The Geographical Bulletin

Volume 56 | Issue 2 Article 2

2024

Quantifying Forest Structure Within Two Managed Units in Rock Cut State Park

Dustin P. Bergman
Northern Illinois University

David Goldblum
University of Calgary, david.goldblum@ucalgary.ca

Quantifying Forest Structure Within Two Managed Units in Rock Cut State Park

Dustin P. Bergman
Department of Geography
Northern Illinois University
DeKalb, IL 60115

*David Goldblum**
Department of Geography
University of Calgary
Calgary, AB T2N 1N4 CANADA
E-mail: david.goldblum@ucalgary.ca

** Corresponding Author*

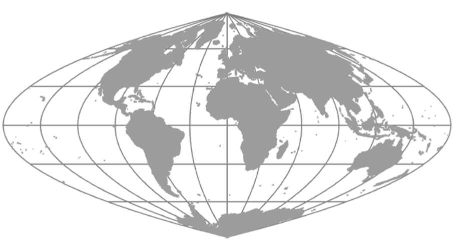
ABSTRACT

The 1251 ha Rock Cut State Park (RCSP) is the largest state park in northern Illinois. Over the past 56 years, management practices have included prescribed burning, regular mowing, and tree plantings. Specifically, we sought to quantify the species composition, age structure, and light environment in two management units within the park. The first unit (campground) was last burned in 2009 and is comprised of primarily small trees; the second unit (Willow Creek Natural Area – WCNA) is more open and relatively undisturbed with larger trees. To assess these two units we used several methods, including stand structure analysis, tree coring, and hemispherical photographs. Between the months of June-August (2012 and 2013), eight plots were delineated and sampled. Within the campground unit, median tree age was 52.5 years, with a maximum age of approximately 130 years. This site is mostly dominated by young slippery elm (*Ulmus rubra)* followed by white oak (*Quercus alba*) and hickory (*Carya spp*.). Elimination of landscape-scale fires has likely led to a conversion from oak savanna to the closed forest found today at RCSP. High densities of shade-tolerant species dominating WCNA suggest management fires have been insufficient at maintaining white and bur oak regeneration.

Key words: oak-savanna, Midwest, white oak, fire, restoration

INTRODUCTION

During the last 11,700 years, the earth has been experiencing a warming period known as the Holocene (Pielou 1991). Early Holocene climactic shifts brought about an increased frequency of dry Pacific air masses across the northern Great Plains region causing warming and drying (Baker et al. 1992, Bartlein et al. 1992). From the early Holocene to 5500 yr. B.P., tropical



The Geographical Bulletin 56: 79-92

air from the Gulf of Mexico prevented the Pacific air mass from reaching portions of Wisconsin and Illinois; this allowed for the conversion of xeric to mesic conditions and the formation of deciduous forests. (Winkler et al. 1985, Baker et al. 1992). Taking into account a brief wet. Between 6500 and 6000 yr. B.P. (Bartlein et al. 1984), maritime air began to decrease around 5500 B.P. and Pacific air extended east (Baker et al. 1992). The warming that occurred through southern Wisconsin and northern Illinois resulted in an increase in fire frequency that led to a conversion from mesophytic forests to oak savannas (Winkler et al. 1986, Baker et al. 1992, Anderson 1998). It was not until after 3000 yr. B.P. that Arctic air increased and allowed forests to shift south throughout the Midwest (Baker et al. 1992), where a cooler climate allowed the conversion of savannas to closed oak forests (Abrams 1992). According to Baker et al. (1992), the modern prairie-forests we see today are largely a result of frequent, dry, Pacific air masses.

Oak savannas are one of North America's rarest ecosystems, forming the primary ecotone between temperate deciduous forests to the east and tallgrass prairies to the west (Nuzzo 1986). This is a community commonly defined by a ground layer of forbs and grasses, and an open matrix of trees (Nuzzo 1986) primarily dominated by bur oak (*Quercus macrocarpa)*, black oak (*Quercus velutina)*, white oak (*Quercus alba)*, northern pin oak (*Quercus ellipsoidalis)*, post oak (*Quercus stellata)*, and blackjack oak (*Quercus marilandica)* (Abrams 1992). Oak savannas are characterized by open-grown, fire-tolerant trees (Anderson 1998). Due to the traits of the dominant tree species, the Midwestern oak savanna is highly sensitive to climate fluctuations dictated by three predominant air masses: a warm, dry, Pacific air mass that dominates prairies; a warm tropical air mass from the Gulf of Mexico that provides summer humidity and supports deciduous forests; and a northern continental Arctic air mass conducive to conifer-hardwood forests (Baker et al. 1992).

At the time of European settlement, approximately 11-13 million ha of oak savanna existed in the Midwest, with only 0.02% of original oak savannas remaining today (Nuzzo 1986). Following European settlement, North American ecosystems, particularly oak savannas, experienced extensive land modification through logging, land clearing, exotic disease, insect infestation, and widespread catastrophic fires, which were then followed by fire suppression (Abrams 1992, Abrams 2003). Because oak savannas are highly sensitive to environmental factors such as climate, topography, and fire (Anderson 1998), post-European settlement allowed for the encroachement of mesophytic tree species (i.e., hickory, cherry, maple) into former oak savannas (Nuzzo 1986, Anderson 1998). Subsequently, the few remnant oak savannas existing today have been highly modified and/or exist in areas unsuitable for farming (Asbjornsen et al. 2007).

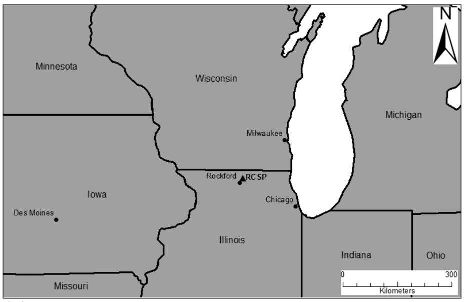
Fire suppression following European settlement led to a shift from oak savanna communities to more shade-tolerant closed canopy mesic forest communities, which further reduced the frequency of low-intensity surface fires (Abrams 1992). This has produced what Abrams (2003) refers to as a "bottleneck" between white oak seedling and sapling regeneration (c.f. Nowacki et al. 1990) – a population drastically reduced by a selective pressure. Although white oaks are well-adapted for moderate light levels (Burns and Honkala 1990), as evidenced by their recruitment in canopy gaps, they grow slowly in densely shaded conditions dominated by late successional species (Abrams 2003). Therefore, strong competition now pressures oak seedlings, as late successional, gap-opportunistic trees cover all but the driest and most nutrient-poor sites (Abrams 2003).

Given the pre-settlement dominance of oaks in the region, their ecological importance, and documented lack of regeneration in areas formerly dominated by oak savannas, assessing the current status of oaks is important for management purposes. Therefore, the objectives of this study are to assess the oak regeneration status within RCSP, quantify the age/size structure of forest trees, describe species composition, and provide a foundation for management so measures can be taken to assure the continued presence of oaks in RCSP.

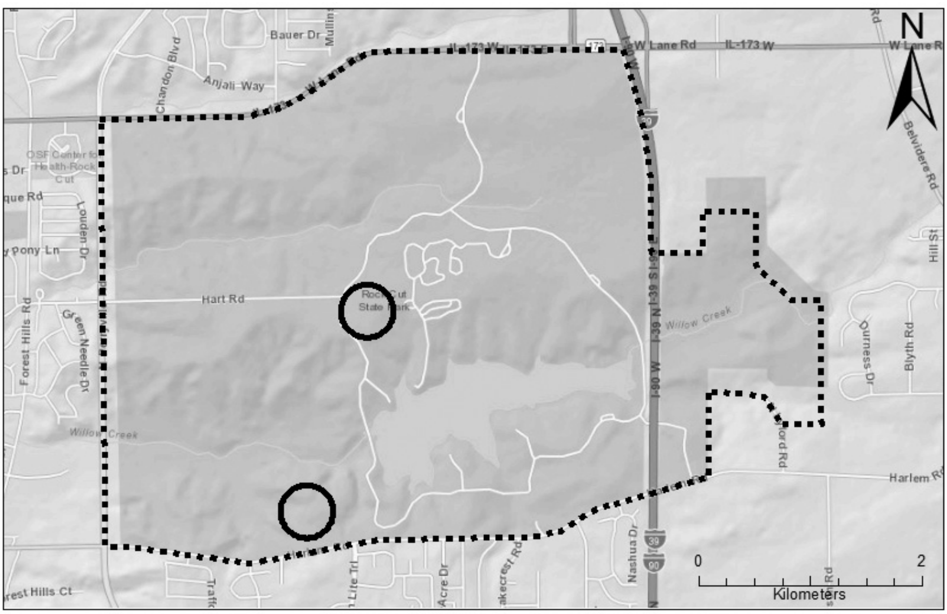
STUDY AREA/METHODS

The area known as Rock Cut State Park (RCSP), located 15 km north of Rockford, Illinois (Fig. 1a), was originally inhabited by Native Americans preceding the Black Hawk War (1832), and later colonized by Scots, Canadians, New Yorkers, and New Englanders (IDNR 2013). Since acquiring it 1957, the Illinois Department of Natural Resources (IDNR) has been responsible for land and wildlife management in the park (IDNR 2013). Over the past 56 years, management practices have included prescribed burning, regular mowing, and tree plantings. However, little research has been conducted to assess the current demographic and regeneration status of the forest communities in the Park.

Within RCSP, we sought to quantify the species composition, age structure, and understory light environment in two management units. To achieve this, we employed several methods including plot surveys, tree coring, and hemispherical photographs. In the summers of 2012 and 2013, we delineated and sampled eight randomly located plots within two management units (Fig. 1b). The first site



(a)



(b)

Figure 1. Map of study area, (a) Great Lakes region with location of RCSP (triangle); (b) Dashed line represents RCSP boundary, north circle is location of campground, and south circle is location of WCNA.

is located in the Willow Creek Natural Area of the park (WCNA). Prior burning attempts by the IDNR have been relatively unsuccessful, since this generally north-facing area is fairly mesic. Our second site, referred to as "campground," is a relatively flat area of RCSP located near the campground and south of the Plum Grove Nature Preserve. The campground site was last burned by the IDNR in 2009, and follows a 2-3 year burning schedule (no detailed IDNR burn records before 2007); however, climatic fluctuations and moisture content alter seasonal burning schedules.

Climate

In the last century, droughts in the mid to eastern United States have become less frequent and less severe (McEwan et al. 2011). More specifically, since 1950, Northwestern Illinois (Illinois Climate Division 1) has experienced a precipitation increase of +1.5 cm/decade, an average temperature increase of +0.5°C/decade, and a Palmer Drought Severity Index (PDSI) increase of +0.24/decade (NOAA.gov). According to the National Oceanic and Atmospheric Administration (2014), normal climate conditions for this region (1981-2010) include an average annual precipitation of 92 cm, including 93.2 cm of snowfall (premelt), and an average mean air temperature of 9.6° C. Climatic fluctuations, from severe, frequent, and prolonged droughts, to a period of increased moisture availability and cooler summer temperatures (McEwan et al. 2011), in addition to a lack of burning, have paved the way for a shifting understory community.

Field Methods

Within the campground site, we delineated three 15 m x 15 m and two 20 m x 20 m plots. The first plot was chosen at random while subsequent plots were selected by following a constant heading off each plot with 50 m spacing. In the WCNA, three 30 m x 30 m plots were created. The first plot in the WCNA was chosen at random; the second and third plots were placed 50 m to the west and east of the first plot. Within each plot, a species inventory was used to establish overall forest structure and composition. Diameter at breast height (dbh) measurements were taken of all trees ≥5 cm dbh, and those trees were cored at ≈30 cm using an increment borer. Extracted tree cores were allowed to air dry then glued to wood mounts. Once dry, we sanded the cores to aid in accurate interpretation and counted tree rings for age determination. Tree cores were not crossdated, but previous studies in the region (Goldblum, unpublished data) find annual ring production is highly reliable. Furthermore, age counts were not corrected for age to coring height (due to lack of harvestable seedlings), thus ages presented are minimum ages.

In addition, eight hemispherical photographs were taken within the campground site, and eight hemispherical photographs were taken within the WCNA site. Hemispherical photographs were taken at 1 m height in each quadrant of the plots to establish understory light levels. Within the campground site, saplings were counted (<5 cm dbh and >30 cm in height) in two 20 m x 20 m plots due to low understory density. In one WCNA plot, to assure an accurate census of a dense sapling layer, we counted the number of saplings in a transect 1 m x 42.5 m. Area sampled within the campground unit totaled 1,475 m^2 and 2700 m^2 was sampled in the WCNA unit. Variation in sampling area/design was due to tree density and accessibility. We obtained the 1837 Government Land Office (GLO) surveys to describe past vegetation. Additionally, we used a 1939 aerial photograph that allowed us to contrast conditions before and after acquisition.

We used Pearson correlation to establish age/size significance to determine if tree dbh alone could be used to assess future growth rates rather than undertaking time-consuming tree coring. Using Gap Light Analyzer 2.0 software[1], we quantified canopy openness per plot using the averages of our hemispherical photos. Individual images were first loaded into Gap Light Analyzer to transform color images to black and white and a value was then generated representing understory light availability. The amount of available light has been shown to be related to understory conditions where oak seedlings establish communities in degraded and restored oak savannas (Brudvig and Asbjornsen 2009).

RESULTS

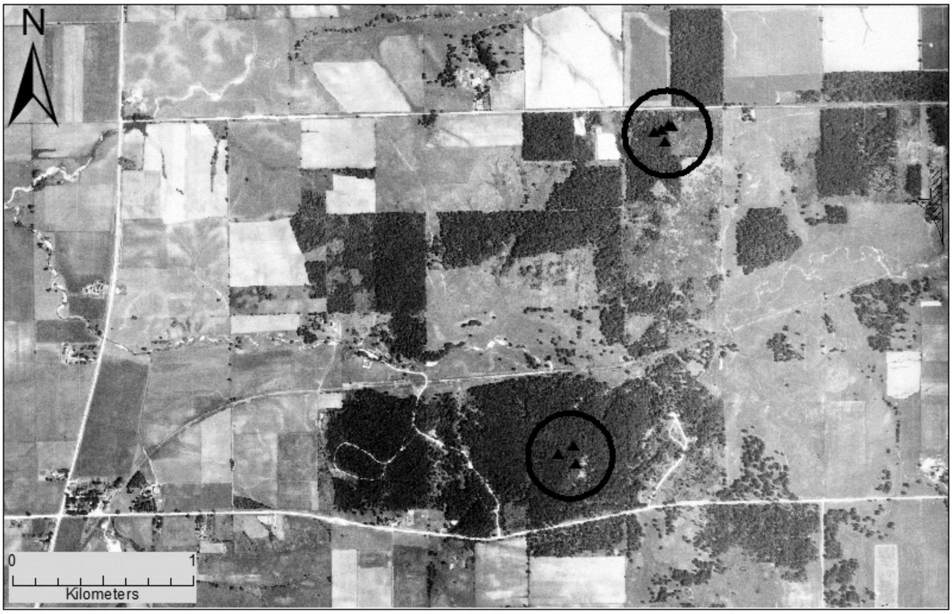
According to 1837 General Land Office (GLO) surveys encompassing RCSP, section 27 of T45N, R2E, contained timber primarily composed of white and bur oak with scattered black oak (*Quercus* spp.). Most of the timber described by surveyors was deemed "second rate" or of "poor quality" for harvest. Land descriptions varied as surveyors fully evaluated section 27 and include: land that was hilly and not suitable for cultivation, land with rolling hills and prairie, broken, wet, soil suitable and not suitable for cultivation. Based on the 1939 aerial imagery (Fig. 2a), the WCNA appears to be a closed canopy forest untouched by agriculture; alternatively, the campground is less vegetated and segmented by agriculture or grazing. The 2006 aerial photograph revels the WCNA has experienced minimal change since 1939, while vegetation in the campground has expanded significantly (Fig. 2b).

In contrast to the 1837 survey, the campground site was dominated by young slippery elm (*Ulmus rubra)* (Fig. 3b) followed by a broad age distribution of white oak (*Quercus alba*) and bur oak (*Quercus macrocarpa*) that range from 50-140 years (Fig. 3d), and hickory (*Carya spp*.) that range in age from 10-100 years (Fig. 3c). This site also had a median number of rings of 52.5 years with a maximum of 130 years (Fig. 3a).The campground site had a total tree density of 908.5 stems/ha, a basal area of 33.0 m^2/ha (Table 1), and a mean canopy openness of 14.5%. The WCNA site had a median ring count of 52.1 years and a maximum ring count of 156 years (Fig. 4a). This site contained greater species diversity with red oak (*Quercus rubra*) and black oak (*Quercus velutina*) (Fig. 4e), white oak (*Quercus alba*) (Fig. 4d), bitternut hickory (*Carya cordiformis)* and shagbark hickory (*Carya ovata)* (Fig. 4c), hackberry (*Celtis occidentalis*), ironwood (*Ostrya virginiana*), boxelder (*Acer negundo*), black walnut (*Juglans nigra*), slippery elm (*Ulmus rubra*) (Fig. 4b), basswood (*Tilia americana*), sugar maple (*Acer saccharum*), black cherry (*Prunus serotina*), choke cherry (*Prunus virginiana*), green ash (*Fraxinus pennsylvania*), and white ash (*Fraxinus americana*). The WCNA site had a total tree density of 658.6 stems/ha, a basal area of 28.8 m^2/ha (Table 1) and a mean canopy openness of 15.1%. Sapling counts totaled 0.012 stems/ha in the campground and 0.54 in the WCNA (Table 2).

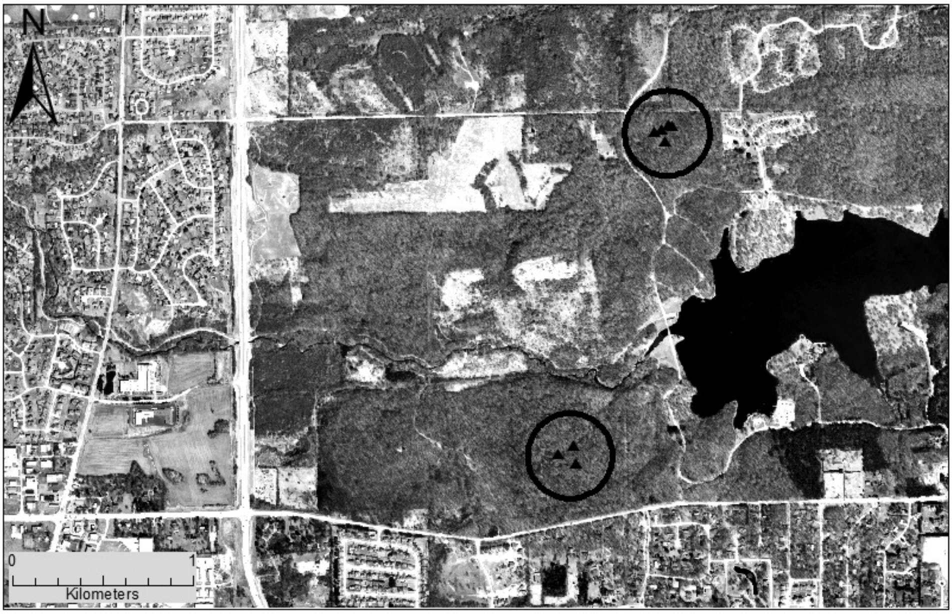
Slippery elm comprises a large portion of the overall stem density (63% of total) in the campground site but constitutes a small portion (15%) of total basal area indicating numerous small stemmed individuals. In contrast, white oak has a low relative stem density (16%) and high relative basal area, accounting for 52% of the total basal area in campground indicating few, but large individuals. Tree density in the campground was 155.9 stems/ha for white and bur oak (*Quercus macrocarpa*), 135.6 stems/ha for hickory, and 576.3 stems/ha for slippery elm. Basal area was 18.1 m^2/ha for white and bur oak, 5.6 m^2/ha for hickory, and 4.9 m^2/ha for slippery elm.

In the WCNA site, oaks make up 30% of total stem density and 63% of total basal area. Tree density in the WCNA site was 103.6 stems/ha for hickory, 114.7 stems/ha for white oak, 81.4 stems/ha for red and black oak, 103.6 stems/ha for slippery elm, 37.0 stems/ha for white and green ash, 51.8 stems/ha for ironwood, and 66.6 stems/ha for hackberry. Basal area in the WCNA site was 2.1 m^2/ha for hickory, 10.5 m^2/ha for white oak, 7.7 m^2/ha for red and black, 2.2 m^2/ha for slippery elm, 0.2 m^2/ha for white and green ash, 0.4 m^2/ha for ironwood, and 1.3 m^2/ha for hackberry (Table 1).

A Pearson correlation of dbh vs. age revealed



(a)



(b)

Figure 2. (a) 1939 aerial photograph showing campground (north), WCNA (south), and plot locations (triangles); (b) 2006 aerial photograph showing campground (north), WCNA (south), and plot locations (triangles).

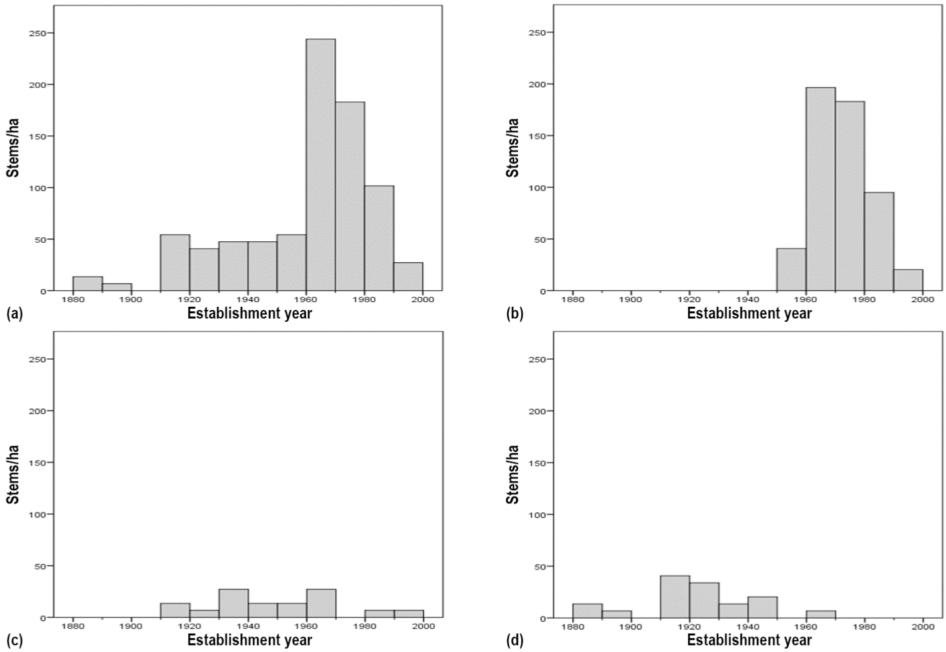
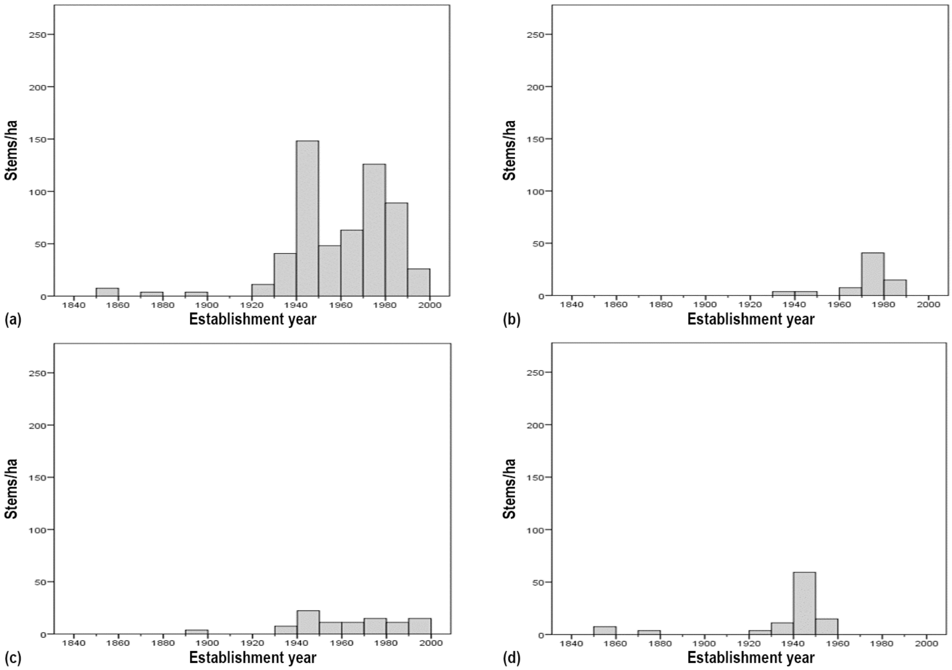


Figure 3. Age structure histograms for (a) all trees at campground site, (b) slippery elm, (c) hickory species, and (d) white/bur oak.

Table 1. Density and basal area of tree species (stems ≥ 5cm dbh) in campground and WCNA.

	Campground		**WCNA**	
Species	**Density (stems/ha)**	**Basal Area (m^2/ha)**	**Density (stems/ha)**	**Basal Area (m^2/ha)**
Basswood *(Tilia americana)*	6.78	0.18	33.30	3.16
Bitternut Hickory *(Carya cordiformis)*	20.34	1.14	59.20	1.07
Bur Oak *(Quercus macrocarpa)*	6.78	1.03	-	-
Red Oak *(Quercus rubra)*	27.12	3.84	77.70	7.52
Shagbark Hickory *(Carya ovata)*	115.26	4.43	44.40	1.02
Slippery Elm *(Ulmus rubra)*	576.30	4.98	103.60	2.19
Sugar Maple *(Acer saccharum)*	6.78	0.25	14.80	0.07
White Oak *(Quercus alba)*	149.16	17.11	114.70	10.49
Black Cherry *(Prunus serotina)*	-	-	29.60	0.58
Black Oak *(Quercus velutina)*	-	-	3.70	0.20
Black Walnut *(Juglans nigra)*	-	-	11.10	0.62
Boxelder *(Acer negundo)*	-	-	3.70	0.01
Choke Cherry *(Prunus virginiana)*	-	-	7.40	0.02
Green Ash *(Faxinus pennsylvanica)*	-	-	11.10	0.06
Hackberry *(Celtis occidentalis)*	-	-	66.60	1.25
Ironwood *(Ostrya virginiana)*	-	-	51.80	0.40
White Ash *(Faxinus americana)*	-	-	25.90	0.11
Total	**908.52**	**32.97**	**658.60**	**28.77**



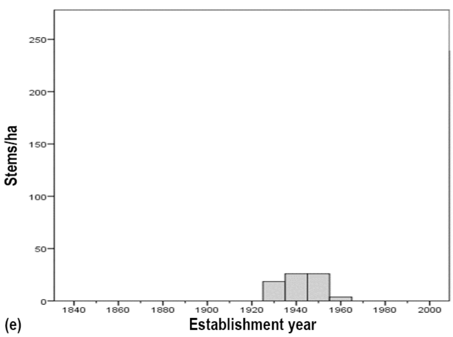


Figure 4. Age structure histograms for (a) all trees at WCNA site, (b) slippery elm, (c) hickory species, (d) white oak, and (e) red/black oak.

Table 2. Sapling count in two 20 m x 20 m plots at campground; sapling count for WCNA transect.

	Campground	WCNA
Species	**Sapling/m²**	**Sapling/m²**
Slippery Elm (*Ulmus rubra*)	0.012	0.09
Bitternut Hickory (*Carya cordiformis*)	-	0.14
Shagbark Hickory (*Carya ovata*)	-	0.07
Ironwood (*Ostrya virginiana*)	-	0.07
Sugar Maple (*Acer saccharum*)	-	0.07
White Ash (*Faxinus americana*)	-	0.09
Total	0.012	0.54

the trees in the campground site to have a significant ($p<0.01$) positive correlation ($r = 0.84$ for all trees (Fig. 5a), 0.32 for slippery elm (Fig. 5b), 0.63 for hickory (Fig. 5c), and 0.63 for white oak and bur oak) (Fig. 5d). Red oaks did not have a significant relationship between age and dbh. The WCNA site had significant ($p<0.01$) Pearson correlations between age and dbh with $r = 0.84$ for all trees (Fig. 6a), 0.83 for hickories (Fig. 6c), 0.80 for hackberry, 0.87 for slippery elm (Fig. 6b), and 0.70 for white oaks (Fig. 6d). Age/size correlations for red/black oak (Fig. 6e), ironwood, and white/green ash were not significant in the WCNA site, thus dbh was not a good surrogate for tree age in these species.

DISCUSSION

The overall goal of our research was to quantify forest structure and composition within two managed units in RCSP. Based on the GLO surveys, we noted witness trees, which early surveyors used to mark property corners and boundary lines (Munger 1991), along with landscape conditions in the mid-1800s. Although these surveys were subject to sampling bias (Black and Abrams 2001), and only constitute a small portion of the forest observed, they provide a valuable historical representation of pre-settlement vegetation (Abrams 2003). As such, GLO surveys indicated our sites were primarily composed of white, bur, and black oak in the mid-19th Century. Additionally, the 1939 aerial photograph revealed the campground site was slightly fragmented and located near grazing and farmland. Therefore, during the 1890s, agricultural conversion most likely led to the destruction of oak savannas previously at our sites. We theorize that the elimination of fire disturbance by neighboring farmers following acquisition has led to the encroachment of slippery elm and other shade-tolerant trees in

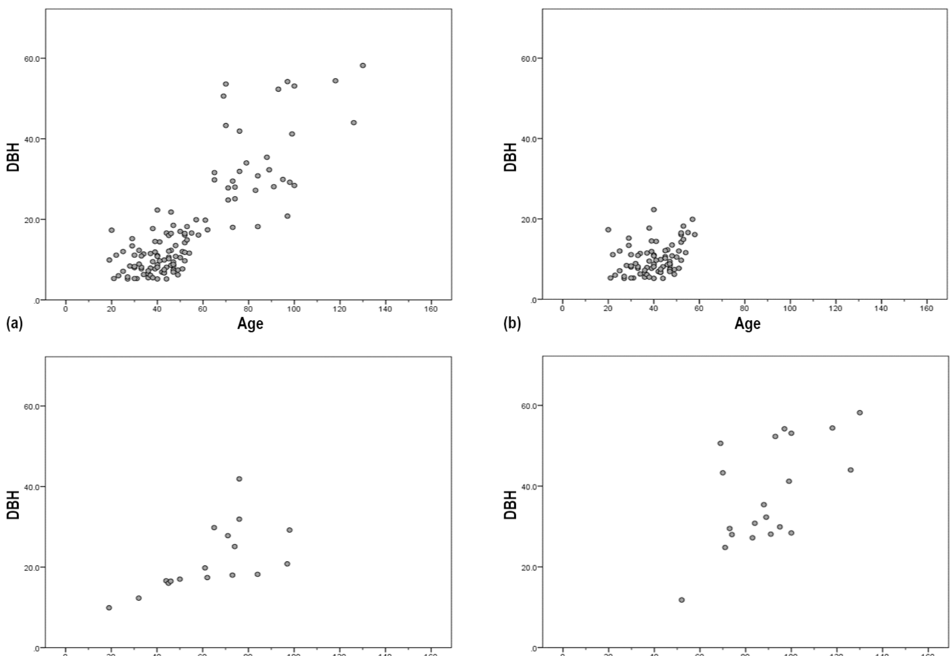
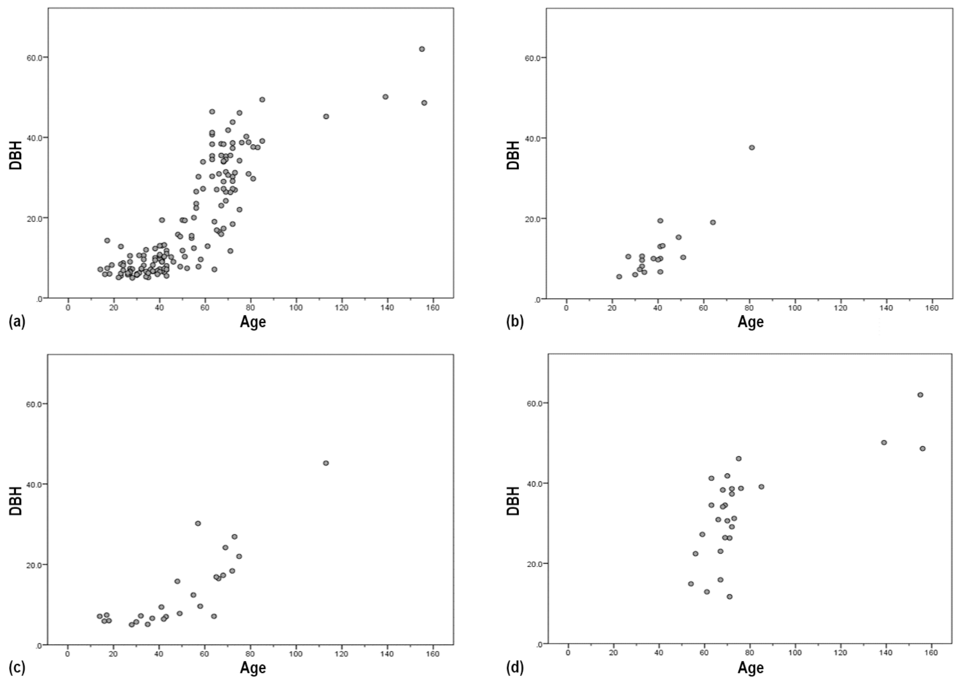


Figure 5. Age/dbh relationships for (a) all trees at campground, (b) slippery elm, (c) hickory species, and (d) white/bur oak.



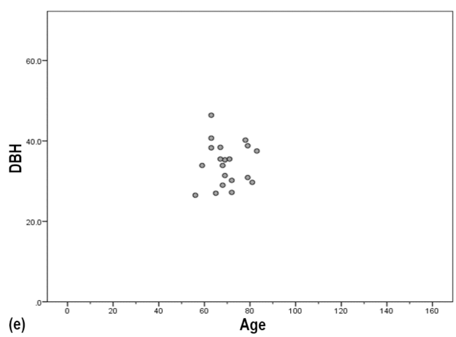


Figure 6. Age/dbh relationships for (a) all trees at WCNA, (b) slippery elm, (c) hickory species, (d) white oak, and (e) red/black oak.

the campground site. Furthermore, slippery elm age results indicate a considerable population increase ~30-60 years ago, around the time RCSP was designated as a protected area in the late-1950s, which also corresponds to the steady increase in regional moisture availability during the 1970s (NOAA.gov). This, in addition to the absence of grazing or fire has allowed the invasion of shade-tolerant, fire-sensitive slippery elms.

Moreover, the variation in species composition and diversity seen in both the WCNA and campground sites may be indicative of substrate differences. In the WCNA, forest plots were on fine-loamy soils with 6-12% slopes while the campground consists of fine-loamy soil on 2-4% slopes (USDA 2013). Overall, the flatter sites we sampled at the campground indicate a higher water holding capacity. In contrast, the three sites sampled at the WCNA had a steeper slope that maintains a lower water holding capacity. Although current understory conditions within the WCNA are not conducive to intense fires, the WCNA may have historically been prone to fires given the steeper of slope and drier conditions, thus contributing to the increased species diversity seen today.

Campground

Although management surface fires do occur in the campground they are of low-to-moderate intensity and insufficient to stimulate oak regeneration since the canopy remains closed. Infrequent, patchy burning allows the buildup of dense understory vegetation that enables competing species to survive and resprout vigorously following fire (Stan et al. 2006). Stan et al. (2006) found that slippery elm, ash, black cherry, and bitternut hickory have greater resilience to fire in sites where infrequent, low intensity burning occurs, resulting in strong seedling and sapling recruitment. Moreover, McEwan et al. (2011) found that single, inconsistent fires, promoted red maple seedlings and were ineffective at encouraging oak recruitment. Even though white oaks have the ability to remain dormant in low-light conditions (Rogers 1990), the inconsistent burning regime at the campground site, an increase in acorn grazing by white- tailed deer (Stan et al. 2006, Urbanek et al. 2012), shifting climactic conditions, and lack of disturbance over the last 56 years has promoted a closed canopy community. Additionally, the increase in precipitation levels since the 1970s has contributed to an increase in mesophytic species that are intolerant of severe and frequent droughts (McEwan et al. 2011). This has led to a shifting understory where shade tolerant species can readily establish and outcompete waning oak populations.

WCNA

The WCNA had a higher tree species diversity in addition to a more even age distribution, however, there is no oak regeneration – only fire-intolerant, shade-tolerant trees are regenerating. Peterson and Reich (2001) refer to these trees as "avoiders", requiring a long fire-free period to establish where mature trees can develop a slight resistance to fire. The dominant tree species in the WCNA with regard to basal area are red and white oak ranging in age from 60-80 years and a dbh ranging from 10-50 cm. Similar forest patterns were seen in Marengo Ridge Conservation Area (30 km west of RCSP) where Stan et al. (2006) noted a major compositional shift had occurred and a similar trend of developing dominance toward shade-tolerant and fire-sensitive species (slippery elm, black cherry, and ash) accompanied by poor white oak regeneration due to a dense understory and low light levels near the forest floor. In a 1986 study of 24 Midwest oak savannas, Apfelbaum and Haney (1987) noticed a young mesic understory forming in areas where fire had been excluded and oak regeneration had ceased. Nowacki and Abrams (2008) observed "mesophication" of fire-dependent forest ecosystems occurring across much of the eastern United States due to reductions in fire occurrence. This has promoted a moist, cool, microclimate that increases the production of fuel loads not conducive to burning, thus, "fireproofing" of the forest floor has occurred (Nowacki and Abrams 2008). By altering understory conditions at both the WCNA and campground, shade tolerant species have been effective at reducing the likelihood of fire by decreasing canopy light levels, and allowed what Nowacki and Abrams (2008) refer to as highly competitive, gap-opportunistic, late successional trees, such as maple and cherry, to invade and regenerate.

Future Management

Because white and bur oak are of conservation value, based on their ecological importance (Abrams 2003), short-term and long-term management practices should be implemented that will address the lack of oak generation occurring at both sites. Given the current land-use and location of RCSP, using large-scale fire to restore the two sites to oak savanna is not feasible. This is due to RCSP being bordered by state and interstate highways and under heavy recreational use year round. Therefore, mechanical thinning with <5 year intervals (Brudvig and Asbjornsen 2007) could serve as an immediate method for oak restoration; however, encroaching vegetation has been shown to quickly resprout from mechanically thinned stumps. Therefore, to rapidly reduce tree canopy density, annual low-intensity burning should occur, which can later be adjusted to 1-3 year intervals depending on management goals, and combined with mechanical thinning (Peterson and Reich 2001). Additionally, herbicide application could be incorporated to effectively control encroaching vegetation (Brudvig and Asbjornsen 2007).

While fires of moderate intensity are possible within the campground, well-established elms are already dominant and surface management fires would likely be ineffective at removal of mature elms (Stan et al. 2006). IDNR fire records indicate the WCNA maintains high moisture content and prior burns have been relatively unsuccessful, thus mechanical thinning may be the best course of action in the short term until canopy openness leads to reduced soil moisture levels. Moreover, once mechanical thinning had occurred, white oak seedling transplants could be an alternative at both sites, however, Stan et al. (2006) indicated poor survivorship of seedlings in Marengo Ridge as a result of low light levels, herbivory by white-tailed deer, and transplant shock. Additionally, Urbanek et al. (2012) noted that heavy browsing by white-tailed deer in mixed-deciduous forest caused an understory dominance of ferns, grasses, rushes, and sedges, and to increase overall floristic quality of communities white-tailed deer population should remain <20 deer/km^2. Therefore, mechanical thinning followed by prescribed annual burns and increased white-tailed deer hunting (if applicable) may be the most effective approach for oak longevity before considering seedling transplants. Should seedling transplants be deemed necessary, then we suggest using tree shelters (Kittredge et al. 1992) to increase growth rate and survivorship of white oak seedlings.

CONCLUSION

Regardless of any management practices intended to restore dwindling oak populations, it could take decades for oaks to benefit from restoration efforts (Kittredge and Ashton 1990). However, fire, immediately following other disturbance processes (such as thinning) has shown to be most effective (Albrecht and McCarthy 2006, McEwan et al. 2011). The elimination of fire, climactic shifts, land-use change, and increased herbivory, has transformed the once dominant oak savannas of the Midwest into closed forests. In order to preserve what few remnants exist, aggressive management is required to keep shade-tolerant, fire-sensitive species from entirely eliminating white oak regeneration and permanently transforming RCSP to a closed forest community dominated by mesophytic tree species. Given that mature pre-settlement oaks remain intact within degraded Midwestern savannas (Brudvig and Asbjornsen 2008), management that creates light gaps in areas with ample white oak seed production would likely lead to effective white oak restoration. Because this is the only study the authors are aware of in RCSP, future research should be conducted that explores the impact a consistent fire regime has on forest structure and composition within our sites - as it is has now been actively burned by the IDNR since 2007.

ACKNOWLEDGMENTS

We would like to thank Steven M. Schnell and two anonymous authors for providing helpful comments to improve this manuscript. In addition, we would like to thank the Illinois Department of Natural Resources and Rock Cut State Park for granting permission to conduct our research.

NOTES

1. Available from http://www.rem.sfu.ca/forestry/downloads/gap_light_analyzer.htm.

REFERENCES

Abrams, M. D. 1990. Adaptations and Responses to Drought in *Quercus* Species of North America. *Tree Physiology,* 7: 227-238.

Abrams, M. D. 1992. Fire and the Development of Oak Forests. *Bioscience,* 42(5): 346-353

Abrams, M. D. 2003. Where Has All the White Oak Gone? *BioScience,* 53(10): 927-939.

Albrecht, M. A. and McCarthy, B. C. 2006. Effects of Prescribed Fire and Thinning on Tree Recruitment Patterns in Central Hardwood Forests. *For. Ecol. Manage,* 226: 88-103.

Anderson, R. C. 1998. Overview of Midwestern Oak Savanna. *Transactions of the Wisconsin Academy of Science, Arts, and Letters,* 86: 1-18.

Apfelbaum, S. I. and Haney, A. 1987. Structure and Dynamics of Midwest Oak Savannas. *Unpublished report to Illinois Non-game Fund. Applied Ecological Services.* [http://www.appliedeco.com/Projects/StructureDynamicsSavannas.pdf]. Last accessed 1 January 2015.

Asbjornsen, H., Tomer, M. D., Gomez-Cardenas, M., Brudvig, L. A., Greenan, C. M., and Schilling, K. 2007. Tree and Stand Transpiration in a Midwestern Bur Oak Savanna after Elm Encroachment and Restoration thinning. *Forest Ecology and Management,* 247: 209-219.

Baker, R. G., Maher, L. J., Chumbley, C. A., and Van Zant, K. L. 1992. Patterns of Holocene Environmental Change in the Midwestern United States. *Quaternary Research*, 37(3): 379-389.

Bartlein, P. J., Webb, T. III, and Fleri, E. 1984. Holocene Climatic Change in the Northern Midwest: Pollen-derived Estimates. *Quaternary Research,* 22(3): 361-374.

Black, B. A. and Abrams, M. D. 2001. Influences of Native Americans and Surveyor Biases on Metes and Bounds Witness Tree Distribution. *Ecology*, 82(9): 2574-2586.

Brudvig, L. A. and Asbjornsen, H. 2007. Stand Structure, Composition, and Regeneration Dynamics Following Removal of Encroaching Woody Vegetation from Midwestern Oak Savannas. *Forest Ecology and Management,* 244: 112-121.

Brudvig, L. A. and Asbjornsen, H. 2008. Patterns of Oak Regeneration in a Midwestern Savanna Restoration Experiment. *Forest Ecology and Management,* 255(7): 3019-3025.

Brudvig, L. A. and Asbjornsen, H. 2009. The Removal of Woody Encroachment Restores Biophysical Gradients in Midwestern Oak Savannas. *Journal of Applied Ecology,* 46(1): 231-240.

Burns, R.M. and Honkala, B. H. 1990. *Silvics of North America*. United States Forest Service Agriculture Handbook 654. USDA: Washington, D.C.

Illinois Department of Natural Resources. 2013. Rock Cut – State Park. [http://dnr.state.il.us/lands/Landmgt/PARKS/R1/ROCKCUT.HTM]. Last accessed 1 January 2015.

Illinois Natural Resources Geospatial Data Clearinghouse, Illinois State Geological Survey. 2005. Illinois Digital Orthophoto Quadrangle Data. [http://crystal.isgs.uiuc.edu/nsdihome/]. Last accessed 1 January 2015.

Kittredge, D. B. and Ashton, P. M. S. 1990. Natural Regeneration Patterns in Even-aged Mixed Stands in southern New England. *Northern Journal of Applied Forestry*, 7(4): 163-168.

Kittredge, D.B., Kelty, M.J., and Ashton, P.M.S. 1992. The Use of Tree Shelters with Northern Red Oak Natural Regeneration in Southern New England. *Northern Journal of Applied Forestry*, 9(4): 141-145.

McEwan, R. W., Dyer, J. M., and Pederson, N. 2011. Multiple Interacting Ecosystem Drivers: Toward an Encompassing Hypothesis of Oak Forest Dynamics across Eastern North America. *Ecography*, 34(2): 244-256.

Munger, D. B. 1993. *Pennsylvania Land Records: A History and Guide for Research*. Lanham, MD: Rowman & Littlefield.

National Oceanic and Atmoshperic Administration. 2014. National Weather Service Forcast Office. [http://www.ncdc.noaa.gov/cag/]. Last accessed 1 January 2015.

Nowacki, G. J. and Abrams, M. D. 2008. The Demise of Fire and "Mesophication" of Forests in the Eastern United States. *BioScience,* 58(2): 123-137.

Nowacki, G. J., Abrams, M. D., and Lorimer C.G. 1990. Composition, Structure, and Historical Development of Northern Red Oak Stands along an Edaphic Gradient in North-central Wisconsin. *Forest Science*, 36(2): 276-292.

Nuzzo, V. A. 1986. Extent and Status of Midwest Oak Savanna: Presettlement and 1985. *Natural Areas Journal*, 6(2): 6-36.

Peterson, D. W. and Reich, P. B. 2001. Prescribed Fire in Oak Savanna: Fire Frequency Effects on Stand Structure and Dynamics. *Ecological Applications*, 11(3): 914-927.

Pielou, E.C. 1991. *After the Ice Age: The Return of Life to Glaciated North America.* Chicago: Chicago University Press.

Rogers, R. 1990. White Oak. Pp. 605-613 in R.M. Burns and B.H. Honkala, tech. cords., *Silvics of North America, Vol. 2. Hardwoods*. USDA Agricultural Handbook 654. USDA: Washington, D.C.

School of Resource and Environmental Management, S. F. 1999. Gap Light Analyzer 2.0. [http://www.rem.sfu.ca/forestry/downloads/gap_light_analyzer.htm]. Last accessed 1 January 2015.

Stan, A. B., Rigg, L. S., and Jones, L. S. 2006. Dynamics of a Managed Oak Woodland in Northeastern Illinois. *Natural Areas Journal,* 26(2): 187-197.

Urbanek, R. E., Nielsen, C. K., Glowacki, G. A., and Preuss, T. S. 2012. White-tailed Deer (*Odocoileus virginianus* Zimm.) Herbivory in Herbaceous Plant Communities in Northeastern Illinois. *Natural Areas Journal*, 32(1): 6-14.

USDA. 2013. Natural Resource Conservation Service. [http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx].Last accessed 1 January 2015.

Winkler, M. G., Swain, A. M., and Kutzback, J. E. 1986. Middle Holocene Dry Period in the Northern Midwestern United States: Lake Levels and Pollen Stratigraphy. *Quaternary Research,* 25(2): 235-250.