RESEARCH ARTICLE

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Dynamics of a Managed Oak Woodland in Northeastern Illinois

Amanda B. Stan[1,2]
Lesley S. Rigg
Linda S. Jones[3]
Department of Geography
Northern Illinois University
DeKalb, Illinois 60115 USA

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[1] Corresponding author:
astan@geog.ubc.ca; 604-827-5754
[2] Present address:
Department of Geography
University of British Columbia
Vancouver, British Columbia V6T 1Z2
Canada
[3] Present address:
Department of Geology and Environmental Geosciences
Northern Illinois University
DeKalb, Illinois 60115 USA

Natural Areas Journal 26:187–197

ABSTRACT: We examined the current composition and structure of a woodland in northeastern Illinois and evaluated the early effect of two prescribed burns. In an effort to increase white oak (*Quercus alba* L.) regeneration, managers are reintroducing fire into the woodland understory. We assessed canopy species and compared understory vegetation and light, along with soil nutrient characteristics, between a burned and an unburned area. In addition, we monitored transplanted white oak seedlings to better understand their growth and survivorship in the woodland. The canopy was dominated by white oak, but non-oak species, particularly slippery elm (*Ulmus rubra* Muhl.), ash (Fraxinus spp. L), and black cherry (*Prunus serotina* Ehrh.), dominated the smaller size classes. There were no differences in woody and herbaceous vegetation, soil, and light characteristics between the burned and unburned area. White oak regeneration was poor which appeared to be due to low understory light levels associated with high density of the shrub prickly ash (*Zanthoxylum americanum* Mill.) and high numbers of non-oak saplings. Transplanted seedlings also performed poorly, with low survival rates throughout the woodland as a whole. Mammalian herbivory is a likely cause of additional stress to white oak regeneration. Evidence of browsing of transplanted white oak seedlings was apparent throughout the study area. If white oak is to be a component of the future woodland, managers should consider: (1) implementing a more intensive management program aimed at reducing competition from non-oak species and (2) increasing light in the understory.

Index terms: oak regeneration, prescribed burning, seedling transplant, U.S. Midwest, white oak

INTRODUCTION

Oaks (*Quercus* spp. L.) are a major component of many forests throughout much of eastern North America, and historically, they were an important part of the regional landscape at the prairie-forest ecotone in the United States Midwest prior to Euro-American settlement (Gleason 1913, Abrams 2003). Oak savannas covered approximately 11 to 13 million ha of the Midwest at the time of settlement (Nuzzo 1986), and upland presettlement woodlands and forests were often dominated by white oak (*Q. alba* L.) and black oak (*Q. velutina* Lam.) (Gleason 1913, Rogers and Anderson 1979). In the last few decades, it has become unclear whether oaks will retain their dominance in wooded areas of the region. Understory communities comprised predominately of fire-sensitive and shade-tolerant species suggest that the structure and composition of many oak dominated woodlands and forests will change significantly (Miceli et al. 1977, McCune and Cottam 1985, Parker et al. 1985, Pallardy et al. 1988, Cowell and Jackson 2002).

The shift toward increasing numbers of non-oak species in woodlands currently dominated by oaks is primarily due to the changed disturbance regime following Euro-American settlement (Crow 1988, Abrams 1992). For centuries in the Midwest, both low-intensity surface fires initiated by lightening or understories maintained by early Native Americans in more open conditions allowed oak species to persist (Gleason 1913, Whitney 1994). Fire was advantageous to understory oaks because of their thick bark and post-burn sprouting ability (Lorimer 1985, Larsen and Johnson 1998, Huddle and Pallardy 1999). These fires reduced competition from less fire-resistant species and increased light levels in the understory (Crow 1988). Following Euro-American settlement, the dominant fire regime changed, as fire frequency and intensity decreased due to land development, agriculture, livestock grazing, and wildfire suppression (Whitney 1994). Initially, oak dominance increased over the region, as oaks expanded into tallgrass prairies, and savannas and woodlands succeeded into closed forests (Gleason 1922, Nuzzo 1986, Anderson 1990). Today, a lack of disturbance by fire has resulted in understories becoming dominated by shrubs and non-oak tree species, which in turn is inhibiting oak establishment and growth, particularly beyond the seedling stage of development (Abrams 1992).

In recent years, prescribed burns have been incorporated into the management plans of woodlands and forests with the aim of promoting oak regeneration (e.g., Kruger and Reich 1997, Blake and Schuette 2000, Gilbert et al. 2003). Low-intensity surface fires can alter understory competition and nutrient availability, and ultimately influence canopy structure and composition (Reich et al. 1990, Kruger and Reich 1997, Huddle and Pallardy 1999). A combination of prescribed burning and harvesting of tall understory vegetation has been suggested as a viable method for increasing growth and density of oak regeneration (Lorimer et al. 1994). Larger trees and shrubs are more resistant to low-intensity burns, and removal of tall understory vegetation prior to a burn may be required for successful oak regeneration. Other management strategies for increasing oak regeneration include combining prescribed low-intensity burns with partial harvesting of overstory trees (Brose et al. 1999, Rentch et al. 2003). The management assumption is that more continuous canopy disturbance, together with low-intensity fires that both directly and indirectly benefit oak, will better emulate the presettlement disturbance regime experienced by older oak-dominated stands.

In this study, we determined the impact of two, late-fall burns prescribed for restoration of a white oak dominated woodland. We characterized stand structure and compared understory species composition, soil nutrient characteristics, and understory light levels between a burned and an unburned area. White oak seedlings were transplanted and monitored to determine the impact of previous burns on the growth and survivorship of this species in the woodland.

METHODS

Study Area

The study was conducted in the Kelly Hertel Woods section of the Marengo Ridge Conservation Area (MRCA), McHenry County, Illinois (42°17' N, 88°35' W), approximately 105 km west of Chicago (Figure 1). Kelly Hertel Woods is a 40 ha tract of open-structured, upland, dry-wet mesic woodland, located in the northeastern corner of the MRCA and is the least human-disturbed section. MRCA is a 162 ha preserve surrounded by a matrix of old fields, agriculture, and rural/suburban development and is situated on what would have been the northeastern boundary of the midwestern tall grass prairie at the time of Euro-American settlement (Swink and Wilhelm 1994). McHenry County's climate is temperate, humid continental with mean winter and summer temperatures of -5.7 and 21.5°C, respectively (Calsyn 1995). Total annual precipitation for the area is 92 cm, with approximately 66% falling from April to September and seasonal snowfall averaging 90 cm (Calsyn 1995).

MRCA lies on the Marengo Moraine, a prominent north-south end moraine running through northeastern Illinois (Swink and Wilhelm 1994). Tiskilwa Till, the oldest member of the late Wisconsinan Wedron Formation, comprises the Marengo

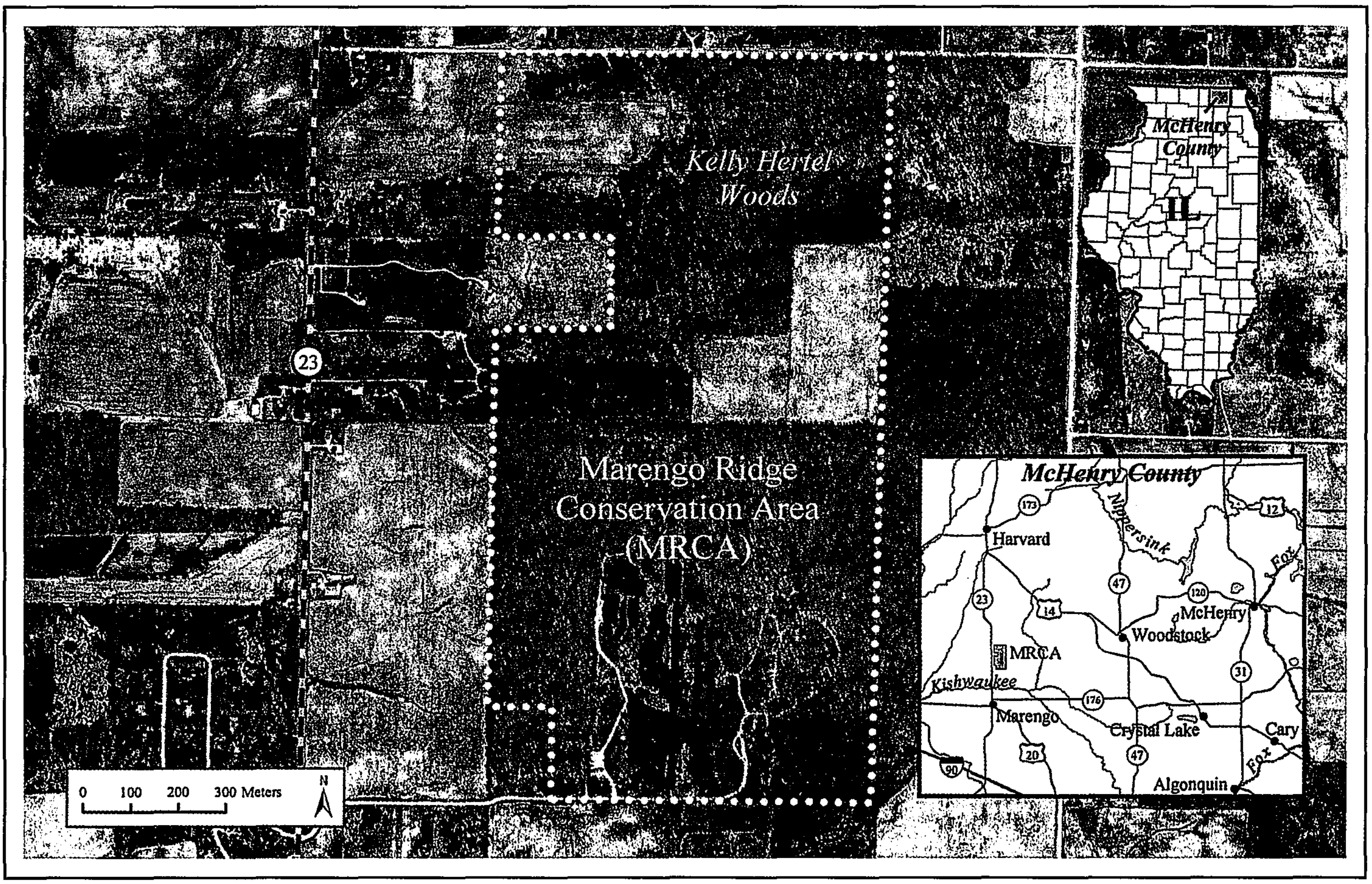

Figure 1. Location of Kelly Hertel Woods, Marengo Ridge Conservation Area (MRCA), McHenry County, Illinois, USA.

Moraine (Calsyn 1995). Kidami silt loam (an Oxyaquic Hapludalf) formed in this till member and dominates the Kelly Hertel Woods. Herbert silt loam (a Udollic Epiaqualf) and Senachwine silt loam (a Typic Hapludalf) are also found in the woodland.

Canopy tree species in the Kelly Hertel Woods include white oak, red oak (*Q. rubra* L.), and black walnut (*Juglans nigra* L.). Slippery elm (*Ulmus rubra* Muhl.), black cherry (*Prunus serotina* Ehrh.), and ash (*Fraxinus* spp. L) are present in smaller size classes, and there are visually fewer oak saplings and small trees in the woodland understory. The shrub layer includes a thick cover of prickly ash (*Zanthoxylum americanum* Mill.) and gooseberry (*Ribes* spp. L.), and several herbaceous species, particularly wild geranium (*Geranium maculatum* L.), are present in spring and early summer.

Management practices within the MRCA are currently aimed at the maintenance, restoration, and expansion of the woodland ecosystem. Prescribed burns are being utilized in sections of Kelly Hertel Woods as a mechanism to control shrubs and halt transition to non-oak species by facilitating the establishment, growth, and survival of white oak seedlings and their persistence to the sapling stage. McHenry County Conservation District (MCCD) personnel implemented prescribed burns on 3 November 1994 and 16 November 1998. A hiking trail loop around the woodland served as a firebreak. During the 1994 burn, air temperature was 15.6°C, relative humidity was 80%, and winds were from the southeast at 8 km hr^{-1}. At the time of the 1998 burn, air temperature was 8.3 °C, relative humidity was 63%, and winds were from the northwest at 24 km hr^{-1}. Fire behavior was variable for both burns, with ignition of lowland areas difficult (B. Woodson, MCCD, pers. comm.). The 1994 and 1998 burns were described as low and moderate in intensity, respectively.

Field and Laboratory Methods

We used the point-centered quarter method (Cottam and Curtis 1956) to sample the tree layer (stems $\geq$ 5 cm diameter at breast height (dbh)) in the Kelly Hertel Woods. Points were spaced at 20 m intervals along parallel transects placed 20 m apart that followed an east-west compass reading. In order to minimize edge effects arising from different land use boundaries, the first transect was set 15 m from the northern edge of the woodland and 10 m from its eastern boundary. The area around each point was divided into quadrants. Distance, dbh, and species identity were recorded for the individual live tree in each quadrant nearest to the sampling point.

We established 30 permanent vegetation plots throughout the woodland. Seventeen (5-m x 5-m) permanent vegetation plots (T1-T17) were randomly established within the burned (n=7 plots) and unburned (n=10 plots) area. The plots covered a range of upland/lowland sites and understory vegetation densities, and avoided animal (e.g., deer) trails as much as possible. Within each plot, five bare-root white oak seedlings were transplanted and tagged with a permanent, numbered metal tag. Seedlings, approximately 15 to 30 cm tall, were purchased from the Kane-DuPage Soil and Water Conservation District (Kane and DuPage counties lie to the south and southeast of McHenry County, respectively). The initial height to the apical growth tip of all transplanted individuals was recorded in May 2000. We originally intended to record seedling heights on an annual basis, but mammalian herbivore damage noticed halfway through the first season after transplantation complicated accurate measurements, because many seedlings were chewed early in the summer and resprouted later that same season. As a result, only presence of new growth and survivorship were recorded for transplanted seedlings in late August/early September 2000-02. An additional 13 (5-m x 5-m) permanent vegetation plots (NR1-NR13) were established within burned (n=6 plots) and unburned (n=7 plots) woodland in areas where natural white oak regeneration had occurred.

Twenty-six temporary vegetation plots were established to quantify tree regeneration in the understory. Sixteen (10-m x 10-m) temporary vegetation plots were randomly established in the burned (n=9 plots) and unburned (n=7 plots) area of the woodland. In addition, 10 smaller (5-m x 5-m) temporary vegetation plots were randomly established in burned (n=4 plots) and unburned (n=6 plots) woodland. We quantified density of tree regeneration in each plot using a classification scheme in which seedlings were stems $\leq$ 30 cm in height, class I saplings were stems > 30 cm and $\leq$ 137 cm in height, and class II saplings were stems > 137 cm in height and < 5 cm dbh.

Understory species composition was sampled in all permanent vegetation plots. We recorded percent cover of herbaceous species in plots T1-T17 (n=17) in late May 2000 and woody/shrub species in plots T1-T17 and NR1-NR13 (n=13) in early September 2000. Only woody/shrub species were surveyed in plots NR1-NR13, as these plots were established after spring ephemerals had died back. One fairly abundant herbaceous species, black raspberry (*Rubus occidentalis* L.), was not present until the woody/shrub species survey and, therefore, was not included as part of the herbaceous data. Vascular plant species nomenclature followed Mohlenbrock (1986).

Black and white hemispherical photographs of the forest canopy were taken in mid-September 2000 within all permanent vegetation plots for estimation of understory light levels. Photographs were taken in the center of each plot using a 35-mm camera equipped with a Sigma 8-mm fisheye lens mounted on a tripod. The height of the camera was adjusted so the plane of the lens was 1 m above the woodland floor. The camera body was leveled horizontally and oriented by a compass so the top of the photograph pointed in the direction of magnetic north. Two photographs were taken within each plot under overcast skies, as bright days will produce scattering of light through small holes in the canopy and create problems with image analysis (ter Steege 1996). One photograph was chosen for analysis based on visual quality (e.g., lack of blurriness, contrast between sky and vegetation, and over/under exposure). The computer program WINPHOT version 5.0 (ter Steege 1996) was used to estimate percent openness of the canopy and the photosynthetically-active photon flux density (PPFD, mol m^{-2} day^{-1}) in the woodland understory.

Surface soil (0-5 cm depth) samples were collected from all permanent vegetation plots. After removal of the litter layer, soil was taken from three random locations within each plot and combined into a single sample. Soil from each plot was analyzed for exchangeable cations (calcium, magnesium, and potassium), cation exchange capacity (CEC), available phosphorus, soil pH, percent organic matter, percent total carbon, and percent total nitrogen. Analyses of soil pH, exchangeable cations, CEC, available phosphorus, and percent organic matter were performed by Key Agricultural Services, Incorporated. The Iowa State University Plant and Soil Analysis Laboratory performed analyses of percent total carbon and percent total nitrogen. Total carbon was assumed to equal organic carbon since the samples were not calcareous (M. Konen, Department of Geography, Northern Illinois University, pers. comm.). An attempt was made to measure decomposition rates of the litter layer from a subset of plots within the burned and unburned area. Because browsing mammals (most likely deer) destroyed decomposition bags, no data were collected

Data Analyses

Density and basal area were calculated for tree-sized individuals (stems $\geq$ 5 cm dbh) of each species in both burned and unburned woodland. Size-class diagrams were created for the two dominant species. Densities of seedlings and saplings were compared between plots from the burned and unburned area using the Mann-Whitney U-test.

The Mann-Whitney U-test and the t-test were used to analyze differences in environmental variables (light, canopy openness, and soil) between the burned and unburned area. A one-tailed t-test was used to examine differences in percent openness of the canopy and below canopy light values, since light levels were expected to be greater in the burned area of the woodland; all other tests were two-tailed. Transformations were used when necessary to meet the normality requirements of the t-test. No statistical analyses were performed on data from transplanted seedlings due to low rates of survivorship and high incidences of completely browsed or missing individuals.

The program PC-ORD version 4.0 (McCune and Mefford 1999) was used for detrended correspondence analysis (DCA) ordination of species percent cover data (Hill and Gauch 1980). DCA ordination generates scaled axes with units that reflect the mean rate of species turnover between sample plots. An axis length of 400 (i.e., four standard deviation units) represents, on average, a complete turnover in species composition between plots (Kent and Coker 1992). DCA ordinations were performed

Table 1. Density and basal area of tree species (stems ≥ 5cm dbh) in burned and unburned woodland, Kelly Hertel Woods, Marengo Ridge Conservation Area, in 2000. Nomenclature follows Mohlenbrock (1986).

	Burned		Unburned	
Species	Density (stems ha^{-1})	Basal area (m^2 ha^{-1})	Density (stems ha^{-1})	Basal area (m^2 ha^{-1})
American elm (*Ulmus americana* L.)	8	0.33	20	0.44
Ash (*Fraxinus* spp. L.)	110	1.05	40	0.5
Basswood (*Tilia americana* L.)	18	0.65	7	0.18
Bitternut hickory (*Carya cordiformis* (Wang.) K. Koch.)	11	0.03	23	0.33
Black walnut (*Juglans nigra* L.)	29	1.79	57	4.43
Bur oak (*Quercus macrocarpa* Michx.)	11	0.66	3	0.27
Cottonwood (*Populus deltoides* Marsh.)	5	2.26	-	-
Hawthorn (*Crataegus* spp. L.)	5	0.03	25	0.17
Honey locust (*Gleditsia triacanthos* L.)	-	-	2	0.25
Quaking aspen (*Populus tremuloides* Michx.)	13	0.59	3	0.4
Red oak (*Quercus rubra* L.)	58	4.85	54	5.59
Scarlet oak (*Quercus coccinea* Muenchh.)	-	-	1	0
Slippery elm (*Ulmus rubra* Muhl.)	179	4.04	205	3.45
White oak (*Quercus alba* L.)	266	14.99	224	13.2
Black cherry (*Prunus serotina* Ehrh.)	53	0.22	51	0.49
Total	765	31.49	719	29.49

separately on 14 herbaceous and 21 woody species and used to identify gradients of species compositional change between plots from the burned and unburned area (Peet et al. 1988). Species that occurred in very low abundance (i.e., 1-2% cover) in only one sample plot or could not be identified with confidence were excluded from the ordination analyses. Sample scores from the first two axes generated from the ordinations were correlated with soil nutrient concentrations and below canopy light using Spearman's rank correlation to explore relationships between environmental variables and the positions of plots in ordination space.

RESULTS

Structure and Composition of the Tree Layer

The Kelly Hertel Woods was dominated by white oak and slippery elm, with tree densities of 266 and 179 ha^{-1} within the burned area and 224 and 205 ha^{-1} in the unburned section, respectively (Table 1). The most notable difference here was in the size class distributions between white oak and slippery elm, regardless of location within the woodland (Figure 2). The majority of slippery elm were restricted to the smallest size classes, with most tree-sized individuals being < 10 cm dbh and basal area was only 4.04 and 3.45 m^2 ha^{-1} in the burned and unburned area, respectively. Seedlings and saplings of slippery elm were also well represented throughout the woodland (Figure 2). In contrast, basal area of white oak was 14.99 m^2 ha^{-1} in the burned area and 13.20 and m^2 ha^{-1} in the unburned section of the woodland. The majority of white oak were in larger size classes relative to slippery elm, with most individuals of the former species in the range of 15 to 35 cm dbh in the burned area and 15 to 40 cm dbh in the unburned section.

There were no significant differences ($P<0.05$) in densities of seedlings and saplings class I and II between burned and unburned woodland (Table 2). The seedling layer was dominated by bitternut hickory (*Carya cordiformis* (Wang.) K. Koch.) and slippery elm. In the sapling class I layer,

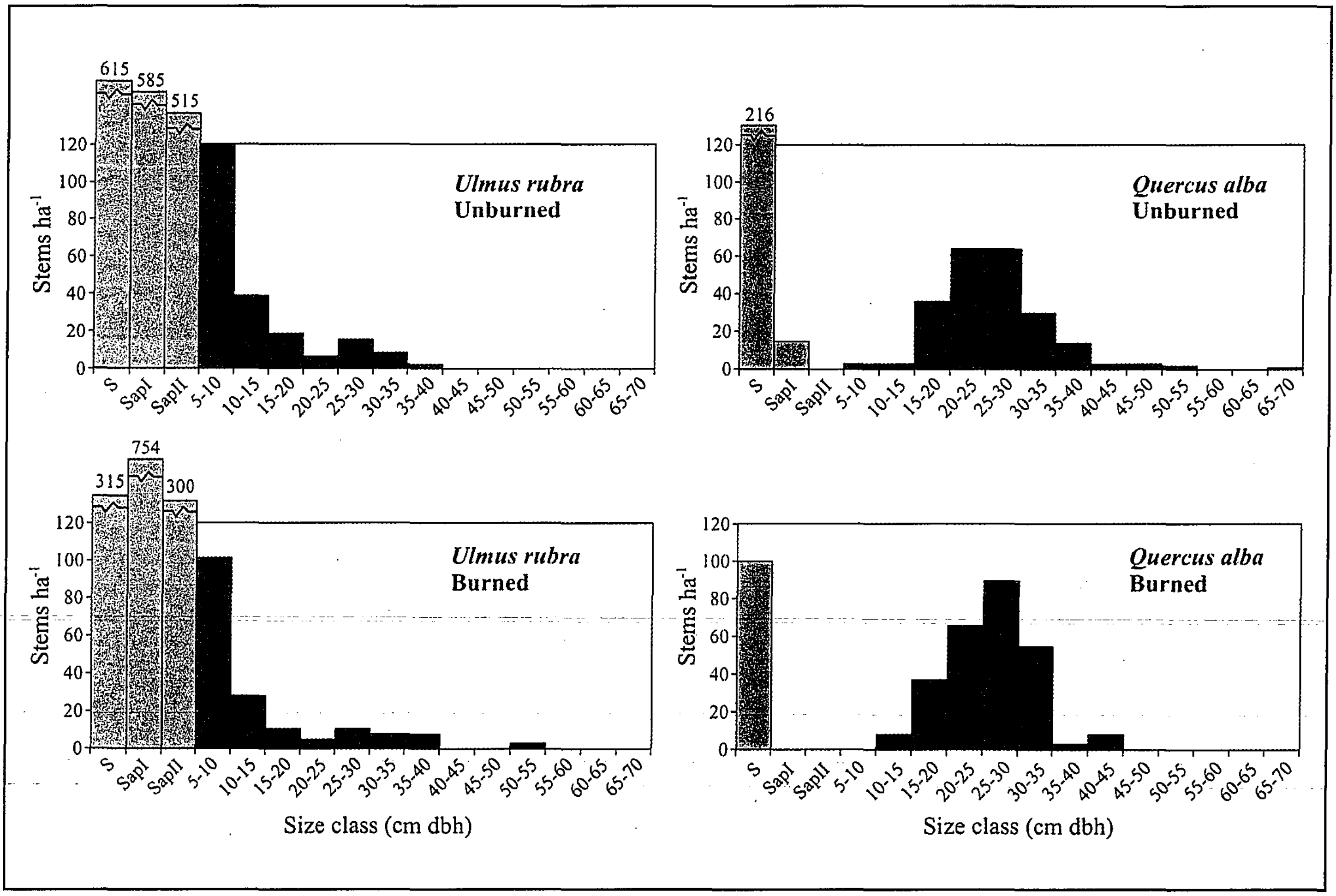

Figure 2. Size class distribution of white oak (*Quercus alba*) and slippery elm (*Ulmus rubra*) in burned and unburned woodland, Kelly Hertel Woods, Marengo Ridge Conservation Area, in 2000. Seedlings (S) are stems ≤ 30 cm in height, saplings class I (SapI) are stems > 30 cm and ≤ 137 cm in height, and saplings class II (SapII) are stems of > 137 cm height and < 5 cm dbh. Values at the top of columns indicate mean density for that size class based on random plots from the burned (n=13) and unburned (n=13) area. Densities of tree-sized individuals (stems ≥ 5 cm dbh) were determined using the point-centered quarter method.

Table 2. Density of dominant tree regeneration and white oak (*Quercus alba*) from plots in burned (n=13) and unburned (n=13) woodland, Kelly Hertel Woods, Marengo Ridge Conservation Area, in 2000. Seedlings are stems ≤ 30 cm height, saplings class I are stems > 30 cm and ≤ 137 cm in height, and saplings class II are stems of > 137 cm height and < 5 cm dbh. Values are means (SE).

	Seedlings		Saplings class I		Saplings class II	
Species	Burned	Unburned	Burned	Unburned	Burned	Unburned
Ash (*Fraxinus* spp. L.)	85	146	800	1269	231	300
	(36)	(67)	(137)	(588)	(58)	(117)
Bitternut hickory (*Carya cordiformis* (Wang.) K. Koch.)	908	646	992	385	123	169
	(505)	(198)	(556)	(154)	(74)	(78)
Black cherry (*Prunus serotina* Ehrh.)	315	23	2615	608	185	215
	(242)	(17)	(866)	(255)	(80)	(120)
Slippery elm (*Ulmus rubra* Muhl.)	315	615	754	585	300	515
	(143)	(264)	(237)	(111)	(92)	(137)
White oak (*Quercus alba* L.)	100	246	0	16	0	0
	(85)	(246)	(0)	(16)	(0)	(0)

Note: Additional species found in the regeneration layer included box elder (*Acer negundo* L.), hackberry (*Celtis occidentalis* L.), hawthorn (*Cratageus* spp. L.), black walnut (*Juglans nigra* L.), apple (*Malus* spp. Mill.), hornbeam (*Ostrya virginian* a (Mill.) K. Koch.), large-toothed aspen (*Populus grandidentata* Michx.), red oak (*Quercus rubra* L.), basswood (*Tilia americana* L.), and American elm (*Ulmus Americana* L.). Each additional species accounted for ≤ 3% of the total density in all plots combined.

black cherry was most abundant, but ash, bitternut hickory, and slippery elm each had high densities as well. Slippery elm dominated the sapling class II layer. In general, mean densities of the dominant species in all three size classes did not show clear patterns related to burning (Table 2). Regeneration of white oak was poor throughout the woodland. Mean densities of white oak were highest in the seedling layer, with 100 ha^{-1} and 246 ha^{-1} in the burned and the unburned area, respectively. In the sapling class I layer, mean density of white oak was 0 ha^{-1} in the burned area and only 16 ha^{-1} in the unburned area. No white oak individuals were present in the sapling class II layer in either burned or unburned woodland.

Community Composition

There was no discernible separation in ordination space of study plots from burned and unburned woodland, suggesting that there was very little compositional difference between site types (Figure 3). Wild geranium had the highest herbaceous species cover, regardless of location in the woodland. Woody species of prickly ash, black cherry, and slippery elm all had high percent cover in both the burned and unburned area.

Species composition did vary slightly across all plots (Figure 3) and was influenced by several measured environmental variables. For the ordination of herbaceous cover data, scores on the first DCA axis were positively correlated (P<0.05) with percent total nitrogen (N), percent organic matter (OM), and below canopy light. Soil pH, magnesium (Mg), calcium (Ca), percent organic carbon (C), and cation exchange capacity (CEC) were also positively correlated (P<0.01) with scores on the first DCA axis. Thus, plots with high scores on the first DCA axis, such as T10 and T11, contained soils that were higher in exchangeable cations and organic material and were located in portions of the woodland in which below canopy light levels were greater (Figure 3). Scores on the second DCA axis were not significantly correlated (P<0.05) with any of the measured environmental variables.

Scores on the first DCA axis of the ordination of woody cover data were negatively correlated (P<0.05) with percent organic carbon, percent total nitrogen, and percent organic matter. This indicated that plots with low scores on the first axis were located in areas of the woodland where the soils contained lower amounts of organic material and N relative to other sections of the woodland. The majority of the plots had low scores on the first DCA axis. Scores on the second axis were not significantly correlated (P<0.05) with any of the measured environmental variables.

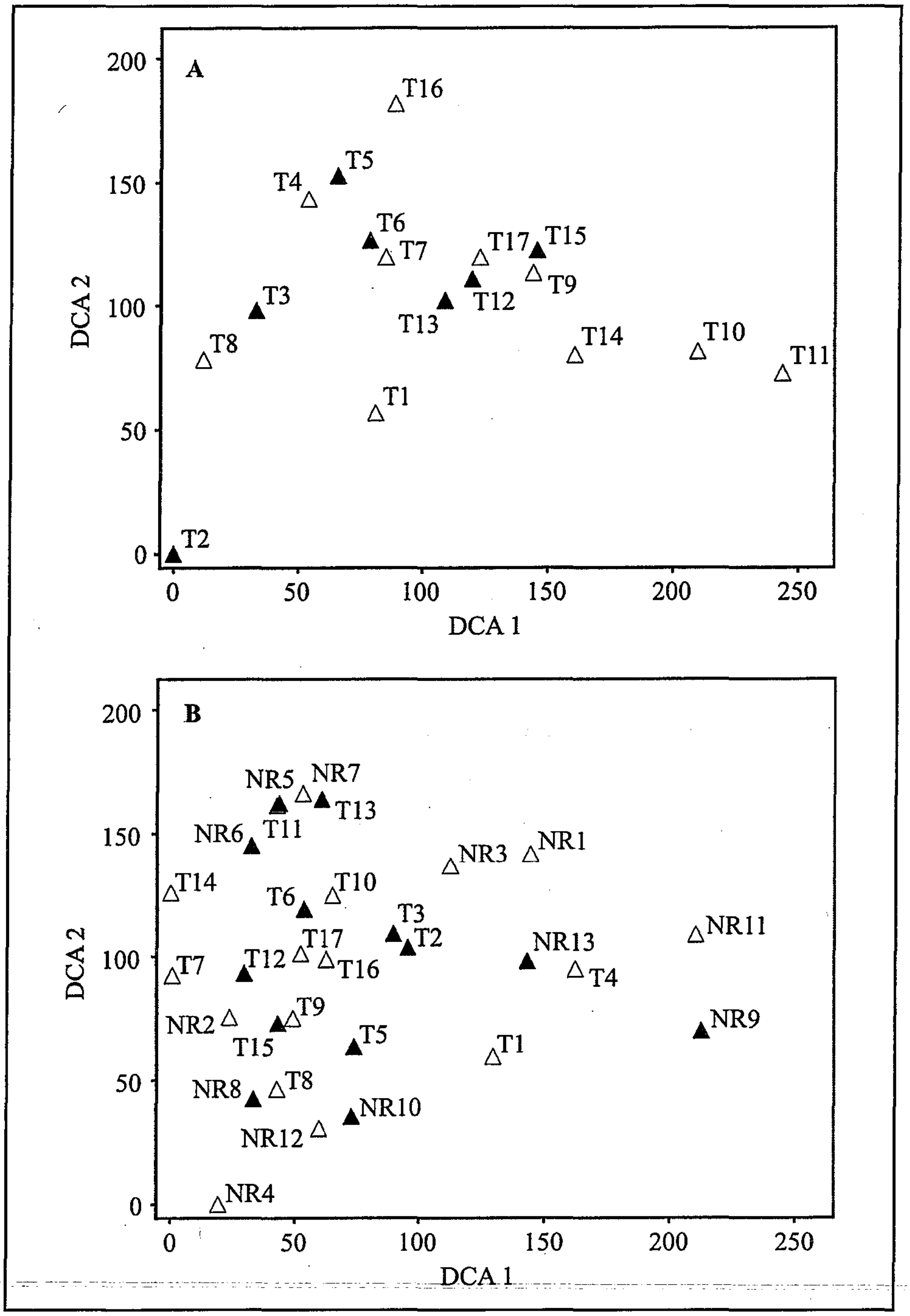

Figure 3. Detrended correspondence analysis (DCA) ordination of (A) herbaceous and (B) woody species percent cover data from burned (▲) and unburned (△) woodland, Kelly Hertel Woods, Marengo Ridge Conservation Area, in 2000.

Light Environments and Soils

Understory light and percent canopy openness were not significantly different (P<0.05) between burned and unburned woodland (Figure 4). Nevertheless, light and canopy openness values were slightly higher in the burned area and considerably more heterogeneous in the unburned portion of the woodland. The mean light value was 13 mol m^{-2} day^{-1} in the burned section and 10 mol m^{-2} day^{-1} in the unburned section. Mean canopy openness was 34% in the burned area and 28% in the unburned area. There was no significant difference (P<0.05) in understory light levels between plots in which natural white oak seedlings occurred and those in which none were found.

None of the measured soil variables were significantly different (P<0.05) between burned and unburned woodland. All values except soil pH and available P were slightly higher in the unburned section (Table 3). Soil pH was moderately acidic, with a mean value of 5.8 in the burned and 5.6 in the unburned portion. Total nitrogen had a mean value of 0.34 % in the burned area and 0.35 % in the unburned area. Total carbon had a mean value of 2.74 % and 2.86 % in burned and unburned areas, respectively.

Performance and Survivorship of Transplanted Seedlings

Survivorship of transplanted white oak seedlings was poor throughout the entire woodland, and very few individuals remained in the sample plots after three years (Table 4). At the end of the first growing season, 62% had new growth, 31% had died or showed no signs of new growth, and 7% could not be relocated and were recorded as missing. After three growing seasons, new growth was found on only 8% of the total number of transplanted seedlings, 21% had died or did not have any new growth, and 71% were missing.

DISCUSSION

Structure and Composition of the Kelly Hertel Woods

Size distributions of individual tree species in the Kelly Hertel Woods suggest this woodland is undergoing a major shift in composition. The white oak population is comprised mainly of trees in mid-diameter size classes (15-40 cm dbh), with limited numbers of seedlings, saplings, and small trees (Figure 2). In contrast, high numbers of slippery elm occur in the 5-10 cm dbh size class (Figure 2); and this species, along with black cherry, ash, and bitternut hickory, shows strong seedling and sapling recruitment in the woodland (Table 2). Increasing numbers of seedlings and saplings

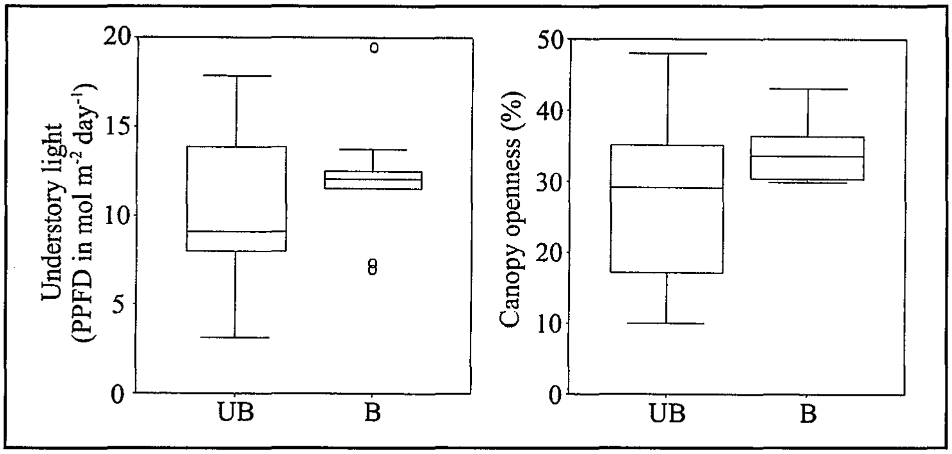

Figure 4. Box plot summaries of understory light characteristics and understory canopy openness in burned (n=13) and unburned (n=17) woodland, Kelly Hertel Woods, Marengo Ridge Conservation Area, in 2000. Shaded boxes represent the middle 50% of data, horizontal lines are the medians, vertical lines are the 95% confidence intervals, and circles represent extreme values (more than three box lengths from the upper or lower edge of the box).

Table 3. Soil pH, percent organic matter (OM), percent organic carbon (C), percent total nitrogen (N), exchangeable cations (potassium (K), magnesium (Mg), calcium (Ca)), cation exchange capacity (CEC), and available phosphorus (P) in soils 0-5 cm depth from plots in burned (n=13) and unburned (n=17) woodland, Kelly Hertel Woods, Marengo Ridge Conservation Area. Values are means (SE).

	Burned		Unburned	
Characteristics	Mean	SE	Mean	SE
pH	5.8	(0.17)	5.6	(0.17)
OM (%)	3.4	(0.26)	3.6	(0.35)
total C (%)	2.74	(0.20)	2.86	(0.23)
total N (%)	0.34	(0.02)	0.35	(0.02)
K (meq 100 g^{-1})	0.18	(0.01)	0.19	(0.02)
Mg (meq 100 g^{-1})	3.42	(0.50)	3.50	(0.54)
Ca (meq 100 g^{-1})	6.70	(1.27)	7.30	(1.37)
CEC (meq 100 g^{-1})	12.5	(1.64)	13.6	(1.78)
P (kg ha^{-1})	42.7	(4.61)	36.6	(3.12)

Table 4. Performance of transplanted white oak (*Quercus alba*) seedlings, Kelly Hertel Woods, Marengo Ridge Conservation Area. Values in parentheses are number of seedlings.

Performance (%)	2000 (85)	2001 (50)[a]	2002 (85)[b]
New growth	62	26	8
No new growth/dead	31	46	21
Missing	7	28	71

[a] Not all transplanted seedlings were relocated in 2001.

[b] Values represent cumulative performance.

of the former species, at the expense of white oak, is striking. If minimal seedling establishment and persistence to sapling classes continues to be the norm for white oak, there will be few to replace mature individuals as they die. Such a shift in species assemblages is occurring in other oak woodlands in Illinois (e.g., Roovers and Shifely 1997, Laatsch and Anderson 2000, Cowell and Jackson 2002) and surrounding areas (e.g., McCune and Cottam 1985) in which fire has been suppressed.

Effect of Prescribed Fire

A lack of significant differences between the burned and unburned area in terms of seedling and sapling densities, understory light levels, and soil properties implies that past burning episodes have had little impact on the woodland environment. Furthermore, ordination results do not reveal differences in vegetation communities between the burned and unburned area (Figure 3). Increases in herbaceous species cover and decreases in woody species cover have been reported following burning in other studies from fire-dependent communities (Tester 1989, Laatsch and Anderson 2000), although some report a decrease in height, but not necessarily cover, of woody species (Nuzzo et al. 1996). In Kelly Hertel Woods, we found only minor changes in total woody and herbaceous cover, with a decrease in woody and an increase in herbaceous cover following burning.

Increases in oak seedling density might be expected in burned areas, particularly when understory cover has been substantially reduced. Seedling density of white oak is not significantly different between the burned and unburned area. Nevertheless, results indicate that this species is capable of establishing in the woodland. Successful establishment is not surprising, as white oak is considered moderately tolerant of shade and capable of surviving in understories for many years by means of carbon and nutrient reserves contained in their large acorns (Rogers 1990). However, low densities of oak saplings relative to other species indicate that there is a severe "bottleneck" in oak growth between the seedling and sapling stages (Crow 1988, Nowacki et al. 1990). Without fire to reduce dense understory vegetation and enhance light levels, growth of natural oak seedlings is slow (Crow 1988, Lorimer et al. 1994). The high percent cover of woody species in the understory of the Kelly Hertel Woods might be an important limiting factor hindering the growth of established white oak seedlings and their recruitment into sapling classes. One shrub species, prickly ash, is particularly abundant and forms a tall, thick layer in many areas of the woodland. Heavy shading from prickly ash, along with cover from seedlings and saplings of non-oak species, may prevent adequate light from reaching the forest floor, compromising performance of white oak seedlings. Throughout the woodland, we find extremely low densities of white oak saplings compared to other species, with individuals of the former species often very small in height or displaying weak and unhealthy development. Thus, although oak seedlings are able to establish and persist for a certain period of time in this and other present-day stands, these individuals frequently fail to survive and recruit due to the influence of understory vegetation (Lorimer et al. 1994, Brose and Van Lear 1998, Kuddes-Fischer and Arthur 2002).

While fire is often important for reducing understory vegetation cover, it is also directly advantageous to oaks due to physiological adaptations of the species. Thick bark and resistance to rot after scarring increase oak survival following fire (Lorimer 1985, Abrams 1992). Furthermore, oaks emphasize root instead of shoot growth during early stages of development, and large rootstocks often send up a single, vigorous sprout when fire kills existing stems (Brose and Van Lear 1998). These characteristics are especially beneficial in situations of more frequent burns that remove competitive, fire-sensitive species from the understory. However, understory vegetation is dense in many present-day stands, and burns that are less frequent or of lower intensity may be counter-productive to oak regeneration, as they may not kill competing individuals, but instead cause them to resprout vigorously. Higher numbers of bitternut hickory seedlings and black cherry saplings in the understory of the burned area might be a result of resprouting. Both species are fire sensitive, but have the ability to resprout when burns are not intense or frequent enough to kill existing individuals. In such a scenario, understory cover will not be reduced to allow white oak to effectively compete. Moreover, the long fire-free period in the Kelly Hertel Woods has allowed non-oak species to increase in both number and size over time. Larger saplings and small trees of slippery elm and ash may be resistant to the types of burns being conducted in the Kelly Hertel Woods, decreasing the overall efficacy of the fires at promoting white oak regeneration.

Fires also have the potential to substantially alter the quantity, form, and availability of soil nutrients (Raison 1979, Menaut et al. 1993). In the Kelly Hertel Woods, there is little variation in soil nutrient concentrations between the burned and the unburned area. Greater nutrient availability is often reflected in increases in soil pH following fire, as oxides in ash react with hydrogen ions (Ahlgren and Ahlgren 1960). Soil pH is only slightly higher in the burned area relative to the unburned area. However, any increase in soil nutrient concentrations because of fire may no longer be apparent, due to uptake by plants or immobilization by microbes over time. Minor losses of total nitrogen and carbon in the burned area further suggest that past fires were not intense enough to alter the woodland environment.

Performance of Transplanted Seedlings

Poor performance of transplanted seedlings over the 2000 growing season was likely due to the influence of a number of factors, including reaction to disturbance from transplantation, low understory light levels, and herbivory by white-tailed deer (*Odocoileus virginianus* (Boddaert)) and smaller mammals (e.g., rabbits). However, the large number of missing seedlings after three years is striking (Table 4). During the first growing season in the Kelly Hertel Woods, leaf removal and stem damage to transplanted white oak seedlings were noted on several visits to the study area and assumed to have been caused by browsing. In addition, some seedlings were found pulled out of the ground during their first season in the woodland. Removal or weakening of seedling anchorage by fauna, followed by rainfall events that eradicate transplanted individuals from the local area, might be one explanation for the high number of missing white oak seedlings over three years, especially considering the undulating topography of the woodland and heavy downpours that are common during the summer months. In addition, naturally low survival rates of seedlings coupled with browsing might weaken anchorage and further facilitate seedling disappearance.

While the impact of mammalian herbivores on seedling and sapling longevity and performance is not entirely understood, studies often report more negative than positive effects of browsing on the vegetation of an area (reviews by Russell et al. 2001, Côté et al. 2004). McCarthy (1994) found over 50% of all seedling mortality in an oak-hickory woodland to be the result of deer and rabbit browsing. Meiners and Martinkovic (2002) found that mortality was higher for transplanted red oak seedlings that had been damaged by deer and rabbits. Exclosure experiments often show fewer seedlings and saplings outside versus inside structures, suggesting deer-related reductions in growth or survival (see review by Russell et al. 2001). In the MRCA, aerial counts from helicopters indicated densities of 21-67 deer km^{-2} between 1998 and 2005

Table 5. Density of deer based on aerial counts from helicopters, Marengo Ridge Conservation Area.

Year	Density (deer km^{-2})
1998	67
1999	50
2000	58
2001	31
2002	28
2003	32
2004	22
2005	21

(Table 5). Such high numbers of deer might be an additional factor behind the shifting composition occurring in the Kelly Hertel Woods. Interestingly, studies by Rossell et al. (2005) and Tilghman (1989) found that browsing by deer caused a shift in understory species composition towards greater dominance by black cherry and ash. In the Kelly Hertel Woods, deer might be favoring white oak over other tree species. However, even in the instance that deer are browsing the dominant understory tree species, higher densities of such individuals and the sprouting ability of some might equate to only minor adverse effects on these populations.

CONCLUSIONS

White oak is currently the dominant canopy species in the Kelly Hertel Woods. However, evidence suggests that this woodland is developing toward dominance by more shade-tolerant and fire-sensitive species. Slippery elm, black cherry, and ash are present in smaller size classes, with substantially fewer white oak in the understory and mid-story. Poor development of white oak in the Kelly Hertel Woods appears to be the result of competition from dense understory vegetation and subsequent lack of adequate light near the woodland floor. Deer might also be negatively impacting the white oak population through preferred browsing of this species relative to others in the woodland.

Management practices in the Kelly Hertel Woods must involve more intensive modification of the understory if white oak is to remain a canopy dominant in the future. Periodic burning events do not seem to be altering the woodland environment in any substantial way. If anything, the current management approach might be favoring species that gained dominance in the understory during years of fire suppression. A number of techniques may be considered as means to help ensure the existence of white oak within this woodland. Managed burns could be more severe to allow for a decrease in the density of the understory vegetation layer. However, fires that are more intensive are not a feasible option due to the presence of homes and adjacent farmland. Perhaps a more realistic management approach is to incorporate removal of the understory layer though cutting. The combination of recurring fire and understory vegetation removal might favor the white oak component of the stand through increased light levels in the understory and improved stem form due to resprouting following fire. Rather intensive monitoring of the woodland environment in order to ensure that the effects of burning and cutting are beneficial to the establishment, growth, and survival of white oak seedlings must follow these practices. Furthermore, research should be conducted on the effects of deer and rabbit browsing on the growth and survival of white oak and other seedlings in the woodland. Considering that many oaks are highly preferred browse species, and deer are a substantial component of this woodland ecosystem, deer populations may be further exacerbating the white oak regeneration problem.

ACKNOWLEDGMENTS

We thank the McHenry County Conservation District (MCCD) for permission to conduct this research. C. Blackwood, A. Diochon, and T. Jones provided excellent assistance in the field. Special thanks to W. Schennum and B. Woodson of the MCCD for logistical support. We are grateful to Sigma Xi, The Scientific Research Society, for providing financial assistance. One reviewer provided helpful comments on an earlier version of the manuscript.

Amanda Stan is a Ph.D. Candidate in the Department of Geography at the University of British Columbia. Her current research focuses on using dendroecological techniques for quantifying growth responses of trees to canopy gap disturbances in old-growth forests.

Lesley Rigg is Associate Professor in the Department of Geography at Northern Illinois University. Her research interests are in tree population and regeneration dynamics, the effects of disturbance on vegetation communities, and plant/soil relationships.

Linda Jones is a Ph.D. Candidate in the Department of Geology and Environmental Geosciences at Northern Illinois University. Her current research focuses on the use of x-ray spectrometry to analyze heavy metal concentrations and pollutants in trees.

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