapping or uprooting large stems. Wind disturbances in the forest remove canopy shade and competitors of the lower strata resulting in a release event which may result in a shift of species dominance depending on the severity of the disturbance and the composition of the species below the canopy (Oliver & Larson, 1990).

The ecological relationships between forest dwelling animals and forest composition involves a myriad of interactions affecting seed dispersal, germination, recruitment, and productivity. The Passenger Pigeon (*Ectopistes migratorius*) once existed in the billions of individuals as they few over Midwestern forests. Damaging trees by the roosting and nesting in great numbers, the pigeon caused disturbances on 1,000 to 5,000 acres across their range by breaking branches, uprooting trees, and defecating, a dramatic flux of nutrients whenever they nested (Ellsworth & McComb, 2003). *E. migratorius* tended preferred white oak acorns and was thought to be a key endozoochortic dispersal agent. The human induced extinction of this massive disturbance agent has resulted in the loss of this type of forest disturbance and the associated impacts on forest dynamics.

Forest Management in the Midwest

Timber Harvesting

Historically, timber harvesting occurred across the Midwest at varying intensities depending on the needs of the landowner. The Jersey County historic atlas from 1872 depicts one sawmill within Elsah Township on John Lock's property. A detailed analysis of changes to forest cover since Euro-American settlement in the township is presented in Chapter 2.

The modern timber industry in the Midwest, specifically in Illinois, is disadvantaged by an overall lack of access to sawmills, which is highly variable from state to state. For example, Illinois has lost 72% of its mills since 1961 and sends approximately 30% of the harvested roundwood to adjacent states (Illinois Statewide Forest Assessment, 2008). Indiana has a wood processing facility within 30 miles of every part of the state (Indiana Statewide Forest Assessment, 2010). Without adequate timber buyers to create steady demand for forest products, timber prices stagnated and declined. In Illinois, the average price for all species and grades declined $18.96 per thousand board feet between 1977 and 2011 after adjusting for inflation according to the timber price bulletin produced by Illinois Department of Natural Resources. Small diameter markets are non-existent thereby making large diameter timber the only commercially viable source of wood products. Without a market and subsequent incentive to harvest less desirable trees, widespread high grading occurs throughout the Midwest. If the forest owner is inclined to enter a forest management plan, small diameter trees may be cut at a short term economic loss to the forest owner in order to improve future timber growing conditions. Therefore, silvicultural treatments which facilitate shade intolerant and intermediate species are seldom employed except on an experimental basis. High grading and commercial thinning accelerate species composition shifts away from historical conditions if not mediated by timber stand improvement treatments such as prescribed fire and thinning of later seral species. With the popularity of single tree selection systems, few landowners express an interest in setting an oak regeneration goal within their forest management plan (Moser, Leatherberry, Hansen, & Butler, 2009).

Invasive Species Management

Disruptions to normal ecological functioning in Midwestern forests are caused by the nearly ubiquitous presence of invasive plant species such as garlic mustard (*Alliaria petiolata*), bush honeysuckle *(Lonicera maackii, L. tatarica, and L. morrowii)*, autumn olive *(Elaeagnus* *umbellata),* common buckthorn *(Rhamnus cathartica),* and burning bush *(Euonymus alatus);* as well as the insect species Emerald Ash Borer *(Agrilus planipennis)* Gypsy Moth *(Lymantria dispar).* The vegetative invasive species alter soil chemistry, fuel arrangement and quantity, and shade levels (Kolbe, Townsend-Small, Miller, Culley, & Cameron, 2015). In addition, most invasive plant species compete aggressively with native vegetation for resources and have deleterious effect on tree growth rates and regeneration (Black, 2017; Hartman & McCarthy, 2007). Management of invasive species is expensive and eradication may not be feasible in every situation (Liu, Sheppard, Kriticos, & Cook, 2011). Many forest managers seek to reduce the density of invasive species to a level that allows for general ecological functioning to continue with a combination of foliar spraying, mechanical removal, or prescribed fire in the case of plants while insects are largely left unmanaged (Hansen, Hamm, & Campbell, 1990). Invasive species management appeals to a limited demographic of forest owners who know the effects of invasive species and have the resources to absorb the cost of management (Gobster, 2011). Any concerted effort to check the spread of invasive species has not been achieved at the landscape level (Fan et al., 2013).

Fire

The use of prescribed fire has been found to provide numerous benefits to forest ecosystems in the Midwest. Among the more salient aspects related to management objectives, prescribed fire reduces stem density in smaller diameter classes and filters out species not adapted to fire through repeated burning (Holzmueller, Groninger, & Ruffner, 2014). Not unlike the limitations to invasive species management, applied fire is costly and logistically difficult to implement which are problems that only magnify as the scale of operational complexity increases. Creative solutions have evolved to pool resources and initiate more burns such as the

Southern Illinois Prescribed Burn Association, Illinois Prescribed Fire Council, and annual meetings of the burning community (Riechman, Park, Ruffner, & Groninger, 2014).

Wildlife Habitat Enhancement

Forest landowners in the Midwest are typically not driven by a motivation to invest in fiber production due to limitations in accessing timber markets and lack of available professional forestry assistance. Utilizing the forest for recreation in the form of hunting is a leading motivation for forest management. Specifically, enhancing wildlife habitat by increasing palatable species and diversifying forest structure are methods to retain desirable game species populations. Consideration given to non-game species is not high on private land unless regulation requires action, but it becomes an important factor in the management of public forests.

Research in Upland Hardwoods

Within the upland oak range, forest managers are challenged with cultivating the conditions requisite for oak germination and survivorship resulting in recruitment and eventual site dominance. Oak is largely considered a mid-seral species on mesic sites and climax on lower quality or dry sites (Burns & Honkala, 1990). Therefore, when the site is of high quality with deep, rich soils and adequate access to moisture, for example 60-75 Site Index with 110 sq ft basal area, silvicultural prescriptions with oak regeneration as a goal have employed single-aged regeneration systems that focus on reducing competitors and maximizing conditions for oak in the light environment. Conversely, lower quality sites have the capacity to regenerate oaks with uneven-aged management in some cases due to reduced competition. However, with reduced burning frequency, most of these sites have multiple cohorts of mesophytic species (Nowacki & Abrams, 2012). Oak regeneration failures have been attributed to excessive acorn predation, seedling herbivory, low acorn mast production, and competition by other plant species, namely winged elm (*Ulmus alata*) and ironwood (*Ostrya virginiana*) (Ward, 2015).

The importance of fire as a mechanism for establishing oak dominance has been tested and confirmed in several regional studies. A review of 32 oak regeneration successes identified a common set of conditions that favored oak species, which included a minor overstory disturbance in conjunction with a growing season burn, or multiple burns in an undisturbed canopy forest (Brose, Dey, Phillips, & Waldrop, 2013). Oak regeneration in oak shelterwoods was maximized in plots with high intensity spring burns (Brose, 2014). In shelterwood systems of central Virginia, the long term effects of varying levels of burn intensity, including non-burned areas, were evident in study areas that were re-measured 11 years following the treatments and shown to favor oak-hickory over yellow-poplar and red maple when the burn intensity was high (Brose, 2010).

The light environment experienced by oak seedlings has been shown to play a significant role in oak dominance (Holzmueller et al., 2014). Low shade has a greater impact on light environments at the seedling level than does high shade and this effect was tested in a study that examined the impact on survival, growth, and competiveness of seedlings when the midstory was removed. The results indicated that oak advance regeneration experienced grew faster when the midstory was removed and mortality of natural oaks was not different when compared to the control, but underplanted oaks displayed a higher mortality rate (Craig, Lhotka, & Stringer, 2014).

Each stand requires an individual assessment to determine the site and forest characteristics. Thinning and timber harvests may risk accelerating succession by removing mature pyrophobic species and releasing mesophytic species, resulting in a complete forest dominance shift. Avoiding unintended successional acceleration is achievable by several methods including variable retention harvesting (VRH) (Franklin & Johnson, 2012; Xing, Nielsen, Macdonald, Spence, & He, 2018) and a two stage oak shelterwood (Dey, Kabrick, & Schweitzer, 2017; Holzmueller et al., 2014; Miller, Brose, & Gottschalk, 2017). Any canopy disturbance should be preceded by the effective control of invasive species. On non-hydric sites, VRH provides a range of benefits to the diversity of tree species as well as providing refugia for wildlife. Because tree species range in shade tolerance and moisture requirements, VRH supplies the entire light gradient to the establishing cohort in each topoedaphic setting, resulting in the highest probability of ideal growing conditions for the target species. Furthermore, VRH is extremely adaptable to spatial variability of stand characteristics and allows the manager to adjust to changing conditions. The two stage oak shelterwood unifies historic forest conditions with management objectives. By removing the mesophytic trees in the small and mid-diameter size classes, understory light levels increase enough to allow the germination and growth of shade intermediate species (most of the oaks and hickories) (Ruffner & Groninger, 2004). As the new cohort establishes and grows into the stem exclusion phase, an overstory harvest of the mature canopy trees can occur, thus releasing the younger cohort with the addition of full sun and resources. Both VRH and oak shelterwood are suitable for ecological restoration goals if target conditions approximate pre-fire suppression era forest parameters (Kirkman, Mitchell, Kaeser, Pecot, & Coffey, 2007). Any forest restoration project would require the corresponding herbaceous layer restoration since the historic low density forest coexisted with prairie species (Dey et al., 2017; Peterson, Reich, & Wrage, 2007). Silvicultural strategies to restore stand conditions will necessarily create stands of lower density and greater diameter distribution diversity.

Prescribed fire serves the two primary ecological functions of reducing pyrophobic stem density and stimulating growth of graminoids and forbs (Ruffner & Groninger, 2006; Vander-Yacht et al., 2017). Therefore, fire aids in silvicultural and ecological restoration objectives when applied in coordination with mechanical thinning operations (Holzmueller et al., 2014). Applying fire prior to a mechanical entry may reduce the overall thinning load by causing mortality in small diameter stems (Knapp et al., 2015; Stambaugh et al., 2014). Fire applications following thinning are necessary to reduce the vigor of competitive pyrophobic species and enhance and perpetuate the prairie species component (Ruffner & Groninger, 2004). High intensity fire may occur where felled tree crowns are located and could cause undesirable mortality in larger oak or hickory stems. The frequency and seasonality of the prescribed fire events should be adjusted to the silvicultural or ecological goals (Vander-Yacht et al., 2017).

In today's environment, any forest disturbance may provide an opportunity for non-native invasive species to grow and proliferate without effective measures for treatment. Invasive species present a significant challenge to the forest manager who is seeking to maximize ecological integrity and potential economic returns. A major threat to forest stability is the invasion of *L. maackii* which dominates the shrub layer in non-hydric sites in 1 to 6 cm size classes. Seed dispersal is primarily endozoochoric through avian species (Bartuszevige & Gorchov, 2006) and white-tailed deer (*Odocoileus virginianus*) (Castellano & Gorchov, 2013). Although many methods exist to control *L. maackii*, herbicide treatment is proven to be the most cost effective due to the species' re-sprouting ability (Nyboer & Edgin, 2017). Herbicides can be applied with aerial methods (Leahy et al., 2017), misting with power blowers, or by a cut stump treatment (Schulz, Wright, & Ashbaker, 2012). Each method has different advantages and trade-offs (Bailey, Saunders, & Lowe, 2011).

Conclusion

Low density oak forests and associated prairie species are considered ecologically valuable systems that warrant restoration and maintenance effort. Historically stable for 8,000 years, savanna and woodland conditions have declined sharply in the Midwest. The formation of these ecosystems occurred in the midst of significant anthropogenic activity which irrevocably influenced the ecological trajectory towards pyrophilic species. The dominant anthropogenic disturbance was the use of fire to alter forest structure to be open and park-like. Ecosystem management in the Midwest would be improved by acknowledging and incorporating historically appropriate disturbance regimes with adaptation to expanding threats like invasive species proliferation.

CHAPTER 2

EVIDENCE OF ITERATIVE SHORT TERM DYNAMICS WITHIN FOREST TRANSITION THEORY USING HETEROGENOUS SPATIAL DATASETS IN A TOWNSHIP IN MIDWESTERN U.S.A.

Abstract

Forest transition theory is used to describe the impacts of settlement and development activities on forest ecosystems across the world. Researchers have identified the need for information related to changes of forest attributes such as composition and structure, improved descriptions short- and medium-term dynamics within the context of the long-term transition, and the integration of biophysical drivers of forest change. In Midwestern U.S.A., forest dynamics were historically influenced by frequent, low intensity disturbance events that mediated forest composition and stand structure. The onset of Euro-American settlement was accompanied by detailed land-use records with information related to forest attributes, agricultural activities, and parcel ownership. We sought to aggregate multiple sources of historic forest conditions into a geodatabase in order to document changes over the past 200 years in Elsah Township, Illinois, where the pre-settlement (1820) forest, once dominated by oak and hickory species, has largely shifted to a maple-dominated system with a declining oak-hickory component. Based on ordinary kriging interpolation, forest density was estimated at 8.7 stems per acre on average with a mean basal area of 14.6 square feet per acre prior to settlement. Conservation practices of the early 1900s, including fire suppression and erosion control resulted in changes to forest structure with density increases to 127 trees per acre with a basal area of 175.8 square feet per acre. The high degree of topographic variability near the Mississippi River influenced forest cover changes as slopes with low angles were the first to be converted from

forest cover to other land uses (circa 1850). Forest re-initiation occurred in areas with higher than average slopes due to a lack of human activities. Forest cover declined to the lowest point in 1927 and has been rebounding steadily throughout this century. Of the original 15,252 forested acres, 11.6% remained covered throughout the past 200 years and coincided with slopes with an average of 39.1 degrees. This information can provide a spatially explicit and historically relevant tool to guide land management decisions including restoration, disturbance regime management, and land use preservation in similarly heterogeneous environments.

Introduction

Changes in forest communities are well documented due to recent advances in global mapping by satellites and airborne sensors which have allowed the detection of fine-scale forest changes for the past five decades (e.g. Goymer & Davis, 2017). Despite limitations of historic data sources, such as USGS topographical maps, plat maps, and county-level survey notes, the digital conversion of these sources allows spatial analysis to reveal empirical evidence of forest trends over time, which are often useful to practitioners of forest restoration (Foster, Olsen, Dale, & Cohen, 2010) and allow short- and medium-term patterns in forest transition to be analyzed in terms of species composition, stand structure, and the spatial extent of forest coverage. Historical data provide reference waypoints for the trajectories of ecological systems and changes to the extent, composition, and structure of forested areas (Whitlock, Colombaroli, Conedera, & Tinner, 2018).

According to forest transition theory, the broad patterns of forest change are driven by human development events such as cutting, agriculture, grazing, and fire, resulting in declines in the areal extent of forest followed by preservation of remnant forest patches or regrowth of formally cleared land (Mather, 2001; Ness, Drake, & Brechin, 1993). Mapping changes in forest coverage using heterogeneous data sources can increase the temporal scale of analysis when these documents exist (Skalos, Engstova, Trpakova, Santruckova, & Podrazsky, 2012) and permits more recent ecological developments to be calibrated according to historic conditions. Researchers who seek to reveal drivers of forest change have modeled the effects of various explanatory variables within the Midwest and elsewhere using agent-based modeling (Evans & Kelley, 2008), cellular automata and spatial interaction models (Clarke & Gaydos, 1998; Messina & Walsh, 2001), and dynamic systems models (Evans, Manire, de Castro, Brondizio, & McCracken, 2001). Critical analysis of forest transition theory studies identified multiple research needs including an investigation into changes of forest attributes such as composition and structure in addition to descriptions of short- and medium-term dynamics within the context of the long-term transition. Furthermore, biophysical drivers of forest change, in addition to the socio-economic context, could provide important explanatory variables of trends described by the forest transition theory (Perz, 2007).

The contextual factors accompanying the decline in forest extent as posited by the forest transition theory may enhance forest change models. Prior to settlement, anthropogenic activities have been linked to the occurrence of oak forests (Black, Ruffner, & Abrams, 2006; Guyette et al., 2002). Euro-American settlers modified forest disturbance regimes by increasing the frequency of fire across many systems (Guyette, Dey, & Stambaugh, 2003; Guyette et al., 2002), which reduces fire severity due to a lack of fuel buildup, and increasing forest light levels by cutting. These effects resulted in favorable conditions for shade intolerant and fire adapted species to establish and compete, thus perpetuating the historically congruent forest systems of savannas and woodlands (McEwan & McCarthy, 2008). Following the initial settlement effects on forest conditions, ecological regimes began a departure from the original ecological assembly processes thereby resulting in an overall system shift. Post-settlement land use practices were influenced by a conservation ethic that considered fire to be antithetical to the development of quality timber resources (Graves, 1910; Miller, 1920). The loss of frequent landscape fires resulted in the establishment and increasing dominance of mesophytic species across the eastern US (Nowacki & Abrams, 2008, 2015), consequently altering the historic disturbance regime that generated open forest conditions including savannas and woodlands.

The comparison of forest composition prior to settlement and current conditions is typically conducted with Government Land Office records of surveyor notes describing the diameter and species of witness trees prior to settlement and comparing the results against current data originating from the Forest Service or Forest Inventory and Analysis data (Deines, Williams, Hamlin, & McLachlan, 2016; VanDeelen, Pregitzer, & Haufler, 1996). While these studies compare relative abundance, they typically do not calculate density or basal area, which are important forest metrics for determining reference conditions when planning forest restoration projects.

The purpose of this study is to use forest transition theory to examine and describe 200 years of spatial variations in forest cover, composition, and structure within a township using multiple data sources. We describe the conditions of the pre-settlement forest as observed in 1820 during the township survey and compare to current conditions using relative values and in terms of density and basal area. The 1820 Government Land Office records containing witness tree information, the original plat maps from 1853, a USGS topographic map from 1927, aerial photographs from 1941, and satellite imagery from 2015 provided evidence for changes to forest cover during settlement, farmland abandonment, and forest regrowth. Forest cover changes including, loss, gain, and area remaining, were assessed in relation to the topographic factor of slope as a critical driver of change. As a case study, the results are applicable to forest transition theory by providing a full account of forest attributes from pre-settlement to current conditions, short- and medium-term dynamics of forest cover, associations with biophysical factors, and fine-scale resolution of compositional and structural forest attributes within the forest cover. This study combines several commonly used historical ecology methods to describe changes to the forest community over nearly 200 years of anthropogenic activities related to Euro-American settlement and development.

Study Area

The Elsah Township is located in the south-east portion of Jersey County, along the limestone bluffs of the Mississippi River between the confluences of the Missouri River and the Illinois River and at the northern edge of the American Bottoms (Figures 4 and 5). From circa 900 CE to 1300 CE, approximately 20,000 Native Americans lived across Cahokia, a major agricultural complex 23 miles downriver, (Denevan, 1992) and likely hunted, foraged, and burned in the Elsah Township area. The bluffline contains numerous Native American burial mounds and assorted features, indicating that it was a significant spiritual site (Charles, 1992). Additional Native American, (i.e. the Hopewell era, Kaskaskia, and the Illinois tribes) activities took place throughout the late Woodland and Contact periods within the area before and after the Cahokia civilization (Charles, 1992).

In the study area, the soil is comprised of windblown loess that accumulated on the bluffs as the glaciers retreated 12,000 to 19,000 years ago. Precipitation averages 38.41 inches, of which 21.5 inches fall during the growing season. Temperatures average 29.9 degrees F during the winter and 74.4 degrees F in the summer, with daily highs averaging 85.6 degrees F (USDA NRCS 2002).

In 1820, John Carrol was the first settler to establish a residence in the Elsah Township (*Atlas Map Of Jersey County, Illinois.* , 1872). Elsah supported a fuel wood industry for the barges on the Mississippi River, limestone quarries, a ferry, a mill, and eventually the estates and farms of wealthy St. Louis families that desired a summer residence with a view of the river from atop the bluffs throughout the early 1900s. As coal rose in importance, the fuel-wood industry declined and farming became the main economic focus of the area with many residents commuting to the city for employment opportunities (Hosmer & Williams, 1986). In 1930, Principia College purchased 2,600 acres along the bluff line from Lockhaven to Chautauqua to build a river-bluff village and campus (Hosmer & Williams, 1986).

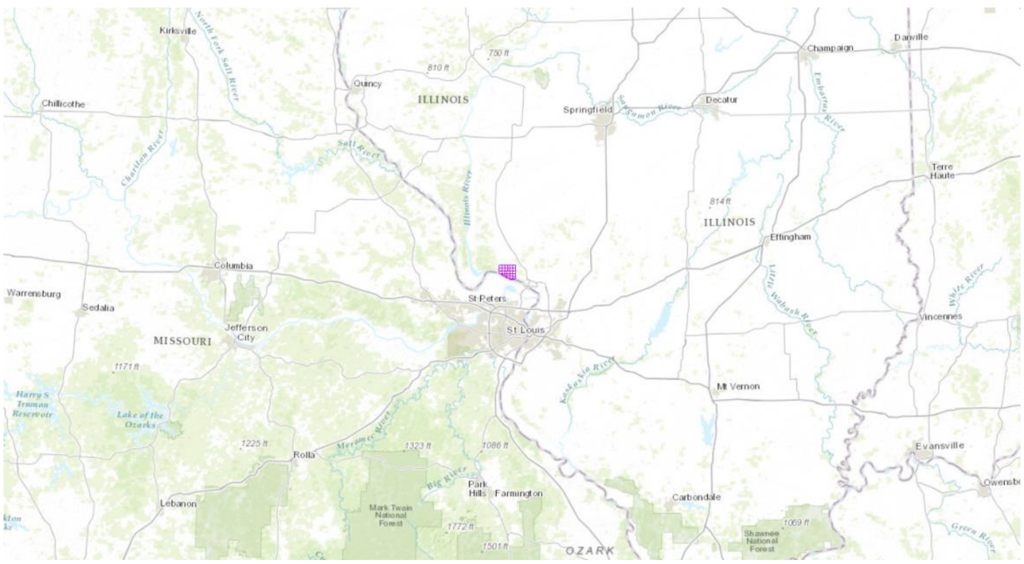

Figure 5. Locational map of Elsah Township, north of St. Louis, MO.

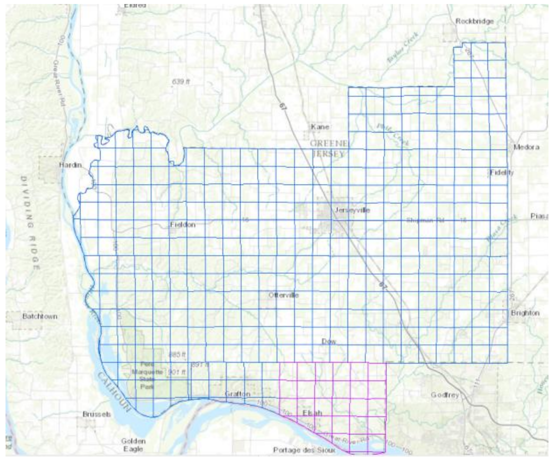

Figure 6. Location of Elsah Township within Jersey County, IL.

Within Jersey County, Elsah Township is located in the south-central portion and along the bluffs of the Mississippi River and downstream from the confluence of the Mississippi and Illinois Rivers.

Methods

The spatial details of land-use history, often in disparate sources and formats, were recompiled and stored in a geodatabase. The datasets include witness tree records, a plat map of the county and township published in 1872, USGS topographic map from 1927, aerial imagery from 1941, and satellite imagery from the past 50 years.

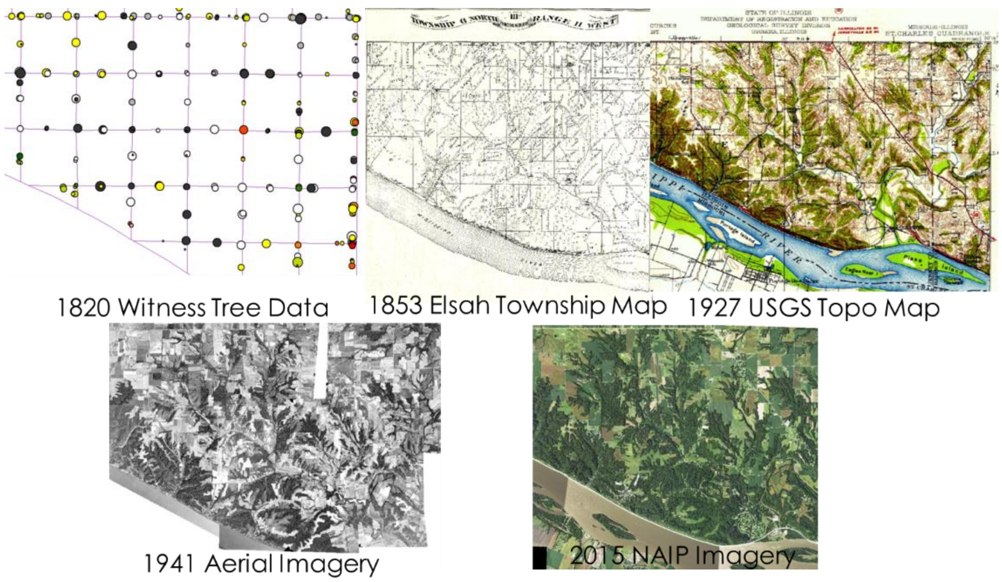

Figure 7. Spatial datasets used to measure forest changes from 1820, 1853, 1927, 1941, and 2015.

Witness tree data were obtained from Brugam, Kilburn, and Luecking (2016), who conducted an analysis of pre-settlement vegetation in Greene, Jersey, and Macoupin counties and populated the locational data with witness tree attributes in a spreadsheet. Elsah Township witness trees were queried and selected from the dataset, and exported as a separate shapefile. Surveyor bias during witness tree selection can present a problem when reconstructing forest structure and composition. Although these witness trees can serve as long-lasting reference points, bias in the survey trends towards larger, healthy trees over smaller or decaying trees, thereby introducing errors into species composition, density, and basal area (Bouldin, 2008).

Bias has been detected in other studies where surveyors selected trees close to the center of area between ordinal directions (Anderson, Jones, & Swigart, 2006). Detecting the nature of the bias is difficult due to the lack of suitable datasets to serve as a cross-reference. The 32 species identified in the Government Land Office (GLO) survey is diverse enough to be representative of the landscape and its forest patterns and bias is not presumed.

Tree density for the 1820 GLO witness tree data was calculated using adjustable exclusion angle method for pair random samples found in GLO witness tree data (Anderson, Jones, & Swigart, 2006). This method was selected because it provides the highest estimate of tree density compared to other methods and underestimating tree density is a perennial problem with witness tree data (Anderson, Jones, & Swigart, 2006). Pairwise distance among trees was calculated with the “near distance as a table” tool in ArcGIS 10.1, which includes the angle at which the near distance measurement was made. The table was joined to the large tree data where a field for density was calculated. Elsah Township witness tree data contain 41% of the second tree of the pair in adjacent quadrants and 58% in opposite quadrants which enable the standard 180 degree adjustment factor of 0.8 to be used when using the tree-to-tree distance in calculating the square root of the mean area (Anderson, Jones, & Swigart, 2006).

The equation for stem density in trees per acre:

$$\frac{43560}{(\mathrm{tree}-\mathrm{to}-\ \mathrm{tree\ distance(ft)} * 0.8)^2}$$

Basal area in square feet per acre was determined by the equation:

$$\left(\frac{\pi(\frac{D}{2})^2}{144}\right) \times DEN$$

where D equals diameter of a stem in inches and DEN equals the stem density in stems per acre.

The tree density and basal area were interpolated using the ordinary kriging method and clipped to the forest extent with a variance prediction surface included in the output. Species composition was analyzed using relative density and relative dominance, which were averaged as statistics of species for the entire township.

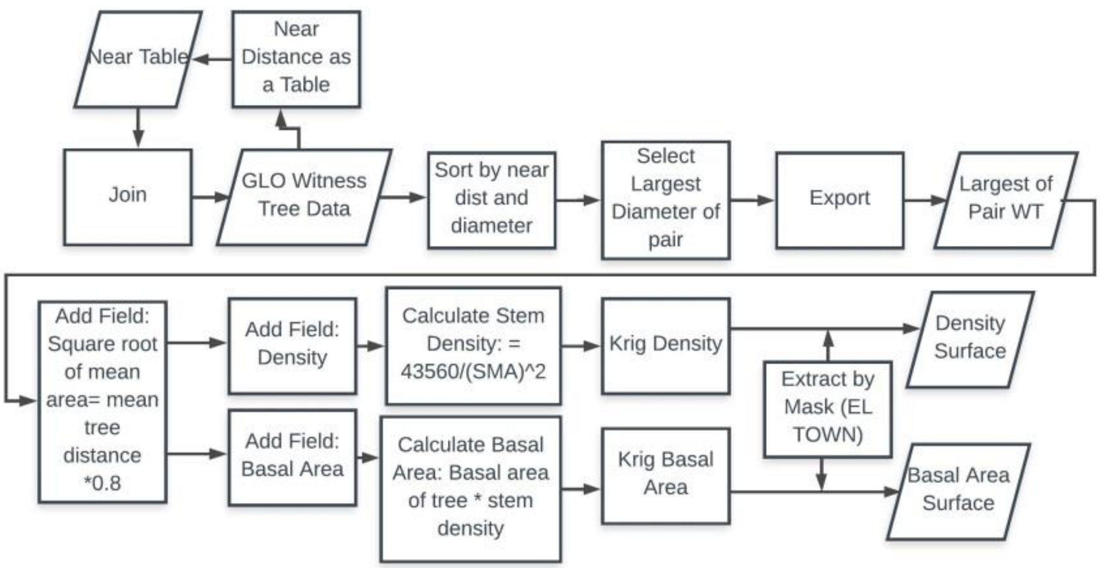

Figure 8. A GIS workflow that describes the process of analyzing forest structure from the 1820 GLO data.

The Map Atlas of Jersey County, Illinois (Figure 8) developed in 1872 contained parcel ownership and land cover maps at the township level, as well as biographical sketches of the first settlers and the details of their occupations and farm status. Numerous prominent estates were drawn in ink pen and most depicted the dwelling and surrounding farm and landscape, which were geotagged in reference to the parcel and farm house features. The Elsah Township map displays the settlement progress as of 1853 including forest cover, farm houses, orchards, and vineyards. The blank space between the features is assumed to be pastureland (grasslands) or cropland. The township map was initially scanned as a jpeg file, then georeferenced following the 2010 Jersey County parcel lines, and finally saved as a geoTIFF file. All of the map features were heads-up digitized into a geodatabase with a State Plane Illinois West projection. The total area in acres was calculated for each land-category. The 1853 parcel files were joined with a table found within the map atlas that contained setter's name, occupation, country or place of origin, and Elsah Township settlement date. The settlement date was used to create a time-series analysis that mapped the progression of parcel settlement within Elsah Township, thereby providing approximate dates for the initiation of tree cover removal and the start of agricultural practices.

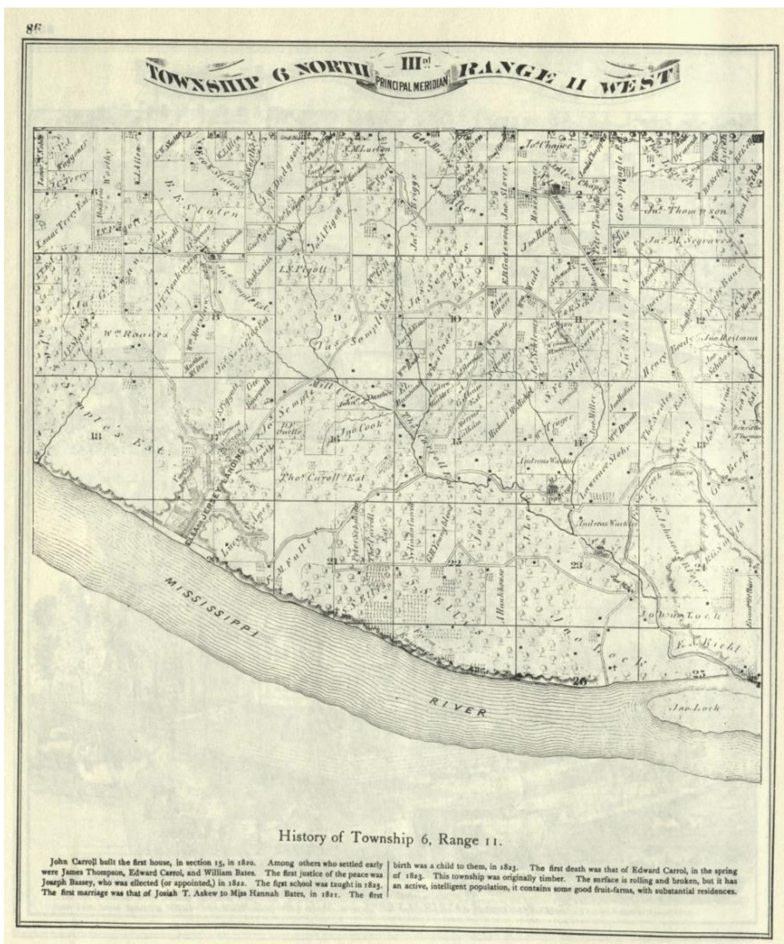

Figure 9. Elsah Township plat map depicting ownership and land cover in 1853.

The USGS topographical map (https://ngmdb.usgs.gov/topoview/) published in 1927 documents land-use changes since 1853. The digital topographical map was converted from a geoTIFF file into a categorical raster by performing an interactive supervised classification which categorized the features into water, forest cover, and pasture-agricultural land. No delineation was made by the map makers for orchards or vineyards at this time. The area of each land-use category was totaled and compared to the totals from 1853.

The first aerial imagery of the township was obtained in the summer of 1941 with black and white photography. The imagery was downloaded from the Illinois Geospatial Data Clearinghouse (http://clearinghouse.isgs.illinois.edu/data/imagery/1937-1947-illinois-historical-aerial-photography) and georeferenced using control points identified on current aerial imagery. The imagery contained black borderlines, which were removed by clipping the image and the multiple images were mosaicked together to create a single image file from which image classification could occur using the Mosaic to New Raster tool. Interactive supervised classification was performed and created spatial extents of each respective land-use category.

Finally, the summer 2015 ortho-imagery from the National Agriculture Imagery Program was downloaded from the USDA Geospatial Data Gateway (https://datagateway.nrcs.usda.gov/). The imagery was classified into the main land-use categories using the interactive supervised classification, which was stored in the geodatabase. Land-use area totals were calculated and the results were added to the land-use change data (Figures 18 and 19).

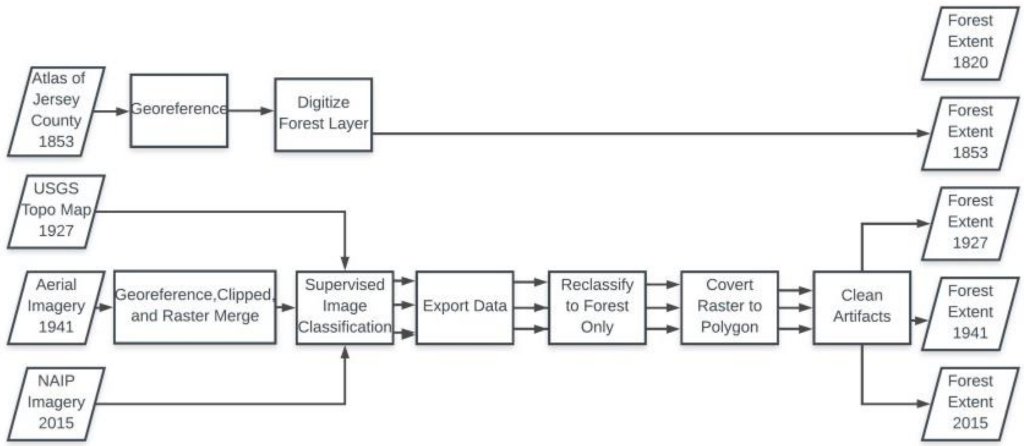

Figure 10. The process for obtaining the forest extent for 1820, 1853, 1927, 1941, and 2015. Note that the entire township was considered a low density forest in 1820.

The extents of forests were analyzed for spatially explicit changes during each time period to determine the patterns of forest cover loss and gain. The "erase" tool was used to erase the older forest extent from the newer forest extent in order to produce forest gain. Likewise, the new was erased from the older to produce forest loss. The remnant forest cover was the area that did not experience any amount of loss during the 200 year time frame. Due to the heterogeneous topographical conditions found within the township, slope provides a suitable proxy for the intensity of agricultural activities including grazing and cropping that preferred utilizing land with relatively flat slopes compared to steeper slopes. The loss and gain layers were used with a LiDAR derived slope layer during an "extract by mask" in ArcGIS 10.1 procedure to obtain the slope attributes of the loss or gain forest extents for each time frame.

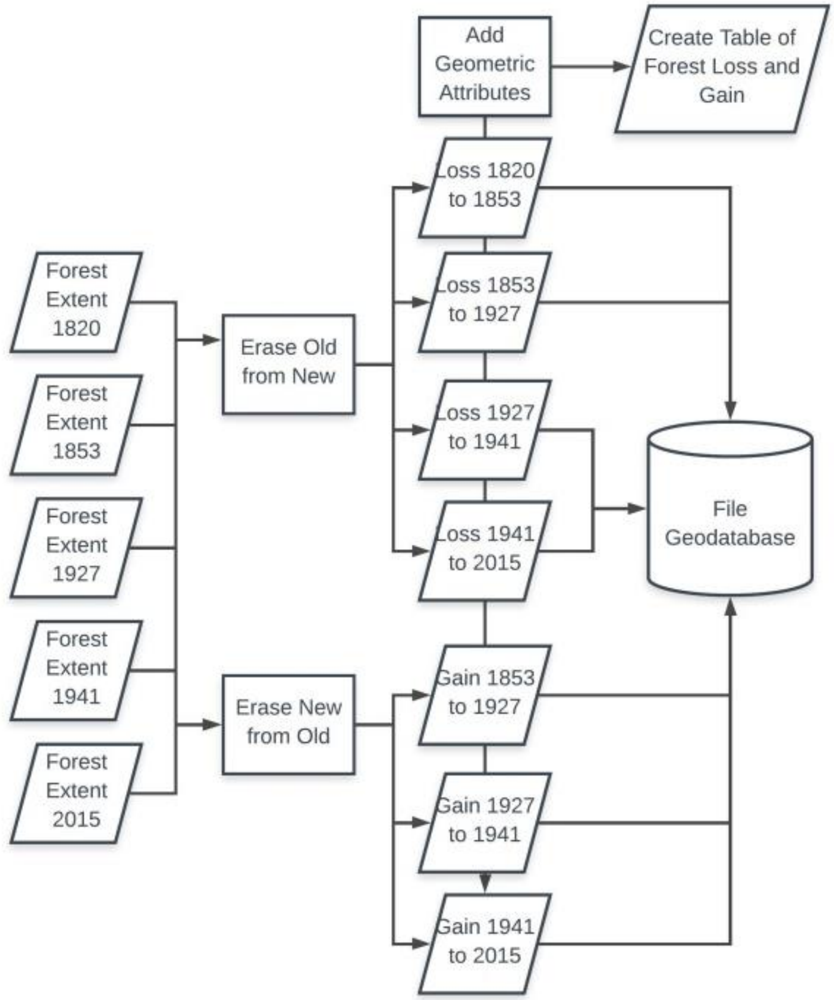

Figure 11. The workflow for determining the extent of forest loss and gain for each time period.

The relationship between slope and forest loss, gain, and coverage was calculated by clipping the slope layer to the spatial extent of each dataset for forest loss, gain, and coverage.

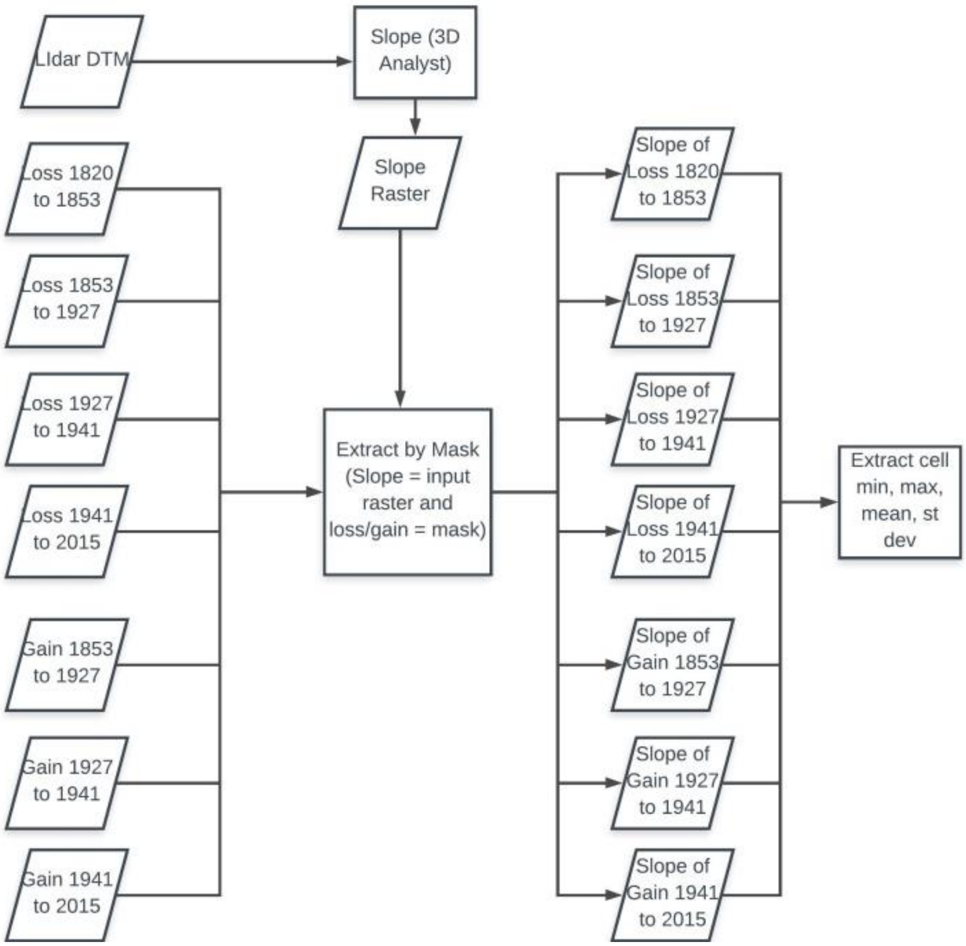

Figure 12. The process of calculating slope for each dataset of forest loss and gain.

Current forest composition and structure was obtained from 79 plots, each 25 m^2 located in the upland region of Elsah Township. All stems greater that 3 inches dbh were measured and identified. The importance value for each species was calculated using the average of relative dominance and relative density. Relative dominance is the sum of basal area for a species divided by the total basal area of all species. Relative dominance is the sum of density for a specie divided by the total density of all species. The importance values for each species in 1820 and 2017 were compared and the differences were graphed.

Results

Changes in Species Composition and Structure

As seen elsewhere across the Midwest, the forest shifted in species composition and structure during the 200 years of settlement and development (Figure 8). Pyrophobic species, such as *A. saccharum* (+14.66%), *F. Americana* (+5.28%), and *J. nigra* (+5.15%), increased in relative importance value while pyrophylic species, including most *Quercus* species, declined between -6.77% and -14.70%. Two pyrophobic species that increased were *Q. rubra* (+7.91%) and *S. albidum* (+3.39%). One pyrophobic species, *P. deltoides*, declined by -3.29%.

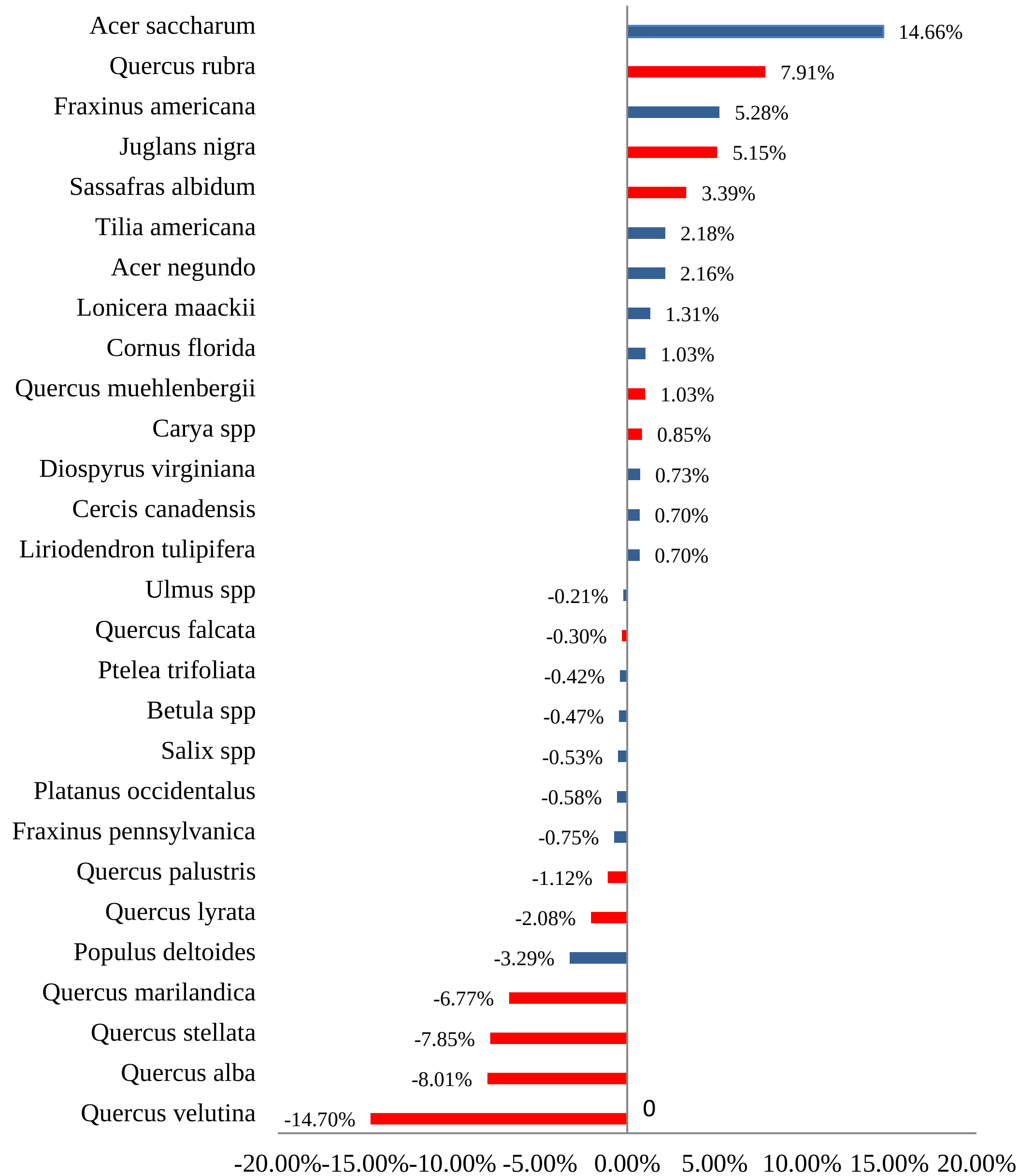

Figure 13. The change in importance value from 1820 to 2017 of all species.

The witness tree record in Elsah Township was compared to current forest inventory data using changes in importance value by species (Figure 13). Red bars indicate pyrophylic species while blue bars represent pyrophobic species.

Stem density and basal area also changed significantly during the past 200 years. In the Elsah Township, ordinary kriging analysis applied to the GLO data produced a forest density estimate of 8.7 stems per acre with a mean basal area of 14.6 square feet per acre for the entire township. (The non-spatial analysis of the GLO data without kriging resulted in forest density with an average of 7.5 stems per acre and a mean basal area of 13.1 square feet per acre.) Current upland forest conditions consist of 127 trees per acre with a basal area of 175.8 square feet per acre.

The results of the ordinary kriging analysis indicated that stem density was lower on the southern portion of the township which borders the Mississippi River. The basal area interpolation generated a patchy pattern of high and low values.

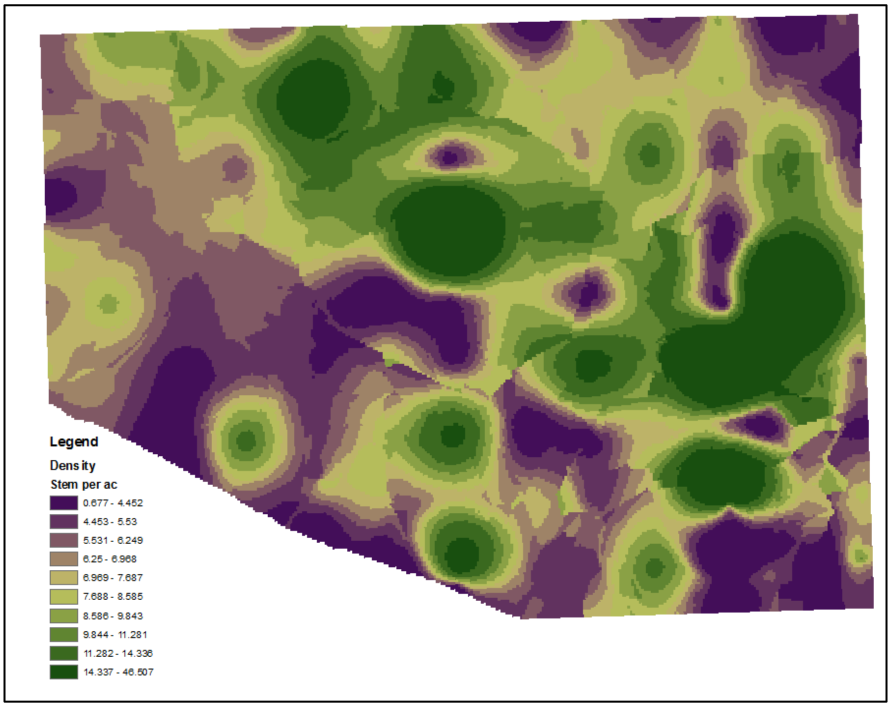

Figure 14. Ordinary kriging of stems per acre for 1820 GLO witness tree data.

The forest density (stems per acre) was determined for each section corner and midpoint and the values were used for interpolating the surface through the method of ordinary kriging. The resulting surface is symbolized with 10 quantiles.

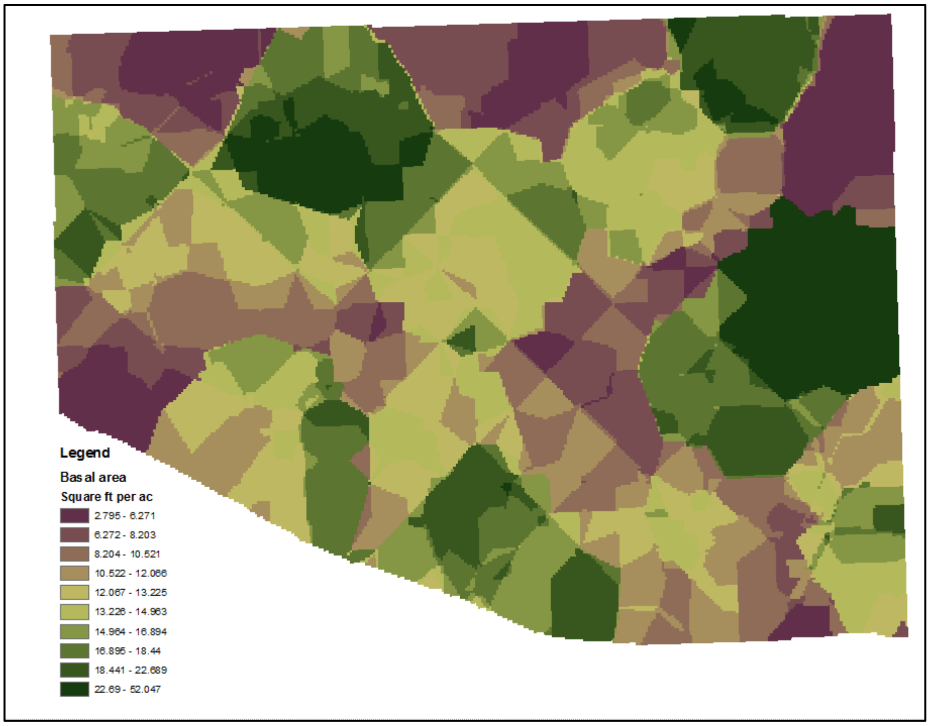

Figure 15. Ordinary kriging of basal area in square feet per acre for 1820 GLO witness tree data.

Basal area per acre (square feet per acre) was determined and used in ordinary kriging to produce a basal area surface symbolized in 10 quantiles.

Changes in Forest Coverage

Elsah Township experienced significant change in land-use patterns and forest coverage over the past 200 years. The entire township was covered in a low density forest at the time of initial surveying in 1820. Settlement activities occurred and by 1853, a total of 9,344 acres, 61.8% of forest were converted into pasture, vineyards, orchards, and crops, leaving 5,864.38 acres of forest remaining (figure 16). Over the next 74 years, 46.4% of the remaining forest was cleared while an almost equivalent acreage re-grew. By 1941, gains in forest coverage, 3,067.64 acres, outpaced losses, 1,993.03 acres, resulting in a total of 6,779.65 acres of forest. The trends from 1941 remained consistent for the next 74 years with 3,411.85 acres of forest re-growth and 2,126.12 acres of loss for a total forest coverage of 8,070.43 acres. Of the original forested area in 1820, 11.6% or 1,769.07 acres of forest did not experience clearing at any time period (figure 18).

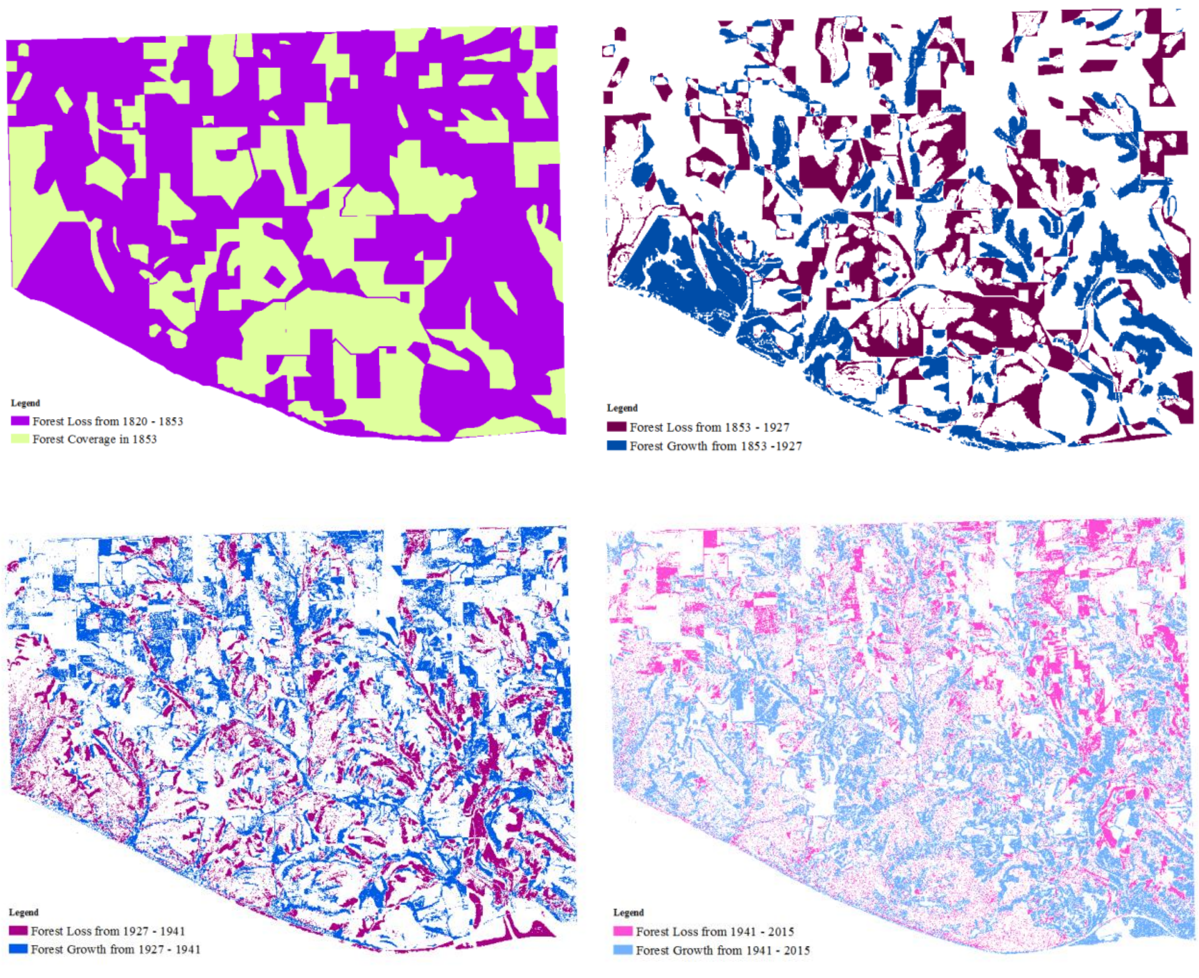

Figure 16. Forest cover loss and gain for the Elsah Township in 1853, 1927, 1941, and 2015.

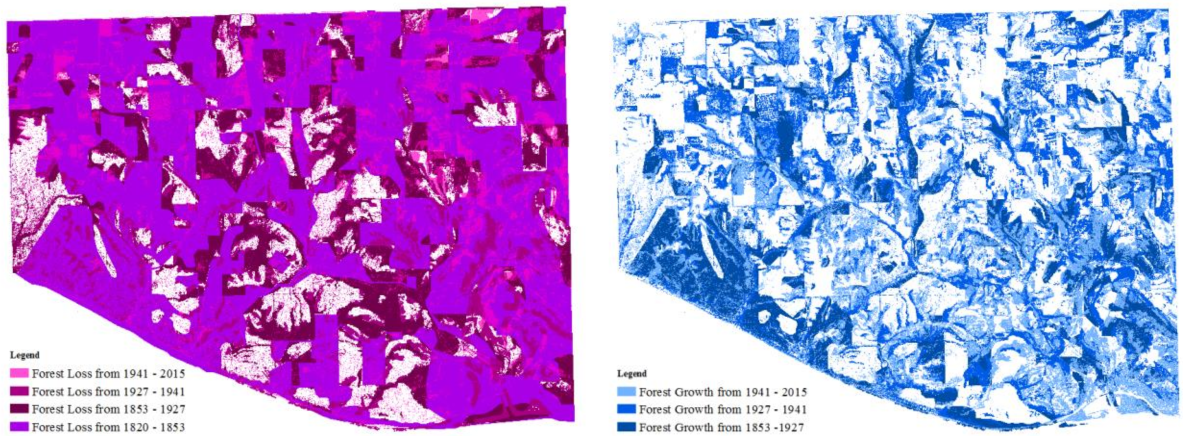

Figure 17. Total forest loss and forest gain in Elsah Township since settlement.

Figure 18. Remnant forest cover in the Elsah Township consists of 11.6% of the 1820 cover.

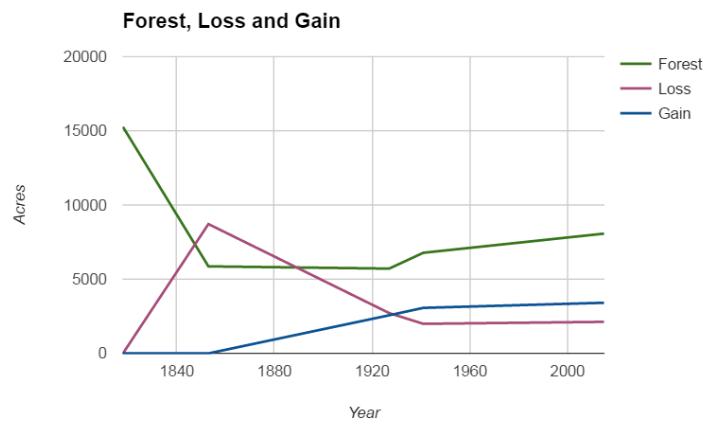

Figure 19. Forest cover, loss, and gain from 1820 to 2015 in Elsah Township.

Changes to forest cover followed the trend identified by the Forest Transition Theory with initial loss of area in forest cover following settlement and subsequent regrowth as development continued into the 20th century.

The average slope of forested areas and areas that experience forest loss or gain provides evidence of prioritization of land-use decisions (figure 19). Elsah Township has an average slope of 24.49 degrees. Forest loss occurred on increasingly steeper slopes in each time period until the last time period of 1941 to 2015. The slope of forest loss during 1820 to 1853 (21.56 degrees) was less than the township slope average (24.49 degrees) as was the time period between 1853 and 1927 (23.07 degrees). The re-growth of forest coverage occurred on the steepest of the initially cleared slopes with an average of 33.87 degrees. The forested area for each time period steadily increased as the relatively flat land was utilized for other purposes and steep slopes were returned to forest cover.

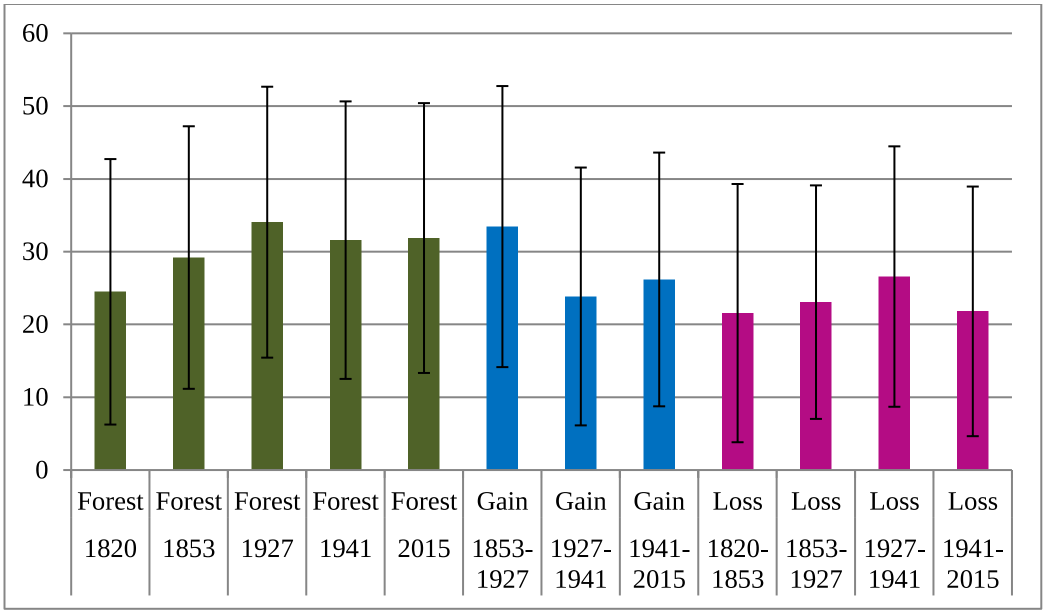

Figure 20. Average slope of forested, forest gain, and forest loss area for each time period with standard deviation error bars.

After the extent of forest cover, forest loss, or forest gain was calculated, the average slope of each area was determined (Figure 20). For the entire township, the average slope was 24.49 degrees and slope of forested areas at other dates can be compare to this value. The average slope of forest areas increased until 1941 when it decreased and held level. Areas with forest lost first occurred on the flattest slopes and steeper areas were the only option available as flat areas were used. The first areas to re-grow with forest cover were steep areas that were unsuitable for intense agriculture or development.

Discussion

Spatially explicit models of land-use change are limited to the data that are available for any given location and time period. This study aggregated five spatial datasets to compare changes in forest structure and composition over a 200-year time frame in the Elsah Township in order to portray the dynamic unfoldment of forest transition that led to current conditions. By integrating forest coverage data with five points in time (1820, 1853, 1927, 1941, 2015) and forest composition and structure data at the beginning of settlement in 1820 and currently in 2017, short- and medium-trend in forest transition are identified and described in relation to slope, and the biophysical parameter of topography.

Forest Cover Loss and Gain

Forest cover during the 1820 time period was derived from the GLO witness tree data in which only two records in the Elsah Township were classified as "prairie" thereby indicating the entire 15,252 acre township was considered forested. Furthermore, the 1853 settlement map stated the township consisted of "timber." The stem density and basal area analysis of the pre-settlement forest indicated that the township had large trees that were widely spaced as found in a savanna, which is consistent with descriptions from early European explorers who indicated quality pasture land on the bluffs (White, 2000). The average slope for the 1820 forested area was 24.49 degrees (Figure 10), representing topographically rough landscape due to the presence of the 300 foot bluff escarpment on the township's southern border.

Settlement quickly followed the GLO survey in 1820 and by 1853, farmers, merchants, boatmen, fruit growers, horticulturists, stone masons, carpenters, and capitalists were represented by 57 landowners in Elsah Township (*Atlas Map Of Jersey County, Illinois.* , 1872). The flattest portions of the undulating terrain were cleared for farms and the average slope of forest cover increased from 24.49 to 29.19 degrees. The land converted from forest cover at a rate of 249.01 acre per year and had an average slope of 21.56 degrees

After more than a century of settlement activities, the initial cleared areas with steep slopes (average slope of 33.45 degrees) were not used for farming or development resulting in the re-initiation of forest development totaling 2,568.41 acres or an average of 34.71 acres per year between 1853 and 1927. The majority of the loess soil is classified as highly erodible which requires extra effort to farm and manage. The suitable farmland that evaded clearing during the first wave of settlement was found and cleared at a rate of 36.74 acres per year over the 74 year period, possessing an average slope of 23.07 degrees and consisting of 2,718.67 acres. The lowest amount of forest cover was found in 1927 at 5,713.53 acres or 37.44% of the original forested area.

Conservation measures, namely soil and water conservation in addition to fire prevention for the protection of timber resources, began to establish across the nation in the first half of the 20th century (Foster, Zebryk, Schoonmaker, & Lezberg, 1992). In the 1941 Elsah Township, the rate of forest gain outpaced forest lost at 219.12 to 142.36 acres per year. Forest gain occurred on an average of 23.85 degree slopes while forest loss averaged 26.58. The lower slopes of forest gain may be due to the regrowth on narrow ridgetops that were shaded and difficult to farm profitably. Many of the areas experiencing regrowth were found in the floodplains of tributaries to the Mississippi River. The aerial imagery from 1941 provides the first view of forest structure which is generally open with widely spaced trees on the ridges and southern slopes while closed in the valley bottoms.

The forest growth trend strengthened from 1941 to 2015 resulting in 3,411.85 acres of forest re-initiation on slopes with an average of 26.19 degrees (Figures 3 and 4). The 8,070.43 acres of forest cover exists on an average of 31.88 degree slopes. Forest loss occurred on acres with an average slope of 21.80 degrees, thus reinforcing the conservation practices associated with soil protection by allowing forest cover on the steeper slopes.

The remnant forest cover consists of areas that maintained forest cover during each of the time periods captured in the five datasets (Figure 18). Woodlots were common features during settlement and provided important fuelwood for heating and building supplies after the initial clearing for farmland occurred. Woodlots would be lightly cut for timber products and grazed by livestock, but would maintain an overall forest cover. The 1,769.07 acres of remnant forest (11.6% of the original forest cover) was left to slopes with an average of 39.14 degrees.

Forest Structure and Composition

Forest density and basal area were calculated for 1820 and 2015 using GLO witness tree data and forest inventory data from Principia College in Elsah. The development of forest structure is largely a function of time since the previous disturbance and the severity and extent of the disturbance. Prior to settlement, upland oak-hickory forests experienced regular, low intensity burns that cause greater mortality in small diameter pyrophobic species. The forest structure of upland forests typically contained a low density of large trees due to the dominant surface fire disturbance regime. In the Elsah Township, the GLO data, after performing the ordinary Kriging analysis, suggests that forest density averaged 8.66 stems per acre with a mean basal area of 14.57 square feet per acre. The analysis of the GLO data without Kriging resulted in forest density with an average of 7.48 stems per acre and a mean basal area of 13.12 square feet per acre (Figures 14 and 15). Studies that examined a broader scale of pre-settlement vegetation in the same area found slightly higher stem density in the uplands at 15 stems per acre (Nelson, Sparks, DeHaan, & Robinson,1998). Current forest conditions represent the culmination of management decisions including fire suppression with increases to 148.95 trees per acre with a basal area of 114.04 square feet per acre.

Due to the tree selection bias within all GLO witness tree records for vigorous, long lived trees over small or decaying trees, these results are likely an under-estimate of actual forest structure. Kriging provides a geostatistical approach to interpolating forest structure values, but has significant limitations related to locational accuracy due to inability to include the effects of slope, topographic position, and aspect into the values. The tree-to-tree distances were randomly distributed across the township indicating a lack of spatial autocorrelation using the Moran's I (z-score: -0.593, p-value: 0.582779) and a lack of high or low clusters in the high-low cluster report using General G (z-score: -0.593625, p-value: 0.552763). Slope and diameter were poor explanatory variables of density in a geographically weighted regression analysis (r^2: 0.081661).

The indexed scores for forest composition of GLO witness tree data and forest inventory data from Principia College in Elsah were compared to determine basic changes from 1820 to 2017 (Figure 2). While each dataset was collected from a different spatial extent and a different sampling methodology, the indexed values still serve as a reference for observing overall changes. Additional studies could serve to validate the changes by replicating the GLO methodology. *A. saccharum*, a shade-tolerant pyrophobic species, gained the most, particularly in relative density, to elevate its importance value to the highest overall, which is a common trend in mesophication throughout the Midwest (Fralish & McArdle, 2009; McEwan, Dyer, & Pederson, 2011; Nowacki & Abrams, 2015). Declining to the second highest IV, *Q. alba* experienced a relative reduction in density and increase in basal area indicating that there are fewer, but larger *Q. alba* and a problem with regeneration and recruitment in recent years. Trees that respond to fire by re-sprouting and quickly growing with a large root mass, as in the case of *Q. velutina*, experienced precipitous declines as seen elsewhere (Fralish, Crooks, Chambers, & Harty, 1991). The recovery of species generally associated with particular climatic and disturbance were mediated by economic and cultural values placed on their properties. Ridge-top species, and species associated with low density savannas, were especially susceptible to declines due to conversion of the flat topography to agriculture such as orchards, vineyards, and row crops. *Carya* species were prized for their high heat content when used for fuelwood (Whitney, 1994) and could have been cut at a higher rate thereby lowering the relative density in subsequent generations. The shift from open canopy, oak dominated system to a closed canopy maple dominated stem is advancing rapidly.

The broad pattern of forest cover loss and gain as described by forest transition theory in advanced industrialized nations is evident in the ecological history of Elsah Township over the past 200 years. The interim dynamics of forest coverage demonstrate a strong relationship with slope due to the difficulties of farming and managing highly erodible soil on steep slopes. Forest composition and structure were the cumulative result of a range of management practices throughout the settlement and development phases of the township which is causing a transition from a low-density oak dominated forest to a forest with mesophytic and pyrophobic species dominance. Where remnant conditions exist, the prairie-forest gradient of the bluffs for example, opportunities for the restoration of historic attributes are available. Thinning, re-introduction of native grass and forb species, herbicide applications for persistent invasive species, and frequent prescribed fire will be required to restore and maintain historically representative systems.

Conclusion

The variety of sources for investigating historical ecology within a township is found in a multiple scales and formats. By aggregating evidence into a geodatabase, the data share a common spatial scale that can be grouped into temporal or thematic layers for analysis. Change detection, limited by the resolution of the data, is readily performed and an overlay analysis of forest loss and gain for each time period with a slope layer revealed short- and medium-term the patterns of forest transition decoupling based on topography. The areas with low slope were converted from forest to pasture, orchards, or fields first. In contrast, the high slope areas initially deforested, but canopy cover returned due to the unsuitable topography for economically supporting any other land use. Conservation practices and fire exclusion resulted in a steady increase in forest cover on these lands since 1927. While 11.6% of the forest cover remained intact throughout the settlement and conservation phases due to its relatively inaccessible steep slopes, the forest likely experienced selective harvesting, burning, and grazing. The forest structure and composition in the Elsah Township experienced an increase in density which closed the canopy, evident as a shift in dominance to mesophytic species with declines in oak and hickory. *A. saccharum* and *Q. alba* underwent a reshuffling in dominance due to more recent changes in land-use patterns, particularly a lack of a disturbance regime that favored oak dominance. Although forest cover has rebounded to 53% of the original coverage, the species composition, density, and basal area of the forest has departed from pre-fire suppression and pre-settlement conditions.

CHAPTER 3

LANDSCAPE-LEVEL ANALYSIS OF FOREST COMMUNITY STRUCTURE IN THE CONFLUENCE REGION OF THE CENTRAL MISSISSIPPI RIVER VALLEY

Abstract

Forest communities along the Middle Mississippi River Bluffs Region contain distinct compositions of tree species and stand structure associated with specific topographic positions of floodplain, transition talus slope, bluff top, and upland. In order to assess current stand characteristics and ecosystem trajectory, we measured all woody stems in 316 fixed radius plots (79 plots per topographic position) with a plot area of 25 m^2. Alpha and Beta diversity and diameter distributions were determined for seedling, shrub layer, and overstory stems. Previous studies were used to determine patterns in changing composition and structure (Chapter 2). Stem density increased following the re-growth of cleared land and with ingrowth of low density forests. For upland forest, stem density increased from 21.4 stems ha^{-1} in 1820 to 613 stems ha^{-1} in 1936 followed by reduction to 314 stems ha^{-1} in 2017. Average stand diameter decreased from 40.9 cm in 1820 to 25.3 cm in 2017 (for upland stems greater than 7.5 cm) while basal area increased from 3.3 m^2 ha^{-1} in 1820 to 40.4 m^2 ha^{-1} in 2017. Alpha diversity (diversity of sites) was highest in the upland overstory and in the river island shrub layer. Beta diversity (diversity among sites) in the overstory was highest (0.67) between the bluff and the upland while the lowest (0.08) was between the bluff and the river island. Mesophytic species are no longer restricted to watercourses and valleys as reported in historical ecological accounts and confirmed in the spatial analysis of witness tree records. Invasive species dominate the shrub layer in non-hydric sites of the talus slope, upland, and particularly for bluff top where *Lonicera maackii* is an

indicator. Across all forest sites in the study, evidence of a community shift to less diversity and more mesophytic species is occurring.

Introduction

Within the confluence region of the Great Rivers, unique forest community types exist in the floodplain, the transition zone, the bluff edge, and the uplands (Turner, 1936). The composition and structure of these forest communities are influenced by a multitude of complex interacting factors including climate, topoedaphic factors, disturbance regimes including anthropogenic and natural causes, and species interactions (Kilburn & Brugam, 2010; McEwan et al., 2011; Nuttle, Royo, Adams, & Carson, 2013). These factors govern each site with varying influence on the overall forest community depending on the most limiting factor for a given species' growth requirements (Burns & Honkala, 1990; Robertson, 1992). Forest inventory data provides a baseline for assessing the status of current forest attributes which can be compared to historic inventory data or used in the future to measure changes (Costanza, Faber-Langendoen, Coulston, & Wear, 2018). As the drivers of forest dynamics undergo change, forest structure and composition respond to reflect these changes (Lorimer, 1980).

As shifting patterns in disturbance regimes produce novel conditions, the envelope of possible forest trajectories expand correspondingly. Disturbance regimes alter forest community structure by selecting for species with adaptations to the disturbance, creating new growing space and opportunities, and altering the site characteristic that influence growing conditions (Frelich, 2002). The fundamental ecological role of disturbance is the freeing up and altering of resource availability, primarily of light, water, and nutrients, for utilization by another individual or group, thereby creating the potential for higher diversity (Connell, 1978, 1980). Yet, the lack of historic fire disturbance patterns and the addition of new disturbances (e.g. aggressive invasive species) present a new definition of ecosystem disruption. Disturbances common to Midwestern forests that maintain ecosystem structure and composition include high frequency and low intensity fire, drought and flooding, insect outbreaks, wind and storm damage, ice and snow damage, as well as anthropogenic cutting, clearing, and changing land-use (Parker & Ruffner, 2004; Nowacki & Abrams, 2015). The frequency, intensity, and extent of a disturbance influence the forest community and can have enduring effects that provide legacies for the next dominant community (Nowacki & Abrams, 2008). A lack of information on shifting disturbance regimes presents a challenge to identifying options for continued management of intact ecosystems and restoration targets for the processes that govern forest dynamics.

As the forest manager considers the range of ecological conditions found in the diverse landscape, homogenizing ecological drivers or management actions can be mitigated or replaced with actions that promote heterogeneity. Specifically, heterogeneity across the landscape and within each topographic position offers multiple management possibilities in the future and the increased potential for overall biodiversity, timber production, and non-consumptive uses. Maintaining or restoring a portion of the landscape in approximant pre-fire suppression and pre-hydrological regulation structure and composition provides temporal heterogeneity and options for ecological restoration.

The purpose of this study is to identify current forest conditions on the river island, talus slope, bluff top, and upland topographic positions and describe the historic trends of community development and likely future conditions. Early historical accounts and witness tree data, in addition to early floristic studies prior to the onset of hydrological and fire control, were analyzed to provide a starting point in assessing the natural historic range of variability and evaluating ecological trajectories. Understanding the trajectory of an ecosystem in the context of environmental gradients is fundamental in adapting to new conditions and managing effectively. Community diversity, measured with Alpha and Beta diversity indices were calculated to reveal trends in community composition, since understanding diversity across the landscapes is integral to supporting ecological resiliency as conditions change. Diameter distributions in each topographic position and by species were assessed for both shrub and overstory strata.

Materials and Methods

Site Description

The interaction of climate, topoedaphic factors, disturbance regimes, and species interactions produced four major community types, floodplain, talus slope, bluff, and upland, in the greater confluence region of the Illinois and Mississippi River as was documented by Turner (1936). This study describes patterns of forest composition and structure in four discrete sites that collectively represent the forest ecosystems of the confluence of the Great Rivers landscape as referenced in the previous presentation of written record (chapter 1), landscape paintings (chapter 1), GLO records (chapter 2), and our own sampling data presented in this chapter to adequately profile the historic dynamics that have shaped and influenced these four distinct ecosystem types (figure 21).

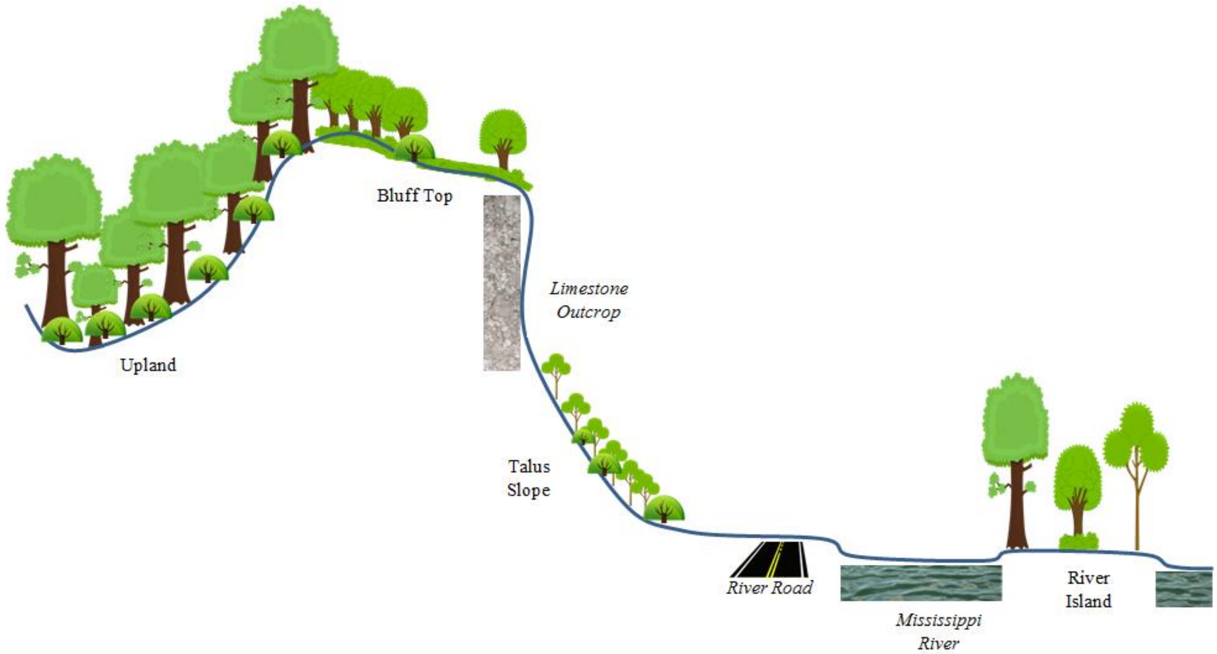

Figure 21. The relative location of vegetation zones in the study area within the Middle Mississippi River section of the American Bottoms, Illinois.

Climatic patterns influence the growing conditions of trees (Douglass, 1937; Fritts, 2012). Climate variation is particularly important during the establishment phases, seedling and sapling stages, when individuals have a low tolerance for temperature and moisture extremes (Burns & Honkala, 1990). A species' ability to endure a given climatic pattern depends upon the adaptations of the species as well as growing conditions and overall vigor of the individual tree. Most Midwestern tree species possess a wide ecological amplitude (i.e. plant plasticity) which allows for survival in a variety of climatic conditions that exist according to elevation, latitude, and microclimatic conditions derived from topoedaphic factors (Harper, 1967, 1977). Across our study area, the river island site receives an annual precipitation of 37 to 47 inches. The average air temperature ranges between 52 and 57 degrees F with 184 to 228 frost free days annually.

Talus slope, bluff top, and upland regions receive an annual precipitation of 37 to 45 inches. The average air temperature is 54 to 57 degrees F with 180 to 200 frost free days (Tegeler, 2007).

Topographic variation creates microclimates and influences soil properties that affect growing conditions (Beatty, 1984; Fralish, 1997). Aspect of a slope as well as slope position and angle determines the amount of solar radiation a site receives (Stage & Salas, 2007). Southern aspects and ridges are typically warmer and dryer in the northern hemisphere. Soil properties vary according to the parent material and the process of weathering, biotic interactions, time, topography, and climate (Binkley & Fisher, 2012). Together, topography and soils contribute towards shaping the resource that provides the majority of nutrients and water to a tree (Burns & Honkala, 1990).

In our study area, the river island site is found on Portage Island, in St. Charles County, MO and has a concave landform of flood-plain steps that consists of Carlow silty clay loam with 0 to 2 percent slopes and is frequently flooded. The parent material is Alluvium. The soil has a hydric soil rating and is poorly drained with a depth to water table of 0 to 12 inches and a depth to restricted feature of more than 80 inches (Tegeler, 2007). To prevent shoreline erosion on the upstream portion of the island, a bullnose consisting of 25,067 tons of stone was constructed in 2005 (US Army Corp 2014).

Talus slope and bluff top consist of the backslope and footslope of the bluff landform on slopes 35 to 60 percent. These well drained soils are a complex of limestone rock outcrops and Lacrescent and similar soils. A typical profile has channery silt loam 0 to 21 inches, very gravelly silt loam 21 to 38 inches, and very flaggy silt loam 38 to 60 inches. Both the depth to a restrictive layer and the water table is greater than 80 inches (Tegeler, 2007).

Upland regions contain Goss-Menfro complex and Menfro silt loam on hillslopes and loess hill landforms, respectively. The Goss Menfro complex occurs on well drained slopes 35 to 60 percent. The depth to a restrictive feature varies from 2 to 30 inches and the water table is deeper than 80 inches. The typical profile has gravelly stilt loam 0 to 11 inches and very gravelly silty clay 11 to 80 inches. Menfro silt loam occurs on well drained, eroded slopes 5 to 10 percent. The depths to a restrictive feature and to the water table are more than 80 inches. A typical profile has silt loam 0 to 7 inches, silty clay loam 7 to 56 inches, and silt loam 56 to 80 inches. Menfro silt loam is considered farmland of statewide importance (Tegeler, 2007).

River island forest disturbances are currently dominated by flood events. Fires and tree cutting occurred on the river islands until the Two Rivers National Wildlife Refuge of the US Fish and Wildlife Service obtained ownership and management responsibilities. During the field measurements, no evidence of recent tree cutting or stumps was observed. Historic river floods have occurred in 58 events where the water level crested above 21 feet since 1844 (USGS, 2018) The creation of Pool 26, first dammed in 1938 in order to improve navigation for barge traffic (Frankie & Mikulic, 2007), altered flood dynamics in floodplain and river island forests (Nelson & Sparks, 1998).

Preliminary analysis and field observations of fire scars as well as historical accounts suggest that frequent and low intensity surface fires were common on the talus slope, bluff top, and upland regions in the late 1800s and early 1900s. The Bluff Line railway line existed at the base of the bluff from 1890 to 1933 (Hosmer & Williams, 1986) and sparks from the locomotives were reported as the source of many fires that traveled up the talus slope and reached the top of the bluff where a fire trail was constructed to contain the spread of these frequent fires. This example of fuel fragmentation suggests that fire frequency would be less on the upland forest regions than the talus and bluff sites. From at least 1860 to 1930, burning of the bluffs was an annual event in order to preserve and enhance the view of the Mississippi River from the estates perched atop the bluff (Ross, 1974). Livestock grazed the bluffs, fields, and forests from 1820 to about 1930.

Jack White (2000) compiled ecological accounts of the Big River Assessment Area for the Illinois Department of Natural Resources' Critical Trends Assessment Program which includes Elsah Township. These accounts were analyzed for references to forest conditions within close proximity to Elsah Township and within the confluence region of the Big Rivers. In addition, accounts of fire behavior, fire ecology, and protection from fire as well as tree cutting were included for insight into two major ecological drivers of change that shape the vegetation communities depending on the application or suppression of these activities.

Data Collection

For each of the four forest sites, 79 plot centers were randomly located within the respective study zones using the "Random Point Generator" tool in ArcGIS 10.1. The points were uploaded to a Juno Trimble GPS device with the mobile mapping software ArcPad 10.0 for navigation to the plot's location. Each fixed circular plot consisted of a 2.82 m radius (25 m^2 area). All living woody stems larger than 1 cm dbh (1.37 m above ground) were identified and diameters were measured at dbh to the nearest 10^{th} of a centimeter. Woody stems less than 1 cm dbh were tallied according to species. Using species area curve function in PC-ORD 6.21, the flattening of the slope in the tail of the species curve indicated that the sampling intensity was sufficient to accurately represent the species of the area. For future dendrochronological analysis, the largest tree of each species in a plot was cored with an increment borer as close to the ground as the handle of the increment borer would allow, typically within 0.25 meters. In addition, the herbaceous vegetation within a 1 m^2 subplot at the center of the 25 m^2 was identified and coverage was estimated. Canopy coverage was estimated with convex hemispherical densitometer. The longitude and latitude for each plot was captured and buffered with a 2.82 m radius which allowed topographical characteristics from a LiDAR derived DEM to be obtained with the “Zonal Statistics” tool in ArcGIS 10.1. Historical data was collected from Turner’s 1936 study of the lower Illinois River Valley forest communities.

Analysis

Within each site, river island, talus slope, bluff face, or upland, the stems ha^{-1} and basal area in $m^2\ ha^{-1}$ were calculated by multiplying the sum of density and sum of basal area by 5.063 each since the 79 plots in each site totaled 1975 m^2. Seedlings density was determined by multiplying the count of seedlings by 5.063 within each site. The diameter distributions with individual species’ contributions for each site were graphed for shrub and overstory layers.

Alpha diversity, a reference to the overall diversity of a site, was calculated for each site using a dominance index (Simpson Diversity Index) for the seedling, shrub, and overstory layers. The Simpson Diversity Index supplies the probability of two randomly selected data points representing the same species.

$$\text{Simpson Index (D)} = 1 - \Sigma_{i=1}^{s} p_i^2$$

where p is the proportion (n/N) of individuals of one particular species (i) found (n) divided by the total number of individuals found (N), Σ is the sum of the calculations, and s is the number of species.

Beta diversity was by calculating the Sorenson Similarity Index for each site comparison for seedling, shrub, and overstory layers to assess overall community similarity based upon the species present. Additionally, current forest composition was compared to Turner's 1936 forest composition study using the Sorenson Similarity Index.

$$\text{Sorenson's Coefficient} = \frac{2C}{S1+S2}$$

where C is the number of species that are shared between the two communities, S1 and S2 are the total numbers of species found in community 1 and 2, respectively.

Indicator species analysis using the Dufrêne and Legendre method (1997) was conducted in PC-ORD 6.21 with density and basal area data for the common species. An indicator value is calculated by using the relative abundance and relative frequency of a species for each predefined group. The groups were assigned as the four zones of river island, talus slope, bluff top, and upland. Density and basal area for species with significant values ($p < 0.05$) were reported for each zone (Peck, 2010).

Results

Despite the close proximity of the river island, talus slope, bluff top, and upland forest communities, each community type exhibits unique structural and compositional attributes. Following the period of settlement, forest regrowth occurred and early stages of stand development contained densities at high levels. Stem density increased from 21.4 stems ha^{-1} in 1820 to 613 stems ha^{-1} in 1936 followed by reduction to 314 stems ha^{-1} in 2017, which is consistent with the principles of stand dynamics (Oliver & Larson, 1990). Average stand diameter decreased from 40.9 cm in 1820 to 25.3 cm in 2017 (for upland stems greater than 7.5 cm) while basal area increased from 3.3 m^2 ha^{-1} in 1820 to 40.4 m^2 ha^{-1} in 2017.

The river island forest contained the greatest basal area of 85.49 m^2 ha^{-1} in overstory trees (>15 cm dbh) and the most seedlings (<1 cm dbh) at 64,810 stems ha^{-1}, yet the fewest shrub layer (>1 and <15 cm dbh) stems at 60.76 stems ha^{-1} and lowest basal area at 2.79 m^2 ha^{-1} (Table

4). The talus slope had the greatest density of overstory trees at 384.81 stems ha^{-1} and highest basal area of shrub layer stems at 5.6 m^2 ha^{-1} and yet possessed the fewest seedlings at 9,580 stems ha^{-1}. The bluff top contained the greatest density of shrub layer stems at 5,245.57 ha^{-1} and the lowest basal area of overstory trees at 23.91 m^2 ha^{-1}.

Table 4

Stem density and basal area for each topographic zone.

	Overstory		Shrub Layer		Ground Layer Seedlings
Zone	Stem ha^{-1}	BA m^2 ha^{-1}	Stem ha^{-1}	BA m^2 ha^{-1}	ha^{-1}
Bluff	308.9	23.9	5245.6	3.7	29,646
River	354.4	85.5	860.8	2.8	64,810
Talus	384.8	32.5	3326.6	5.6	9,580
Upland	313.9	40.4	3483.5	2.8	12,577

The river island had the lowest alpha diversity of the overstory and seedling layers at 63.9 and 6.6, respectively, yet the highest shrub layer diversity at 93.7. The bluff top contains the highest seedling diversity at 78.3 and nearly the highest overstory diversity at 93.6, but the lowest shrub layer diversity at 59.7. The upland region had the highest overstory diversity at 95.3.

Table 5

Simpson Diversity Index for each topographic zone.

Strata	Zone	Simpson Diversity Index	Max Diversity 1-1/n	Simpson's Index as % of max.
Overstory Layer	Bluff	0.88	0.94	93.57
	River	0.57	0.89	63.87
	Talus	0.73	0.92	80.01
	Upland	0.9	0.94	95.3

Shrub Layer	Bluff	0.58	0.97	59.67
	River	0.83	0.89	93.74
	Talus	0.72	0.96	74.9
	Upland	0.67	0.96	69.73
Seedling Layer	Bluff	0.77	0.98	78.33
	River	0.06	0.88	6.6
	Talus	0.47	0.95	49.4
	Upland	0.72	0.96	74.65

Beta diversity was calculated using the Sorenson Similarity Index (Table 6) which provides a comparison of species found within each zone. In general, the river island zone possessed the least similarity with each of the other zones in each stratum. For the overstory stratum, the bluff and upland contain the greatest similarity with a Sorenson Coefficient (SC) of 0.67 followed by the talus and upland SC at 0.55. In the shrub stratum, the bluff and talus shared the highest SC at 0.62 followed by the bluff and upland SC at 0.59. The seedling stratum SC was highest in the talus and upland at 0.59 and followed by the same SC of 0.52 in the bluff and talus as well as the bluff and upland.

Table 6

The Sorenson Similarity Index for overstory, shrub, and seedling for each zone.

	Sorenson Similarity Index		
Zone	Overstory Layer	Shrub Layer	Seedling Layer
Bluff vs River	0.08	0.10	0.04
Bluff vs Talus	0.50	0.62	0.52
Bluff vs Upland	0.67	0.59	0.52
River vs Talus	0.10	0.12	0.14
River vs Upland	0.15	0.18	0.06
Talus vs Upland	0.55	0.53	0.59

The shift in species composition from 1936 to 2017 was calculated using the Sorenson Similarity Index (Table 4). The upland region remained the most stable while the talus slope had the lowest amount of similarity. For the upland region, species with diminutive growth forms such as *Cercis canadensis*, *Cornus florida*, *Morus rubra*, *Rhus glabra*, *Vibrunum rufidulum*, and *Cornus asperifolia*, were absent in the 2017 data while larger species including *Carya glabra, Carya tomentosa, Celtis tenuifolia, Diospyros virginiana, Tilia americana, Acer negundo*, and *Ulmus rubra* established during the 80 year period. The overall forest density decreased by 51% or 321 stems ha^{-1} with *Quercus alba* decreasing by 77% or 154 stems ha^{-1} and *Acer saccharum* increasing by 59% or 44 stems ha^{-1}. Both *Quercus velutina* and *Quercus rubra* decreased 59% and 44%, respectively. The talus slope experienced significant change during the past 80 years with 9 of the original 29 species and 3 new species currently occupying the zone. The stem density decreased 65% to 385 stems ha^{-1}. The two most numerous current tree species, *Acer saccharum* and *Quercus muhlenbergii*, both decreased by 32% and 60%, respectively, thus indicating a greater decrease for *Q. muhlenbergii*. A shift in species composition on the river island is characterized by significant declines in *Ulmus americana, Carya illinoiensis*, and *Quercus palustris*, while *Acer saccharinum* increased 58%. The overall stem density decreased 39% to 230 stems ha^{-1}.

Table 7

Sorenson similarity index for community composition from 1936 to 2017.

Change 1936 to 2017	Sorenson	Stems ha^{-1} 1936	Stems ha^{-1} 2017
Bluff	*NA*	*NA*	*NA*
River	0.48	585	354
Talus	0.44	1110	385
Upland	0.59	635	314

Indicator species analysis (Table 8) for the density and total basal area for each species was conducted using the zones as the grouping variable. The bluff had the most indicator species, 13, which included *Lonicera maackii*. The individuals in the *Quercus* genus existed primarily on the bluff with 287 individuals (including seedlings) representing all five species with indicators of *Q. velutina* (den), *Q. stellata* (BA), and *Q. muehlenbergii* (den). Three species of *Quercus* with 97 individuals were located on the talus slope with indicators of *Q. muehlenbergii* (BA) and *Q. rubra* (BA). Four species of *Quercus* on the upland were found with 40 individuals with *Quercus alba* (BA) and (DEN) as the indicators. No members of *Quercus* were identified on the river island. *Acer saccharum* (BA) and (Den) were strong indicators for the talus slope, but also found on the bluff and upland regions. On the river island, *Acer saccharinum* (BA) and (Den) were strong indicators and were not found on other sites.

Table 8

Indicator species analysis for each topographic zone.

Species Density or Basal Area	Indicator Value	p-value
Bluff		
Cercis canadensis (den)	26.1	0.0002*
Celtis tenuifolia (den)	30.8	0.0002*
Fraxinus americana (den)	47.2	0.0002*
Lonicera maackii (den)	48	0.0002*
Parthenocissus quinquefolia (den)	37.2	0.0002*
Quercus muehlenbergii (den)	39.8	0.0002*
Rhus aromatica (den)	55.1	0.0002*
Vitis aestivalis (den)	20.5	0.0002*
Quercus stellata (BA)	9	0.0004*
Cornus drummondii (den)	17.2	0.0008*
Juglans nigra (den)	7.8	0.0018*
Quercus velutina (den)	9.4	0.0028*
Lonicera maackii (BA)	22.6	0.0054*
Upland		
Asinima triloba (den)	13.1	0.0002*
Lindera benzoin (den)	48.4	0.0002*
Sassafras albidum (den)	19.4	0.0002*
Quercus alba (BA)	8.3	0.0016*
Carya ovata (BA)	6.2	0.0026*

Sassafras albidum (BA)	9.5	0.0058*
Carya tomentosa (BA)	5.7	0.01*
Quercus alba (den)	6.5	0.0134*
River		
Acer saccharinum (BA)	39.2	0.0002*
Acer saccharinum (den)	92.4	0.0002*
Celtis laevigata (den)	17.7	0.0002*
Fraxinus pennsylvanica (BA)	20.6	0.0002*
Morus rubra (BA)	21.5	0.0002*
Ulmus americana (den)	15.5	0.0008*
Salix nigra (den)	7.6	0.001*
Acer negundo (BA)	5.4	0.0304*
Populus deltoides (BA)	3.8	0.0444*
Salix nigra (BA)	3.8	0.0464*
Talus		
Acer saccharum (BA)	29.8	0.0002*
Acer saccharum (den)	25.3	0.0002*
Celtis occidentalis (BA)	21.9	0.0002*
Celtis occidentalis (den)	28	0.0002*
Quercus muehlenbergii (BA)	13.7	0.0024*
Quercus rubra (BA)	9.1	0.0102*

Note: P-values with * are significant at the 0.05 level.

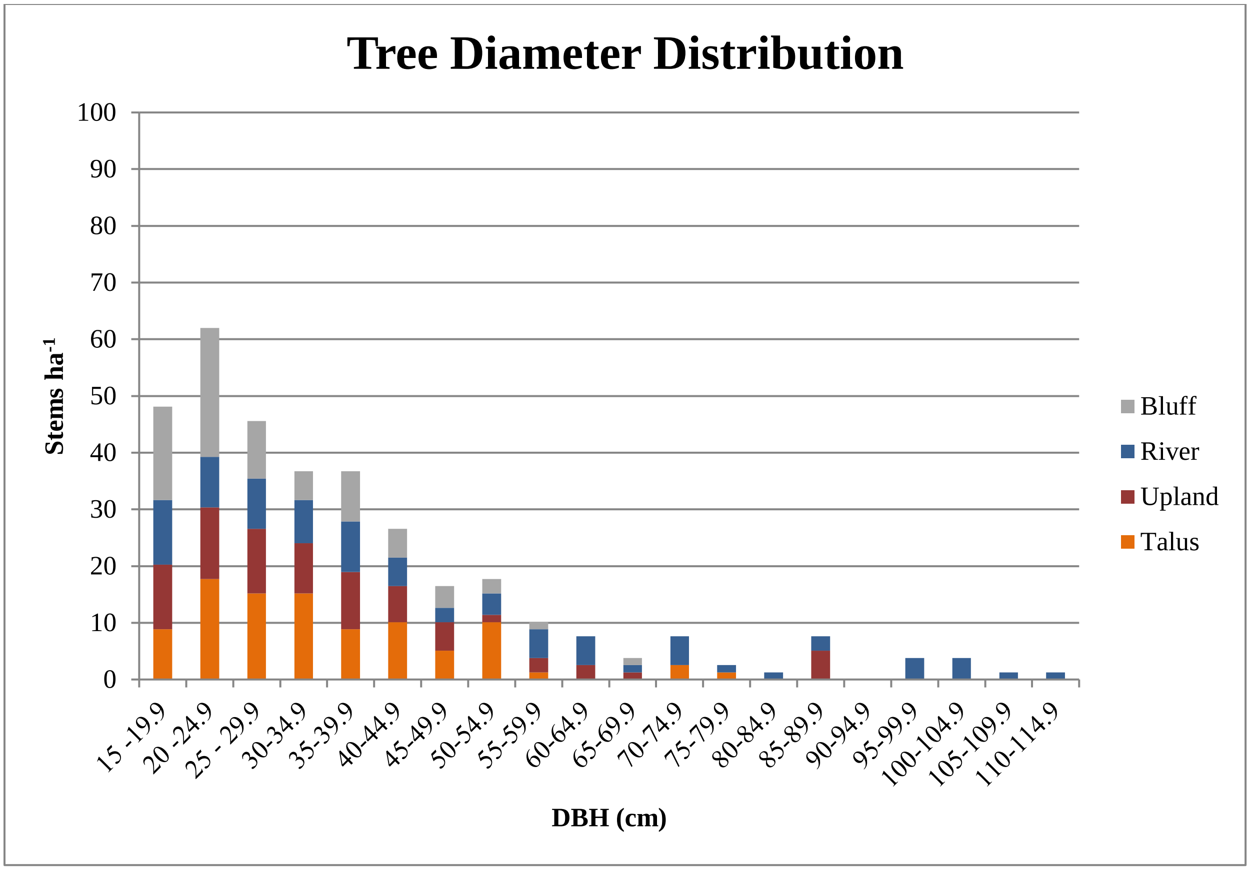

Figure 22. Tree diameter distribution for stems greater than 15 in dbh across the Middle Mississippi River landscape.

Across the four zones of the landscape, the majority of smaller trees are found on the talus slope and bluff top, and the majority of the larger trees are located on the river island and in the upland regions.

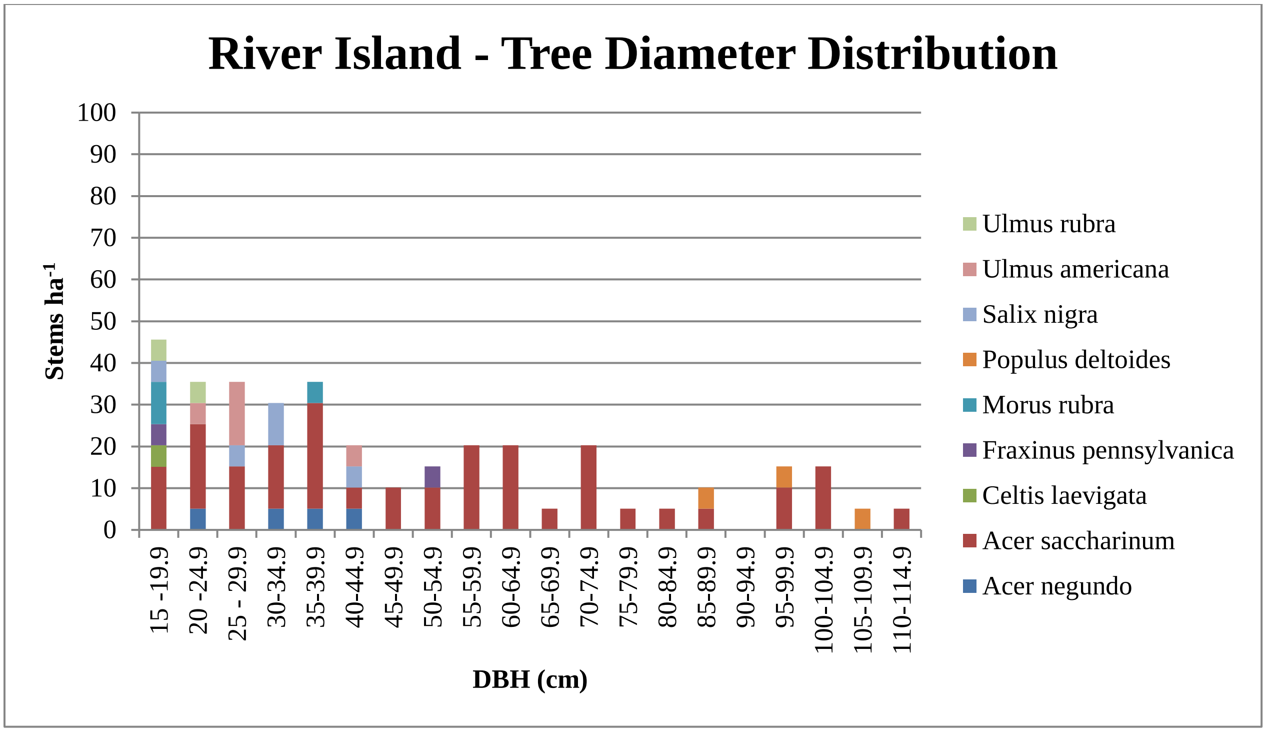

Figure 23. Diameter distribution of river island stems greater than 15 in dbh.

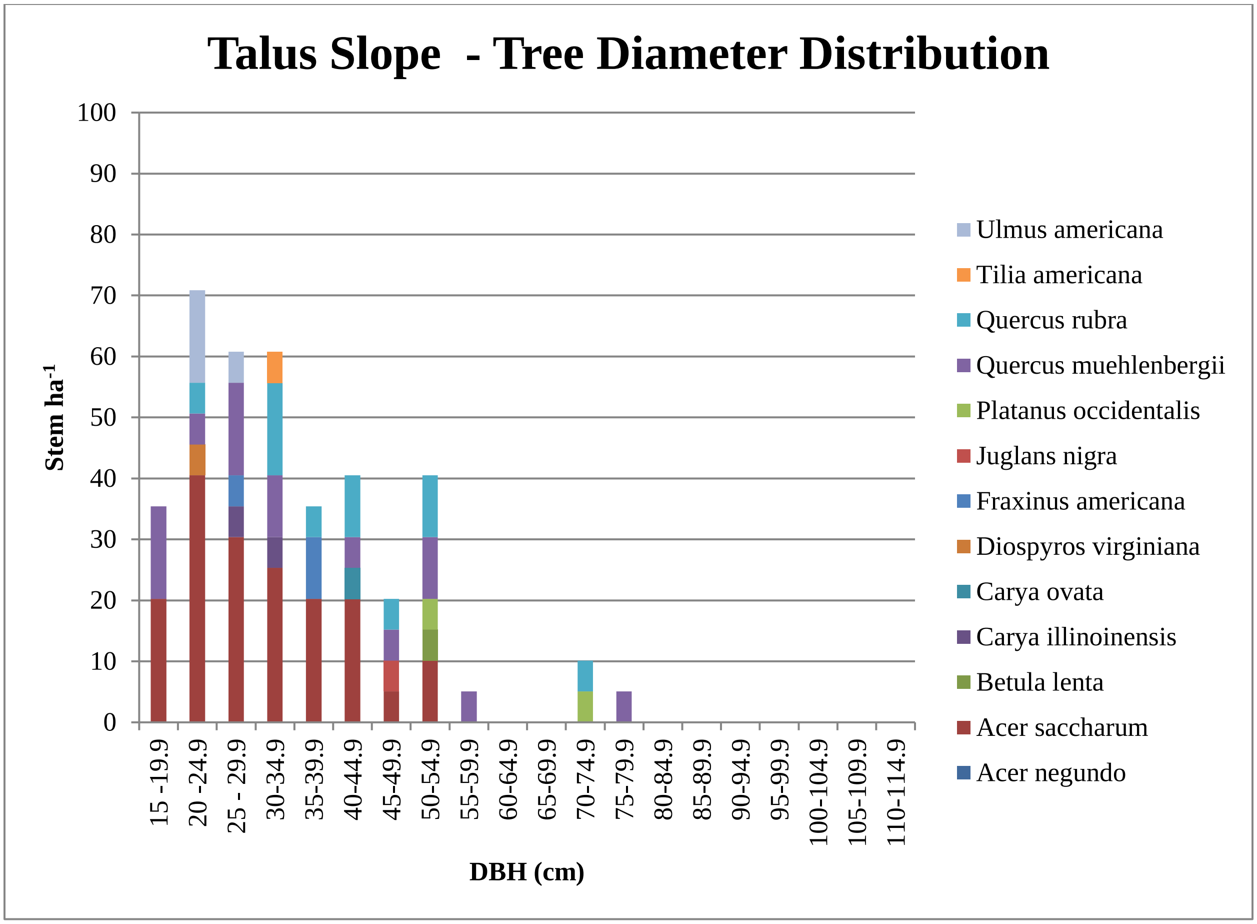

Figure 24. Diameter distribution of talus slope stems greater than 15 in dbh.

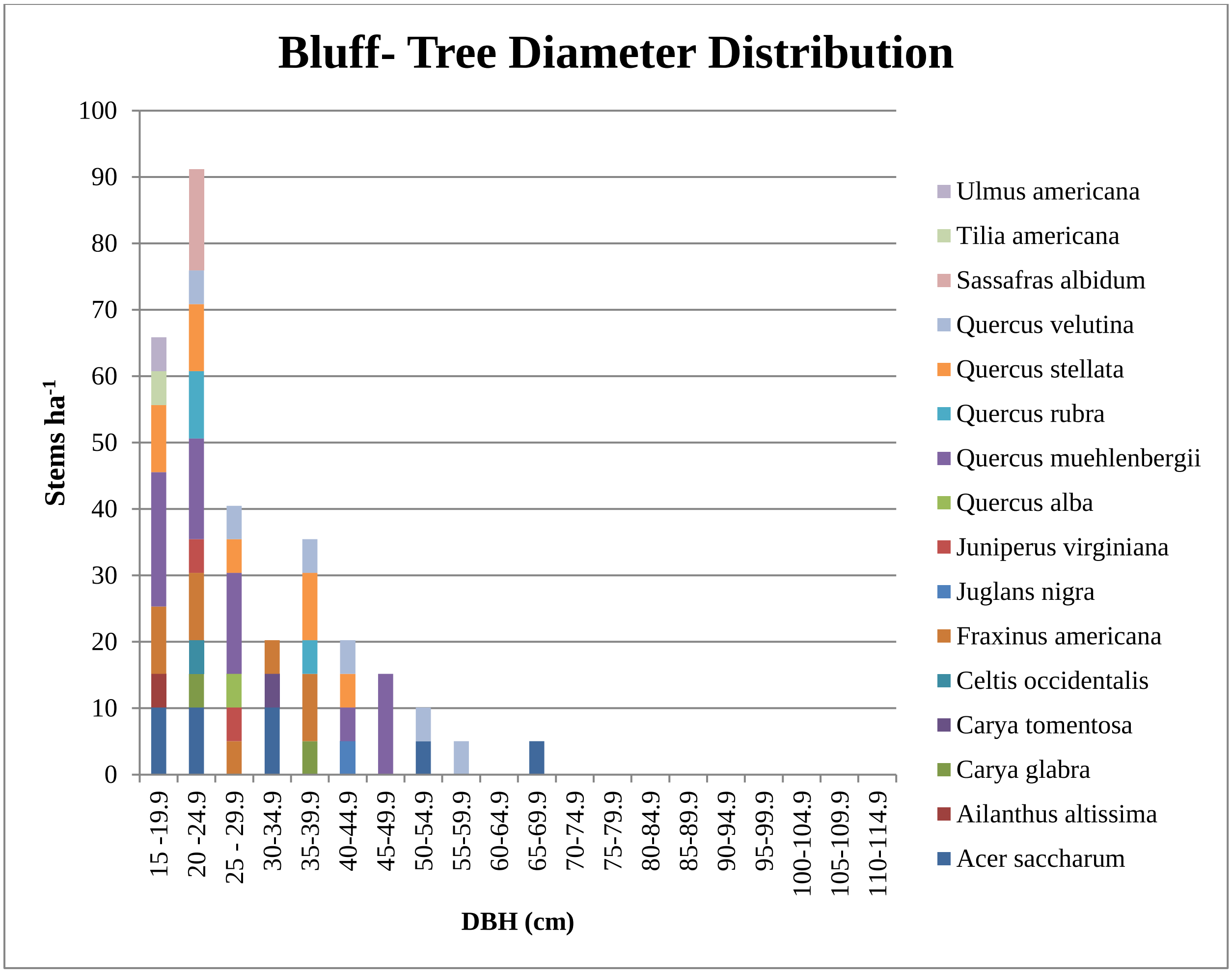

Figure 25. Diameter distribution of bluff top stems greater than 15 in dbh.

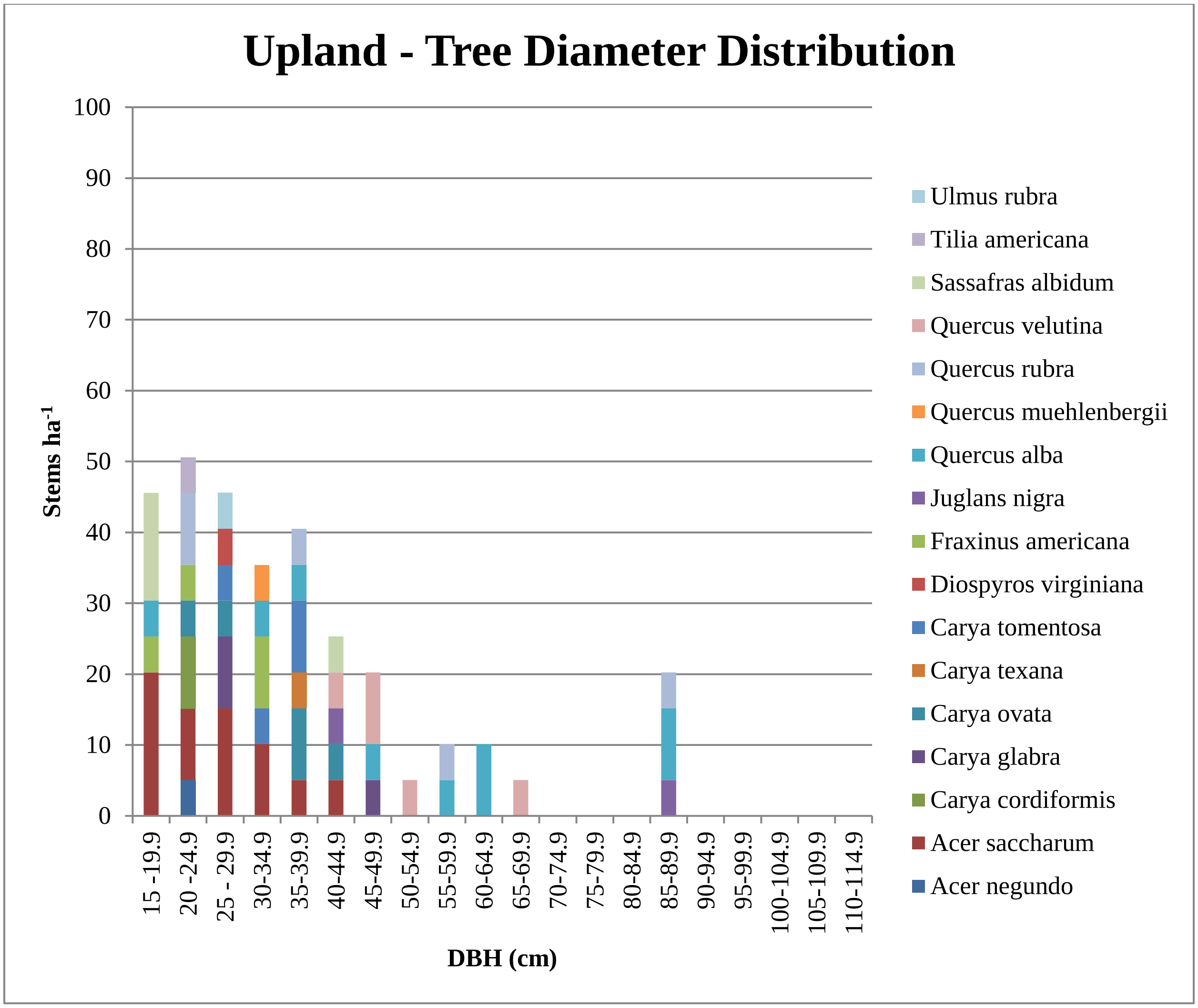

Figure 26. Diameter distribution of upland stems greater than 15 in dbh.

The overstory diameter distributions for trees in the four study zones follow an irregular inverse-J with a mixed species composition. The river island community (Figure 22) had 9 species and the flattest distribution due to the numerous large trees and low quantities of small trees. In nearly all of the size classes, *A. saccharinum* is found and is joined by minor amounts *F. pennsyvanica* and *P. deltoides* in the size classes 45 cm and above. The talus slope community (Figure 23) had 13 species and is dominated by *A. saccharum* in diameters 15-45 cm. The largest trees include *Q. muehlenbergii, P. occidentalis,* and *Q. rubra*. The bluff top community (Figure

24) had 16 species and the steepest inverse-J distribution of the four communities. The largest trees, 45-70 cm are dominated by *Q. muehlenbergii*, *Q. velutina*, and *A. saccharum* while the remaining distribution remains diverse. The upland community (Figure 25) had 17 species and contains a cohort of large stems (85-89.9 cm dbh) made up of *Q. alba*, *Q. rubra*, and *C. glabra* at a cumulative density of 20 stems ha^{-1}. Stems in the range of 45-70 cm dbh include *Q. velutina* in addition to *Q. alba*, *Q. rubra*, and *C. glabra*. At the small end of the distribution, *A. saccharum* occupies each diameter class 15-45 cm dbh.

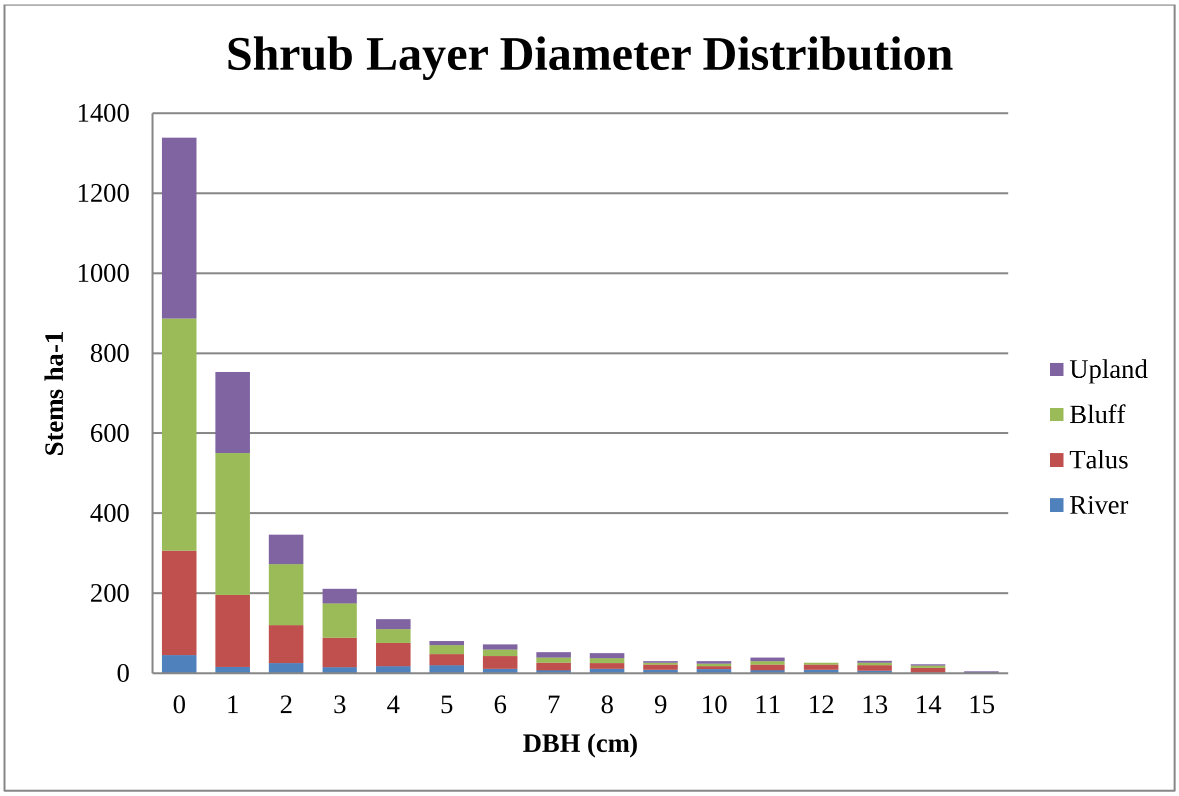

Figure 27. Diameter distribution of stems less than 15 in dbh.

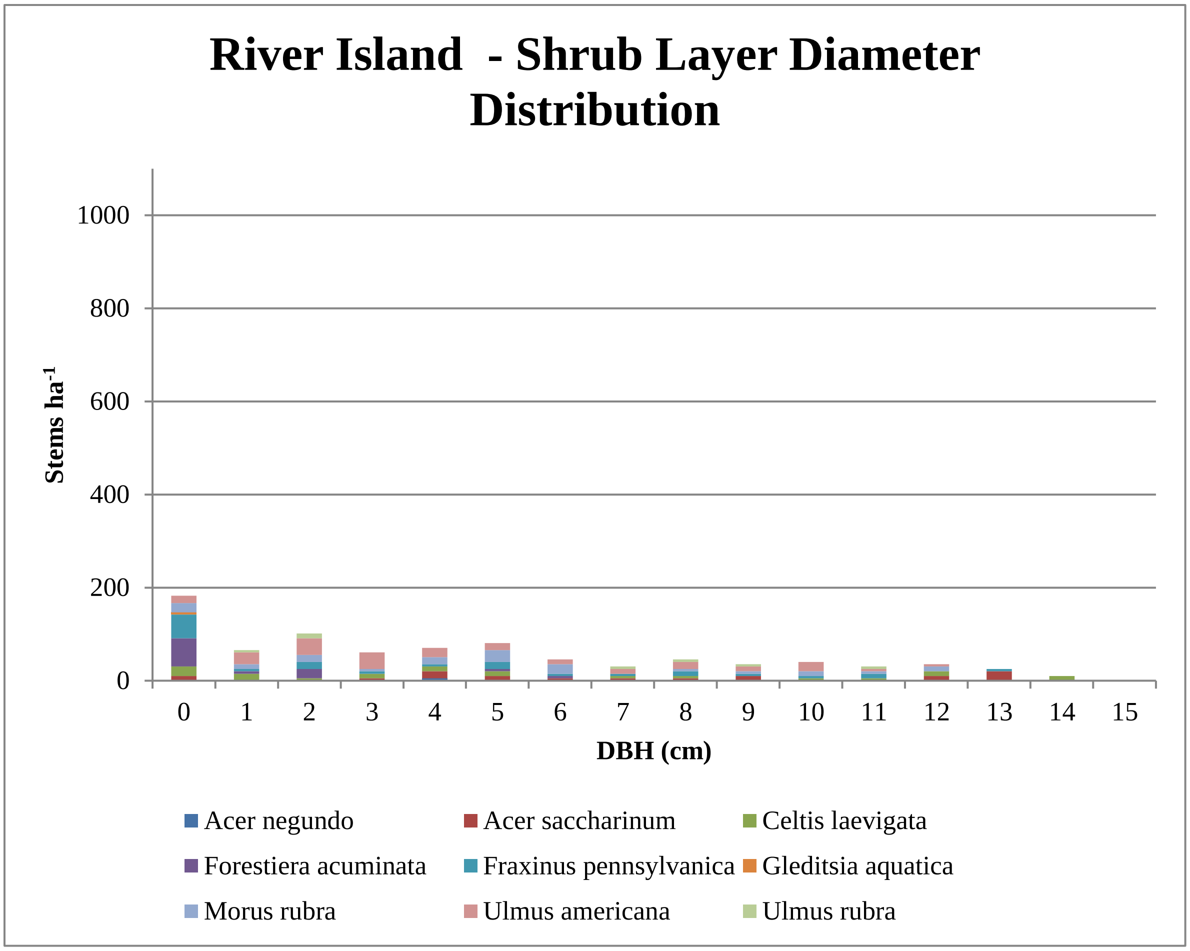

Figure 28. Diameter distribution of river island stems less than 15 in dbh.

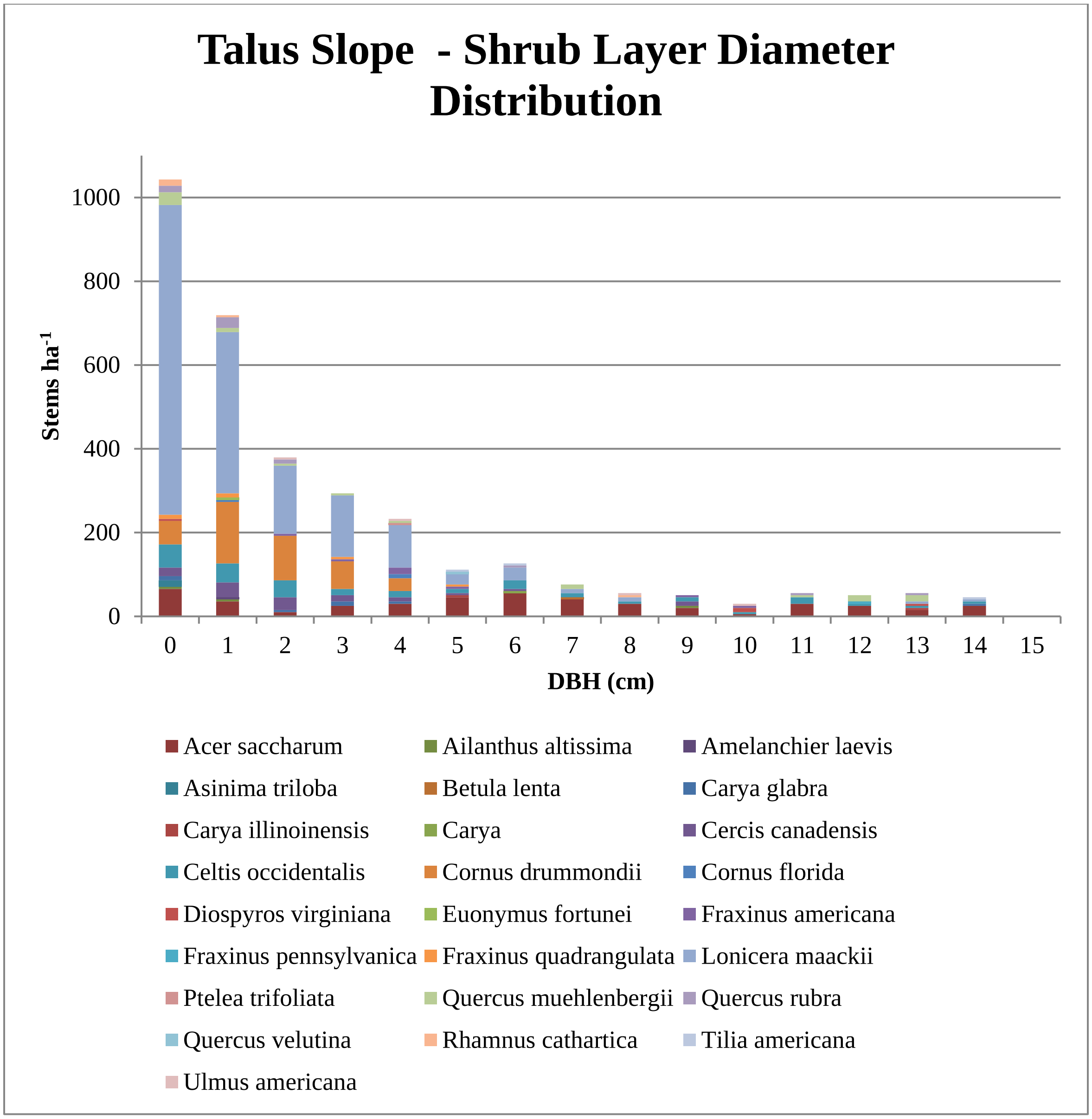

Figure 29. Diameter distribution of talus slope stems less than 15 in dbh.

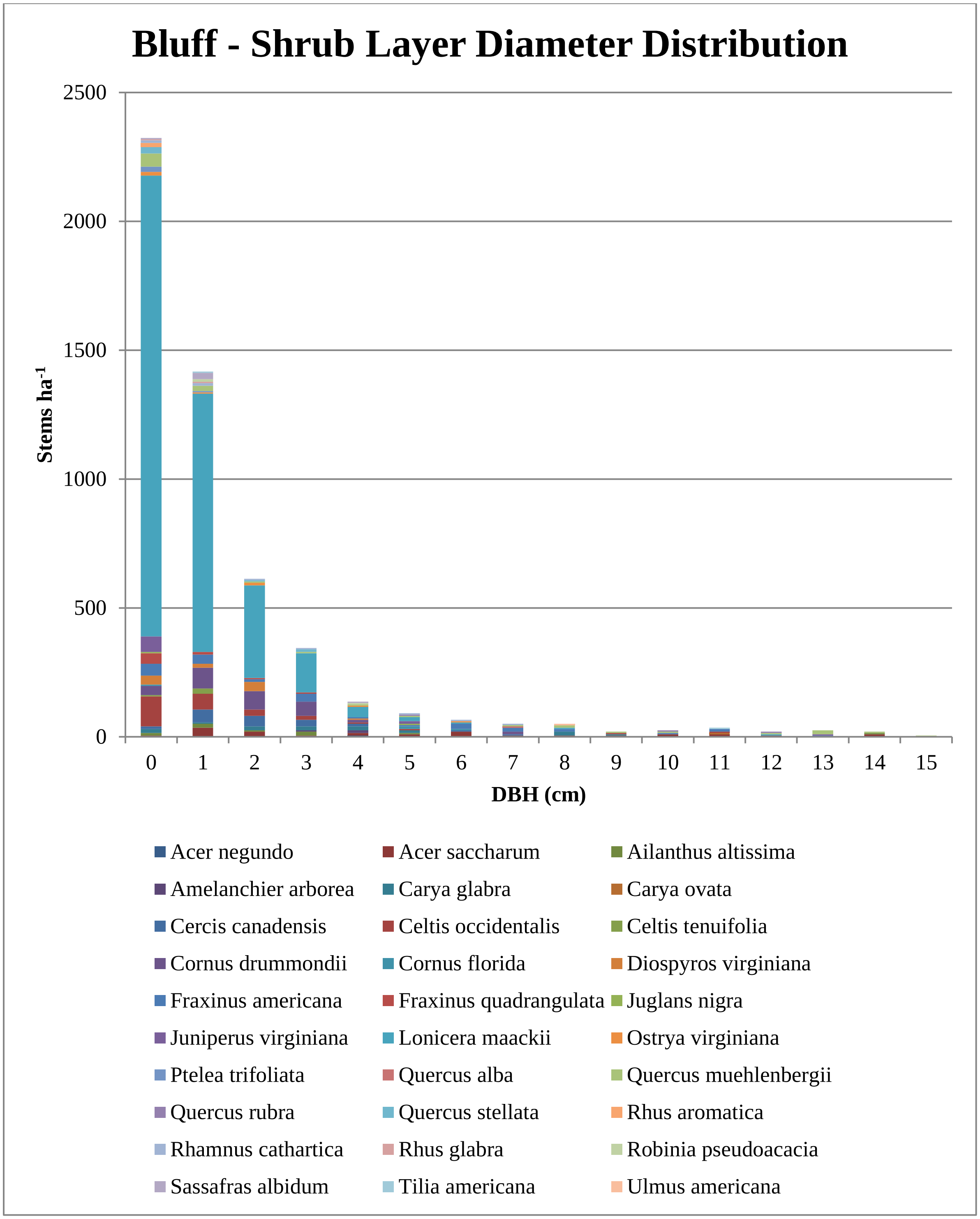

Figure 30. Diameter distribution of bluff top stems less than 15 in dbh.

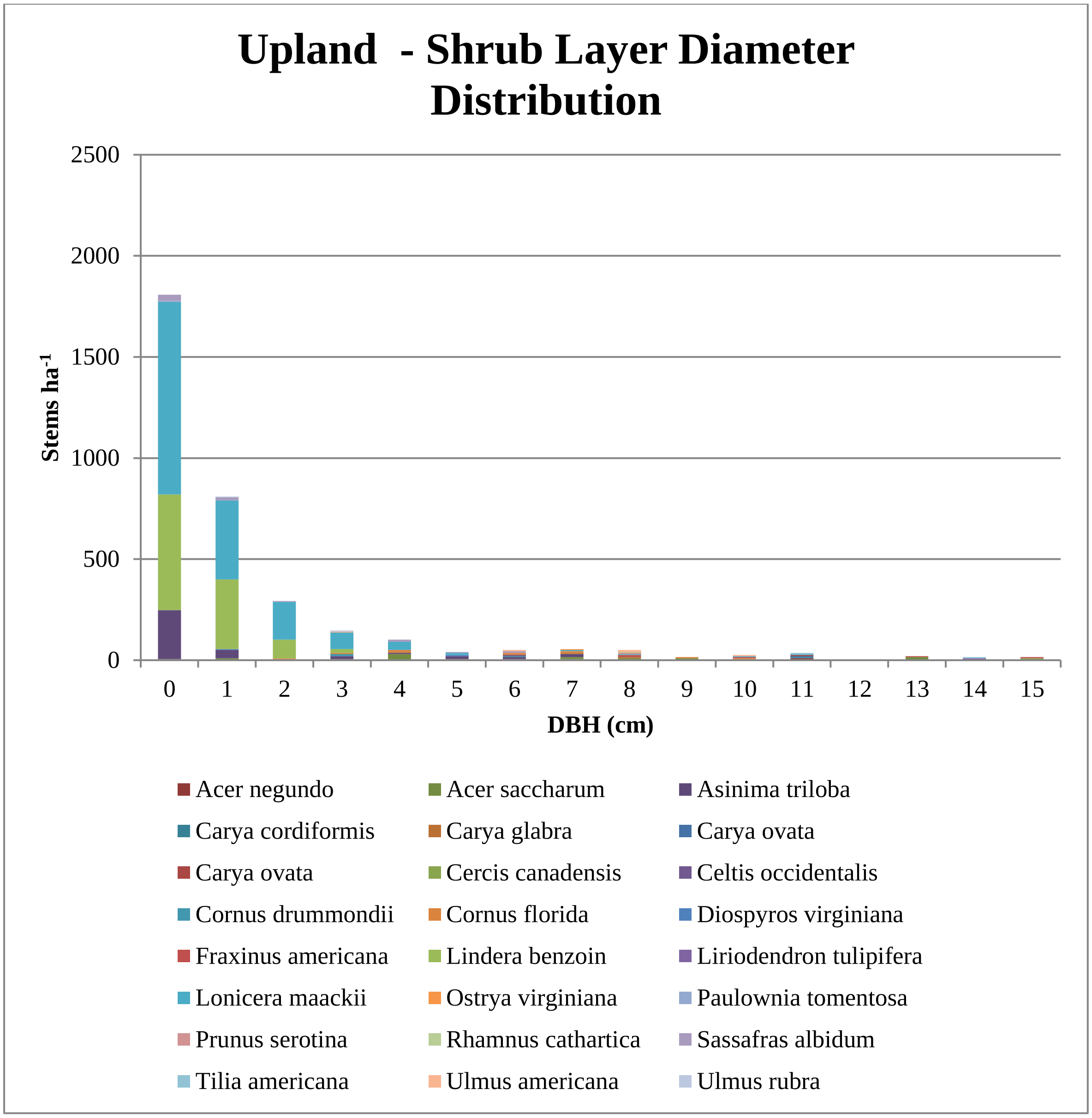

Figure 31. Diameter distribution of upland stems less than 15 in dbh.

Although containing the fewest number of species of the four zones at the shrub layer, the overall alpha diversity is the highest on the river island (Figure 27). The nine river island species are present in each size class. As found to be the most dominant overstory species on the river island, *A. saccharinum* was found in 10 of the 15 shrub layer size classes, but another co-dominant overstory species, *P. deltoides*, was absent from the shrub layer. In the talus slope, bluff top, and upland zones, *L. maackii* was a dominant component of the shrub layer, particularly in size classes 0-6 cm dbh. On the talus slope (Figure 28), *C. drummondii* was a major component of 0-4 cm dbh size classes while *A. saccharum* was present in every shrub size class. The bluff top (Figure 29) had the greatest shrub density with representation from 30 species. Diversity from several shrub and tree species was present, but significantly less dense than *L. maackii*. The upland region (Figure 30) was occupied with 24 species. In the smaller diameter classes, *L. benzoin* and *A. triloba* comprised a significant portion of the density.

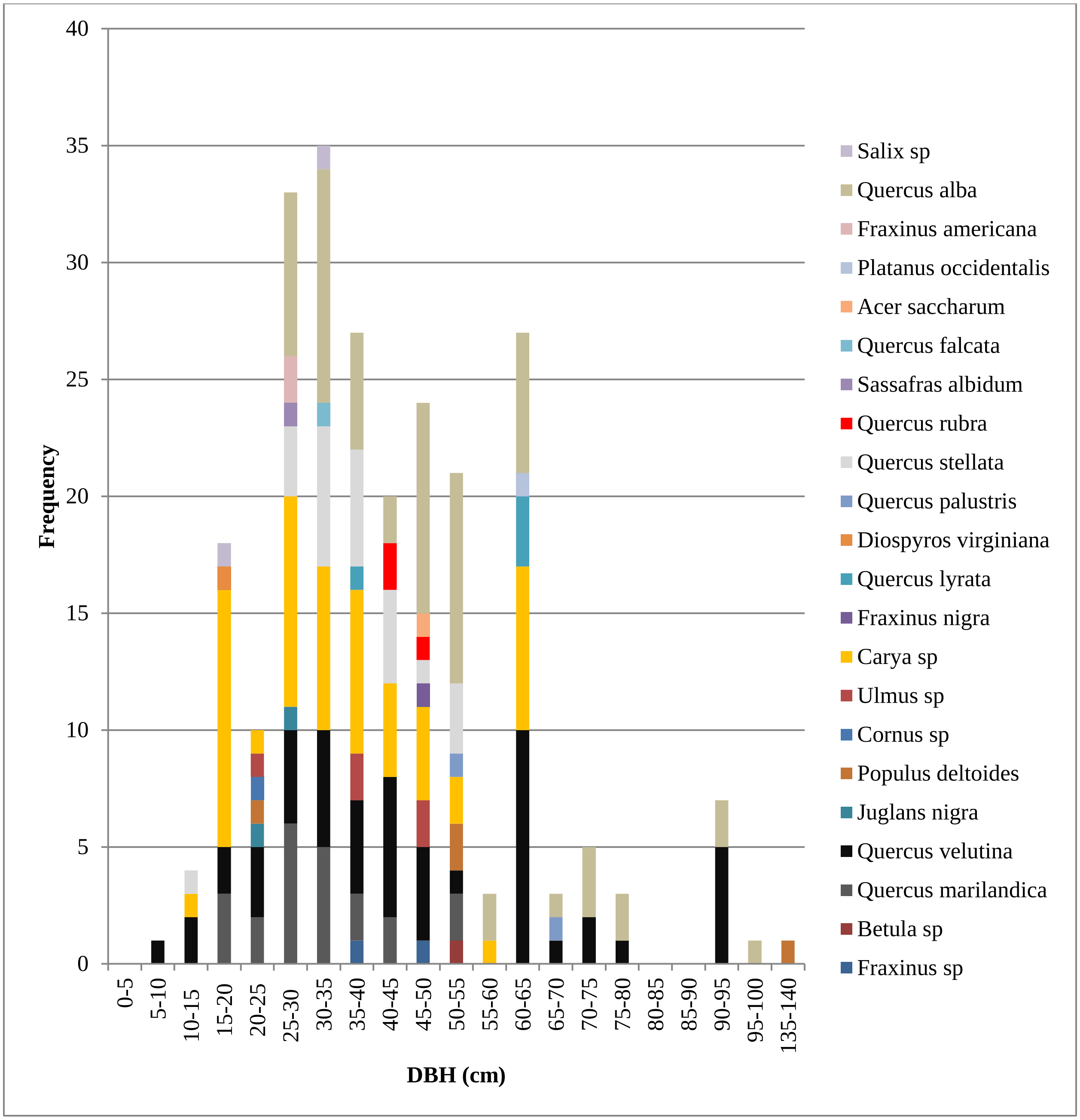

Figure 32. Diameter distribution of 1820 witness trees based on frequency in Elsah Township.

The diameter distribution of the pre-settlement forest (Figure 11) in Elsah Township shows a multimodal distribution with minor components of mesophytic species, particularly just one record of *A. saccharum* which is found in the 40-45 cm dbh class. *Q. alba* is present is most size classes 20 cm and above while *Q. velutina* is widely present throughout the distribution.

Carya sp. *Q. stellata*, and *Q. marilandica* were prominent in the midsection of the distribution. Relative dominance is primarily attributed to *Q. alba* (31%), *Q. velutina* (27%), and *Carya sp* (15%) with minor elements of *Q. stellata* (6%), *Q. marilandica* (4%), and *P. deltoides* (4%). Other species were each less than 2% of the relative dominance.

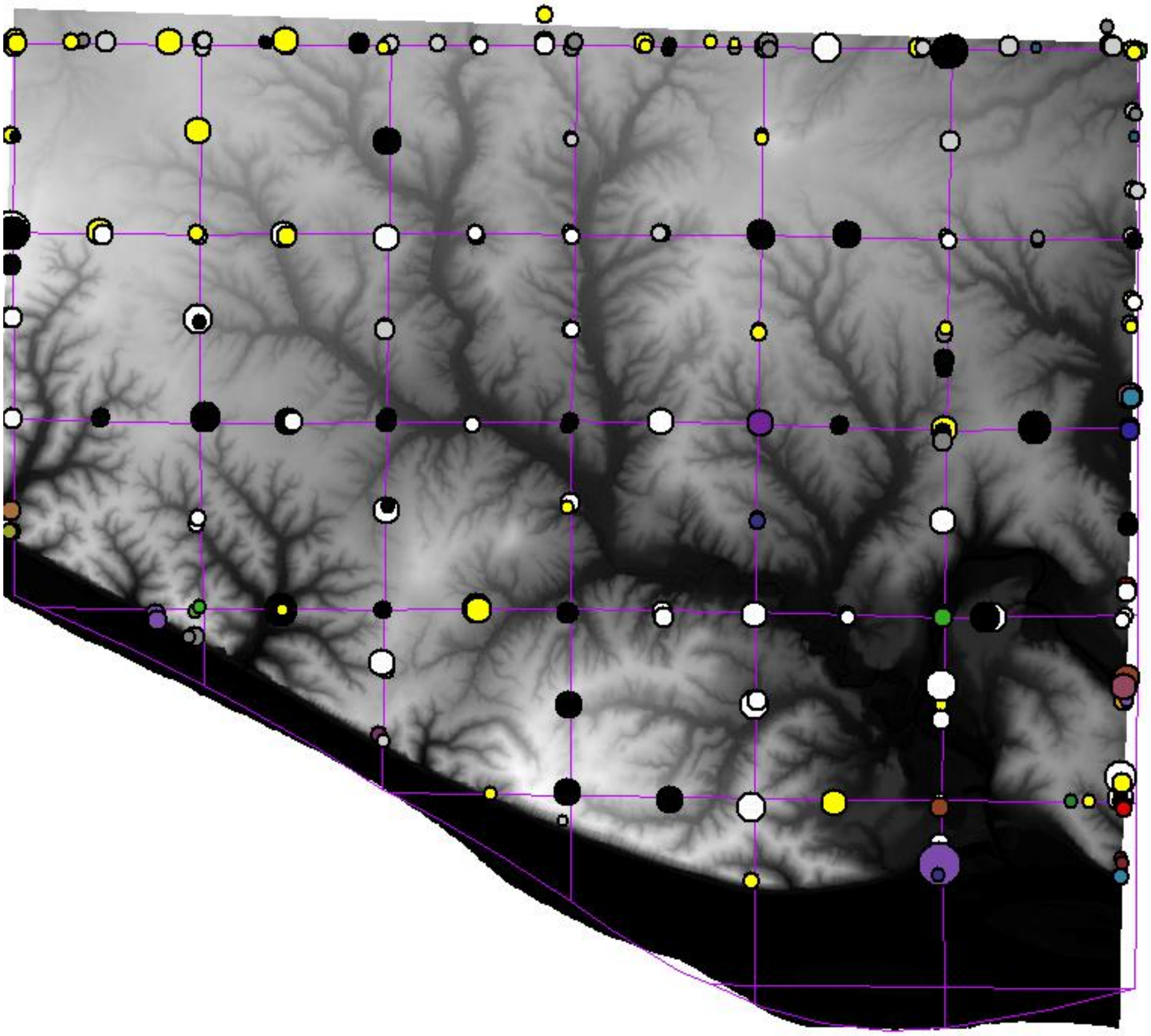

Figure 33. Map of the witness trees symbolized by species and proportional symbols representing diameter size. Yellow represents hickory, black is *Q. velutina*, white is *Q alba.*

The witness tree record was uploaded into a GIS and symbolized according to species and diameter. The oak-hickory forest type dominated in the uplands while the valley bottoms contained more diverse mesophytic species. Note that the overlapping symbols prevent all species to be represented in this map layout.

Discussion

Regional pre-settlement Public Land Survey vegetation studies concur with the historical narratives of early visitors and settlers of the area. Green, Jersey, and Macoupin Counties were analyzed for relationships between forest community attributes and topoedaphic variables and found floodplains hosted *Salix* sp., *Populus deltoides*, *Acer* spp., and *Fraxinus* spp, the bluffline contained *Quercus alba*, *Quercus velutina* and *Carya* spp., and prairie with low density groupings of *Quercus palustris*, *Quercus stellata,* and *Quercus marilandica* (Brugam, Kilburn, & Luecking, 2016). This study did not empirically address density or basal area other than analyzing average species' diameters and distance from the quarter section corner. Prairie, barrens, scattering timber, and forest were analyzed in Greene and Jersey Counties and the average distance from the quarter section point to an observed tree for each species were calculated (Figure 33) (Kilburn, Tutterow, & Brugam, 2009). These data indicate general forest density by species and ecosystem structure (i.e. prairie, barrens, scattering timber, and forest) across the landscape at the time of the survey and when converted to density, range between approximately 1 to 15 stems ha^{-1}.

The indicator species results (Table 8) are generally consistent with the observations made in the Kilburn, Tutterow, and Burgam study, except for some small but notable exceptions. *Q. palustris* and *Q. marilandica* were not present in the 2017 data.

Alpha and Beta Diversity

Diversity across the landscape remained consistent with the intermediate disturbance hypothesis wherein diversity is highest in systems where disturbances are neither so severe that only ruderal and pioneer species can persist nor infrequent enough that only climax species exist, but intermediate where both ruderal and climax species can exist within the system (Connell, 1978, 1980). Large tree diversity was highest on the upland site where flooding does not exist and fire was less frequent than the bluff top or talus slope. The establishment of overstory diversity occurred prior to the invasion of *L. maackii* and fire suppression. Diversity in the shrub layer was highest on the river island which is the only site where *L. maackii* was absent, suggesting the competitive ability of the invasive shrub negatively impacts diversity. Seedling diversity was highest on the bluff top where fire had been introduced as a management tool in sections of the study area thereby creating a range of conditions. *Lonicera maackii*, although found in all non-hydric zones, is an indicator for former prairie-savanna structure on the bluff top where light levels are moderate to high, disturbance was historically frequent, and topoedaphic conditions permitted an extended duration of prairie-savanna systems. The canopy coverage is non-contiguous and the leaf area index of the trees in this area is relatively low, allowing light resources to pass to the lower strata. Overstory diversity is highest in the upland area which contains a variety of micro-sites, deep and well drained soils that do not flood, and less frequent fire.

Stability of Historic Forest Conditions

Witness tree analysis in Elsah Township supplies evidence that prior to Euro-American settlement, trees were widely distributed with 21.4 stems ha^{-1} and a basal area of 3.3 m^2 ha^{-1} in 1820 in the upland. A floodplain study of witness tree records collected from 1815-1817 at the

Illinois confluence found that stem density averaged 86.8 stems per hectare with notes of "scattering timber" and "thinly timbered" in the GLO surveyor notes (Nelson, Redmond, & Sparks, 1995). Prior to settlement, early ecological descriptions of the region confirm that the margins of waterways and valleys were densely forested with mesophytic species while the uplands were primarily prairies with islands of oaks and hickories. These accounts depict a landscape with vast stretches of prairie ecosystems across flat land and near the tops of ridges and mature trees, primarily maple, willow, cottonwood, sycamore, and pecan with close spacing near water courses. Ascending from the valley bottoms, tree composition shifted to oak and hickory dominance and tree spacing increased until woodland became savanna and finally transition to prairie. After a century of settlement activities that involved the clearing and regrowth of forest in a large portions of the area resulted the establishment of a dense young forest with a higher mesophytic percentage. By 1936, the stem density in the wider upland area increased to 613 stems ha^{-1} following the abandonment of farmland and the implementation of fire suppression (note that basal area is not available for this time period) (Turner, 1936). As the forest advanced through the stages of stand development, stem density reduced to 314 stems ha^{-1} with a basal area of 40.4 m^2 ha^{-1} in 2017. However, average stand diameter decreased from 40.9 cm in 1820 to 25.3 cm in 2017 (for upland stems greater than 7.5 cm, which was the lowest value for diameters in the 1820 data and applied to the 2017 data in order to accommodate comparisons). Forest density and basal area increases are reflected by concomitant compositional changes in species dominance within size classes. Forest density on mid slopes and ridges appears unstable, shifting from low density to high density. Species composition is shifting to mesophytic and pyrophobic species, particularly in the lower to mid strata.

Trends of Forest Composition and Structure

Comparing the current stem density data to Turner's 1936 data suggest the forest communities have transitioned from the stem exclusion stage to the understory re-initiation or old growth stage. In three of the zones, river island, talus slope, and upland region, stem density decreased by 39%, 65%, and 51%, respectively. Each of these areas displays an inverse-J diameter distribution which indicates that this mixed community is multi-aged. In the progression of stand dynamics, stem initiation occurs after a disturbance resulting in the availability of new growing space and a high density of seedlings and saplings. At the time of Turner's surveys, forest development would have been in the early stages with high stem densities following the forest clearances that occurred during settlement. In addition, fire suppression as a cultural value had been employed for two decades. The lack of fire combined with the establishment and growth of new stems resulted in forests with high stem density. Since all trees were greater than 15 (cm), the stem exclusion phase of forest development was likely common across the landscape in 1936. Aerial photographs from 1941, just five years after Turner's studies, indicate a mixture of open grown trees with the forest floor clearly visible and areas with continuous forest canopy coverage in the upland regions.

Across the Eastern US, mesophication has been documented widely in a variety of forest types and sites (Nowacki & Abrams, 2008; Shotola, Weaver, Robertson, & Ashby, 1992). Evidence of mesophication is expressed uniquely in each of the four study zones using *Acer* genus as an example. Whereas the presence of *A. saccharum* was found in each non-hydric site, the shrub layer and the overstory layer of the talus slope, where rooting conditions favor its requirements, was pervaded by *A. saccharum* in each size class. The upland region contains a cohort of *A. saccharum* in diameter class 15-45 cm dbh, with minor amounts in the shrub layer and none larger than 45 cm dbh. The bluff top contained *A. saccharum* at periodic intervals and at the large side of the diameter distribution. The xeric bluff top contains micro-valleys with deep soil and access to calcareous limestone which provides suitable growing conditions for *A. saccharum*. On the river island, *A. saccharinum* dominates every size class. Similar floristic studies have observed a rise in *A. saccharinum* and decline in bottomland hardwood species due to a change in hydrology following the impoundment of the Mississippi River in 1938 (Nelson & Sparks, 1998). The rising dominance of the genus Acer across the landscape serves as a homogenizing agent that reduces sub-canopy light resources, inhibits fire spread, and will eventually lead to a reduction in diversity if not check by management interventions. For now, overstory diversity is highest in the upland area which contains a variety of micro-sites, deep and well drained soils that do not flood, and less frequent fire.

Lonicera maackii, although found in all non-hydric zones, is an indicator for former prairie-savanna structure where light levels are moderate to high, disturbance was historically frequent, and topoedaphic conditions permitted an extended duration of prairie-savanna systems. The canopy coverage is non-contiguous and the leaf area index of the trees in this area is relatively low, allowing light resources to pass to the lower strata.

Indicator Species Analysis

Indicator species analysis assists with determining important members of a community. The bluff top contained significant indicator values for 11 species with density and 2 species for basal area, *Quercus stellata* and *Lonciera maackii*. Because *Q. stellata* is slow growing, shade intolerant, and drought resistant with long, thick taproots (Burns & Honkala, 1990), the exposed conditions of the bluff top reduce the competitive ability of other species. Although *L. maackii* is shade tolerant, secondary diameter growth is rapid with abundant light resources. The 11 species with significant values for density (i.e. 5,246 shrub stratum stems ha^{-1}) suggests that many species are establishing in the absence of disturbance. The upland region is characterized by 4 species with density and 4 species with basal area indicator values. Large shade intermediate and fire resistant *Q. alba*, particularly wolf trees with large open grown crowns, are abundant in the upland region. The supportive role of *Carya* species in the dominance of the oak-hickory forest type is found in the significant indicator values for basal area in *C. ovata* and *C. tomentosa*. Due to the few species that were found on both the river island and the other forest types, most of these species are indicators, 4 for density and 6 for basal area. The talus slope contained 4 species with basal area and 2 species with density for indicators. *A. saccharum* and *C. occidentalis* had density and basal area as significant indicator values for the talus slope. Both are pyrophobic while *A. saccharum* is shade tolerant and *C. occidentalis* is intermediate shade tolerant. Basal area significant indicator values occurred for shade intermediate *Q. muehlenbergii*, and *Q. rubra*, but notably not for density, thus suggesting that the *Quercus* component established under different disturbance and light conditions. The soil of the talus slope had variable texture with a deep rooting zone (greater than 80 inches) with abundant moisture, mitigating the effects of typical late summer dry periods or severe drought conditions. *A. saccharum* had a higher leaf area index that demands greater water resources which allows the species to thrive when water is a limiting factor in growth in less favorable sites.

Disturbance as a Driver of Forest Composition

The pattern of contemporary forest development diverged from historic patterns due to the alteration of disturbance regimes. Frelich (2002) synthesized disturbance ecology for the Lake States and connected ecosystem development to the effects of disturbance regimes. Prior to river impoundment, the river island was subjected to variable river flows with expressed dry periods that permitted the establishment and growth of hardwoods. Following the regulation of river flows by the lock and dam system in 1938, seasonal droughts failed to have a material effect on river levels. Furthermore, no evidence of active management on the river island to promote the establishment and growth of hardwoods was found. Prior to governmental ownership of the river island, fuelwood and other forest products were harvested, creating higher light conditions that would allow hardwood regeneration. Until recently, fire management focused on the suppression of fires caused by a variety of ignition sources thereby limiting the ecological effects of frequent surface fires. This lack of fire coincided with the removal of grazing pressures and the regrowth of woody stems across many open sites. Pyrophobic species otherwise filtered by fire, were allowed to persist and grow. The talus slope and bluff top had the most fire, same topoedaphic conditions, particularly a southern aspect, and had the highest community similarity for shrub layers, and the second most similar communities within the overstory and seedling layers.

Conclusion

Within the past 200 years, the forest communities in the confluence region of the Mississippi and Illinois rivers have undergone significant change in forest density and composition. Stem density increased from 21.4 stems ha^{-1} in 1820 to 613 stems ha^{-1} in 1936 followed by reduction to 314 stems ha^{-1} in 2017. Average stand diameter decreased from 40.9 cm in 1820 to 25.3 cm in 2017 (for upland stems greater than 7.5 cm). The diameter distribution of the forest prior to Euro-American settlement was multimodal and contained only a trace of mesophytic species. The forest across all landscape positions is currently represented by an inverse J-distribution with a large contingent of mesophytic species in the smaller diameter classes. Furthermore, since 1990 new exotic invaders are spreading rapidly on non-hydric sites and impairing the ability of hardwoods to regenerate and outcompeting herbaceous layer plants. Alpha diversity was highest in the upland overstory and in the river island shrub layer. Beta diversity in the overstory was highest (0.67) between the bluff and the upland while lowest (0.08) between the bluff and the river island. Management considerations for the bluff top community are addressed after further analysis in chapter 5. General management of upland areas as related to historical trends in forest development and anthropogenic influences in forest disturbance are discussed in chapter 1.

CHAPTER 4

FLORISTIC ANALYSIS OF THE FOREST-PRAIRIE GRADIENT AND MANAGEMENT RECOMMENDATIONS ALONG THE BLUFFS OF THE MISSISSIPPI RIVER IN JERSEY COUNTY, ILLINOIS

Abstract

Hill prairie vegetation on the limestone bluffs of the central Mississippi River Valley represents a significant portion of the remaining xeric prairie, savanna, and woodland systems of the Midwest. This study examines the structure, composition, and temporal community patterns of the forest-prairie gradient by employing hierarchical cluster analysis and non-metric multi-dimensional scaling in combination with indicator species analysis and dendrochronological methods. Results suggest that the four general community types exist on the forest-prairie gradient: Group 1 consists of the woodland community structure with significant indicator values for the density of *Juniperus virginiana* (indicator value 58.4, p-value = 0.0002), *Carya glabra* (45, 0.0022), *Quercus stellata* (23.7, 0.0424), and *Lonicera maackii* (74.2, 0.0002) and a high basal area (BA) of *J. virgniana* (21.4, 0.0276) and *L. maackii* (47.9, 0.0054). The first year of *L. maackii* presence was 1964 with the primary wave of invasion beginning in 1990 (N=410). Group 2 contains bare soil coverage in the subplot (40.4, 0.0002) as the one indicator at a significant level. The species with the highest BA in Group 2 include *Acer saccharum* (9.08 m^2 ha^{-1}), *Q. velutina* (5.89 m^2 ha^{-1}), and *Q. muehlenbergii* (5.32 m^2 ha^{-1}). Group 3 typifies the hill prairie community with the sole indicator of grass coverage in the subplots (39.7, 0.0196). Group 4 represents the stage of forest development following the cessation of disturbance events and the trajectory advancing towards a mesophytic forest and contains 14 significant indicators. This

research can be used to plan forest management at the landscape level with multiple forest types in the Middle Mississippi River Bluffs Region.

Introduction

Practitioners of ecological restoration in Midwestern oak savannas and woodlands have identified a declining trend in areal extent and sometimes complete loss of these natural communities over the past 70 years (McClain & Anderson, 1990; McClain & Ebinger, 2012; McClain, Moorehouse, & Ebinger, 2009; Owens & Cole, 2003; Robertson, Schwartz, Olson, Dunphy, & Clarke, 1995; Schwartz, Robertson, Dunphy, Olson, & Trame, 1997; Taft & Kron, 2014). The changing landscape has prompted regional initiatives that seek to restore and enhance prairies, savannas, woodlands, and forests (McTaggert, 2017). The management focus broadly favors xeric adapted species with lower woody stem densities by applying prescribed fire, reducing density of smaller size classes, and managing invasive species with herbicide treatments (Kilburn, 1970; McTaggert, 2017; Taft & Kron, 2014).

The hill prairie enclaves of grass and forb dominated vegetation within an otherwise contiguous upland hardwood forest garnered the attention of botanists due to their floristic diversity and relative rarity following the loss of wide prairie expanses to agricultural development (Brugam et al., 2016). The midsection of forest-prairie continuum, consisting of woodland and savanna structure, received limited attention in the botanical literature despite the rapid rate of loss and critical role in mediating prairie-forest dynamics.

Awareness of hill prairies as an element of the forest-prairie gradient initiated scientific studies related to the mechanisms that enabled prairie community composition to exist (Evers, 1955; McClain & Anderson, 1990; Vestal, 1918). In an 1918 study in Illinois, Vestal described a pattern of small prairie communities found on south-facing slopes at the top of ridges where the topography contained excessive slopes unsuitable for converting to farmland and where disturbances such as fire, cutting, grazing, and trampling limited, but did not prevent, the encroachment of the surrounding forest (Vestal, 1918). Later, Evers (1955) suggested that the topoedaphic conditions in hill prairies on high cliffs created a microclimate that was unfavorable for mesophytic forest invasion. However, hill prairies on lower cliffs were subject to the modifying microclimate effects of a forest canopy and therefore subject to invasion. Seasonal rainfall may allow for the establishment of seedlings until a dry year extinguished the seedling cohort resulting in a stable equilibrium between forest and prairie systems. Evers did not attempt to describe successional patterns in hill prairies, but he provided maps of prairies communities and their spatial extent. These early attempts at assessing the stability of hill prairies transition to an examination of community trajectories as mounting evidence of ecosystem instability began to grow. Photographic documentation of hill prairie encroachment and loss at Pere Marquette State Park in Grafton, Illinois demonstrated a shift towards seedling survival and the establishment of a woody stem cohort including *Cornus drummondii* (rough-leaved dogwood) and *Lonicera maackii* (bush honeysuckle) leading to the loss of the prairie vegetation within 15 to 22 years (McClain & Anderson, 1990). Forty years after Evers, Robertson et al. (1995) examined changes to select hill prairie communities as described by Evers and found that the average extent decreased by 63 percent, despite various management interventions including burning and cutting, with the most common prairie invaders including *C. drummondii* (rough-leaved dogwood), *Juniperus virginiana* (Eastern redcedar), and *Rhus glabra* (smooth sumac). Community composition of the prairie-forest gradient shifted to a forest dominated system.

The purpose of this study is to identify current vegetation communities and compositional changes to the hill prairie-forest gradient community over the past century. An understanding of vegetation patterns provides managers with a historical context of community change trajectories and likely future conditions under select management applications. Coupling stem age data with community composition and structure allows a temporal pattern of forest-prairie dynamics to emerge beyond the initial observation of identifying the occurrence of forest encroachment. Pairing management activities to stand conditions will result in better continuity with historical disturbance regimes and improved ecological restoration success.

Methods

Site Description

The study site was located on Principia College campus in Jersey County on the limestone bluffs of the Mississippi River in west-central Illinois. The soil consisted of wind-blown loess with an average of more than 80% sand, less than 20% silt, and less than 2% clay (Kilburn & Warren, 1963). Slopes ranged from 21 to 71 degrees with an average of 54 degrees. Aspect averaged 206 degrees for a southwest orientation and the average elevation was 615 feet above sea level.

Pre-settlement forest conditions found in Elsah Township consisted of low density oaks and hickories with an average density of 8.7 stems per acre with a mean basal area of 14.6 square feet per acre. Euro-American settlement activities decreased the areal extent of forest coverage resulting in all but 11.6% of the township losing forest coverage at some point (Chapter 2). Accounts of European explorers contain observations of suitable pasture land on the bluffs, confirming the low tree density of the area prior to settlement (White, 2000) (also see Chapter 1).

Vegetation Sampling

Using ArcGIS 10.4, the study area was outlined based upon bluff top areas with a historically herbaceous ground cover as observed in historic photographs. The random point generator tool from the Data Management toolbox was used to create 79 points within the study area. The points were downloaded onto a Trimble Juno 3B device in order to navigate to the center of the points. In June and July of 2016, vegetation measurements were obtained in 79 circular, each 25 m^2 in area. All woody stems were identified and stems >1 cm dbh were measured for diameter and height. Stems <1 cm dbh. were identified and counted. In each plot, 1 m^2 subplots were delineated and percent cover of forb, grass, woody stems, and bare soil/leaf litter were estimated. Canopy cover was estimated using a convex spherical densitometer at the center of each plot. Aspect and slope were measured using a compass and clinometer, respectively. Soil samples were obtained and analyzed by SGS North America, Inc. for pH, macro- and micro-nutrients, and CEC.

Dendrochronological Methods

We obtained tree cores from all stems with a dbh >10 cm and cross sections from all stems with a dbh <10 cm. Samples were prepared following the procedures presented by Stokes and Smiley (1968). The small cross sections were crossdated using the Yamaguchi (1991) List Method (N=590) and the cores and larger cross sections were measured using a Velmex measuring station with Measure J2X software to the nearest 0.001 of a millimeter (N=101). Each group of species were validated using COFECHA with a 22 year cubic smoothing spline examining and a 30 year segment with a successively lagged 15 years. The critical correlation with a 99% confidence level is .4226. For each plot, two columns were added, one for the oldest tree age and one for the average tree age, to be included in the ordination analysis.

Statistical Analysis

Importance values for each species were calculated by averaging relative density, relative dominance, and relative frequency. Cluster analysis using a hierarchical agglomerative polythetic process in PC-ORD 6.21 was performed to identify similar groups of community composition and structure. The parameters of the cluster analysis utilized the Euclidean distance measure and Ward's method of group linkage methods resulting in a 2.98 percent chaining which is below the 15 to 25 percent chaining threshold that indicates poor performance if exceeded (Peck, 2010). Group selection was conducted automatically by allowing the hierarchical cluster analysis to identify and assign groups based on group-average linkages. Indicator values were determined for each species' basal area and density using the species' abundance and constancy of occurrence of a species in a group.

Non-metric multi-dimensional scaling was preformed using PC-ORD 6.21 with the guidance of Peck (2010) and McCune and Grace (2002). A 2D solution was selected with a mean stress of 11.25 which is between the optimal range of 5 to 15.

Results

The sampling effort of 79 circular plots each with an area of 25 m^2 provided sufficient saturation to capture the diversity of species within the study site (Figure 34). We observed one woody species in very low abundance, *Liriodendro tulipifera,* in the study site but not present in the sampling.

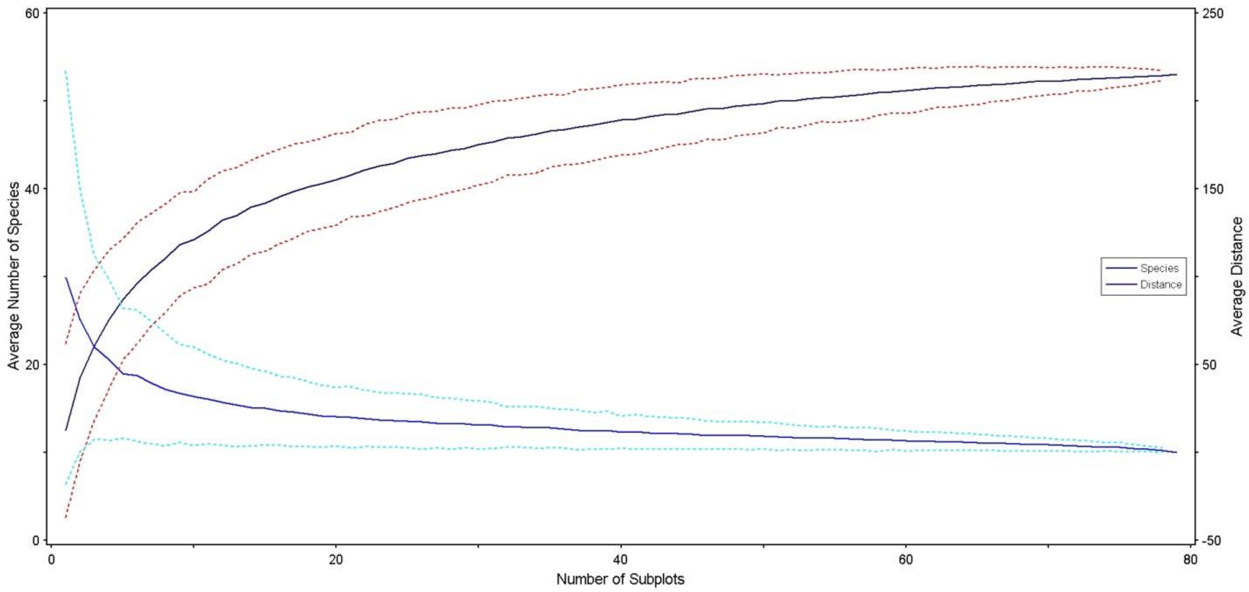

Figure 34: The species area curve with a flattening curve approaching sampling saturation for 53 woody species in 79 plots.

Table 9.

Importance values for the woody stem species using averaging their relative basal area, relative density, and relative frequency.

Species/Coverage	Total Basal Area	Total Stems	Frequency	Relative Basal Area	Relative Density	Relative Frequency	Importance Value
Lonicera maackii	4.24	3217	75	21.07	46.27	11.01	26.12
Rhus aromatica	0.00	1084	44	0.01	15.59	6.46	7.35
Fraxinus americana	2.04	393	54	10.11	5.65	7.93	7.90
Cercis canadensis	0.41	286	35	2.05	4.11	5.14	3.77
Celtis occidentalis	0.50	260	45	2.48	3.74	6.61	4.28
Cornus drummondii	0.66	182	24	3.30	2.62	3.52	3.15
Quercus muehlenbergii	3.03	177	43	15.05	2.55	6.31	7.97
Celastrus orbiculatus	0.00	146	25	0.00	2.10	3.67	1.92
Parthenocissus quinquefolia	0.00	134	29	0.00	1.93	4.26	2.06
Rhus typhina	0.00	107	1	0.00	1.54	0.15	0.56
Rhus glabra	0.01	88	8	0.05	1.27	1.17	0.83
Sassafras albidum	0.42	79	11	2.11	1.14	1.62	1.62
Acer saccharum	2.42	63	24	12.04	0.91	3.52	5.49
Quercus stellata	1.26	61	9	6.24	0.88	1.32	2.81
Carya glabra	0.76	61	27	3.76	0.88	3.96	2.87
Fraxinus quadrangulata	0.05	61	20	0.27	0.88	2.94	1.36

Diospyros virginiana	0.16	57	12	0.80	0.82	1.76	1.13
Cornus florida	0.10	52	14	0.48	0.75	2.06	1.09
Ostrya virginiana	0.10	50	18	0.48	0.72	2.64	1.28
Ptelea trifoliata	0.01	48	16	0.07	0.69	2.35	1.04
Juniperus virginiana	0.42	39	19	2.10	0.56	2.79	1.82
Rhamnus cathartica	0.16	33	22	0.78	0.47	3.23	1.49
Vitis aestivalis	0.00	33	16	0.00	0.47	2.35	0.94
Prunus serotina	0.00	30	11	0.00	0.43	1.62	0.68
Juglans nigra	0.25	27	7	1.26	0.39	1.03	0.89
Ailanthus altissima	0.32	25	2	1.57	0.36	0.29	0.74
Quercus velutina	1.31	20	12	6.53	0.29	1.76	2.86
Symphoricarpos orbiculatus	0.00	18	3	0.00	0.26	0.44	0.23
Quercus rubra	0.59	16	8	2.92	0.23	1.17	1.44
Lindera benzoin	0.00	14	5	0.00	0.20	0.73	0.31
Quercus alba	0.18	12	4	0.92	0.17	0.59	0.56
Campsis radicans	0.00	12	3	0.00	0.17	0.44	0.20
Ulmus americana	0.15	11	4	0.74	0.16	0.59	0.50
Robinia pseudoacacia	0.04	11	3	0.18	0.16	0.44	0.26
Rubus allegheniensis	0.00	8	1	0.00	0.12	0.15	0.09
Celtis tenuifolia	0.03	5	3	0.14	0.07	0.44	0.22
Toxicodendron radicans	0.00	5	3	0.00	0.07	0.44	0.17
Amelanchier arborea	0.07	4	2	0.37	0.06	0.29	0.24
Tillia americana	0.16	3	3	0.78	0.04	0.44	0.42
Acer negundo	0.02	3	3	0.11	0.04	0.44	0.20
Elaeagnus umbellata	0.00	3	3	0.00	0.04	0.44	0.16
Lonicera Japonica	0.00	3	2	0.00	0.04	0.29	0.11
Euonymus fortunei	0.00	3	1	0.00	0.04	0.15	0.06
Carya tomentosa	0.25	2	2	1.25	0.03	0.29	0.52
Euonymus alatus	0.00	2	2	0.00	0.03	0.29	0.11
Rosa carolina	0.00	2	1	0.00	0.03	0.15	0.06
Asimina triloba	0.00	1	1	0.00	0.01	0.15	0.05
Quercus imbricaria	0.00	1	1	0.00	0.01	0.15	0.05
Totals	20.132	6952	681	100	100	100	100

The species with the highest importance value across the south facing bluff ridge were *L. maackii* (26.1), *Quercus muehlenbergii* (7.9), *Fraxinus Americana* (7.8), *Rhus aromatica* (7.3), *Acer saccharum* (5.4), *Celtics occidentalis* (4.3), *Cercis canadensis* (3.7), *Cornus drummondii* (3.1), *Carya glabra* (2.8), and *Quercus velutina* (2.8). The species with the highest relative basal area include *L. maackii* (21.0), *Quercus muehlenbergii* (15.1), *Acer saccharum* (12.0), *Fraxinus*

Americana (10.1), and *Quercus velutina* (6.5). Relative density was dominated by *L. maackii* (46.3), *Rhus aromatica* (15.6), *Fraxinus americana* (7.9), *Cercis canadensis* (5.1), and *Celtics occidentalis* (4.3).

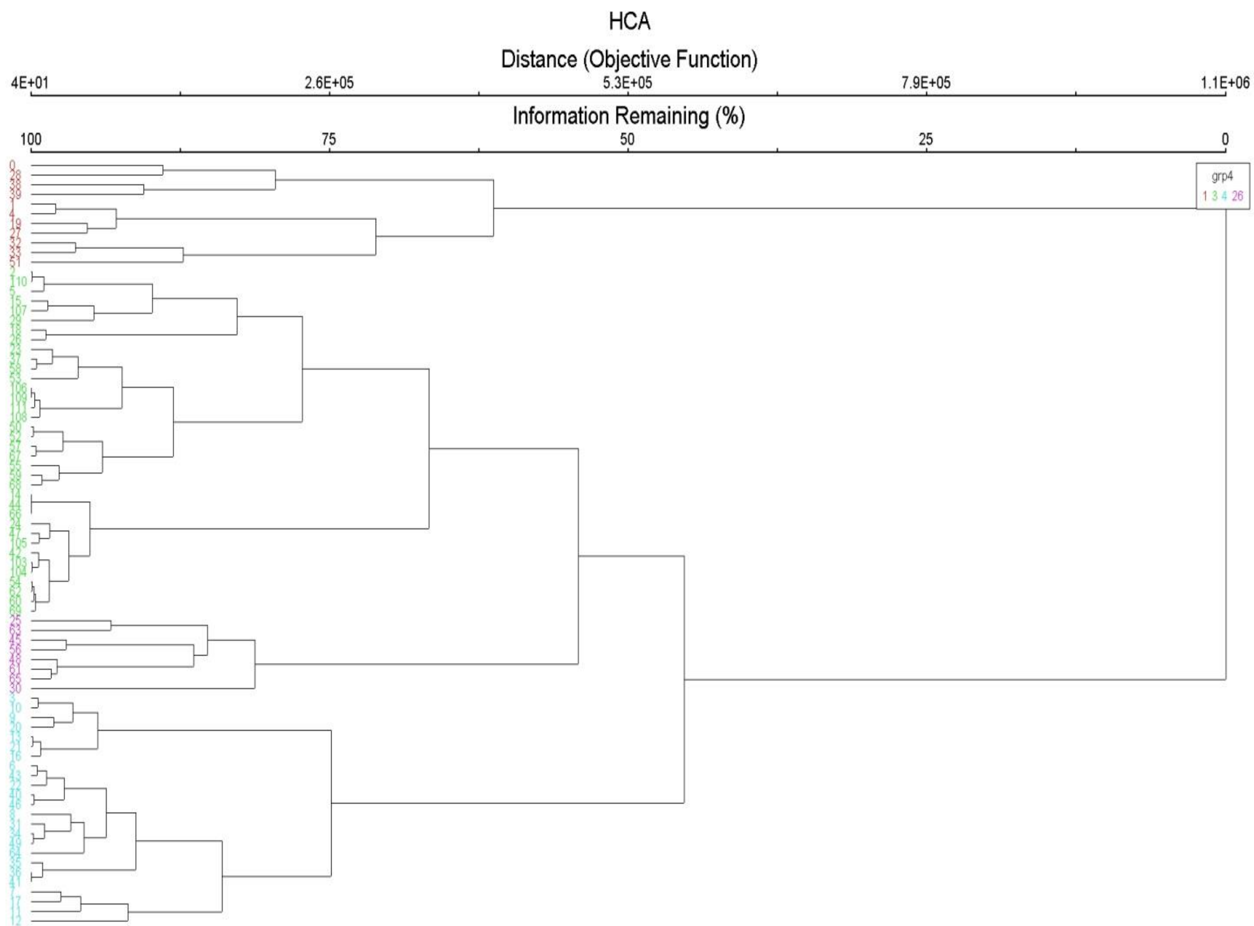

Figure 35: Hierarchical cluster analysis for identifying groups.

The hierarchical cluster analysis for identifying groups based on community similarity found 4 groups (Figure 35). Using Euclidean distance measure and Ward's method of group linkage method, a 2.98 percent chaining effect occurred. Group selection was assigned automatically, but limited to 4 due to the practicality of interpretation and considerations of management scenarios. Groups 1 and 3 consisted of the remnant savanna structure and the hill prairie community, respectively. Groups 2 and 4 consisted of the *Acer* dominated areas and stem initiation/transition areas, respectively.

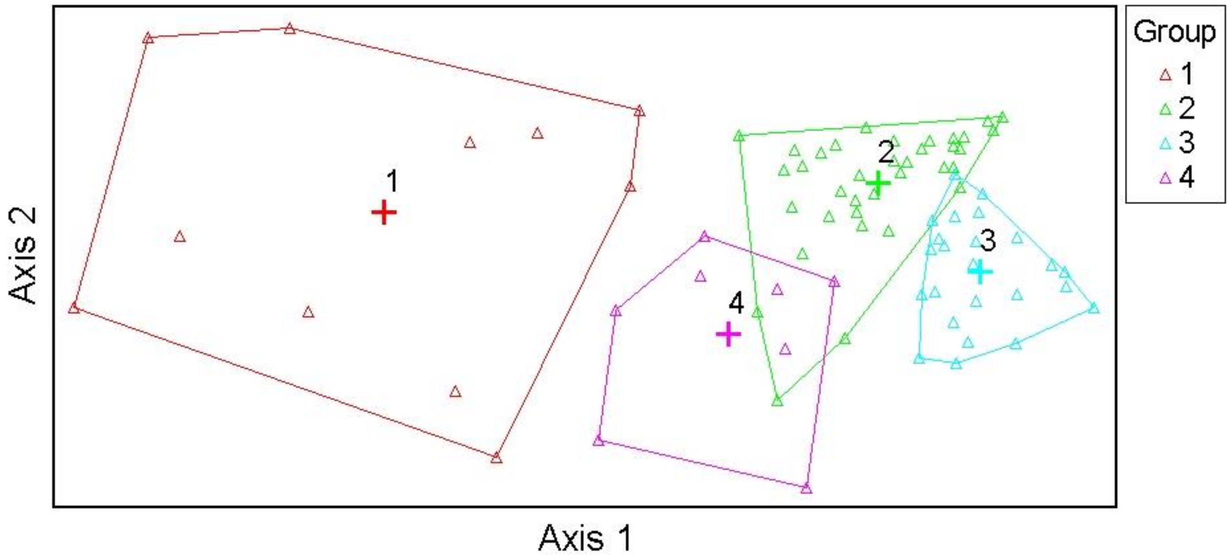

Figure 36. Non-metric multidimensional scaling of the four groups.

The ordination results from the non-metric multidimensional scaling revealed separation of the four groups found in the hierarchical cluster analysis, with centroids shown. Minor plot overlap exists between groups 2 and 3 and also 2 and 4.

Table 10

Indicator species analysis for the bluff groups.

Species	Group	Indicator Value	Mean	S.Dev	P-value
Remnant Savanna Group					
Juniperus virginiana	1	58.4	14.9	6.03	0.0002
Lonicera maackii	1	74.2	33.6	5.38	0.0002
Seedings	1	49.1	31	3.31	0.0002
Carya glabra	1	45	17.9	6.03	0.0022
Lonicera maackii (BA)	1	47.9	25.9	5.98	0.0054
Juniperus virginiana (BA)	1	21.4	9	4.93	0.0276
Woody Stem Coverage	1	36.1	28.7	3.54	0.0368
Quercus stellata	1	23.7	12	5.97	0.0424

Fraxinus americana	1	45.3	30.1	7.57	0.0522
Carya glabra (BA)	1	20.8	11.3	5.58	0.064
Celtis occidentalis (BA)	1	18.6	12.7	6.08	0.1452
Rhus aromatica (BA)	1	9.1	5.1	3.25	0.2454
Carya tomentosa (BA)	1	8.2	6.2	3.59	0.2707
Lonicera japonica	1	7.9	6.3	3.67	0.3303
Quercus stellata (BA)	1	9.8	8.9	4.91	0.3313
Juglans nigra (BA)	1	7.8	6.1	3.87	0.3391
Toxicodendro radicans	1	7.2	6.9	4.01	0.3445
Amelanchier arborea (BA)	1	7.7	6.3	3.52	0.3547
Carya tomentosa	1	7	6.3	3.46	0.4239
Amelanchier arborea	1	7	6.3	3.45	0.4351
Quercus rubra	1	8	9.8	5.24	0.5349
Ostrya virginiana	1	5.5	7.5	4.36	0.6047
Robinia pseudoacacia (BA)	1	4.4	6.2	3.63	0.7187
Elaeagnus umbellata	1	5.2	7	3.83	0.7776
Acer Group					
Bare soil/Leaf Litter Coverage	2	40.4	27.6	3.04	0.0002
Acer negundo	2	8.3	7	3.88	0.2533
Sassafras albidum	2	13.5	11.8	5.88	0.2975
Sassafras albidum (BA)	2	8.3	7	4.29	0.3409
Acer saccharum (BA)	2	15.3	15	6.27	0.3751
Ailanthus altissima (BA)	2	5.6	6	3.64	0.5365
Ailanthus altissima	2	5.6	6	3.64	0.5365
Ptelea trifoliata (BA)	2	5.6	6.1	3.47	0.6549
Rhus glabra (BA)	2	5.6	6.4	3.48	0.7349
Tilia Americana (BA)	2	4.5	7	4.04	0.802
Lindera benzoin	2	4.2	8.2	4.75	0.9052
Acer negundo (BA)	2	2.8	5.1	3.25	1
Euonymus alatus	2	2.8	5.1	3.24	1
Hill Prairie Group					
Grass Coverage	3	39.7	22.1	6.37	0.0196
Rhus glabra	3	16.8	10.6	5.69	0.1234
Cornus florida (BA)	3	6.3	6.9	3.75	0.4761
Ptelea trifoliata	3	12.4	13.9	6.11	0.5143
Asimina triloba	3	4.2	5	3.17	0.5459
Rubus allegheniensis	3	4.2	5.1	3.24	0.5481
Quercus imbricaria	3	4.2	5	3.19	0.5493
Celtis tenuifolia	3	5.8	6.9	4.02	0.6237
Celtis tenuifolia (BA)	3	4.9	6.9	4.04	0.6757
Quercus alba (BA)	3	3.6	6.1	3.83	0.8078
Rhamnus cathartica (BA)	3	5.2	9.7	5.23	0.8464
Quercus muehlenbergii (BA)	3	10	16.2	6.07	0.8992

Symphoricarpos orbiculatus	3	2.9	7	4.18	0.9496
Transition Group					
Cornus drummondii (BA)	4	48.1	14	5.73	0.0008
Cercis canadensis	4	54.1	21.2	6.41	0.0014
Prunus serotina	4	40.9	11.5	5.78	0.0024
Quercus muehlenbergii	4	45.8	22.8	5.51	0.0032
Cornus florida	4	41	13.1	6.18	0.0044
Cercis canadensis (BA)	4	33.1	11.1	5.54	0.005
Cornus drummondii	4	40.1	17.3	6.26	0.0076
Rhus aromatica	4	42.5	24.8	6.83	0.0216
Celtis occidentalis	4	37.3	23	5.93	0.0264
Quercus velutina	4	24.5	11.8	5.68	0.0348
Celastrus orbiculatus	4	33.6	18.5	6.81	0.0352
Fraxinus quadrangulata	4	31.5	16.4	6.62	0.0358
Ulmus americana	4	18.4	7.5	4.37	0.036
Diospyrus virginiana (BA)	4	20.4	10.1	5.46	0.0498
Forb Coverage	4	36.8	27.4	5.1	0.0514
Quercus rubra (BA)	4	17	8.1	4.68	0.0578
Acer saccharum	4	25.5	16.4	5.75	0.0766
Rhamnus cathartica	4	24.5	15.7	5.78	0.083
Vitis aestivalis	4	21.9	13.7	6.03	0.0918
Rhus typhina	4	12.5	5	3.2	0.0954
Rosa carolina	4	12.5	5.1	3.27	0.1066
Parthenocissus quinquefolia	4	26.2	19.1	6.35	0.1218
Juniperus virginiana	4	15.2	9.6	5.27	0.1362
Diospyrus virginiana	4	20.5	13.8	6.88	0.1552
Campsis radicans	4	10.3	7	4.19	0.158
Robinia pseudoacacia	4	10.2	6.9	4.16	0.162
Tilia americana	4	8.7	7	3.79	0.1728
Ostrya virginiana	4	19.1	14.8	6.25	0.198
Quercus alba	4	8.4	7.5	4.5	0.2891
Euonymus alatus	4	7.2	6.4	3.59	0.3069
Fraxinus quadrangulata (BA)	4	6.9	7.5	4.39	0.3559
Ulmus Americana (BA)	4	7.3	6.3	3.59	0.4069
Fraxinus ameriana (BA)	4	15.7	16.5	6.1	0.4445
Quercus velutina (BA)	4	6	8.5	5.08	0.5997

Indicator species analysis identified the significant species in each group of hill prairie vegetation types. Indicator values are based on a scale of 100 with higher values showing corresponding to stronger associations. Significant indicators have p-values <0.05. Indicators without significant values are placed in a group even though their presence in other groups is strong. The remnant savanna group, group 1, consists of the community with a significant ($p<0.05$) indicator values of the density of *J. virginiana* (indicator value 58.4, p-value = 0.0002), *C. glabra* (45, 0.0022), and *Q. stellata* (23.7, 0.0424) and a high basal area *of J. virgniana* (21.4, 0.0276). The sugar maple group, group 2 contains one indicator coverage at a significant level, bare soil or leaf litter coverage in the subplot (40.4, 0.0002). The hill prairie group, group 3, has the sole indicator of grass coverage in the subplots (39.7, 0.0196). Group 4, the transition group has 14 significant indicator species.

Table 11

Average stem density per ha and average basal area for each bluff group.

Group	**Type**	**Average Stem Density per ha**	**Average Basal Area (m2) per ha**
1	Remnant Savanna Group: *J. virginiana, C. glabra, Q. stellata* with *L. maackii*	95,454.45	36.40
2	Sugar Maple Group: Bare/Litter with *A. saccharum*	25,911.08	32.25
3	Hill Prairie Group: Grass with *Q. velutina* and *F. americana*	59,950	30.85
4	Transition Group: *C. florida* and *C. canadensis*	13,266.69	15.70

Stem density and basal area was highest in the remnant savanna group and lowest in the transition group (Table 11).

Dendrochronology Results

The earliest tree ring on a stem served as the establishment year and was plotted according to species and group membership (Figure 37). Tree ring width series were cross-dated using the COFECHA program. Several species failed to meet the .4226 threshold, but *Q. velutina* achieved a series intercorrelation of .503 with an average mean sensitivity of .243 over a mean length of series of 80.5 years. The number of stems that establish each year is positively correlated, $r(635) = 0.212$, $p = .003$) with the 10 yr moving average of the Palmer Drought Severity Index (PDSI), as well as the raw PDSI values, $r(635)=.142$, $p = .049$. In 1990, the invasion of *L. maackii* significantly increased. In the 1940s, a cohort of *A. saccharum* established in addition to steady recruitment in the 1960s and 1970s.

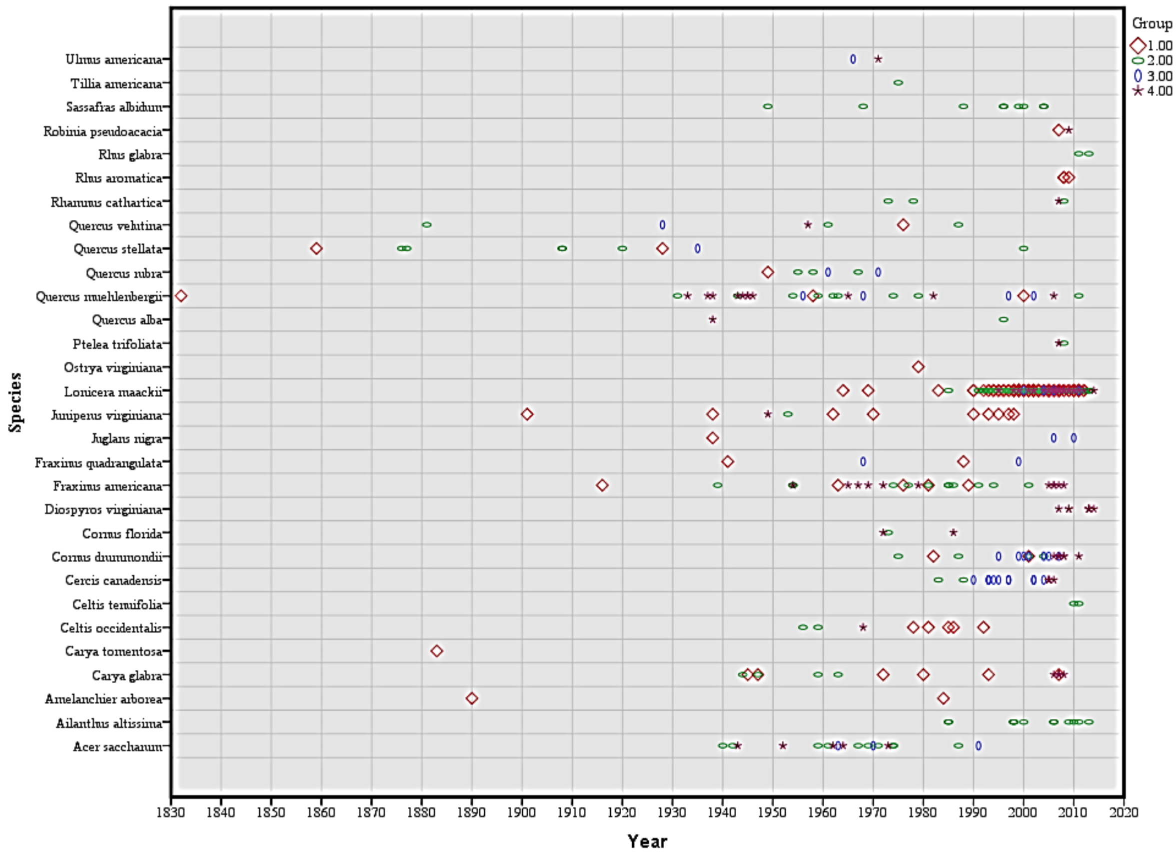

Figure 37. The establishment dates of stems for each species by group.

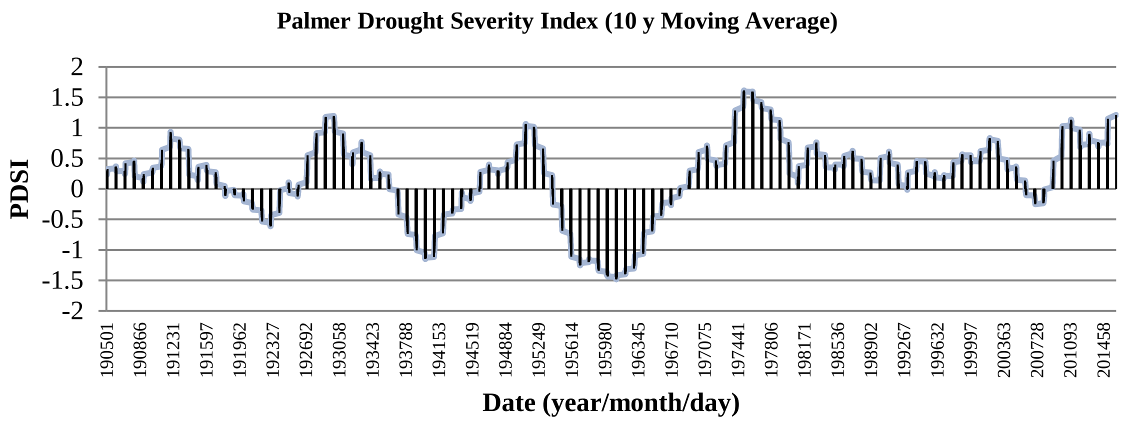

Figure 38. The Palmer Drought Severity Index for area including Elsah Township since 1905.

The Palmer Drought Severity Index (Cook, 2004) was smoothed with a 10 year moving average beginning in 1905 (Figure 38). Positive values indicate higher amounts of moisture that are available for plant use and negative values represent drought conditions. The decadal oscillations between wet and dry periods ended when a prolonged wet cycle beginning in the early 1970s began and persisted with only minor dry periods in this region.

Table 12

Average establishment year for bluff woody stems.

Species	Oldest year on record	Average establishment year	Std. Dev. of Year
Acer saccharum	1940	1965	14.00933
Ailanthus altissima	1985	2002	9.414286
Amelanchier arborea	1890	1937	66.46804
Carya glabra	1944	1979	26.77116
Carya tomentosa	1883	1883	NA
Celtis occidentalis	1968	1982	8.21381
Celtis tenuifolia	2010	2011	0.707107
Cercis canadensis	1983	1997	6.885086
Cornus drummondii	1975	2000	9.523747
Cornus florida	1972	1977	7.81025
Diospyros virginiana	2007	2011	2.615203
Fraxinus americana	1916	1978	21.97642

Fraxinus quadrangulata	1941	1974	25.46894
Juglans nigra	1938	1985	40.46398
Juniperus virginiana	1901	1968	30.9736
Lonicera maackii	1964	2004	6.068465
Ostrya virginiana	1979	1979	NA
Ptelea trifoliata	2007	2008	0.707107
Quercus alba	1938	1967	41.01219
Quercus muehlenbergii	1832	1958	34.53826
Quercus rubra	1949	1960	8.01041
Quercus stellata	1859	1912	41.76422
Quercus velutina	1881	1948	38.58324
Rhamnus cathartica	1973	1992	18.59211
Rhus aromatica	2008	2008	0.57735
Rhus glabra	2011	2012	1.414214
Robinia pseudoacacia	2007	2008	1.414214
Sassafras albidum	1949	1989	18.74166
Tillia americana	1975	1975	NA
Ulmus americana	1966	1969	3.535534

One-way ANOVA and Tukey HSD post hoc test revealed the average age of *L. maackii* in the remnant savanna group (group 1) was significantly older than the sugar maple group and the transition group, $F(3,406)=11.46$ $p = <0.001$, but not different than the hill prairie group. No other post-hoc comparison was significant.

Discussion

The homogenizing influences in the dynamics of the hill prairie and surrounding low-density forest have created a concern about the loss of biodiversity and especially the loss of graminoid and forb species. Since 1955, observers have questioned the stability of the prairie species and noted the gradual encroachment of the hill prairies but the pattern of woody stem initiation was limited to the inside boundaries of the hill prairie (Evers, 1955; Robertson et al., 1995). Unlike any prior hill prairie study, this study sought to include the hill prairies and surrounding low density forest that once contained a prairie assemblage as a single gradient of vegetation communities. This more inclusive view of the system enabled historical conditions to be incorporated into an analysis that factored in the temporal parameters of ecological change.

The results suggest that the prairie-forest dynamic is influenced by a number of complex interacting factors. The steady increase of mesophytic species and the invasion of exotic shrubs coupled with the persistence of a wet cycle and modification to historic disturbance regimes have resulted in a persistent encroachment of hill prairies and the surrounding low density forest. The wet period since the mid 1970's would facilitate the germination and establishment of woody stems, in addition to the growth of extant trees, and accelerate the rate of encroachment. Without widespread frequent surface fires to check the growth of woody stems, the prairie species were outcompeted and largely disappeared.

While this study focused on the pattern of woody stem initiation in the prairie forest mosaic, the impacts of composition, shading, and leaf drop on prairies communities are fundamental elements of a restoration plan and understanding the ecological mechanisms of encroachment. Studies of woody stem encroachment into prairies have observed the shading effect caused declines in C4 grasses, hemi-parasites, legumes, and perennial dicot forbs abundance (Taft & Kron, 2014). Additional studies found that C4 grasses and perennial dicot forbs to be negatively impacted (Briggs, Hoch, & Johnson, 2002; Lett & Knapp, 2003).

This remnant savanna group was highly susceptible to recent forest conversion as demonstrated by high woody stem coverage (indicator value: 36.1, p-value: 0.0368) in the subplots and seedling density of all species (49.1, 0.0002). Of the four main community groups identified, both *L. maackii* density (74.2, 0.0002) and basal area (47.9, 0.0054) were indicators of group 1. The first year of *L. maackii* presence was 1964, however the average establishment year was 2004 (st. dev. 6.1) with the primary wave of invasion beginning in 1990 (N=410).

Notably, 5 of the oldest 10 trees in the study site are *Q. stellata.* The basal area of additional 7 species was assigned to group 1, but not at a significant level. The invasion of exotic woody shrubs is associated with savanna and woodland community structure.

The management of the remnant savanna community is limited to a short timeframe due to the rapidly changing dominance (i.e. instable system dynamics) within the next cohort. Mechanical intervention with stump treatments will return the forest structure to a range of woodland to savanna stem densities. However, establishing a prairie community under the forest canopy will require frequent application of prescribed fire in addition to foliar spraying of herbicides to prevent the establishment of invasive species and undesirable woody stems. Inter-seeding with grass and forb species may be necessary depending on the site (Schramm, 1978, 1990).

The sugar maple group, group 2 contains just one indicator species at a significant level, bare ground or leaf litter coverage in the subplot (40.4, $p = 0.0002$). The lack of ground layer vegetation is due to the high degree of shading and limitation of light resources at the forest floor (Belsky & Canham, 1994). The species assigned to Group 2, but not at a significant value, include *A. negundo* density, *S. albidum* density and basal area, and *A. saccharum* basal area.

Attenuating the mesophytic influence along the forest-prairie gradient involves limiting the island effect by thinning at the edges of the mesophytic patches to reduce shading of prairie and savanna species. Thinning within the patch is viable where xeric savanna structure remains, especially where numerous young mesophytic species are below the canopy of traditional savanna species (e.g. *Q. stellata*). Depending on weather conditions and fuel loading, prescribed fire in this area would cause significant mortality, particularly to the small diameter *Acer* species and *S. albidum,* and the resulting ecosystem trajectory would be uncertain.

The hill prairie group, group 3, typifies the intact hill prairie community with the sole indicator of grass coverage in the subplots (39.7, $p = 0.0196$). These small openings in the canopy with steep southern exposure provide ample light resources for prairie grasses and forbs to persist.

The prairie dominated sites should maintained with frequent fire to reduce the establishment and growth of woody species (Schramm, 1990). Thinning, particularly of mesophytic species, near the prairie edge would increase solar radiation, temperatures, and the desiccating effects of wind (Burns & Honkala, 1990).

The transition group, group 4 represents the stage of forest development following the cessation of disturbance events and the trajectory advancing towards a mesophytic forest. This community has 14 indicators that include *Cornus drummondii* density and basal area, *Cercis canadensis* density and basal area, *Prunus serotina* density, *Quercus muehlenbergii* density, *Rhus aromatica* density, *Celtis occidentalis* density, *Fraxinus quadrangulata* density, *Ulmus americana* density, and *Diospyros virginana* basal area.

The re-introduction of fire to areas with high stem densities would serve to reduce woody stem coverage, but would require frequent application over a long timeframe. However, because the relatively low amount of invasive species is desirable, caution should be exercised since interventions could unintentionally increase the probability of encouraging the establishment and spread of invasive species. Fire would serve as a filter and promote fire tolerant species which have a lower leaf area index (Reich, Walters, & Ellsworth, 1991) and would allow greater light resources to support a prairie component.

Seedlings highly correlated with axis 1 ($r^2 = 0.956$) and found predominately in Group 1 but in descending order of density groups 4, 2, and 3. *L. maackii* highly correlated with axis 1

(r^2=0.745) but followed a slightly different pattern from the seedings, with the greatest density in group 1 and followed by 2, 4, then 3.

Conservation projects are constrained to the financial resources available to meet the objectives and goals. In terms of management priority, Groups 3 and 1 (hill prairie and remnant savanna) should receive the most attention due to the extant connection to historical ecological conditions. The hill prairies represent a significant portion of the remnant prairie in the state of Illinois. The remnant savanna converted to a closed canopy system rapidly and requires frequent disturbance in the form of surface fires (or analogous mechanical and herbicide treatment) to maintain the prairie component with a low density, pyrophylic forest community. Groups 4 and 2 (stem initiation and *Acer*) should be included in treatments if enough resources for management are available. The stem initiation areas have shifted from grass and forb dominance and will require significant management to restore. While fire alone will not restore the ecological conditions of 50 years prior, it will enable the coexistence of prairie species and may reduce the density of the woody stems after annual burns are applied for multiple years. The *Acer* dominated area contains no vestiges of historic ecological conditions and restoration efforts would respond slowly. The most likely outcome in response to canopy removal would be the establishment and dominance of invasive species.

The significant correlation between stem initiation with climatic patterns was observed in this study. Since the early 1970s, the oscillation between wet and dry cycles terminated and an extended wet period, with only minor dry instances, has persisted in the area. This climatic pattern will exacerbate woody stem encroachment within the forest-prairie gradient by mesophytic and invasive species without management activities that promote historic ecological functions.

Conclusion

Restoration and continued management of the forest-prairie gradient advances from an understanding of the main community types within the continuum. Hierarchical cluster analysis was employed to identify groups based on community similarity and found 4 groups within the hill prairie ecosystems along the bluffs of the Mississippi River. Non-metric multidimensional scaling revealed separation of the four groups with minor plot overlap. Groups 3 (hill prairie) and 1 (remnant savanna) should receive the most attention due to their significance as a system similar to historic and diminishing conditions and Groups 4 (transition) and 2 (sparse ground layer with *Acer* overstory) should be included in restoration efforts as funding allows.

CHAPTER 5

A FOREST MANAGEMENT APPROACH THAT INTEGRATES HISTORICAL CONDITIONS FROM DIVERSE SOURCES AT MULTIPLE SCALES

Current ecological trajectories and evolving social forces in the Midwest present the forest manager with difficult choices. As these ecological communities deviate from historical conditions, the impacts to economic potential, wildlife habitat quality, and ecosystem services becomes uncertain. Provisioning for the future includes retaining representative ecological conditions similar to historic conditions (i.e. oak woodland and savanna) across the landscape in addition to allowing current trends to advance towards closed canopy mesophytic forests (McTaggert, 2017). This process of mesophication is in disequilibrium with climatic forces (Nowacki & Abrams, 2015) and if climate trends continue, the result may lead to the collapse of forest ecosystems in the Midwest. Restoration of historical forest structure and composition, in some portion of the total landscape, is a critical element of conserving the range of biodiversity. Studies, like this dissertation, provide the historical context for understanding long-term forest dynamics in a highly variable landscape. In each natural area, the balance between restoration of historic conditions and allowing unchecked ecological development of invasive species and mesophytic forests is situational dependent and constrained by the financial and labor resources of the decision makers.

Managing forest ecosystems requires current inventory data and an understanding of the historical ecological drivers that influenced forest composition and structure. In the confluence area of the Middle Mississippi River Bluffs Region, topographic variation can be divided into four unique settings: upland, bluff, talus slope, and river island. Each setting is governed by different topoedaphic conditions, fire frequency, flooding events, and anthropogenic activity.

Table 13

Stem density and basal area for each topographic zone.

	Overstory		Shrub Layer		Ground Layer
Zone	Stem ha^{-1}	BA m^2 ha^{-1}	Stem ha^{-1}	BA m^2 ha^{-1}	Seedlings ha^{-1}
Bluff	308.86	23.91	5245.57	3.74	29,646
River	354.43	85.49	860.76	2.79	64,810
Talus	384.81	32.52	3326.58	5.60	9,580
Upland	313.92	40.36	3483.54	2.83	12,577

Invasive species became a major management problem over the past 50 years in the Midwest. In the study area, dendrochronology revealed that bush honeysuckle (*Lonicera maackii*) invaded the forest as early as 1964 but proliferated starting in 1990. Influencing the dominance of invasive species by reducing the density and biomass can require significant resources over repeated treatments, but addressing their presence is vital prior to initiating any type of canopy disturbance (Chen & Matter, 2017). Treatments that disturb the soil or increase light levels on the forest floor should be followed by a monitoring routine and targeted treatment of invasive species to prevent their dominance of a site (Shields et al., 2015). The most dominant invasive species *L. maackii*, was found on all non-hydric sites and most dominant on the bluff where light levels were the highest. Other invasive species were observed, but not at high levels or with the potential of site dominance. Over multiple entries, autumnal chemical treatments by aerial spraying, midst spraying, or stump cut of *L. maackii* have been demonstrated to be effective at decreasing its dominance (Nyboer & Edgin, 2017).

Historical Trends in Ecological Development

Across the landscape, forest dynamics were influenced by disturbance patterns and site conditions. The ecological effects of prescribed fire are well documented in oak-hickory systems and restoring a fire regime could have multiple ecological benefits. Nevertheless, fire should be precluded from areas where mesophytic species are desired. Seasonality of the burns can influence the ecological effects, but most burns are conducted in the late winter to minimize the duration of exposed soil. Historically, fire was applied with regularity which favored pryophytic species and lead to the dominance of prairie vegetation with reserves of low oak-hickory stands on the upper slopes. Researchers have posited that even floodplain forests have a fire regime that mediates forest competition and dominance (Nelson et al., 1995). Mespophytic vegetation existed near water courses due to the higher moisture levels and topographic barriers to fire travel. Across the landscape, the application of fire in a range of frequencies, from annually in the forest-prairie gradient of the bluffs to none in areas where pyrophobic vegetation is desired, will promote diversity.

Forest development across the landscape began with low density and high basal area stands at the time of settlement (Table 13). In the early part of the 1900s, disturbance regimes shifted and fire frequency diminished resulting in stem density increasing significantly and basal area decreasing. The stages of stand development progressed and the current mature forest has lost density but gained basal area. These trends are consistent with the general patterns of forest development.

Table 14

Changes in stem density and basal area over time on the river island, talus slope, bluff, and upland positions.

	River Island		Talus slope		Bluff		Upland	
Year	Stem ha^{-1}	BA m^2 ha^{-1}	Stem ha^{-1}	BA m^2 ha^{-1}	Stem ha^{-1}	BA m^2 ha^{-1}	Stem ha^{-1}	BA m^2 ha^{-1}
1820	86.8	NA	NA	NA	NA	NA	21.4	36
1936	584.56	NA	1109	NA	NA	NA	NA	NA
2017	354.43	85.49	384.81	32.52	308.86	23.91	313.92	40.36

Upland Hardwood Forest

Silvicultural treatments in the Midwest have the opportunity to forge a unique approach that utilizes historical conditions as targets for management and combine ecological restoration with economic returns. The evidence presented in this dissertation supports the use of silvicultural methods that reduce stem density, favor pyrophilic species with the use of fire, and establish an herbaceous ground layer. Witness tree analysis for Elsah Township (circa 1820) suggests that forest was dominated by a variety of oaks with a density of 21.4 stems ha^{-1} and a basal area of 36 m^2 ha^{-1}. The few but large stems is confirmed by Rebecca Burlend in 1831, "Not a few (trees) are to be found in the last stage of decay, their patriarchal dignity gradually submitting to the all-subduing influence of time." In particular, she noticed that, "Numbers (of) more (trees) are quite hollow, in which bees, owls, and rabbits … find shelter" (White, 2000). Cuttings should often be paired with prescribed fire and invasive species treatments depending on the site. The primary befit of including silvicultural options in management planning is the potential income produced by harvesting over-mature trees. The concept of a regulated forest that reliably and indefinite produces a consistent oak harvest may be possible across the Midwestern landscape. The two primary silvicultural methods consistent with historical conditions include variable retention harvesting and oak-shelterwood. Both methods produce suitable light environments for the germination and establishment of oak and hickories species and require a minimum of 5 hectares to implement. Future studies should detail the relative benefits and drawbacks of each approach.

Variable retention harvesting uses an individualized approach to reaching management goals and preparing the forest for desired future conditions. Trees are removed based on their maturity, effects on neighboring trees, species, and impact on the regeneration of a new cohort.

For example, if oak regeneration was one of the management goals, a variable retention harvest would focus on removing trees with a significant shading effect and reducing canopy coverage so that light would penetrate to the forest floor, which would constitute about 50% of the cutting unit. About 20% of the area would be retained as closed canopy forest and serve as refugia for shade tolerant species, including both flora and fauna. In an area with topography, the region along the drainages or valleys could serve as this retention which would be historical consistent with the spatial orientation of forest structure. In 1830, James Hall observed that the forests were distributed as “marking the course of some tributary stream and sometimes in vast groves” and on the slopes and ridges, trees were “standing alone like islands, in this wilderness of grass and flowers.” Likewise, Henry Allyn was a surveyor in 1816 and noted that “The country all prarie [sic] except here & there an island of timber of from 100 to 500 acres, & a narrow list of timber along the margins of the largest streams.” In addition, stream management zone (SMZ) regulations from best management practices (BMP) would be satisfied with the location of the retention along the ephemeral or perennial streams. The variable retention method requires an intimate knowledge of the forest and the spatial arrangement of tree species and size classes. The remaining 30% of the area may be cleared as small to large patches.

The oak-shelterwood relies on a preparatory cutting to reduce unwanted vegetation, an establishment cutting to allow oak regeneration to initiate, and a final overstory removal to harvest mature trees and release the next cohort. The historical basis for the oak shelterwood is noted by James Hall’s description of the landscape as “hundreds of acres embellished with a kind of open woodland” and that trees “occasionally collected in clusters, while now and then the shade deepens into the gloom of the forest.” The primary objective of this oak-shelterwood is the establishment of advance oak regeneration, which is a niche currently occupied my maples, associated mesophytic species, and invasive species. Shelterwood can retain the overstory for extended periods to add additional growth to the overstory trees. Clearcutting presents a number of challenges to perpetuating oak forests including loss of legacy trees to provide light, heat, and moisture moderation and seed sources. Single tree selection is problematic in providing the proper regeneration conditions on most sites and will lead a forest conversion to a dominance of shade tolerant species.

Table 15

Comparison of variable retention and oak-shelterwood harvest methods.

Attribute	Variable Retention	Oak-Shelterwood
Light	Low to high	Medium to high
Moisture	Dry to moist	Dry
Closed canopy reserves	~20%	0%
Low density canopy	~50%	100%
Ease of implementation	Moderate	Easy
Preservation of legacies	High	Medium
Entries per cycle	1	3
Min. cutting unit (ha)	5	5
Example residuals of an upland stand with 314 stems ha^{-1} and a basal area of 40.36 m^2 ha^{-1}		
Residual density (stems ha^{-1})	87.8	50
Residual basal area (m^2 ha^{-1})	20	23.9

To establish an herbaceous ground layer the seedbed can be prepared by clearing leaf litter with fire or mechanically as in following a timber harvest. Providing seed to the site may be necessary to re-introduce species. Typically, broadcast spreading the seed by hand directly following a burn is effective. Annual burns for the first 5 years will assist in establishing the herbaceous coverage and prevent the suppressing influence of accumulating leaf litter.

Fire can be an effective tool for reaching management goals. Provided a trained fire crew and proper containment measures are implemented, burns can quickly treat a large area, discriminating against species with sensitivity to heat, thin bark, small diameters, or weak re-sprouting abilities. Surface fires reduce the mulching effect of forest litter and allow more herbaceous plant germination and growth. Although fires can initially and temporarily accelerate soil erosion, the establishment of a widespread herbaceous layer reduces the long-term erosion rates. Mechanical interventions that mimic some the ecological effects of fire may be suitable in areas where fires are inappropriate.

The upland region of Principia College land contains 314 stems ha^{-1} with a basal area of 40.36 m^2 ha^{-1}. The large diameter trees are dominated by oaks and hickories, while the small end of the diameter distribution contains maples, elms, and sassafras with small components of oak and hickory. The middle of the distribution is a mix of all species. Oaks have received special attention due to their economic importance, wildlife connections, and difficulty in regenerating. The field forester knows that a stand prescription must be adapted to each acre in the stand. A shelterwood in this forest type with a goal of oak regeneration would focus on retaining stems above 45 cm which results in a retaining of 50 stems ha^{-1} with a basal area of 23.9 m^2 ha^{-1} and removing 264 stems ha-1 with a basal area of 16.5 m^2 ha^{-1}. This is for stems greater than 15 cm dbh. These metrics are approaching the reference conditions from 1820 of 21.4 stems ha^{-1} and a basal area of 36 m^2 ha^{-1}. Shrub layer (between 1 and 15 cm dbh) contains 3483.5 stems ha^{-1} with a basal area of 2.8 m^2 ha^{-1} and is dominated by invasive shrubs. All shrubs layer stems, except those of oaks, hickories, and other desired species, can be removed, and will likely be damaged or removed during the overstory operations.

A variable retention harvest would have similar residual values as the shelterwood, but the spatial arrangement of the trees would be different. As an example, let's use 10 ha as a potential harvest unit for variable retention. If the forest on mesic sites were retained and consisted of 20% of the area (2 ha), approximately 628 stems with a basal area of 81 m^2 would exist in the reserves. In the gaps which occupy 30% of the area (3 ha), 942 stems ha with a basal area of 121 m^2 would be removed. The remaining area, 50% (5 ha), would receive a treatment similar to shelterwood. Stems above 45 cm would be removed which results in a retaining of 250 stems with a basal area of 119.5 m^2 and removing 1320 stems with a basal area of 82.5 m^2. The total residual stand in the 10 ha of variable retention harvest unit would consist of 878 stems with a basal area of 200.1 m^2 or 87.8 stems ha^{-1} and basal area of 20 m^2 ha^{-1}.

Table 16

Stem density and basal area comparison.

Stand	Density (stems ha^{-1})	Basal Area (m^2 ha^{-1})
Current condition	314	40.36
Reference condition from 1820	21.4	36
Residual shelterwood	50	23.9
Residual variable retention	87.8	20.1

Further silvicultural considerations include the idea of under-planting with oaks and the pressure of herbivores on seedlings. Under-planting with oaks is a possibility for establishing a cohort, but the cost of artificial regeneration is usually prohibitive. In addition, newly planted seedlings are often preferred by browsers like deer and rabbits. Assisted natural regeneration, or weeding near desired seedlings and providing fencing, may allow naturally established oaks to advance to the sapling stage. Although regenerating an oak dominated forest is a goal of managing a regulated forest, diversity of tree species will be found in the regeneration and contribute to overall diversity. Prescribe fire after the slash has partially decomposed and the herbaceous layer can support the fire spread can tilt the composition to pyrophylic species and mechanical thinning can release crop trees and aid in establishing dominance.

Bluff Forest-prairie Gradient

The ecology on the bluffs contains four primary vegetation communities, each with a need for an individualized approach to management. Initially, the bluff region would have occasional trees such as post oak (*Quercus stellata*), Blackjack oak (*Quercus marilandica*), and various hickories (*Carya spp*) with distant spacing or in small clusters. Higher density forest would occur in the micro-valleys and contain a wider range of species. Oil paintings of the area by Fredrick Oakes Sylvester in the early 1900s depict the extensive prairie vegetation and location of trees (figs 2 and 3). As the era of fire suppression, conservation, and economic shifts initiated, the vegetation community began to change. In 1950, Evers predicted that the hill prairie communities were stable due to the thin soil and southern aspect. However, as the decades progressed, woody invasion began to accelerate. Aerial photographs of the bluffs in the 1970s indicate that although the forest was encroaching, vast prairie components existed . In the 1960s, bush honeysuckle (*L. maackii*) spread to the forest and the invasion began in 1990. The understory of the oak savanna/woodland was the initial area to be invaded. The prairies continue to exist only in the absence of overstory trees. Hierarchal cluster analysis detected the four main communities as open prairie, recently encroached prairie, former woodland/savanna with major shrub invasion, and closed canopy mesophytic forest with no prairie elements.

Table 17

Average stem density and average basal area for each bluff group.

Group	Type	Average Stem Density ha^{-1}	Average Basal Area (m2) ha^{-1}
1	Remnant Savanna: *J. virginiana*, *C. glabra*, *Q. stellata* with *L. maackii*	95,454.45	36.40

2	Sugar Maple: Bare/Litter with *A. saccharum*	25,911.08	32.25
3	Hill Prairie: Grass with *Q. velutina* and *F. americana*	59,950	30.85
4	Transition: *C. florida* and *C. canadensis*	13,266.69	15.70

In all vegetation types except the sugar maple type, regular prescribed fire would be beneficial. Experiments that assess the benefits and costs of burn frequency and seasonality would help the manager optimize restoration activities. At least annual burning is required until the woody stems decline to smaller numbers. As Gershom Flagg described in the area between 1817 and 1853, “the fire kills & checks the growth every year” and “the timber is all destroyed” (White, 2000) The ecological effects of fire in this system also support the use of annual fire. The treatment of invasive species is especially important with alterations to the canopy. Using herbicide to check the regrowth of invasives following cutting or fire will be essential to maintaining a resilient system. Fire is especially effective since stem density ranges between 13,267 and 95,454 stems ha^{-1} and cutting by hand would be labor intensive except at a small scale. There is little evidence to suggest that the hill prairies can persist into the future without significant management intervention to restore the processes that allowed grasses and forbs to dominate. Without management, hill prairies will be lost just as the savanna and woodland disappeared.

River Island Forest

The management of the river island forest is heavily influenced by the hydrological patterns of the Mississippi River (Yin, 1998). Rainfall and snowmelt provide volume to the flow level and are regulated by the Army Corps of Engineers to accommodate a variety of demand including maintaining adequate levels for barge traffic (Grubaugh & Anderson, 1989). Post river impoundment, sugar maple (*Acer saccharinum*) ascended to the primary position of ecological importance and the bottomland hardwoods declined significantly (Nelson & Sparks, 1998; Nelson et al., 1995). River island forest provides essential habitat to avian species along the Mississippi Flyway (Twedt & Loesch, 1999). Currently, the river island contains the forest with the highest amount of basal area at 85.5 m^2 ha^{-1} in the overstory the least amount in the shrub layer at 2.8, indicating that this forest is mature. However, the overstory contained the lowest diversity at 63.9% of the maximum potential diversity. Because *Lonicera maackii* is intolerant of flooding condition, it is not found on the river islands, elevating the shrub layer to the highest diversity at 93.7% of the maximum. In addition the seedling diversity was exceptional low at 6.6% of the maximum and the lowest of all four topographic positions, thus indicating a homogenizing influence is suppressing diversity with impacts lasting into the future. Due to the historical diversity found in the forest prior to river impoundment and the lack of current diversity, management activities should focus on restoring diversity, especially trees in the bottomland hardwood group. Regenerating hardwoods is hindered by an uncertain hydrological regime that could terminate a newly established cohort.

Stand regeneration methods in bottomland hardwood forests have been studied using seeds (Kroschel, King, & Keim, 2016), stump sprouts (Knapp, Olson, & Dey, 2017), cuttings, bare root, and containerized stock (Gardiner & Oliver, 2005). Due to the difficulty of achieving restoration targets and establishing trees, as evident in the 90% failure rate of the 1992 Wetlands Reserve Program in Mississippi, the restoration of functions and natural landscape patterns instead of narrowly defined reference conditions is a favored management approach (Groninger, 2005; Stanturf, Schoenholtz, Schweitzer, & Shepard, 2001). Defining restoration goals in realistic terms, utilizing ecological processes like the migration and establishment of volunteer vegetation, and integrating flexibility into the approach could increase the success rate of bottomland silviculture (Groninger, 2005).

Talus Slope Forest

The talus slope transition forest comprises the small percentage of the landscape and has been impacted by development activities. Stem density in the overstory (384.8 stems ha^{-1}) and shrub layer basal area (5.6 m^2 ha^{-1}) were highest on the talus slope, indicating that this forest may have the youngest cohort of the four topographic positions. The forest is dominated by a strong *Acer saccharum* component in the smaller diameter classes and *Quercus muehlenbergii* throughout the diameter distribution. Historically, this forest type is likely the most similar to pre-settlement conditions since, as Daniel Harmon Brush noted, "Great groves of sugar maples were common along the little streams that came down through the hills, from which came most of the sugar used by the settlers for many years." Interestingly, when comparing diversity from 1936 to 2017, the talus slope had the lowest consistency and the greatest density reduction from 1110 to 385 stem ha^{-1}. The change of diversity could be subject to the declining influence of fire as well as the maturation of the forest through the stages of stand development. Historic photographs from the 1800s show a sparse talus slope. This area was closest to the river and steam ships on the river would supply their fuelwood with the closest available resources. Fire would be regularly sparked by railways along the river and consume any newly established vegetation. Management of the talus slope has no clear mandate since it is a small area with steep slopes, except for tourism officials who have expressed interest in clearing views to the magnificent bluffs from the River Road.

Conclusion

Incorporating ecological history into stand prescriptions and forest restoration projects will strengthen the viability of the project and ensure continuity in historical trajectories. By doing so, mangers will create the most conservative approach to preserving biodiversity as rapidly changing conditions affect trends in forest development. As ecosystems advance into novel states in the absence of historic disturbance regimes, the manager must decide what percentage of the landscape can be representative of the desired conditions found in historical processes, structure, and composition. Each stand will require an assessment of historic and current conditions to determine when the departure from ecological baseline conditions began and how far the departure has progressed. Based on this information, stands can be optimal prioritized for management based on the ability and resources of the landowner.

REFERENCES

Abrams, M. D. (1992). Fire and the Development of Oak Forests. *BioScience, 42*(5), 346-353. doi:10.2307/1311781

Abrams, M. D., & Nowacki, G. J. (2008). Native Americans as active and passive promoters of mast and fruit trees in the eastern USA. *Holocene, 18*(7), 1123-1137. doi:10.1177/0959683608095581

Abrams, M. D., & Nowacki, G. J. (2015). Exploring the Early Anthropocene Burning Hypothesis and Climate-Fire Anomalies for the Eastern U.S. *Journal of Sustainable Forestry, 34*(1/2), 30-48. doi:10.1080/10549811.2014.973605

Alagona, P. S., Sandlos, J., & Wiersma, Y. F. (2012). Past imperfect: using historical ecology and baseline data for conservation and restoration projects in North America. Environmental Philosophy, 9(1), 49-70.

Anderson, R. C., Jones, S. L., & Swigart, R. (2006). Modifying Distance Methods to Improve Estimates of Historical Tree Density from General Land Office Survey Records. *The Journal of the Torrey Botanical Society*, *133*(3), 449-459.

Atlas Map Of Jersey County, Illinois. . (1872). Davenport, Iowa: Andreas, Lyter, & Co.,.

Bailey, B. G., Saunders, M. R., & Lowe, Z. E. (2011). *A cost comparison of five midstory removal methods.* Paper presented at the Proceedings of the 17th Central Hardwood Forest Conference. USDA Forest Service General Technical Report NRS-P-78. Northern Research Station, Newtown Square, Pennsylvania, USA.

Balaguer, L., Escudero, A., Martin-Duque, J. F., Mola, I., & Aronson, J. (2014). The historical reference in restoration ecology: re-defining a cornerstone concept. Biological Conservation, 176, 12-20.

Bartuszevige, A. M., & Gorchov, D. L. (2006). Avian seed dispersal of an invasive shrub. *Biological Invasions*, *8*(5), 1013-1022.

Batek, M. J., Rebertus, A. J., Schroeder, W. A., Haithcoat, T. L., Compas, E., & Guyette, R. P. (1999). Reconstruction of Early Nineteenth-Century Vegetation and Fire Regimes in the Missouri Ozarks. *Journal of Biogeography, 26*(2), 397-412. doi:10.2307/2656124

Beatty, S. W. (1984). Influence of microtopography and canopy species on spatial patterns of forest understory plants. *Ecology, 65*(5), 1406-1419.

Belsky, A. J., & Canham, C. D. (1994). Forest gaps and isolated savanna trees. *BioScience, 44*(2), 77-84.

Binkley, D., & Fisher, R. (2012). *Ecology and management of forest soils*: John Wiley & Sons.

Black, B. A., Ruffner, C. M., & Abrams, M. D. (2006). Native American influences on the forest composition of the Allegheny Plateau, northwest Pennsylvania. *Canadian Journal of Forest Research, 36*(5), 1266-1275. doi:10.1139/X06-027

Black, D. E. (2017). Managing Upland Oak Forests with Disturbance and the Implications for Non-native Species Invasions.

Bouldin, J. (2008). Some Problems and Solutions in Density Estimation from Bearing Tree Data: A Review and Synthesis. *Journal of Biogeography, 35*(11), 2000-2011. doi:10.2307/20143418

Bowman, D. M. J. S., Balch, J. K., Artaxo, P., Bond, W. J., Carlson, J. M., Cochrane, M. A., . . . Pyne, S. J. (2009). Fire in the Earth System. *Science, 324*(5926), 481-484. doi:10.2307/20493785

Briggs, J. M., Hoch, G. A., & Johnson, L. C. (2002). Assessing the rate, mechanisms, and consequences of the conversion of tallgrass prairie to Juniperus virginiana forest. *Ecosystems, 5*(6), 578-586.

Brose, P. H. (2010). Long-term effects of single prescribed fires on hardwood regeneration in oak shelterwood stands. *Forest Ecology and Management, 260*(9), 1516-1524. doi:10.1016/j.foreco.2010.07.050

Brose, P. H. (2014). Development of Prescribed Fire as a Silvicultural Tool for the Upland Oak Forests of the Eastern United States. *Journal of Forestry, 112*(5), 525-533. doi:10.5849/jof.13-088

Brose, P. H., Dey, D. C., Phillips, R. J., & Waldrop, T. A. (2013). A Meta-Analysis of the Fire-Oak Hypothesis: Does Prescribed Burning Promote Oak Reproduction in Eastern North America? *Forest Science, 59*(3), 322-334. doi:10.5849/forsci.12-039

Brugam, R. B., Kilburn, P. D., & Luecking, L. (2016). Pre-settlement Vegetation of Greene, Jersey and Macoupin Counties along the Prairie/Forest Border in Illinois. *Trans Ill State Acad Sci, 109*, 9-17.

Burns, R. M., & Honkala, B. H. (1990). *Silvics of north America* (Vol. 2): United States Department of Agriculture Washington, DC.

Camill, P., Jr, C. E. U., Teed, R., Geiss, C. E., Aldinger, J., Dvorak, L., . . . Walkup, K. (2003). Late-Glacial and Holocene Climatic Effects on Fire and Vegetation Dynamics at the Prairie-Forest Ecotone in South-Central Minnesota. *Journal of Ecology, 91*(5), 822-836. doi:10.2307/3599706

Castellano, S. M., & Gorchov, D. L. (2013). White-tailed deer (Odocoileus virginianus) disperse seeds of the invasive shrub, Amur honeysuckle (Lonicera maackii). *Natural Areas Journal, 33*(1), 78-80.

Charles, D. K. (1992). Woodland demographic and social dynamics in the American Midwest: Analysis of a burial mound survey. *World Archaeology, 24*(2), 175-197.

Chen, H. Y., & Matter, S. F. (2017). Quantification of Changes in Light and Temperature Associated with Invasive Amur Honeysuckle (Lonicera maackii). *American Midland Naturalist, 177*(1), 143-152.

Clarke, K. C., & Gaydos, L. J. (1998). Loose-coupling a cellular automaton model and GIS: long-term urban growth prediction for San Francisco and Washington/Baltimore. *International Journal of Geographical Information Science, 12*(7), 699-714. doi:10.1080/136588198241617

Clements, F. (1929). Combined Edition of Clements' Plant Succession and Plant Indicators. *Ecology, 10*(1), 164-165. doi:10.2307/1940523

Connell, J. H. (1978). Diversity in tropical rain forests and coral reefs - high diversity of trees and corals is maintained only in a non-equilibrium state. *Science, 199*(4335), 1302-1310. doi:10.1126/science.199.4335.1302

Connell, J. H. (1980). Diversity and the coevolution of competitors, or the ghost of competition past. *Oikos, 35*(2), 131-138. doi:10.2307/3544421

Cook, E. R. (2004). North American Summer PDSI Reconstructions. . Data Contribution Series # 2004-045.

Costanza, J. K., Faber-Langendoen, D., Coulston, J. W., & Wear, D. N. (2018). Classifying forest inventory data into species-based forest community types at broad extents:

exploring tradeoffs among supervised and unsupervised approaches. *Forest Ecosystems, 5*(1), 8.

Covington, W. W., & Moore, M. M. (1994). Postsettlement changes in natural fire regimes and forest structure: ecological restoration of old-growth ponderosa pine forests. *Journal of Sustainable Forestry, 2*(1-2), 153-181.

Craig, J. M., Lhotka, J. M., & Stringer, J. W. (2014). Evaluating Initial Responses of Natural and Underplanted Oak Reproduction and a Shade-Tolerant Competitor to Midstory Removal. *Forest Science, 60*(6), 1164-1171. doi:10.5849/forsci.13-602

Deines, J. M., Williams, D., Hamlin, Q., & McLachlan, J. S. (2016). Changes in Forest Composition in Ohio Between Euro-American Settlement and the Present. *American Midland Naturalist, 176*(2), 247-271. doi:10.1674/0003-0031-176.2.247

Delcourt, P. A., Delcourt, H. R., Ison, C. R., Sharp, W. E., & Gremillion, K. J. (1998). Prehistoric Human Use of Fire, the Eastern Agricultural Complex, and Appalachian Oak-Chestnut Forests: Paleoecology of Cliff Palace Pond, Kentucky. *American Antiquity, 63*(2), 263-278. doi:10.2307/2694697

Denevan, W. M. (1992). The pristine myth: the landscape of the Americas in 1492. *Annals of the Association of American Geographers, 82*(3), 369-385.

Dey, D. C., Kabrick, J. M., & Schweitzer, C. J. (2017). Silviculture to Restore Oak Savannas and Woodlands. *Journal of Forestry, 115*(3), 202-211. doi:10.5849/jof.15-152

Douglass, A. E. (1937). Tree rings and chronology.

Ellsworth, J. W., & McComb, B. C. (2003). Potential Effects of Passenger Pigeon Flocks on the Structure and Composition of Presettlement Forests of Eastern North America. *Conservation Biology, 17*(6), 1548-1558. doi:10.2307/3588903

Evans, T. P., & Kelley, H. (2008). Assessing the transition from deforestation to forest regrowth with an agent-based model of land cover change for south-central Indiana (USA). *Geoforum, 39*(2), 819-832. doi:10.1016/j.geoforum.2007.03.010

Evans, T. P., Manire, A., de Castro, F., Brondizio, E., & McCracken, S. (2001). A dynamic model of household decision-making and parcel level landcover change in the eastern Amazon. *Ecological Modelling, 143*(1-2), 95-113. doi:10.1016/s0304-3800(01)00357-x

Evers, R. A. (1955). Hill prairies of Illinois. *Illinois Nat Hist Surv Bull, 26*((5)), 367-446.

Fahey, R. T., Alveshere, B. C., Burton, J. I., D'Amato, A. W., Dickinson, Y. L., Keeton, W. S., . . . Puettmann, K. J. (2018). Shifting conceptions of complexity in forest management and silviculture. *Forest Ecology and Management, 421*, 59-71.

Fan, Z., Moser, W. K., Hansen, M. H., & Nelson, M. D. (2013). Regional patterns of major nonnative invasive plants and associated factors in Upper Midwest forests. Forest Science, 59(1), 38-49.

Fesenmyer, K. A., & Christensen, N. L., Jr. (2010). Reconstructing Holocene fire history in a southern Appalachian forest using soil charcoal. *Ecology, 91*(3), 662-670. doi:10.2307/25661100

Flatley, W. T., Lafon, C. W., Grissino-Mayer, H. D., & LaForest, L. B. (2015). Changing fire regimes and old-growth forest succession along a topographic gradient in the Great Smoky Mountains. *Forest Ecology and Management, 350*, 96-106. doi:http://dx.doi.org/10.1016/j.foreco.2015.04.024

Foster, D. R., Fluet, M., & Boose, E. (1999). Human or natural disturbance: landscape-scale dynamics of the tropical forests of Puerto Rico. *Ecological Applications, 9*(2), 555-572.

Foster, D. R., Orwig, D. A., & McLachlan, J. S. (1996). Ecological and conservation insights from reconstructive studies of temperate old-growth forests. *Trends in Ecology & Evolution, 11*(10), 419-424. doi:10.1016/0169-5347(96)10047-1

Foster, D. R., Zebryk, T., Schoonmaker, P., & Lezberg, A. (1992). Post-Settlement History of Human Land-Use and Vegetation Dynamics of a Tsuga Canadensis (Hemlock) Woodlot in Central New England. *Journal of Ecology, 80*(4), 773-786. doi:10.2307/2260865

Foster, T., Olsen, L., Dale, V., & Cohen, A. (2010). Studying the Past for the Future: Managing Modern Biodiversity from Historic and Prehistoric Data. *Human Organization, 69*(2), 149-157. doi:10.17730/humo.69.2.355u461568976672

Fralish, J. S. (1997). Community succession, diversity, and disturbance in the central hardwood forest *Conservation in highly fragmented landscapes* (pp. 234-266): Springer.

Fralish, J. S., Crooks, F. B., Chambers, J. L., & Harty, F. M. (1991). Comparison of Presettlement, Second-growth and Old-growth Forest on Six Site Types in the Illinois Shawnee Hills. *The American Midland Naturalist, 125*(2), 294-309. doi:10.2307/2426234

Fralish, J. S., & McArdle, T. G. (2009). Forest Dynamics across Three Century-Length Disturbance Regimes in the Illinois Ozark Hills. *American Midland Naturalist, 162*(2), 418-449. doi:10.2307/25602332

Frankie, W. T., & Mikulic, D. G. (2007). *Guide to the geology of the Pere Marquette State Park and surrounding area, Jersey and Madison counties, Illinois*. Illinois State Geological Survey, Illinois Department of Natural Resources.

Franklin, J. F., & Johnson, K. N. (2012). A Restoration Framework for Federal Forests in the Pacific Northwest. *Journal of Forestry, 110*(8), 429-439. doi:10.5849/jof.10-006

Frelich, L. E. (2002). *Forest dynamics and disturbance regimes: studies from temperate evergreen-deciduous forests*: Cambridge University Press.

Frelich, L. E., Jõgiste, K., Stanturf, J. A., Parro, K., & Baders, E. (2018). Natural Disturbances and Forest Management: Interacting Patterns on the Landscape *Ecosystem Services from Forest Landscapes* (pp. 221-248): Springer.

Fritts, H. (2012). *Tree rings and climate*: Elsevier.

Gardiner, E. S., & Oliver, J. M. (2005). Restoration of bottomland hardwood forests in Lower Mississippi Aluvial Valey, USA. *In: Stanturf, JA; Madsen, P. eds. Restoration of boreal and temperate forests. Restoration of bottomland hardwood forests in the Lower Mississippi Alluvial Valley, USA Boca Raton, FL: CRC Press. 235-251*.

Gill, J. L., Williams, J. W., Jackson, S. T., Lininger, K. B., & Robinson, G. S. (2009). Pleistocene Megafaunal Collapse, Novel Platn Communities, and Enhanced Fire Regimes in North America. *Science, 326*(5956), 1100-1103. doi:10.2307/27736485

Gobster, P. H. (2011). Factors affecting people's responses to invasive species management. Invasive and introduced plants and animals: human perceptions, attitudes and approaches to management, 249-263.

Goebel, T., Waters, M. R., & O'Rourke, D. H. (2008). The Late Pleistocene Dispersal of Modern Humans in the Americas. *Science, 319*(5869), 1497-1502.

Goymer, P., & Davis, C. (2017). Forest vision. *Nature Ecology & Evolution, 1*(3), 2. doi:10.1038/s41559-017-0097

Graves, H. S. (1910). *Protection of forests from fire* (Vol. 82): US Dept. of Agriculture, Forest Service.

Grayson, D. K. (1991). Late Pleistocene Mammalian Extinctions in North America: Taxonomy, Chronology, and Explanations. *Journal of World Prehistory, 5*(3), 193-231. doi:10.2307/25800598

Grayson, D. K., & Alroy, J. (2001). Did Human Hunting Cause Mass Extinction? *Science, 294*(5546), 1459-1462. doi:10.2307/3085108

Groninger, J. W. (2005). Increasing the impact of bottomland hardwood afforestation. *Journal of Forestry, 103*(4), 184-188.

Grubaugh, J., & Anderson, R. (1989). Long-term effects of navigation dams on a segment of the Upper Mississippi River. *Regulated Rivers: Research & Management, 4*(1), 97-104.

Guyette, R. P., Dey, D. C., & Stambaugh, M. C. (2003). Fire and human history of a barren-forest mosaic in southern Indiana. *American Midland Naturalist, 149*(1), 21-34. doi:10.1674/0003-0031(2003)149[0021:fahhoa]2.0.co;2

Guyette, R. P., Muzika, R. M., & Dey, D. C. (2002). Dynamics of an Anthropogenic Fire Regime. *Ecosystems, 5*(5), 472-486. doi:10.2307/3658900

Hansen, E. M., Hamm, P. B., & Campbell, S. J. (1990). Principles of integrated pest management. Growing healthy seedlings. Identification and management of pests in northwest forest nurseries. Corvallis, Oregon: Forest Research Laboratory, Oregon State Univ., Special Pub, 19, 92-105.Harper, J. L. (1967). A Darwinian approach to plant ecology. *Journal of animal ecology, 36*(3), 495-518.

Harper, J. L. (1977). Population biology of plants. *Population biology of plants.*

Hartman, K., & McCarthy, B. (2007). A dendro-ecological study of forest overstorey productivity following the invasion of the non-indigenous shrub Lonicera maackii. *Applied Vegetation Science, 10*(1), 3-14.

Hirschmugl, M., Deutscher, J., Gutjahr, K.-H., Sobe, C., & Schardt, M. (2017). *Combined use of SAR and optical time series data for near real-time forest disturbance mapping.* Paper presented at the Analysis of Multitemporal Remote Sensing Images (MultiTemp), 2017 9th International Workshop on the.

Historic Crests.   Retrieved from https://water.weather.gov/ahps2/crests.php?wfo=lsx&gage=alni2&crest_type=historic

Hobbs, R. J., Arico, S., Aronson, J., Baron, J. S., Bridgewater, P., Cramer, V. A., ... & Norton, D. (2006). Novel ecosystems: theoretical and management aspects of the new ecological world order. Global ecology and biogeography, 15(1), 1-7.

Holzmueller, E. J., Groninger, J. W., & Ruffner, C. M. (2014). Facilitating Oak and Hickory Regeneration in Mature Central Hardwood Forests. *Forests, 5*(12), 3344-3351. doi:10.3390/f5123344

Hosmer, C., & Williams, P. (1986). *Elsah: A Historic Guidebook* (Fith Edition ed.). Elsah, Illinois: Historic Elsah Foundation.

Jackson, S. T., & Hobbs, R. J. (2009). Ecological restoration in the light of ecological history. Science, 325(5940), 567-569.

Jackson, S. T., Whitehead, D. R., & Ellis, G. D. (1986). Late-Glacial and Early Holocene Vegetational History at the Kolarik Mastodon Site, Northwestern Indiana. *American Midland Naturalist, 115*(2), 361-373. doi:10.2307/2425872

Johnson, C. N. (2009). Ecological Consequences of Late Quaternary Extinctions of Megafauna. *Proceedings: Biological Sciences, 276*(1667), 2509-2519. doi:10.2307/30245035

Kilburn, P.D., Tutterow, B., & Brugam, R. B. (2009). The Tree Species Composition and History of Barrens Identified by Government Land Surveyors in Southwestern Illinois. *Journal of the Torrey Botanical Society, 136*(2), 272-283. doi:10.2307/27751799

Kilburn, P. D. (1970). *Hill prairie restoration.* Paper presented at the Proceedings of a symposium of prairie and prairie restoration. Knox College, Galesburg, Illinois.

Kilburn, P. D., & Brugam, R. B. (2010). *How Natural is Nature?: The Effect of Burning on Presettlement Vegetation in West-central Illinois*: Lindenwood University Press.

Kilburn, P. D., & Warren, D. (1963). Vegetation-soil relationships in hill prairies. *Transactions of the Illinois State Academy of Science, 56*, 142-145.

Kirkman, L. K., Mitchell, R. J., Kaeser, M. J., Pecot, S. D., & Coffey, K. L. (2007). The perpetual forest: using undesirable species to bridge restoration. *Journal of Applied Ecology, 44*(3), 604-614. doi:10.1111/j.1365-2664.2007.01310.x

Knapp, B. O., Olson, M. G., & Dey, D. C. (2017). Early Stump Sprout Development after Two Levels of Harvest in a Midwestern Bottomland Hardwood Forest. *Forest Science, 63*(4), 377-387. doi:10.5849/fs-2016-029r2

Knapp, B. O., Stephan, K., & Hubbart, J. A. (2015). Structure and composition of an oak-hickory forest after over 60 years of repeated prescribed burning in Missouri, U.S.A. *Forest Ecology and Management, 344*, 95-109. doi:http://dx.doi.org/10.1016/j.foreco.2015.02.009

Kolbe, S. E., Townsend-Small, A., Miller, A. I., Culley, T. M., & Cameron, G. N. (2015). Effect of Lonicera maackii on Soil Carbon and Nitrogen in Southwestern Ohio Forests. *Invasive Plant Science and Management, 8*(4), 375-384. doi:10.1614/ipsm-d-15-00010.1

Kroeber, A. L. (1934). Native American Population. *American Anthropologist, 36*(1), 1-25. doi:10.2307/661755

Kroschel, W. A., King, S. L., & Keim, R. F. (2016). Tree Regeneration by Seed in Bottomland Hardwood Forests: A Review. *Southeastern Naturalist, 15*, 42-60. doi:10.1656/058.015.sp907

LANDFIRE, 2010, Mean Fire Return Interval Layer, LANDFIRE 1.2.0, U.S. Department of the Interior, Geological Survey. Accessed 29 August 2018 at https://www.landfire.gov/version_comparison.php.

Leahy, M. J., Vining, I. W., Villwock, J. L., Wesselschmidt, R. O., Schuhmann, A. N., Vogel, J. A., . . . Maginel, C. J. (2017). Short-term efficacy and nontarget effects of aerial glyphosate applications for controlling Lonicera maackii (Amur honeysuckle) in oak-hickory forests of Eastern Missouri, USA. *Restoration Ecology*.

Lett, M. S., & Knapp, A. K. (2003). Consequences of shrub expansion in mesic grassland: resource alterations and graminoid responses. *Journal of Vegetation Science, 14*(4), 487-496.

Liu, S., Sheppard, A., Kriticos, D., & Cook, D. (2011). Incorporating uncertainty and social values in managing invasive alien species: a deliberative multi-criteria evaluation approach. Biological Invasions, 13(10), 2323.

Lorimer, C. G. (1980). Age Structure and Disturbance History of a Southern Appalachian Virgin Forest. *Ecology, 61*(5), 1169-1184. doi:10.2307/1936836

MacDougall, A. (2003). Guest Editorial: Did Native Americans Influence the Northward Migration of Plants during the Holocene? *Journal of Biogeography, 30*(5), 633-647. doi:10.2307/3554477

Mather, A. (2001). Agricultural Technologies and Tropical Deforestation, eds Angelsen A, Kaimowitz D: CABI Publishing, Wallingford, UK.

McClain, W. E., & Anderson, E. A. (1990). Loss of hill prairie through woody plant invasion at Pere Marquette State Park, Jersey County, Illinois USA. *Natural Areas Journal, 10*(2), 69-75.

McClain, W. E., & Ebinger, J. E. (2012). Flora of Twin Shelters and Twin Mounds Hill Prairies, Pere Marquette State Park, Jersey County, Illinois, Changes Since 1963. *Transactions of the Illinois State Academy of Science, 105*(1-2), 11-18.

McClain, W. E., Moorehouse, A. C., & Ebinger, J. E. (2009). Loss of Hulsebus Loess Hill Prairie, Henderson County, Illinois to Woody Plant Invasion. *Transactions of the Illinois State Academy of Science, 102*(3-4), 141-147.

McCune, B., Grace, J. B., & Urban, D. L. (2002). *Analysis of Ecological Communities*: MjM Software Design.

McEwan, R. W., Dyer, J. M., & Pederson, N. (2011). Multiple interacting ecosystem drivers: toward an encompassing hypothesis of oak forest dynamics across eastern North America. *Ecography, 34*(2), 244-256. doi:10.1111/j.1600-0587.2010.06390.x

McEwan, R. W., & McCarthy, B. C. (2008). Anthropogenic disturbance and the formation of oak savanna in central Kentucky, USA. *Journal of Biogeography, 35*(5), 965-975. doi:10.1111/j.1365-2699.2007.01857.x

McTaggert, S. (2017). Illinois Wildlife Action Plan: Farmland and Prairie. Retrieved from https://www.dnr.illinois.gov/conservation/IWAP/Pages/ForestandWoodlands.aspx https://www.dnr.illinois.gov/conservation/IWAP/Pages/FarmlandandPrairie.aspx

Messina, J. P., & Walsh, S. J. (2001). *Simulating land use and land cover dynamics in the Ecuadorian Amazon through cellular automata approaches and an integrated GIS.* Paper presented at the Open Meeting of the Human Dimensions of Global Environmental Change Research Community in Rio de Janeiro, Brazil.

Miller, G. W., Brose, P. H., & Gottschalk, K. W. (2017). Advanced Oak Seedling Development as Influenced by Shelterwood Treatments, Competition Control, Deer Fencing, and Prescribed Fire. *Journal of Forestry, 115*(3), 179-189. doi:10.5849/jof.16-002

Miller, R. B. (1920). Fire prevention in Illinois forests. *Illinois Natural History Survey Circular; no. 11*.

Morris, J. L., Mueller, J. R., Nurse, A., Long, C. J., & McLauchlan, K. K. (2014). Holocene fire regimes, vegetation and biogeochemistry of an ecotone site in the Great Lakes Region of North America. *Journal of Vegetation Science, 25*(6), 1450-1464. doi:10.2307/24035584

Moser, W. K., Leatherberry, E. C., Hansen, M. H., & Butler, B. J. (2009). Farmers' objectives toward their woodlands in the upper Midwest of the United States: implications for woodland volumes and diversity. *Agroforestry Systems, 75*(1), 49-60. doi:10.1007/s10457-008-9124-7

Nelson, J. C., & Sparks, R. E. (1998). *Forest compositional change at the confluence of the Illinois and Mississippi Rivers*: US Geological Survey, Environmental Management Technical Center.

Nelson, J. C., Redmond, A., & Sparks, R. E. (1995). *Impacts of settlement on floodplain vegetation at the confluence of the Illinois and Mississippi Rivers*: National Biological Survey, Environmental Management Technical Center.

Nelson, J. C., Sparks, R. E., DeHaan, L., & Robinson, L. (1998). Presettlement and contemporary vegetation patterns along two navigation reaches of the Upper Mississippi River. *Perspectives on the land-use history of North America: a context for understanding our changing environment. US Geological Survey, Biological Resources Division. USGS/BRD/BSR-1998-0003*, 51-60.

Nelson, J. L., Groninger, J. W., Ruffner, C. M., & Battaglia, L. L. (2009). Past Land Use, Disturbance Regime Change, and Vegetation Response in a Southern Illinois Bottomland Conservation Area. *Journal of the Torrey Botanical Society, 136*(2), 242-256. doi:10.2307/27751797

Ness, G. D., Drake, W. D., & Brechin, S. R. (1993). Population-environment dynamics: ideas and observations.

Nowacki, G. J., & Abrams, M. D. (2008). The Demise of Fire and "Mesophication" of Forests in the Eastern United States. *BioScience, 58*(2), 123-138. doi:10.1641/B580207

Nowacki, G. J., & Abrams, M. D. (2015). Is climate an important driver of post-European vegetation change in the Eastern United States? *Global Change Biology, 21*(1), 314-334. doi:10.1111/gcb.12663

Nuttle, T., Royo, A. A., Adams, M. B., & Carson, W. P. (2013). Historic disturbance regimes promote tree diversity only under low browsing regimes in eastern deciduous forest. *Ecological Monographs, 83*(1), 3-17. doi:10.2307/23596739

Nyboer, R., & Edgin, B. (2017). Vegetation Management Guideline Bush Honeysuckles: Tartarian, Morrow's, Belle, and Amur Honeysuckle (Lonicera tatarica L., L. morrowii Gray, L. x bella Zabel, and L. maackii (Rupr.) Maxim.). Retrieved from https://www.dnr.illinois.gov/INPC/Documents/VMG/VMG%20Bush%20honeysuckle%20revised%202007%20-%20Copy.pdf

Oliver, C. D. (1980). Forest development in North America following major disturbances. *Forest Ecology and Management, 3*, 153-168. doi:http://dx.doi.org/10.1016/0378-1127(80)90013-4

Oliver, C. D., & Larson, B. C. (1990). *Forest stand dynamics*: McGraw-Hill, Inc.

Owens, N. L., & Cole, G. N. (2003). 25 Years of vegetational changes in a glacial drift hill prairie community in east-central Illinois. *Transactions of the Illinois State Academy of Science, 96*(Supplement), 49-50.

Parker, G. R., & Ruffner, C. M. (2004). Current and historical forest conditions and disturbance regimes in the Hoosier-Shawnee Ecological Assessment Area.

Peck, J. E. (2010). *Multivariate Analysis for Community Ecologists: Step-by-step Using PC-ORD*: MjM Software Design.

Perz, S. G. (2007). Grand theory and context-specificity in the study of forest dynamics: Forest transition theory and other directions. *Professional Geographer, 59*(1), 105-114. doi:10.1111/j.1467-9272.2007.00594.x

Peterson, D. W., Reich, P. B., & Wrage, K. J. (2007). Plant Functional Group Responses to Fire Frequency and Tree Canopy Cover Gradients in Oak Savannas and Woodlands. *Journal of Vegetation Science, 18*(1), 3-12. doi:10.2307/4499193

Puettmann, K. J., Coates, K. D., & Messier, C. C. (2012). *A critique of silviculture: managing for complexity*: Island press.

Pyne, S. J. (2017). *Fire in America: a cultural history of wildland and rural fire*: University of Washington Press.

Reich, P., Walters, M., & Ellsworth, D. (1991). Leaf age and season influence the relationships between leaf nitrogen, leaf mass per area and photosynthesis in maple and oak trees. *Plant, Cell & Environment, 14*(3), 251-259.

Rhemtulla, J. M., Mladenoff, D. J., & Clayton, M. K. (2007). Regional land-cover conversion in the US upper Midwest: magnitude of change and limited recovery (1850-1935-1993). *Landscape Ecology, 22*, 57-75. doi:10.1007/s10980-007-9117-3

Riechman, J. A., Park, L. O., Ruffner, C. M., & Groninger, J. W. (2014). Challenges and Motivations behind Sustaining a Volunteer-Based Forest Management Organization: A Case Study of the Southeastern Illinois Prescribed Burn Association. *Journal of Forestry, 112*(2), 215-220. doi:10.5849/jof.12-110

Ripple, W. J., & Valkenburgh, B. V. (2010). Linking Top-down Forces to the Pleistocene Megafaunal Extinctions. *BioScience, 60*(7), 516-526. doi:10.1525/bio.2010.60.7.7

Robertson, K. R., Schwartz, M. W., Olson, J. W., Dunphy, B. K., & Clarke, H. D. (1995). 50 Years of change in Illinois hill prairies. *Erigenia: Journal of the Illinois Native Plant Society*(14), 41-52.

Robertson, P. A. (1992). Factors Affecting Tree Growth on Three Lowland Sites in Southern Illinois. *American Midland Naturalist, 128*(2), 218-236. doi:10.2307/2426456

Robinson, G. S., Burney, L. P., & Burney, D. A. (2005). Landscape Paleoecology and Megafaunal Extinction in Southeastern New York State. *Ecological Monographs, 75*(3), 295-315. doi:10.2307/4539101

Ross, C. (1974). *A historical Investigation of the Disappearance of the Native Prairie in the Elsah Area of Central Illinois*. A 401 Project. Biology Department. Principia College.

Roy, N., Bhiry, N., Woollett, J., & Delwaide, A. (2017). A 550-year record of the disturbance history of white spruce forests near two Inuit settlements in Labrador, Canada. *Journal of the North Atlantic*(31), 1-14.

Ruffner, C. M., & Groninger, J. W. (2004). *Oak ecosystem restoration and maintenance in southern Illinois.* Paper presented at the Upland Oak Ecology Symposium. Edited by MA Spetich. US For. Serv. Gen. Tech. Rep. SRS-73.

Ruffner, C. M., & Groninger, J. W. (2006). Making the case for fire in southern Illinois forests. *Journal of Forestry, 104*(2), 78-83.

Sample, V. A. (2018). Ecological Forest Management. *Journal of Forestry*.

Schramm, P. (1978). *The" do's and don'ts" of prairie restoration.* Paper presented at the 5th Midwest prairie conference proceedings, Midwest prairie conference, Ames, IA. Ames, IA: Iowa State University.

Schramm, P. (1990). *Prairie restoration: a twenty-five year perspective on establishment and management.* Paper presented at the Proceedings of the Twelfth North American Prairie Conference.

Schulz, K. E., Wright, J., & Ashbaker, S. (2012). Comparison of invasive shrub honeysuckle eradication tactics for amateurs: stump treatment versus regrowth spraying of Lonicera maackii. *Restoration Ecology, 20*(6), 788-793.

Schwartz, M. W., Robertson, K. R., Dunphy, B. K., Olson, J. W., & Trame, A. M. (1997). *The biogeography of and habitat loss on hill prairies*.

Shields, J. M., Saunders, M. R., Gibson, K. D., Zollner, P. A., Dunning, J. B., & Jenkins, M. A. (2015). Short-Term Response of Native Flora to the Removal of Non-Native Shrubs in

Mixed-Hardwood Forests of Indiana, USA. *Forests, 6*(6), 1878-1896. doi:10.3390/f6061878

Shotola, S. J., Weaver, G. T., Robertson, P. A., & Ashby, W. C. (1992). Sugar Maple Invasion of an Old-growth Oak-hickory Forest in Southwestern Illinois. *American Midland Naturalist, 127*(1), 125-138. doi:10.2307/2426328

Shumway, J. M., & Jackson, R. H. (1995). Native American Population Patterns. *Geographical Review, 85*(2), 185-201. doi:10.2307/216062

Skalos, J., Engstova, B., Trpakova, I., Santruckova, M., & Podrazsky, V. (2012). Long-term changes in forest cover 1780-2007 in central Bohemia, Czech Republic. *European Journal of Forest Research, 131*(3), 871-884. doi:10.1007/s10342-011-0560-y

Stage, A. R., & Salas, C. (2007). Interactions of elevation, aspect, and slope in models of forest species composition and productivity. *Forest Science, 53*(4), 486-492.

Stambaugh, M. C., Marschall, J. M., & Guyette, R. P. (2014). Linking fire history to successional changes of xeric oak woodlands. *Forest Ecology and Management, 320*, 83-95. doi:http://dx.doi.org/10.1016/j.foreco.2014.02.022

Stanturf, J. A., Schoenholtz, S. H., Schweitzer, C. J., & Shepard, J. P. (2001). Achieving restoration success: myths in bottomland hardwood forests. *Restoration Ecology, 9*(2), 189-200.

Swetnam, T. W., Allen, C. D., & Betancourt, J. L. (1999). Applied historical ecology: using the past to manage for the future. Ecological applications, 9(4), 1189-1206.

Sylvester, F. O. (1911). *The Great River: Poems and Pictures*: Publishers' Press.

Taft, J. B., & Kron, Z. P. (2014). Evidence of Species and Functional Group Attrition in Shrub-encroached Prairie: Implications for Restoration. *American Midland Naturalist*, *172*(2), 252-265.

Thompson, J. R., Carpenter, D. N., Cogbill, C. V., & Foster, D. R. (2013). Four Centuries of Change in Northeastern United States Forests. *PLoS ONE, 8*(9). doi:10.1371/journal.pone.0072540

Toivanen, T., & Kotiaho, J. S. (2007). Mimicking natural disturbances of boreal forests: the effects of controlled burning and creating dead wood on beetle diversity. *Biodiversity and Conservation, 16*(11), 3193-3211.

Turner, L. M. (1936). Ecological Studies in the Lower Illinois River Valley. *Botanical Gazette, 97*(4), 689-727. doi:10.2307/2471523

Turner, M. G., Baker, W. L., Peterson, C. J., & Peet, R. K. (1998). Factors Influencing Succession: Lessons from Large, Infrequent Natural Disturbances. *Ecosystems, 1*(6), 511-523. doi:10.2307/3658752

Twedt, D. J., & Loesch, C. R. (1999). Forest area and distribution in the Mississippi Alluvial Valley: implications for breeding bird conservation. *Journal of Biogeography*, *26*(6), 1215-1224.

VanDeelen, T. R., Pregitzer, K. S., & Haufler, J. B. (1996). A comparison of presettlement and present-day forests in two northern Michigan deer yards. *American Midland Naturalist, 135*(2), 181-194.

Vander-Yacht, A. L., Barrioz, S. A., Keyser, P. D., Harper, C. A., Buckley, D. S., Buehler, D. A., & Applegate, R. D. (2017). Vegetation response to canopy disturbance and season of burn during oak woodland and savanna restoration in Tennessee. *Forest Ecology and Management, 390*, 187-202. doi:10.1016/j.foreco.2017.01.029

Vestal, A. G. (1918). Local inclusions of prairie within forest. *Transactions of the Illinois State Academy of Science, 11*, 122-126.

Ward, J. S. (2015). Improving Competitive Status of Oak Regeneration Using Stand Management and Prescribed Fires. *Journal of Sustainable Forestry, 34*(1/2), 105-124. doi:10.1080/10549811.2014.973606

Web Soil Survey. (2017). Retrieved from https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

Wenger, K. F. (Ed.). (1984). Forestry handbook (Vol. 84, No. 1). John Wiley & Sons.

Western, D. (2018). Conservation for the Twenty-first Century.

White, J. (Ed.) (2000). *Early Accounts of the Ecology of the Big Rivers Area* (Vol. 5). Urbana, IL: State of Illinois.

Whitlock, C., Colombaroli, D., Conedera, M., & Tinner, W. (2018). Land-use history as a guide for forest conservation and management. *Conservation Biology, 32*(1), 84-97. doi:10.1111/cobi.12960

Whitney, G. G. (1994). *From Coastal Wilderness to Fruited Plain: A History of Environmental Change in Temperate North America From 1500 to the Present*. Cambridge, Great Britain: Cambridge University Press.

Williams, M. (1989). *Americans and Their Forests: A Historical Geography*. Cambridge: Press Syndicate of the University of Cambridge.

Xing, D., Nielsen, S. E., Macdonald, S. E., Spence, J. R., & He, F. (2018). Survival and growth of residual trees in a variable retention harvest experiment in a boreal mixedwood forest. *Forest Ecology and Management, 411*, 187-194. doi:10.1016/j.foreco.2018.01.026

Yin, Y. (1998). Flooding and forest succession in a modified stretch along the Upper Mississippi River. *Regulated Rivers: Research & Management: An International Journal Devoted to River Research and Management, 14*(2), 217-225.

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