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Abstract

The oak savanna in the Midwest was maintained historically in part by fire, topography, climate, and other factors. After agriculture, which left only large fencerow trees, park management of fire, mowing and other minor factors to restore clusters of oaks has proceeded at different frequencies at different sites since the 1960s. I asked how different management frequencies created a range of spatial patterns and composition in the canopy. I compared three 0.37-ha sites that were unmanaged, or managed with more or less frequency by spatially mapping all woody species to the nearest 25 m^2. The oak trees, dominated by bur oak species (*Quercus macrocarpa* Michx.) had the desired clumped distribution in the managed sites, as opposed to a random distribution and a lower oak density without management. In addition, the dominant canopy species shifted from bur oak in managed sites to shade-tolerant black cherry (*Prunus serotina* Ehrh.) and box elder (*Acer negundo* L.) under closed canopy and shagbark hickory (*Carya ovata* (P.Mill.) K. Koch). However, habitat heterogeneity did not decrease with management intensity, as predicted. The less managed site had more spatial heterogeneity than the more managed or unmanaged sites. All sites had woody understory thickets, however, the location and number of patches depended on management. This study shows how spatial dynamics in the canopy is influenced by management frequency.

Keywords: spatial dynamics, oak savanna canopy, *Quercus macrocarpa*, landscape management

Introduction

The oak savanna plant community is located between the tallgrass prairie and woodland communities. The canopy can include few oak trees that are widely spaced or clusters of several species of trees with a varied amount of sunlight reaching the ground (Wovcha and others 1995). Within these clusters, the diversity and oak spatial patterns were maintained by Native American fires (Curtis 1959, Anderson 1983, Cochrane and Iltis 2000, Omernik and others 2000), but topography and local climate are also important. These canopy spatial dynamics drive heterogeneity at a finer scale and are important to management regimes.

Since the time of the first settlers in the mid 1830s, the oak savanna landscape has been increasingly fragmented (Cochrane and Iltis 2000). Its decline is due to clearing, plowing, overgrazing, development, and oak harvest (Baker 1992). In addition, fire stopped abruptly when Native Americans were forced to leave the area. Thus, the current structure and composition patterns reflect years of Euro-American activity and management.

The oak savanna has a highly variable canopy, with a diverse understory composition that responds to the varied sun and shade (Henderson 1995). But over the past several decades, the remaining oak savanna was subject to invasion of shrub and shade-tolerant tree species. Within ten years, the canopy density increased due to saplings and shrub species, and within 20–30 years, the oak savanna resembled thick woodlands of older, larger trees. In one study, invasive woody species encroached into the savanna canopy at an average rate of 7 cm per year. In this savanna, where fire was eliminated, 50% of the landscape was replaced with more a woodland-like canopy. Other studies show how fragmentation could facilitate invasion in the canopy and in the understory (Brothers and Springarn 1992).

A precise measure of canopy spatial dynamics is limited. However, Curtis (1959) suggested at least one tree per acre, but less than 50% tree cover, with a primarily grassy understory, while his student Bray (1960) described the canopy range as a few trees to as high as 60% cover. Yet, the Nature Conservancy classified savanna density to be between 10–30% canopy cover while others suggest as wide ranging as 5% to 80% (Henderson 1993). There are so many interpretations of what the canopy should be, and my goal in this study is to quantify the spatial arrangement of oaks after decades of varying management frequencies to see if the results fall within the range of accepted tree cover.

Understanding how management frequencies affect canopy dynamics is essential in developing and implementing restoration programs for oak dynamics (Sutherland 1997). For instance, fire can facilitate heterogeneity in an oak savanna landscape. Fire and grazing can control invasive trees from closing the canopy and can create diverse canopy spatial patterns in the oak savanna (David and others 1997, Niemuth and Boyce 1998, Omernik and others 2000, Webendofer and others 2001). In one study, Henderson (1982) discussed how

fire frequency can influence the structure of an oak savanna in Indiana. He found that low-intensity, frequent fires did not kill the canopy trees, but maintained an open understory. In addition, high-intensity, infrequent fires killed larger trees and stimulated dense sprouting, leading to thickets rather than an open savanna. Fire suppression affects the canopy structure and survivorship of native species, and in turn, facilitates the spread of invasive species (Wolf and Mast 1998, Batek 1999). These varying management frequencies can affect patches of regeneration.

In this study, canopy and sub-canopy spatial patterns, composition, and patch development were analyzed in canopy clusters in a mesic oak savanna landscape. Here, I define an oak or canopy cluster as a patch of different woody species within the greater savanna landscape. There can be several oak clusters within the oak savanna. The objectives were to study the spatial distribution patterns to determine how canopy development and heterogeneity were affected by different frequencies of management. In asking the question; how will the spatial dynamics in the canopy respond to different management frequencies, the following variables were recorded: (a) spatial distribution of oaks, (b) percent species composition in the canopy, (c) spatial heterogeneity, and (d) size class for basal area that covered the ground. The hypothesis is that these variables would be different depending on management frequency, with the assumption that each site had primarily only the fence oaks before park management began. This is based on historical information and tree age data. Specifically, the age data reveal that the trees in all the sites were less than 40 years old, with the exception of the older fencerow trees (unpublished manuscript). Thus, we can identify each site with similar starting points, with the same opportunity for colonization, expect for different management frequencies.

Understanding tree spatial patterns provides a way to interpret patterns of forest development (Nakashizuka and Numata 1982, Read and Hill 1988, Mast and Veblen 1999). As a forest develops, spatial distributions within the canopy were found to shift from a clumped to a random distribution. This development is due to self-thinning of canopy trees or sub-canopy competition from shade-tolerant species (Cooper 1960, Laessle 1965, Whipple 1980, Good and Whipple 1982, Peet and Christensen 1987). However, if disturbance, such as moderate grazing or fire, is allowed in the plant community, the woody sub-canopy and many of the small canopy trees are removed which benefits other canopy trees (Webendorfer and others 2001). Frequency is also important, however. In overgrazed areas, for example, less biomass created smaller fires (Leopold 1943, Covington and Moore 1992). In this case, the timing of one disturbance (grazing) influenced the fire regime and possibly the plant community.

Study Site

Richard Bong State Recreation Area (BSRA) is located in Kenosha County, Wisconsin, 42.72° N, 88.12° W. Its annual precipitation is 74 cm (29 in) and mean temperature is 16°C (61°F) (April–September). This climate and latitude supports wetland, prairie, and oak savanna communities. By the 1830s, Euro-American settlers homesteaded southeastern Wisconsin. At this time, native plant species were replaced with crop species, the larger oak trees were left along the fence lines, and some of the savanna was left for grazing. After years of homesteading, 1,619 ha (4,000 acres) were destined to become a military airbase. But a failed land-use proposition stopped the plans. Now the area is protected as Bong State Recreation Area (BSRA).

Once the land became BSRA, managers set out to restore the savanna by managing for the remaining oak trees that were found near fence lines, so that clusters of trees would reestablish. Currently, the dominant trees within the reestablished clusters are bur oak (*Quercus macrocarpa* Michx.), but white oak (*Q. alba* L.), and black oak (*Q. velutina* Lam.) are found in smaller numbers (nomenclature from USDA National Plant Data Center 2005). In addition, other species comprise the canopy and sub-canopy layers (Table 1). Since the inception of the park in the 1960, separate reestablishing clusters continue to be managed at different frequencies. This study was conducted in 2001–2003 during the growing seasons in BSRA at three cluster sites, each 0.37 ha (0.91 acre) in extent. The different frequencies of management create a long-term experiment. In the more frequently managed site (0.30 ha = 0.74 acre), burning, mowing, and herbicide spraying occurred every one to three years (Figure 1). In the less frequently managed site (0.40 ha = 0.98 acre), burning and mowing occurred every

Table 1. Canopy and sub-canopy species in oak savanna, Richard Bong State Recreation Area.

Native Woody Species	
Quercus macrocarpa Michx	Bur oak
Quercus velutina Lam.	Black oak
Quercus alba L.	White oak
Carya spp. Nutt	Shagbark and Bitternut hickory
Crataegus spp. L.	Hawthorn
Prunus serotina Ehrh.	Black cherry
Prunus virginiana L.	Choke cherry
Cornus racemosa Lam.	Gray dogwood
Rhus glabra L	Smooth sumac
Invasive or Exotic Woody Species	
Populus tremuloides Michx.	Trembling aspen
Ulmus spp. L.	Elm
Acer negundo L	Box elder
Robinia pseudo-acacia L.	Black locust
Gleditsia triacanthos L.	Honeylocust
Elaeagnus angustifolia L.	Russian olive
Frangula alnus P. Mill.	Glossy buckthorn
Rosa multiflora Thunb. ex Murr	Multiflora Rose
Diervilla lonicera P. Mill.	Dwarf bush honeysuckle
Juniperus virginiana L.	Red cedar
Populus deltoides Bartr. ex Marsh	Cottonwood

four to six years. The unmanaged site (0.42 ha = 1.04 acre) was left alone. Throughout this paper, I will refer to these sites as 'more frequently managed', 'less frequently managed', and 'unmanaged'.

Methods

To determine the spatial distribution of the oak trees, we staked the boundaries of each cluster, mapped the coordinates of the canopy and sub-canopy trees, and tested whether the oak trees were in a clumped, random, or dispersed distribution.To do this, we ran transect lines along the boundaries every 5 m (2 in) and measured the x, y locations for each individual. To calculate the dispersion tendency, we used Morisita's Index to test whether the spatial distribution was random, clumped or dispersed (Morisita 1959). For this test, each site was divided into a grid of equal-sized quadrats. The degree of contagion is determined by quantifying the probability of two points falling in the same quadrat.

To document any differences in species composition and percent dominance, we tagged and identified each individual in each site to the genus and species. We defined dominance as the ratio of one species' abundance to the total abundance of all individuals. Chi-square tests were used to determine the differences in oak presence between sites.

Spatial heterogeneity depended on the location of the woody thicket patches. If the patches were scattered throughout the cluster, it had a higher degree of spatial heterogeneity, and if they were located in only one area of the cluster, it had a lower degree of spatial heterogeneity. Patchiness (or number of patches) played a part in determining heterogeneity as well. A higher number of separate patches indicated a higher degree of patchiness. Statistically, the difference in thicket area was determined with ANOVA tests.

To determine the ground covered by basal area, we measured the diameter at breast height (dbh) for every tagged tree with a diameter >1.5 cm. The size classes were seedlings, 1 cm–5 cm (0.4 in–2 in), 6 cm–15 cm (2.4 in–5.9 in), 16 cm–25 cm(6.3 in–9.8 in), 26 cm–35 cm(10.2 in–13.8 in), 36 cm–60 cm (14.2 in–23.6 in), more than 60 cm (23.6 in), and dead individuals. I used the diameter of the mapped tree sizes (DBH) to determine basal area (BA) in cm^2 as $\pi(DBH/2)^2$ to give a better indication of how much space a species covered on the ground. The basal area is the cross-sectional area of a tree's trunk at breast height. These values were then incorporated into the spatial map. Differences in the individual values were tested with a single-variable ANOVA.

Results

In the point pattern analysis, for the oaktrees, saplings and seedlings, individuals had a clumped distribution in the managed sites, but the oaks were in a random distribution in the unmanaged site (Table 2). Oak density also differed dramatically among the sites: density was lower in the more frequently managed site at 25 trees/ha (62 trees/acre) compared to the less frequently managed site at 47 trees/ha (116 trees/acre) but was lowest in the unmanaged site (6 trees/ha (15 trees/acre) (Figure 2).

Dominant trees in the more frequently managed canopy were oak species, with < 5% consisting of hawthorn (*Crataegus* L.), black cherry (*Prunus serotina* Ehrh.), Russian olive (*Elaeagnus angustifolia* L.), and trembling aspen (*Populus tremuloides* Michx.) (Table 2, Figure 3). Oaks dominated 79% of the less frequently managed canopy. The other 21% were elm (*Ulmus* L.), glossy buckthorn (*Frangula alnus* P. Mill.), and gray dogwood (*Cornus racemosa* Lam.). Less than 4% consisted of red cedar (*Juniperus virginiana* L.), cottonwood

Table 2. Number of trees in different size classes, mean tree size, basal area, and spatial distribution for oak species and for other woody species across management treatments in the oak savanna at Richard Bong State Recreation Area.

Management Frequency	Size Classes for Oak Trees								Mean tree size, range, se		Area Covered (based on diameter)			Spatial Distribution 5-m grid size
	Number of Seedlings	1–5 cm	6–15 cm	16–25 cm	26–35 cm	36–60 cm	> 60	Dead	Oaks Only	All Trees	Oaks Only F=9.42 P=0.002	Other Trees F=6.88 P=0.05	Thicket Patches F=3.52, P=0.05	Oaks Only
More	19	23	23	0	0	0	6	1	6.23, 1.1–5.5, 0.47	9.66, 1–81, 1.56	10%	0.3%	16.5%	Clumped: N=80, F=1.40, P=0.05
Less	49	52	123	20	0	0	6	9	9.50, 1–38, 0.56	12.72, 1–85, 0.78	15%	8.0%	16%	Clumped: N=241, F=3.00, P=0.01
Unmanaged	74	22	21	1	2	0	6	34	8.09, 1–33.8, 0.29	7.34, 1–35, 0.29	3%	2.0%	40%	Random: N=60, F=1.09, P=0.05

Figure 1. Oak cluster in Richard Bong State Recreation Area, restored by using fire, mowing, and herbicide methods. This site has an open canopy.

(*Populus deltoides* Bartr. ex Marsh.), hawthorn (*Crataegus* spp.), hickory (*Carya* Nutt.), black locust (*Robinia pseudoacacia* L.)and honeylocust (*Gleditsia triacanthos* L.). Very few oak trees (29%) were part of the closed canopy in the unmanaged site (Figure 2, lower panels), and 11% of those were dead (Table 2), compared to the managed sites ($X^2 = 37.5$, $P = 0.005$). In the unmanaged site, the canopy and especially the sub-canopy were predominantly shade-tolerant species. The composition included 28% box elder (*Acer negundo* L.), 29% black cherry, 9% hawthorn, and more than 5% of hickory, Russian olive, black walnut (*Juglans nigra* L.) and apple (*Malus* P. Mill.) (Figure 3), yet just beyond the edge, establishment was dominated by hickory and smaller oaks.

Patch dynamics differed between sites. In the more frequently managed sub-canopy, certain species (trembing aspen, gray dogwood, glossy buckthorn and multiflora rose [*Rosa multiflora* Thunb. ex Murr.]) formed thickets scattered in the sunny areas of the canopy, but it also included dwarf bush honeysuckle (*Diervilla lonicera* P. Mill.) and smooth sumac (*Rhus glabra* L.). Oak seedlings were not found in these thickets. More widely scattered in the cluster, the sub-canopy thickets of the less frequently managed site were comprised only of glossy buckthorn and gray dogwood. In this site, oak seedlings were found within the patches (Figure 2, middle panels, oaks appear in the thickets). Patch space differed between sites (P = 0.05) (Table 2). In the unmanaged site, dogwood thickets created the highest density in the cluster (56 individuals/ha = 138 individuals/acre), and much of it was found along the edge (Figure 2, lower panels). In this site, the thickets were continuous and only existed on the edges of the closed canopy (Table 2). One small oak seedling patch was found under the canopy.

Woody thickets played a role in canopy distribution and spatial diversity in managed versus unmanaged sites. The overall canopy had higher heterogeneity of habitat diversity where patches were more scattered, as in the managed sites, and a lower heterogeneity of habitats where patches were not scattered, as in the unmanaged site. In the unmanaged site, thickets were found only along the edges and the closed canopy supported a continuous understory of shade-tolerant species. In time, these thickets influenced the spatial distribution of some canopy trees because the presence of a thicket suppressed their growth and survival. Thus, the managed sites had a higher number of separate thickets, indicating higher patchiness, whereas the unmanaged site had a low degree of patchiness because the thickets create one continuous patch.

The size distribution maps show how larger individuals existed farther away from the oldest fence-line oaks in the more frequently managed site (Figure 2, upper panels) and the smaller oaks were closer to the fence-line oaks. In this site, the average size of an oak tree was less than the average of all trees combined (Table 2), and the oak tree basal areas comprised 10% of the total site area (292 m^2 area) (Figure 2, upper right panel), whereas the other canopy trees comprised 3% of the basal area. The mean size classes in the less frequently managed site was higher than the more frequently managed site (Table 2). This site had the highest cover by oak and other species, and it had a larger mean diameter for all the trees. Controlling for the fence line trees, the basal area differed between sites for all trees (P = 0.05) and for only oaks (P = 0.01). Based on diameter size, the area covered by oak trees in the more frequently managed site was 67% of the area covered in the less frequently managed site. The oaks, as well as other trees, had the lowest basal area cover in the unmanaged site, even though the canopy was closed. In the unmanaged site, oak trees in the closed canopy were of the same size as the other trees, compared to the less frequently managed site (Table 2). Just beyond the edge, the mean size increased to 17.92 dbh (from 8.09 inside the canopy). Although they can germinate, the oaks cannot survive to a larger size in the competition of a shade-tolerant sub-canopy.

Discussion

Understanding the spatial dimension of oak savanna canopies provides crucial data to land managers. Does management frequency make a difference and do the results still represent the oak savanna canopy? In this paper, I investigated how management practices can facilitate biological responses in the canopy, for instance, in terms of tree size, regeneration, competition, and survival. I found that the canopy cover can have a degree of spatial variability, and different spatial distributions that occur from varying management frequencies can

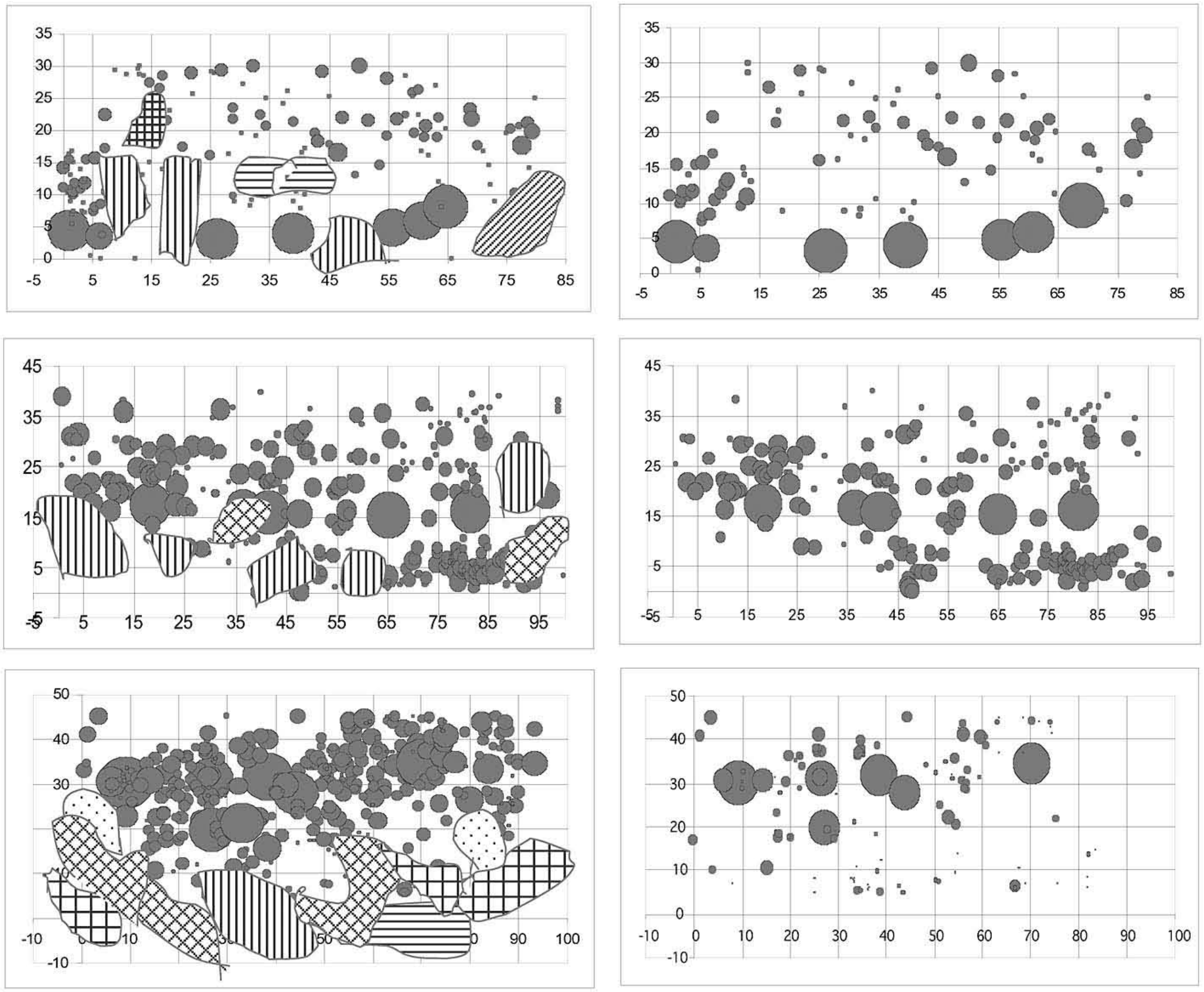

Figure 2. Upper panels – frequently managed site: Spatial distribution of all trees (according to size) with thicket patches (left). Thicket types: square hatch = multiflora rose, vertical lines = gray dogwood, horizontal lines = smooth sumac, diagonal lines = trembling aspen. Spatial distribution of oak trees (right). For only oaks, trees were clumped at 5-m quadrats, N=92, F=1.40.

Middle panels – less frequently managed site: Spatial distribution of all trees (by size) with thicket patches (left). Thicket types: vertical lines = gray dogwood, diamonds = glossy buckthorn. Spatial distribution of only oak trees (right), clumped at 5-m quadrats, N=220, F=3.00.

Lower panels – unmanaged site: Spatial distribution of all trees (according to size) with thicket patches (left). Thicket types: square hatch = multiflora rose, vertical lines = gray dogwood, horizontal lines = smooth sumac, diamonds = glossy buckthorn, dotted areas = bur oak seedlings. Spatial distribution of only oak trees (right). For only oaks, trees were randomly distributed at 5-m quadrats, N=60, F=1.09.

influence species competition, size, and survival success. These patterns can be either beneficial or detrimental to oak compositional and spatial dominance.

There is some spatial autocorrelation to all spatial sampling, since objects closer in proximity are expected to be more similar than objects farther away. Because of this phenomenon, a clumped pattern is expected in early forest development, as explained earlier. Thus, in the managed sites, the spatial patterns represented an early succession plant community with high oak survival. But in time, the unmanaged site resembled a later succession pattern, created by competition and consequent declining oak canopy abundance and oak saplings survival (Peet and Christensen 1987) created a random distribution.

Species composition differed between managed and unmanaged sites. In the unmanaged site, the sub-canopy and

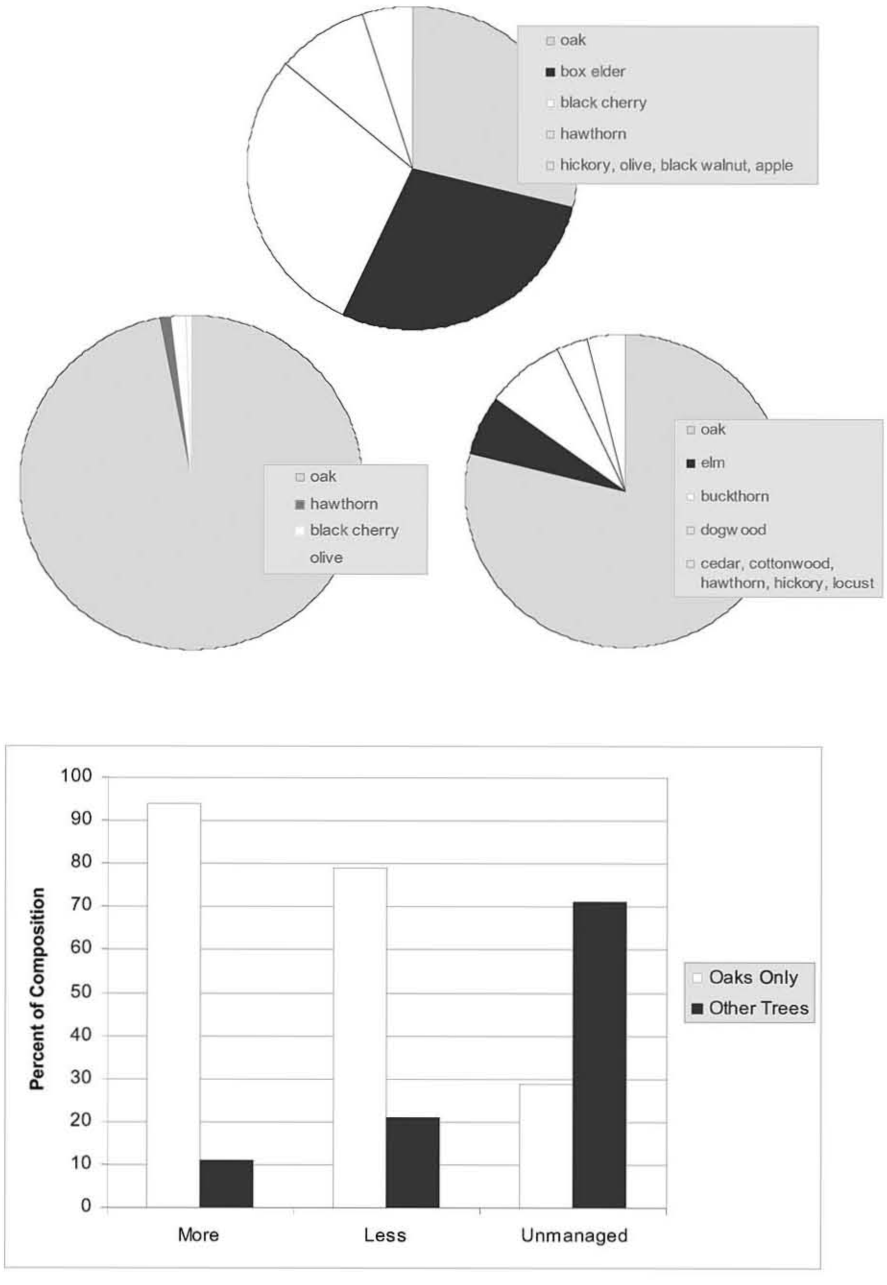

Figure 3. Canopy composition by percent and by species. Bar graph shows oaks versus other trees. Circular graphs (upper = unmanaged sites, lower left = more managed sites, lower right = less managed sites) illustrate percent of other species.

understory layers, which were composed of shade-tolerant woody and perennial woodland forb species, took over the space at the expense of sun-loving grasses and prairie forbs. In the open sun just beyond the unmanaged canopy, the shade-intolerant hickory was expanding outward. However, aspen grew in the open canopy in the most managed site, not hickory. Yet, hickory is an important species expected in oak savanna canopies (Bowles and others 1994). Differences in species composition occurred even between the sites that were managed, depending on management frequency. This may be because while a managed oak savanna can facilitate oak establishment, longer fire-free years can also create distinct age cohorts, and maintain higher species richness (Wolf, unpublished manuscript).

Heterogeneity did not decrease with less frequent management. This is contrary to my hypothesis stating a more intensely managed site would have the highest heterogeneity, and an unmanaged site would have the least heterogeneity. The data illustrate the least spatial and habitat heterogeneity in the unmanaged site, and that less frequent management created a more heterogeneous site. With less frequency, the established buckthorn thickets formed under the canopy and in the open spaces, so in this site, they did not affect canopy development. Here, they created pockets of shade in which the site can sustain a high diversity of oak savanna species of either shade tolerant or sun loving throughout the site. Spatially, this site has more microhabitats by having both opened and closed canopy cover, but in more frequent management, trees were less dense and more evenly spaced. With less frequency, the species composition had a higher proportion and wider size distribution range for other canopy species. A higher frequency created thickets in treeless areas, and suppressed seedling and sapling growth. In comparing heterogeneity and canopy species between the managed sites, less frequency created higher spatial and species diversity. In this study, variability takes into consideration the sub-canopy patches in a cluster.

Size and regeneration patterns responded differently to frequency regimes. In the unmanaged site, I found many oak seedlings and fewer saplings located within the closed canopy. A consistent closed canopy can affect both habitat and species diversity. With a high germination, restoring this site would be successful, but in the present state most of the smaller oak saplings did not survive in the closed canopy. Smaller oaks (dbh > 5 cm or 2 in) thrive in the sun just beyond the canopy edge. Basal area, coupled with density, give a sense of woody ground cover. While larger sizes were found in the less frequently managed site, the canopy still allowed a variety of sunny and shady areas throughout. On the other hand, although smaller sizes were found in the unmanaged site, they were so close together that the canopy did not allow sun to penetrate except for beyond the edges.

Introducing disturbances, such as fire or mowing (to simulate grazing), can sustain a higher level of habitat and species diversity. For instance, in one savanna, moderate fire and grazing increased bird diversity and provided habitat for uncommon or declining bird species (Sample and Mossman 1997, Davis and others 2000). One oak barren insect species indirectly dependent on fire is the Karner blue butterfly (*Lycaeides melissa samuelis* Nabokov) (Shuey 1997). In this case, fire maintained the presence of lupine (*Lupinus perennis*), from which the Karner blue gets its nutrients. Even mowing can impact oak regeneration, and create habitats such as butterfly refugia (Chapman and others 1993). Thus, management practices play a key role in diversity.

One significant point of this study illustrates how an unmanaged regime can 'hide' an oak savanna because the structure and composition resemble a woodland community of densely packed shade-tolerant trees. Not only does this transition further degrade this vulnerable plant community by limiting native diversity still in the soil seedbank, but overgrown unmanaged oak savanna mistaken for woodlands may not warrant the funding it needs for a successful restoration from appropriate management activities. The key to successful restoration lies in the understanding the variability of the oak savanna, and recognizing certain criteria, such as broad canopy trees, a wide range of light intensities, and recent natural or prescribed disturbance frequencies (Leach and Givnish 1996, 1998). Oaks that exist in an oak savanna would be expected to have more broad limbs as a result of fire maintaining a relatively less dense structure compared to woodlands where the oak limbs reach upward as a result of a much more dense forest. Here, the unmanaged site can now be mistaken for a woodland canopy, except that the oak trees have the characteristic horizontal limbs of an oak savanna tree. In this study, although varying frequencies created differences in canopy spatial dynamics in oak savanna, the outcome shows two situations within a range of acceptable composition, disturbance level, and other recognizable criteria for this type of plant community. Other studies recognize a high range of canopy variability in oak savannas (Maloney 1994, Leach 1999).

The oak savanna landscape is reminiscent of our cultural heritage. As far back as when the oak-hickory forests became established in the periglacial climate, indigenous people occupied the land and used fire to maintain its spatial structure (Hicks 1997). In southeastern Wisconsin, the Potawatami camped in this landscape and left behind many artifacts under the oak savanna canopy. But when the oak savanna is unmanaged, we risk losing our cultural history. Intentional management of the oak savanna canopy is required for their existence.

The implications of this study go beyond the canopy dynamics, and it is important to note that the oak savanna harbors key species that are dependent on managing the canopy. For instance, savanna communities support a rich herbaceous understory and provide a habitat for many uncommon, rare, threatened or endangered species (Henderson 1995). This plant community is unique, not only in its canopy but also in the understory, which depends on canopy dynamics. Indeed, the oak savanna may be more diverse and specialized than some studies indicate and are now known to possess oak-dependent understory species (Leach and Givnish 1998). Some of these are feverwort (*Triosteum perfoliatum* L. var. *aurantiacum* (Bickn.) Wieg.), sweet black-eyed Susan (*Rudbeckia subtomentosa* Pursh.), and pale indian plantain (*Cacalia atriplicifolia* (L.) H.E. Robins).Threatened or endangered species include cream gentian (*Gentiana alba* Muhl. ex Nutt.), wild hyacinth (*Camassia scilloides* (Raf.) Cory), prairie bush clover (*Lespedeza leptostachya* Engelm.), pale purple coneflower (*Echinacea pallida* (Nutt.) Nutt.), purple milkweed (*Asclepias purpurascens* L.), and smooth phlox (*Phlox glaberrima* L.) (USDA National Plant Data Center 2005). As the savanna continues to degrade, these species may become less common.

Some species-rich savanna remnants may be overlooked based on accepted canopy parameters, but they can have a diverse understory, especially when managed (Henderson 1993, Bader 2003). Indeed, land managers could expect several key species to reappear in managed oak savanna (Henderson 1995). The point here is that, depending on the frequency of management, the canopy can create different levels of understory diversity. Indeed, the understory can respond to a variety of environmental constraints, including light diversity, with a diverse assemblage of prairie and forb species, and specialized oak savanna species (Maloney 1994, Henderson 1995, Leach and Givnish 1998). Future research for this study site will investigate the understory diversity specifically, but it is not the focus of this paper.

As a priority goal, land managers now seek a better understanding of their management efforts, which will lead to restoration success in the canopy. By accomplishing this goal, the restored canopy would provide a variety of sun and shade habitats, which are created by an oak-dominated canopy arranged in a clumped distribution. The canopy can include a range of oak savanna trees, depending on the management frequency; however, a high frequency might result in more non-native sub-canopy thickets. By understanding canopy spatial patterns in managed areas, land managers can better understand its role in exotic invasion control, native species survival, and maintaining a refugia for oak-dependent plant species. Bur oak can live to 300 to 1,000 years and black oak can live to 500–600 years (Barnes and Wagner 1981). In an attempt to achieve quality oak savanna, land managers need to incorporate information on managed spatial patterns into their plans for these long-lived communities.

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