LANDSCAPE VEGETATION PATTERN, COMPOSITION, AND STRUCTURE OF DUPAGE COUNTY, ILLINOIS, AS RECORDED BY THE U. S. PUBLIC LAND SURVEY (1821-1840)

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Marlin L. Bowles,[1] Jenny McBride,[1] & Lisa Bell[2]
[1]The Morton Arboretum, Lisle, Ill., [2]Ecological Services, Urbana, Ill.

SUMMARY

We mapped and analyzed the notes and bearing tree data from the DuPage County, Illinois Public Land Survey (PLS), which was conducted between 1821 and 1840. Our primary objective was to describe the pattern and structure of vegetation present at that time, and to determine its relationship to landscape fire processes. The vegetation described by the PLS was 80% prairie. The predominant woody vegetation was described as timber, with smaller amounts of scattering timber, barrens, brush, and hazel thickets. Timber was situated along major streams, and was dominated by white oak, bur oak, red oak, and hickory, which are considered fire-tolerant. Maple, basswood, ash, and elm, which are less fire-tolerant, were infrequent and essentially restricted to areas of timber on the eastern sides of water courses. More than 50% of the woody vegetation also had woody undergrowth in which American hazelnut was the most frequent species. Tree density and frequency of woody undergrowth were inversely correlated, with low tree density and high frequency of undergrowth in barrens, and the reverse in timber. We also classified vegetation woody types based on bearing tree densities into open savanna (>0-10 trees/ha) savanna (>10-50 trees/ha), woodland (>50-100 trees/ha) and forest (>100 trees/ha). Among these groups, savanna was the predominant and most widespread type of timber, and was oak-dominated. Woodland and forest were much less abundant and tended to occur on the lee side of landscape firebreaks. They were also oak dominated, but supported maple, basswood, ash, and elm at low densities.

These vegetation descriptions fit an expected landscape fire model, in which timber persisted in landscape positions protected from eastward moving prairie fires driven by prevailing winds. These fires also converted timber into scattering timber and then into barrens by reducing tree densities and promoting post-fire sprouting of woody vegetation. This process restricted forests with high tree densities and fire-intolerant species to landscape positions afforded protection from prairie fires. Prairie and savanna with fire-tolerant oaks developed in areas with little fire protection, primarily on the western sides of landscape fire barriers.

Recommendations for managing and restoring woody vegetation based on pre-European structure and composition must take into account the single time period of the PLS data. A general management objective should be to restore fire processes and oak-dominated vegetation in order to maintain biodiversity associated with oak ecosystems. Landscape features can be used to help focus restoration objectives, with management for greater woody undergrowth and forest species diversity in areas with more fire protection, and management for greater prairie and savanna species diversity in areas with less fire protection. However, the landscape scale and processes in operation prior to settlement are difficult to replicate in modern fragmented ecosystems, and experimentation is needed to understand how to implement many of these objectives.

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TABLE OF CONTENTS

INTRODUCTION

Background

At the time of European settlement, the Chicago region of northeastern Illinois was a broad mosaic of prairie and oak (*Quercus*)-dominated savanna, woodland and forest (Curtis 1959, Davis 1977, Anderson 1983, Anderson & Bowles 1999). This pattern was climatically induced and controlled by fires set by lightning and by indigenous people, with timber persisting on the lee side of fire barriers such as topographic relief and water courses (Gleason 1913, Moran 1978, 1980, Anderson 1991, Leitner *et al.* 1991, Bowles *et al.* 1994) and shifting with changing climatic conditions (Grimm 1983, 1984). Because of wide-scale deterioration from fragmentation, fire suppression, overgrazing, agriculture, and invasion of alien plants, much of Illinois' native vegetation has been lost, and its restoration management is a high conservation concern (Robertson & Schwartz 1994, Leach & Ross 1995, Packard & Mutel 1997, Schwartz 1997). Ecological models that apply presettlement landscape fire processes to vegetation pattern, composition, and structure will best meet these needs (Leach & Ross 1995). In this report on the presettlement vegetation of DuPage County, we interpret landscape vegetation pattern, structure and composition in relation to landscape features and fire processes and make management and restoration

The Public Land Survey

A powerful and useful approach to understanding the landscape pattern and structure of woody vegetation prior to European settlement is analysis of the Government Land Office Public Land Survey (PLS) vegetation notes, maps, and bearing tree data, which were recorded in the early 1800s in Illinois (Hutchison 1988, Ebinger 1997). This survey comprised a square-mile landscape grid upon which the identity, diameter, distance, and direction for two to four bearing trees were recorded at half mile intervals. These data were accompanied by similar measures of trees intercepted by section lines, section line vegetation summaries, other notes, and township maps distinguishing timber, prairie, and other important landscape features.

Despite bias that may have occurred in tree selection (Bourdo, 1956), the bearing tree data represent a low-density vegetation survey that can be used to reconstruct landscape-scale pre-European vegetation (Brugam & Patterson 1996), and occasionally site-specific comparisons (*e.g.* Donnelly & Murphy 1987, Bowles & McBride 1998). These data can provide ecological information when landscape features, such as soils, topography, or fire barriers, are used to interpret different vegetation types based on an expected pattern. For example, in Wisconsin, Leitner *et al*. (1991), and in Illinois, Anderson & Anderson (1975), Moran (1978, 1980), Rogers & Anderson (1979), Bowles *et al.* (1994), and Edgin & Ebinger (1997) used arbitrary tree density classes to map savanna, woodland and forest. They found greater land cover of prairie and savanna in areas without fire protection, and higher tree densities and greater abundance of fire-intolerant trees in fire-protected positions. Such studies may also provide information on the presence and structure of woody understory vegetation, which appears critical to understanding and guiding management and restoration of oak savanna and oak woodlands (Bowles *et al.* 1994).

Study objectives

In this study, we examined pre-European settlement (or "presettlement") woody vegetation pattern and structure in DuPage County based on analysis of PLS maps and data. Research objectives were to: 1) assess how the PLS described and sampled vegetation and relate the results to modern concepts of savanna, woodland, and forest, 2) describe the presettlement woody vegetation, 3) develop an ecological model correlating vegetation patterns with landscape features and processes, and 4) apply this model toward management and restoration of native oak ecosystems. To conduct the analysis, we conducted a quantitative analysis of data collected by the PLS from DuPage Co., and useed this information to refine the PLS township plat maps using Geographic Information System (GIS) technology.

STUDY AREA

Central DuPage County lies about 25 miles (40 kilometers) west of Lake Michigan and the city of Chicago, Illinois. The County comprises 9 complete and one fractional townships, totaling 86,796 hectares (214,386 acres). The DuPage County climate is continental, with hot humid summers and very cold winters. Annual average precipitation is 33 in (84 cm), with about 67% occurring during the growing season, but with great variation due to periodic summer drought. Streams drain DuPage County from north to south, which provide potential refugia from eastward moving prairie fires (Figure 1). The West and East Branches of the DuPage River drain the central and western part of the county south into the DuPage River, while Salt Creek drains the eastern part of the county into the DesPlaines River, which forms the southeastern boundary of DuPage County. Maximum relief in DuPage County is 251 ft (75 m), ranging from 585 ft (178 m) above sea level along the Des Plaines River to 836 ft (255 m) on the West Chicago Moraine. The south-facing bluffs of the Des Plaines River valley provide the most xeric conditions in the county, where elevation drops over 150 ft (46 m) in less than a mile and dolomite is exposed in ravines and along the river valley.

The county is situated of primarily Woodfordian-aged glacial moraines and drift deposited during the close of Wisconsinan glaciation in Illinois. Moraines cover over 61% of DuPage County and are an important surficial landscape feature (Figure 1). The southwestern portion of the county occupies outwash of the West Chicago Moraine, level ground moraine, and a small part of the Minooka Moraine, which is primarily in Kane County to the west. Eastward, the West Chicago, Wheaton, Keeneyville, Westmont, Clarendon, Palatine, and Tinley Moraines are in close proximity, forming an irregular surface stratigraphy. Soils form a mosaic of mollisols (developed primarily under grassland), alfisols (developed primarily under forest), and transitional, or “savanna” soils, which also reflect an interaction between rates of soil genesis and vegetation change (Mapes 1979). Soil substrates are primarily upland silty or clayey glacial till or outwash. Some silty and loamy soils occur on stream terrace outwash or alluvium in the DuPage River valleys, or on dolomite and coarse outwash in the Des Plaines River valley (Mapes 1979).

DuPage County occupies five different sections of three Chicago Region Natural Divisions (Figure 2). Most of the county occurs in the Morainal Natural Division, primarily in its Western Morainal Section, but also in the Kettle Moraine Section in the northwestern part of the county and the Fox River Bluff Section in the southwest. Most of the southwestern part of the county occupies the Grand Prairie Section of the Grand Prairie Natural Division, primarily on ground moraine and adjacent outwash of the West Chicago Moraine. The southeastern border of DuPage County occurs in the Bedrock Valley Section of the Grand Prairie Natural Division, where dolomite bedrock outcrops along the Des Plaines River valley.

METHODS

Interpreting PLS notes and data

The DuPage County PLS was completed between 1821 and 1840 by at least seven deputy surveyors (see Appendix I). European settlement also began during that period, escalating after the 1832 Black Hawk War (Thompson 1985). Each township was mapped after completion of its survey, showing the distribution of timber, watercourses, and settlement features; most of these maps were completed by 1842. The PLS also described four different vegetation types that were large enough in area to map and statistically analyze: *“prairie,” “barrens,” “scattering timber”* and *“timber.”* The PLS indicated distances along section lines for transitions between these vegetation types, which also facilitated their mapping. The primary data collected by the PLS were the identity, diameter, distance, and direction for two to four bearing trees, each in one of the four quadrants at each corner. It also recorded the identity and diameter of “line trees” intercepted by section lines and summarized tree species present along section lines. The PLS also indicated whether woody undergrowth, or understory, vegetation was present in each 1-mile section line, and summarized the species present in undergrowth along each section line. Undergrowth data were apparently not recorded for the fractional township bordering the Des Plaines River (T37N, R11E).

We analyzed the PLS data transcribed from microfilm copies of the original notes and from copies of the notes transcribed in 1875 and kept by the DuPage County Recorder of Deeds. These data were compared with corresponding GIS maps of landscape vegetation pattern made from the PLS notes and maps. GIS softwared (ESRI.com) was used to map the four primary vegetation types, with layers for section lines with woody undergrowth, bearing trees, and section and quarter-corners identified by either savanna, woodland, or forest tree density classes. Features of European settlement, such as fields, were not included in the GIS maps or landscape analysis. The surveyors identified 14 bearing tree species by common name, including most of the dominant native DuPage County trees. However, common wetland trees, such as green ash (*Fraxinus pennsylvanica*), and swamp white oak (*Quercus bicolor*), were not distinguished. The shrub-layer species American hazelnut (*Corylus* *americana*), dogwood (*Cornus* sp.), and witch hazel (*Hamamelis virginiana*), briers, and vines were identified in section line summaries of woody undergrowth. We assume that most bearing tree species were correctly identified and placed them in modern species analogs following Swink & Wilhelm (1994). Separation of oaks provided the greatest difficulty because of abbreviations used by the surveyors (Appendix II). For example, bur oak (*Quercus macrocarpa*) and black oak (*Q. velutina*) could be differentiated when bur oak was recorded as "Bur oak," and black oak as "Black oak." However, neither bur oak nor black oak were recorded in southeastern DuPage County (T37N, R11E); rather "B oak" and "W oak" were recorded. We assigned these trees to bur oak and white oak (*Quercus alba*) respectively based on several lines of evidence. Pure black oak is rare in DuPage County because its dry habitat requirement is rarely met and because it often hybridizes with Hill's oak (*Q. ellipsoidalis*), which was recorded by surveyors as "S. (Spanish or scarlet) oak" (Swink & Wilhelm 1994, George Ware, pers. comm.). Further, a survey (Pierre 1962) for remaining DuPage County bearing trees relocated several bur oak bearing trees originally recorded as "B Oak." However, some black oaks occur along the dry bluffs of the Des Plaines River, and it is possible that their former abundance is under-represented in our analysis. In contrast, white oak is the most abundant Chicago region oak and would have been the most frequently encountered bearing tree. However, misidentifications occurred and this species could have been over-represented. For example, in adjacent Cook County, bearing trees identified as white oak were apparently bur oak (Bowles & McBride 1998).

Statistical analysis

Several procedures were used to test for bias in bearing tree selection. First, an analysis of variance (ANOVA) was used to determine whether the average diameters of the three most abundant bearing tree species differed from unbiased measures of the same species when recorded as section line trees. We tested for bias in selection of 116 bearing trees using the Chi-square Goodness of Fit (Zar 1974, Rogers & Anderson 1979, Leitner *et al*. 1991). As none of the Chi-square tests were significant (see results), we assumed that selection of trees was unbiased and used all recorded distances to calculate trees/hectare for each section and quarter-corner. This procedure followed the modified point-center-quarter sampling method, where trees/hectare = $10{,}000\ m^2 \div (\bar{x}\ d)^2$, and $\bar{x}$ d = the mean distance of bearing trees at each corner adjusted for the number of trees present (Cottam & Curtis 1956). We then calculated the section corner and quarter corner tree densities of all bearing trees in the PLS vegetation types. For comparison, following Anderson & Anderson (1975) we also placed each corner in arbitrary *"savanna"* (>0-50 trees/ha), *"woodland"* (>50-100 trees/ha) and *"forest"* (>100 trees/ha) categories. The total and relative (R) density (D) and basal area (BA) and importance value [IV = (RD + RBA)÷/2] were calculated for each bearing tree species in all vegetation types. Basal area was calculated in square meters by converting from the original measure of diameter in inches. Following Bowles *et al*. (1994) we then divided savanna into groups of *"open savanna"* (>0-10 trees/ha) and *"closed savanna"* (>10-50 trees/ha), and compared the abundance and relative densities of species between these groups and other density classes.

We asked whether landscape features affected vegetation pattern by comparing the distribution and tree densities of scattering timber and timber relative to stream firebreaks. To test this, Chi-square analysis was used to determine the probability that the proportions of bearing tree corners in scattering timber vs. timber differed between their locations north or east vs. south or west of the nearest stream firebreak. This assumes that prevailing southwesterly winds determined the direction of prairie fires that shaped landscape vegetation (Gleason 1913). We then used a one-tailed t-test to determine the probability that tree density in scattering timber was lower than in timber, using log-transformed data. This assumes that tree density affected how surveyors differentiated between these timber types and that landscape fire protection promoted greater density in timber. We determined the proportion of each vegetation type in which woody undergrowth was recorded as present in line summaries. Frequency analysis was used to determine the abundance of woody understory species in these section line summaries, using each half-mile summary as a transect sample.

We used PCORD software (McCune & Mefford 1995) to classify species groups and determine species gradients that might correspond to landscape gradients caused by fire or drainage. For this analysis, we used DECORANA to ordinate N = 340 section line summaries containing presence absence data on 11 species, each with 5 or more occurrences. The matrix was clustered using a Group Averaging linkage and a relative Sorensen distance measure.

RESULTS

Tests for bias in tree selection

White, bur, and red oak (*Q. rubra*) section line trees (N = 43) were significantly larger (F = 9.97, P < 0.001) than their respective bearing trees (N = 348), with line trees averaging about 0.43 (± 0.02 se) meters dbh and bearing trees averaging about 0.37 (± 0.08 se) meters dbh (Table 1). There was also no significant difference among species (F = 1.66, P = 0.192). These results might suggest that surveyors were selecting smaller than average size bearing trees, possibly because of their greater longevity or thinner bark that would facilitate blazing. However, a sampling effect may have contributed to larger line tree diameters, as larger trees have a higher probability of being intercepted by line transects (Brower & Zar 1994). The distribution of 116 bearing trees around each section or quarter corner did not differ from a non-random distribution (X^2 = 1.1, P = 0.776), and the quadrant occurrence of the tree with the shortest distance at each corner was random with respect to quadrant occurrences of all other bearing trees (X^2, P= 0.12, 0.939; 1.5, 0.473; 4.67, 0.098; 1.51, 0.47).

Landscape pattern

The presettlement vegetation of DuPage County was predominantly prairie, which accounted for nearly 80% of the landscape (Table 1). Prairie wetlands (marshes, sloughs, & swamps) comprised less than 2% of the landscape, but were widespread on morainal topography. Open water, including rivers, creeks, lakes, and ponds comprised less than 1% of the landscape. Timber and related vegetation accounted for almost 20% of the landscape, about 6% of which was scattering timber, barrens, brush and hazel thickets.

The largest blocks of timber were associated with the West Chicago Moraine along the West and East branches of the DuPage River, and with the Keeneyville, Westmont, and Clarendon moraines bordering the Des Plaines River (Figure 3). Timber also occurred along the southwest county border as part of the Big Woods, an extensive area of timber along the Fox River in adjacent Kane County (Bowles *et al*. 1994). Smaller groves occurred along Salt Creek, the upper East Branch of the DuPage River, and their tributaries. Scattering timber usually had an intermediate landscape position between either timber and prairie, or timber and barrens, and was represented along each of the major stream drainages and the Des Plaines River. A greater proportion of bearing tree corners occurred in timber north or east of stream firebreaks, as opposed to scattering timber, where 90% of all corners occurred south or west of stream firebreaks (Figure 4). Two large areas of barrens occurred in a mosaic with scattering timber. One occurred on the West Chicago Moraine west of the West Branch of the DuPage River, forming a transition between timber or scattering timber and prairie. The second area of barrens occurred west of the East Branch of the DuPage River, forming a transition from scattering timber to prairie. The landscape pattern of woody vegetation, based on tree density classes, was predominantly open savanna and savanna, accounting for about 65 % of all bearing tree corners (Figure 4). There was no relationship between grove size and its percentage of forest (r^2 = .01, P = .59), woodland (r^2 = .03, P = .38), or savanna (r^2 <.01, P = .95).

Composition, structure and diversity of PLS vegetation types

Timber

Areas mapped as timber by the PLS were dominated by white oak, with secondary importance of bur oak and red oak, and minor importance of hickory (*Carya* sp.). Elm (*Ulmus* sp.), basswood (*Tilia americana*), maple and six other taxa had lower importance (Table 2). Tree density in timber averaged 125.4 trees/ha, with almost equal representation of open and closed savanna, woodland, and forest (Figure 4). Almost 60% of the section lines in timber had woody understory vegetation present (Figure 4). Hazel was the dominant species in undergrowth, red oak was the second most abundant species and 17 other species were recorded (Table 3). Bur oak was rarely identified as a woody undergrowth species.

Scattering timber and barrens

Areas mapped as scattering timber by the PLS were dominated by white and bur oak, with lower importance of red oak, and minor importance of hickory (Table 2). Scattering timber tree density averaged 70.3 trees/ha, which was significantly lower (t = -4.6275, P <.0001) than density in timber (Figure 4), with comparatively low species richness (Table 2). Most of the corners in scattering timber were open savanna, with less than 10% representation of woodland or forest (Figure 4). About 47% of the section lines in scattering timber had woody undergrowth, which was dominated by hazel and red oak (Table 3). Bearing trees were present at only three corners in barrens, where red oak, hickory, and white oak, each had IVs >25 (Table 3). Eighty percent of the barrens section lines had woody undergrowth which had dominance by hazel and red oak (Table 3).

Prairie

Prairie mapped by the PLS had only 23 corners with bearing trees, which comprised less than 3% of all corners in prairie. More than 80% of these corners with trees were open savanna, averaging 8.32 trees/ha (Figure 5). Prairie also supported low tree species richness (Table 2). White oak was the dominant bearing tree, with secondary importance of elm, bur oak, and red oak, and low importance of maple and ash. Bur oak had higher density than elm, which achieved its high importance due to four large trees present at two corners in prairie in the Des Plaines River flood plain. About 17% of the section lines with bearing trees in prairie had woody undergrowth (Table 4). Hazel occurred along three of these lines, while red oak, white oak, oak, and basswood undergrowth were each recorded from one section line.

Composition, structure and diversity of forest, woodland & savanna bearing tree density classes

Comparisons among tree density classes

As indicated, the landscape pattern of woody vegetation, based on tree density classes, was predominantly open savanna and savanna, accounting for about 65 % of all bearing tree corners (Figure 4). However, there was no relationship between grove size and its percentage of forest (r^2 = .01, P = .59), woodland (r^2 = .03, P = .38), or savanna (r^2 <.01, P = .95). Landscape differences also occurred within open savanna vegetation. For example, 76.2% of all corners in scattering timber on the Des Plaines River were open savanna; but, only 42.3% of the corners in scattering timber along the Salt Creek and DuPage rivers were open savanna.

Section and quarter corners classified by tree density as forest, woodland, savanna and open savanna were dominated by white oak (Figure 5). Bur oak, red oak and hickory were subdomnant, usually at 10 % or more relative density. Among these species, bur oak tended toward greater abundance in savanna, red oak had greater abundance in savanna, and hickory was more abundant in woodland. Ash, basswood, elm and sugar maple had greater abundance in woodland and forest, but occurred at less than 10 % relative density. Ash and maple also had a very localized distribution (Figure 6). The Big Woods area of southwestern DuPage County had 55% of all maple-ash occurrences, while 21% were along the Des Plaines River. Maple was also sampled at a single locality along the West Branch of the DuPage River, and along two tributaries of the river's East Branch. Ash was also present along the West Branch of the DuPage River and along the Salt Creek, where it occurred with elm.

Classification and ordination

The cluster analysis and species ordination provides weak support for species groups that share similar ecological adaptations for drainage, light levels, and and fire-tolerance (Figure 7). Three primary cluster groups separated most oaks (excluding black oak) from a second group divided into ash-elm-maple basswood and black oak-ironwood walnut and ash-elm-maple basswood and groups. The association of these groups on the ordination suggests that Axis 1 represents decreasing drainage and fire tolerance, as well as increasing shade tolerance (Curtis 1959, Lorimer 1985). However, Axis 1 had low variance (r-sq = 0.051), indicating the ordination may not be robust. Axis 2 also had low variance (r-sq = 0.056) and appears less interpretable.

Vegetation-soils relationships

The DuPage County PLS vegetation pattern varies across stratigraphy, parent materials, soil groups and soil associations. Almost 70% of all timber, scattering timber, and barrens occurred on moraines, ranging from a high of 82% for scattering timber and a low of 65% for timber. About 80% of the prairie and scattering timber, and 75% of the timber, occurred on silty and clayey upland soils formed in glacial till, which forms most of the county parent material (Table 5). However, prairie was primarily in the Markham-Ashkum association, scattering timber was primarily in the Morely-Ashkum association, and timber was almost equally distributed between both associations. In contrast, almost 70% of the barrens vegetation occurred on silty upland soils formed in glacial outwash of the West Chicago Moraine, comprising the Drummer-Mundelein-Barrington association. Between 15-20% of the scattering timber and timber also occurred on silty and loamy glacial outwash materials in the valleys of the DuPage and Des Plaines Rivers.

DISCUSSION

Landscape vegetation pattern and structure

The presettlement vegetation of DuPage County was predominantly prairie. Timber occurred along streams or river valleys, and there were few isolated prairie groves. This pattern mirrors other studies of presettlement vegetation in northern and central Illinois (Anderson & Anderson 1975, Moran 1976, 1980, Rogers & Anderson 1979, Bowles *et al.*, 1994). It is presumed to have developed with fire-caused fragmentation and deterioration of holocene (post glacial) forests during the eastward extension of the prairie peninsula (Gleason 1922, Transeau 1935, Curtis 1959), which occurred 8-5000 years BP during the xerothermic interval (Geis & Boggess 1967, King 1981, Webb *et al*. 1983, Baker *et al*. 1992). With amelioration of the dry climate, periodic drought induced fire and increasing fire from indigenous people apparently maintained a prairie-oak mosaic that shifted spatially in response to climatic change (Taft 1997, Anderson & Bowles 1999, Grimm 1983). Based on historic descriptions, we expected a savanna transition between prairie and timber, especially along the fire-impacted western borders of timber (Bowles & McBride 1994). For larger blocks of timber, we found these transitions represented as barrens and scattering timber. However, few isolated barrens or scattering timber were mapped, and they also were not mapped in association with smaller groves of timber. This absence may have been an artifact of the large PLS sampling scale, where small blocks of scattering timber or barrens were not distinguishable or were rarely crossed by section lines. Or, smaller prairie groves may have lost any such transition due to a greater vulnerability to fire.

In DuPage County, the distribution of tree species across savanna, woodland, and forest vegetation in the 1800s appears to represent a fire- and shade-tolerance gradient. Savanna was dominated by fire-tolerant and shade-intolerant oaks, with white oak as the dominant species. Red oak preferred savanna and woodland, and hickory was more abundant in woodland and forest. Maple, ash, and basswood, which are fire-intolerant and shade tolerant, preferred forest and woodland tree densities. The dominance of white oak over bur oak at lower tree densities is unexpected, as white oak is thought to be less fire-tolerant than bur oak (*e.g.* Curtis 1959), and bur oak was thought to dominate savanna at low tree densities. However, bur oak was subdominant in savanna, and may have been most abundant in narrow linear patterns at the prairie interface, which would not have been adequately sampled by the large scale PLS sampling grid.

Although the abundance of hazel undergrowth is rarely quantified or emphasized in PLS notes or studies, hazel appears to have been an important species throughout the savanna-woodland continuum (Bowles *et al*. 1994, Edgin & Ebinger 1997). Hazel now appears to be much less abundant in most modern forest or savanna remnants (Bowles & Spravka 1994, Bowles *et al*. 1998). As hazel has high light requirements and is fire adapted (Stearns 1974), its former abundance corresponds to the widespread occurrence of savanna conditions, and suggests that it was extremely fire-tolerant. The abundance of hazel also could reflect surveyor bias, as it was a common food source and easily recognized. The surveyors also may not have known the identity of other common shrubs, or they may have been less abundant at that time. For example, the common gray dogwood (*Cornus racemosa*), which was rarely mentioned, increases with grazing pressure or other human disturbance, such as mowing. The arrowwood (*Viburnum rafinesquianum*) is extremely abundant in oak forests (Swink & Wilhelm 1994, Bowles *et al*. 1998), but was also not mentioned during the PLS of DuPage County.

Comparing the PLS description of presettlement vegetation to modern definitions

The PLS separation of barrens, scattering timber, and timber may have been based in part on the gradients in tree density and tree species among these vegetation types. However, separation of scattering timber also may have relied on the amount of dispersion or "scattering" of timber fragments left by the process of fire-caused deterioration of timber. These vegetation may have been detected most easily at a large landscape scale. Barrens vegetation described for DuPage County corresponds to other descriptions of barrens from glaciated areas of Illinois (*e.g.* Bowles & McBride 1994, White 1994, Edgin & Ebinger 1997). They were characterized by post-fire sprouting shrubs and oaks representing late stages of fire-caused forest deterioration (Gleason 1922), rather than responses to edaphic factors. Barrens may have often lacked bearing trees, and the two corners with bearing trees in DuPage County barrens had a lower tree density and smaller trees than bearing trees in scattering timber or in timber. As expected, the DuPage Co. barrens also had the highest percentage of section lines with woody undergrowth, and 100% frequency of hazel.

The PLS bearing tree corners sampled in prairie have a strong similarity to a modern concept of open savanna. Both had a similar stand density and nearly identical ranking of dominant species, although the PLS vegetation had lower diversity and lower percent cover of woody undergrowth. However, the PLS scattering timber category does not directly correspond to savanna, as its density (70.3 trees/ha) was closer to woodland conditions. Woodland also had much higher species richness than scattering timber.

The PLS timber category was very broad with respect to modern tree density classes, and thus included arbitrary divisions of a tree density and vegetation continuum. The dominance of savanna bearing tree densities and the large sampling scale also prevents mapping of distinct forest and woodland vegetation types. However, the quantitative differences in vegetation structure and individual species distributions support distinction of forest and woodland. The primary ecological factor in this distinction appears to be a landscape fire effect on tree density and composition. For example, tree species richness and diversity, percentage of woody undergrowth, and species diversity of woody undergrowth were usually greater in forest than woodland. Individual tree species also responded to this gradient, with greater importance of fire-resistant bur and white oak at lower tree densities, greater hickory importance at intermediate densities, and greatest abundance of fire-intolerant ash and maple at higher tree densities.

Ecological landscape model

The landscape vegetation pattern in DuPage County fits a landscape fire model, with eastward-moving prairie fires driven by prevailing western winds eliminating timber in fire-prone areas of the landscape (Gleason 1913, Grimm 1984, Moran 1978, Anderson 1991, Leitner *et al*. 1991, Bowles *et al*. 1994). This landscape interaction between fire and fire barriers produced tree density and woody undergrowth gradients that can be interpreted in terms of vegetation described by the PLS.

In an ecological landscape model (Figure 6), highest tree density occurs in timber, with scattering timber, barrens, and prairie having increasingly lower tree density and less fire protection. Percentage of woody undergrowth represents a secondary gradient in this model, with barrens having high woody undergrowth but low tree density due to post-fire sprouting of trees and shrubs under high fire frequency. Tree density and percent undergrowth is lowest in prairie, which has the lowest level of fire protection and highest fire frequency. The gradients represented in this model also represent a fire-caused process of forest deterioration, with barrens and prairie representing advanced stages. These vegetation types differ structurally, with a greater percentage of woody undergrowth represented in barrens. The initial stages of deterioration appear to have included a process of fragmentation of timber, rather than a more simple reduction of tree density. Drought induced growing season fires may have been an important or primary factor in driving these processes and determining the composition, structure, and pattern of woody vegetation (Anderson 1982). Fire, firebreaks and topography would interact in affecting this model (Anderson 1991). In general, prairies develop on fire-prone level outwash or ground moraines, barrens occurred in transition from prairie to savanna in fire-prone areas of former forest, savanna or scattering timber occurred in areas of intermediate fire protection, and woodland or forest persisted on the east flanks or more well-defined fire barriers. Larger streams were more effective in blocking eastward-moving fires and allowing development of timber. Morainic topography reduced fire effects to a lesser extent, allowing development of barrens and scattering timber. The effect of topography is a result of slope and direction (Anderson 1991). Prairie predominates on slopes of 4% or less, and forest or savanna predominate on slopes of 4% or more. The directional effect is due to rising convection air currents associated with fire; eastward-advancing fires move easily up-slope but are retarded in down-slope movement.

The landscape vegetation gradient supporting an ecological fire model for DuPage County is most evident along the major river valleys. For example, on the West Chicago Moraine along the West Branch of the DuPage River, barrens occurred west of the river, forming a transition to either scattering timber or timber. A large block of timber (including woodland and forest bearing trees) occurred adjacent to the east of the river, and many bearing trees corners classified as forest were clustered along the river in this area. Further south, small blocks of timber occurred primarily on the east flank of the river. A second such transition occurred on the East Branch of the DuPage River, directly interacting with topography. Here, the river valley separates the West Chicago and Wheaton moraines, with timber on the west (east-facing) valley wall, and barrens and scattering timber only west of the river. A large tract of scattering timber and timber also occurred on moraines adjacent to the north of the Des Plaines River, with scattering timber located west of timber, where it would have developed in response to eastward-moving fires. The only extensive occurrence of forest on level topography was part of the "Big Woods," a large forested tract on the fire protected east flank of the Fox River, which occurred principally in Kane County (Bowles *et al*. 1994).

Tree species probably interacted with landscape fire, stand density, and soil moisture and nutrients in a complex feedback process. Increased tree density would provide more shade and more soil moisture, favoring shade-tolerant species. For example, black, white, and red oak usually occur along an increasing soil moisture continuum, while bur oak prefers more calcareous conditions (Swink & Wilhelm 1994). As expected, bur and white oak were most abundant at lowest tree densities where fire would be most frequent. Red oak, which apparently has less fire resistance, and higher moisture requirements was more abundant at higher tree densities. The fire-intolerant and shade-tolerant maple and ash bearing and line trees were most abundant at highest tree densities, and were most restricted to areas with fire barriers, such as the Big Woods, and along the Des Plaines River. The abundance of woody undergrowth also appears to have interacted with landscape fire barriers in a predictable manner, and was most abundant in barrens where it would have regenerated as post-fire spouts..

Management and restoration applications

Management and restoration based on pattern, structure and composition of woody vegetation in the early 1800s must take into account the temporal status of these data. While vegetation change is natural and expected (Picket *et al*. 1992), the processes in operation at the time of settlement were those that maintained elements of biological diversity that are now of great conservation concern, and the composition and structure of that vegetation can help provide reference systems necessary for guiding restoration (Aronson *et al*. 1995). However, the landscape-scale fire and species immigration processes and vegetative patterns that occurred prior to settlement may be almost impossible to replicate in the fragmented urban landscape of DuPage County. As a result, restoration of landscape fire-dependent vegetation types, such as barrens or scattering timber may be difficult. In some cases, post settlement vegetation history may have caused changes that could redirect management objectives (Mendelson 1998, Mendelson *et al*. 1992) .

Given these caveats, the DuPage County PLS provides historic information on woody vegetation pattern, composition, and structure before the advent of fire protection, which can be applied to management and restoration. This information allows development of specific restoration goals, and an understanding of the landscape management objectives needed to meet these goals. At the landscape scale, they allow an understanding of the interactive role of fire and landscape in shaping former vegetation pattern, composition and structure. For example, presettlement burning is often assumed to have maintained a savanna-woodland transition with little woody undergrowth in a graminoid fuel matrix (*e.g.* Apfelbaum & Haney 1991, Wilhelm 1991, Packard 1991, Packard 1993). This transition is present, but a more complex structure emerges, with woody understory vegetation characterized by hazel (and many other species) an important component of the continuum of woody vegetation in DuPage County.

In general, management to replicate presettlement savanna and woodland woody vegetation in DuPage County should focus on oak dominance with woody understory vegetation dominance by hazel. More specific guidelines can be related to landscape features, remnant vegetation types, or to arbitrary objectives. Restoration of savanna and barrens would be most applicable in fire-prone areas of moderate topographic relief without protection of stream fire barriers, while woodland management would be most applicable where more relief or watercourses add to fire protection.

Presettlement woody vegetation structure appears to have been either one- or two-layered, depending upon the presence or absence of woody undergrowth. When present, this vegetation may have been an important biodiversity component as it would have provided nesting habitat for some bird species (Whelan & Dilger 1992). Thus, clearing of all native woody understory species should not be an overriding objective for management or restoration of these communities, and in many cases restoration of woody undergrowth with hazel can increase structural and compositional diversity. Because of its high light requirement, management to restore hazel may require canopy opening, which should be conducted experimentally.

Developing guidelines for more fire-protected forest habitats based on PLS information is more difficult and challenging; their management will require experimentation (Bowles *et al*. 1998). Many of these habitats have undergone dramatic loss of canopy oaks and increased maple invasion in the last 20 years, after a series of post-settlement impacts including fire-protection, burning, logging, and grazing. Here, management goals must take into account historic conditions and more recent changes (Bowles *et al*. 1998, Mendelson 1998).

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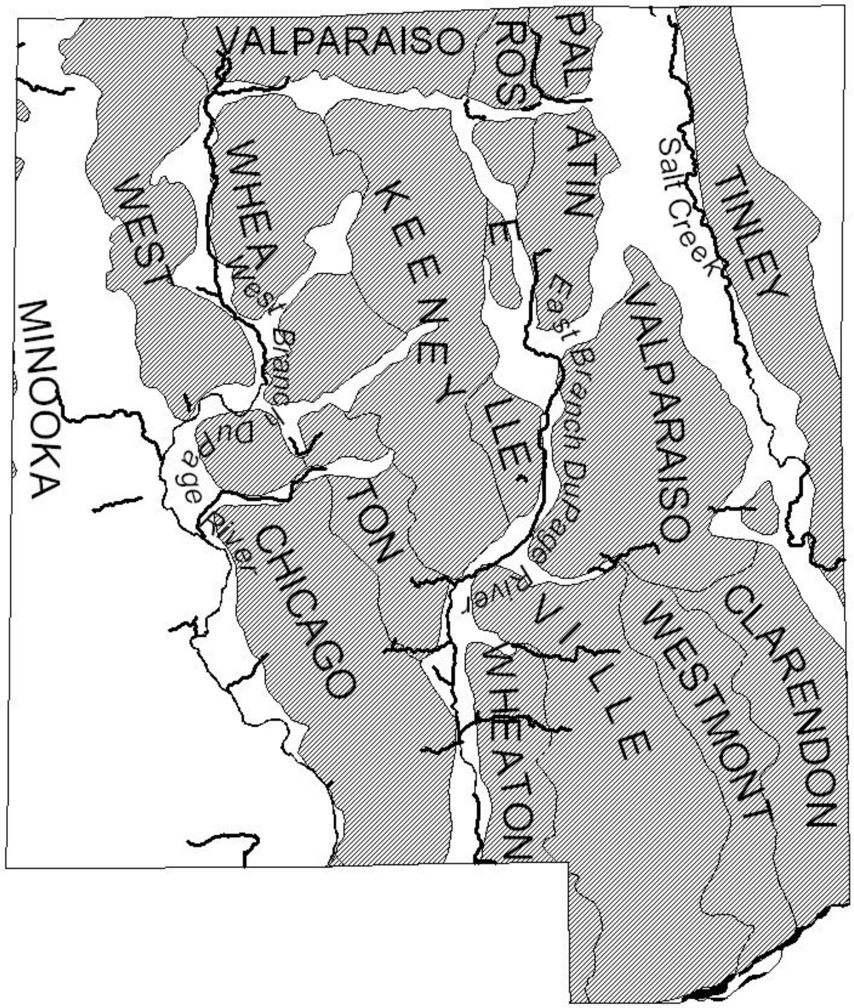


Figure 1.Glacial stratigraphy (with names of moraines and major streams) of DuPage County (Willman et al 1970).

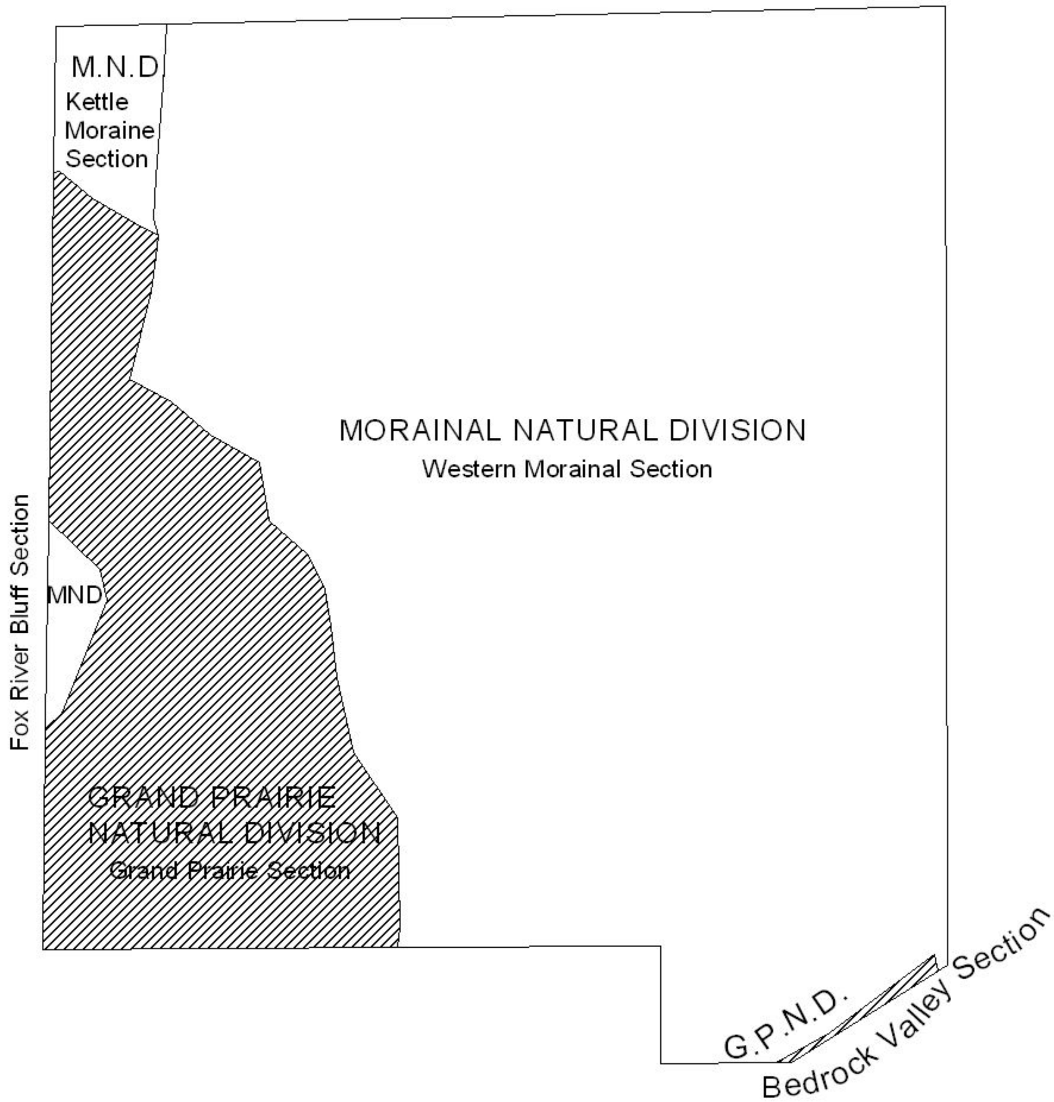


Figure 2. Natural Divisions of The Chicago Region occurring within DuPage County (Swink & Wilhelm 1994).

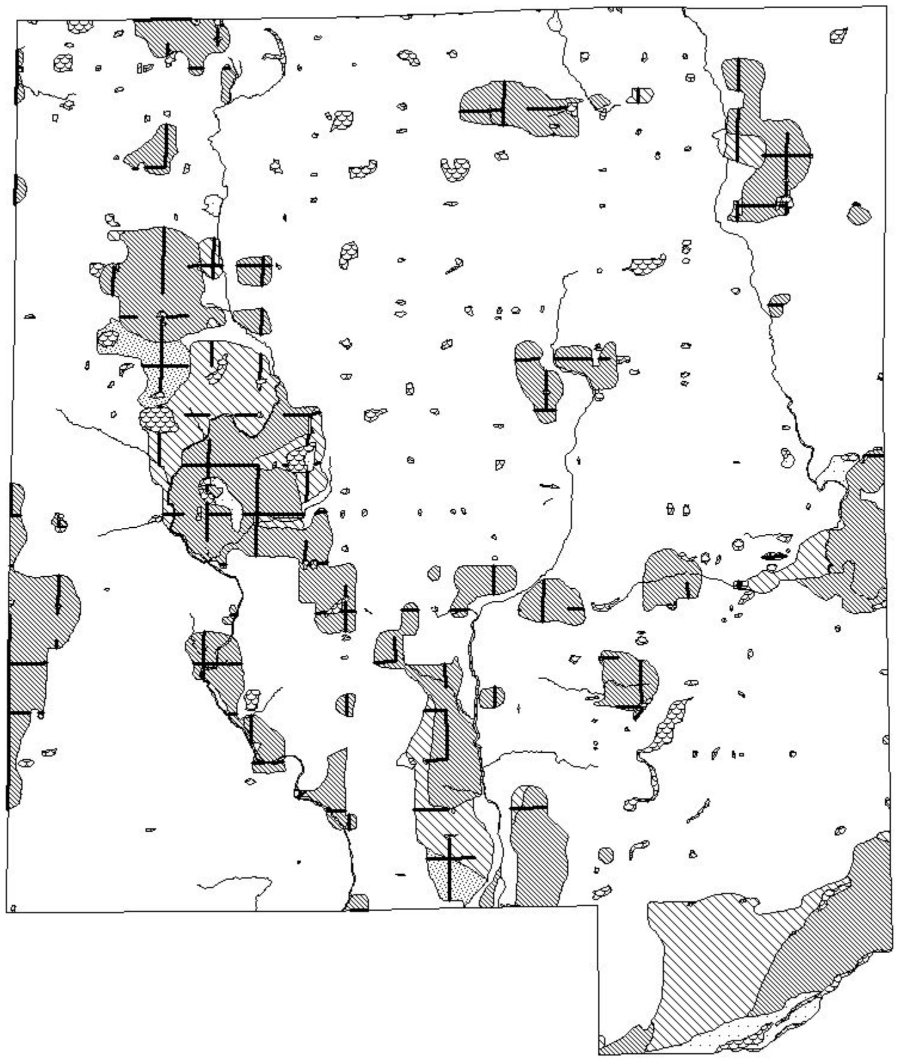


Figure 3. Pattern and structure of presettlement vegetation recorded by the Public Land Survey of DuPage County. Vegetation: no pattern = prairie, stippled = barrens, descending sparse lines = scattering timber , descending dense lines = timber, solid lines = presence of woody undergrowth on section lines, other = wetlands.

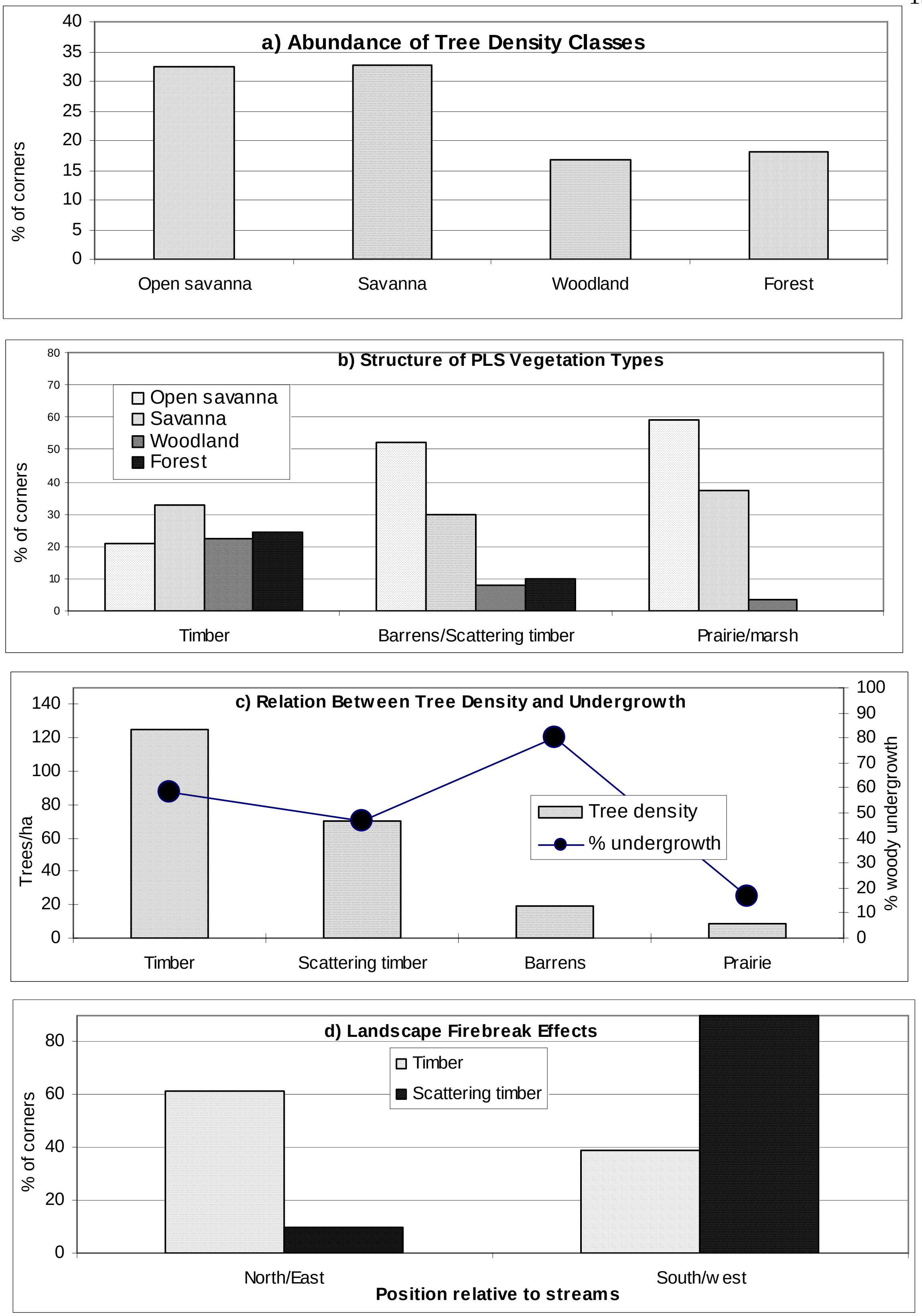
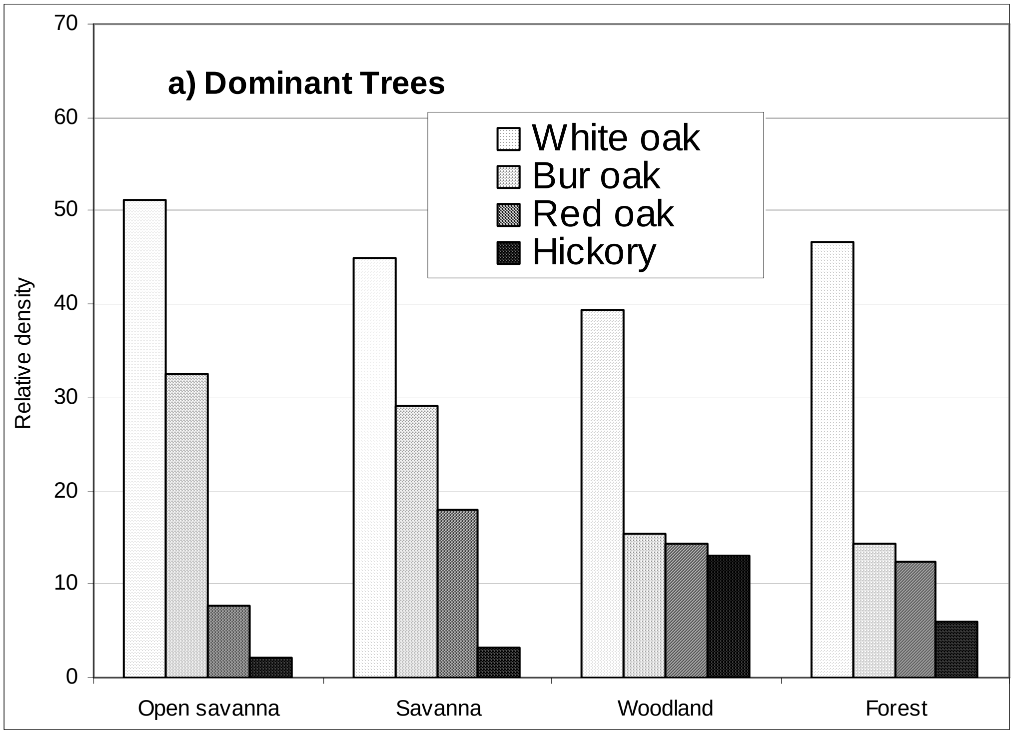


Figure 4. Presettlement landscape vegetation structure recorded by the Public Land Survey of DuPage County based on a) tree density classes, b) PLS vegetation types as interpreted by tree density classes, c) tree density and % undergrowth in PLS vegetation types, and d) firebreak effect of streams on scattering timber and timber.



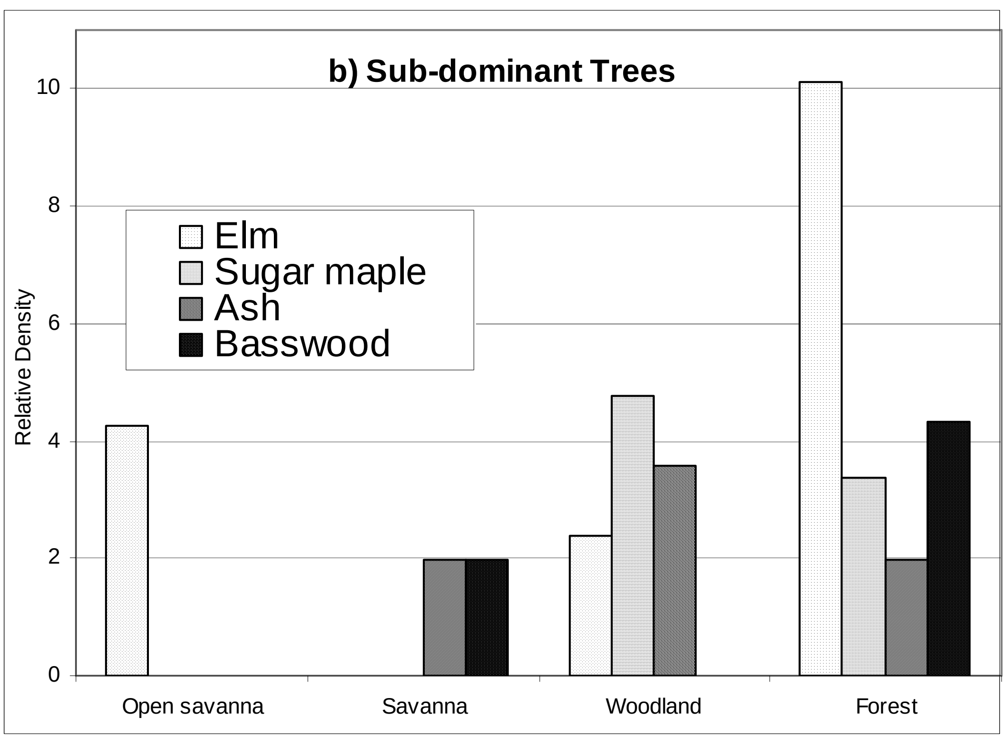


Figure 5. Distribution of dominant and sub-dominant tree species across a tree density gradient in the presettlement vegetation of DuPage County. Based on bearing trees recorded by of the Public Land Survey of DuPage County.

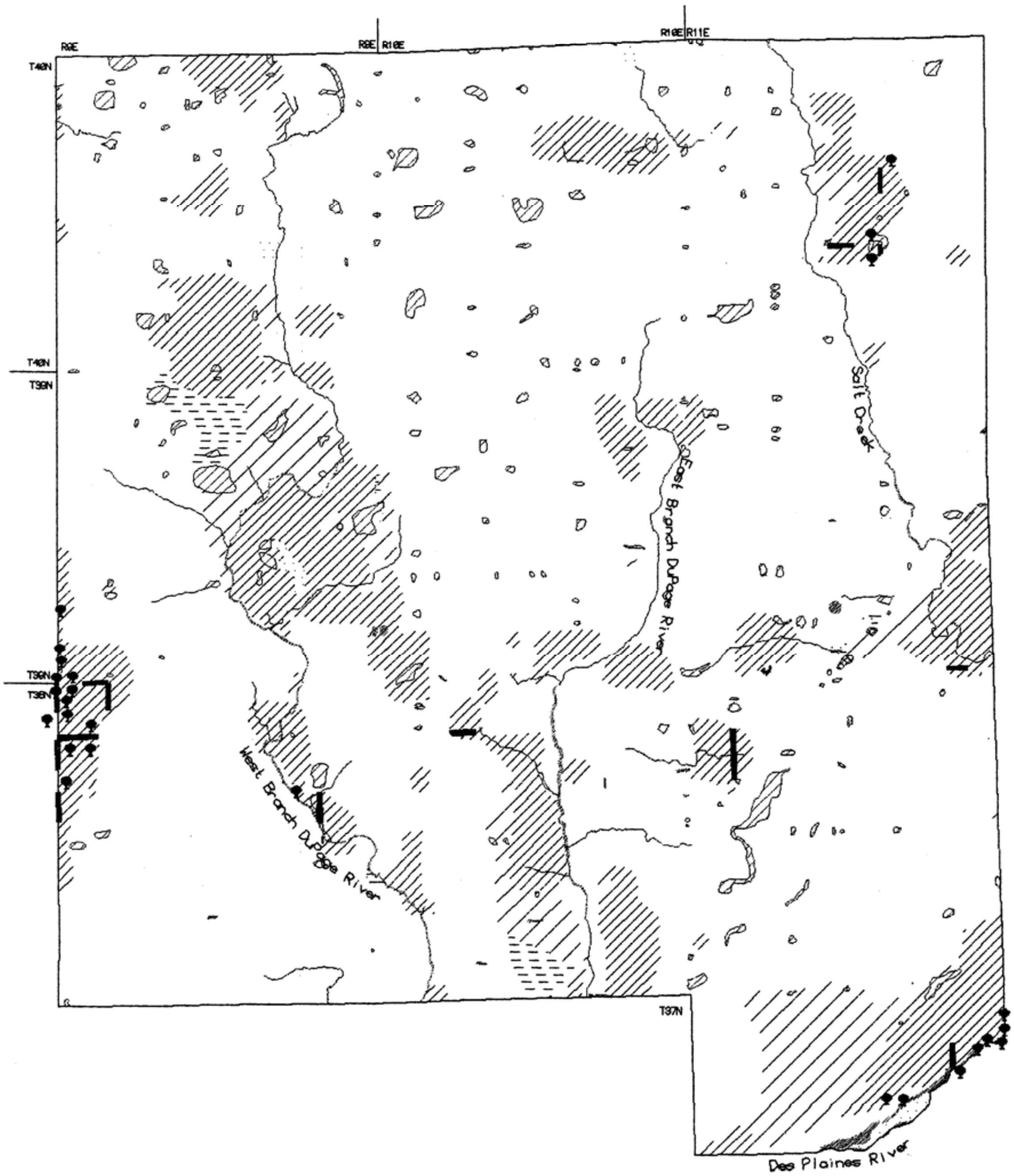
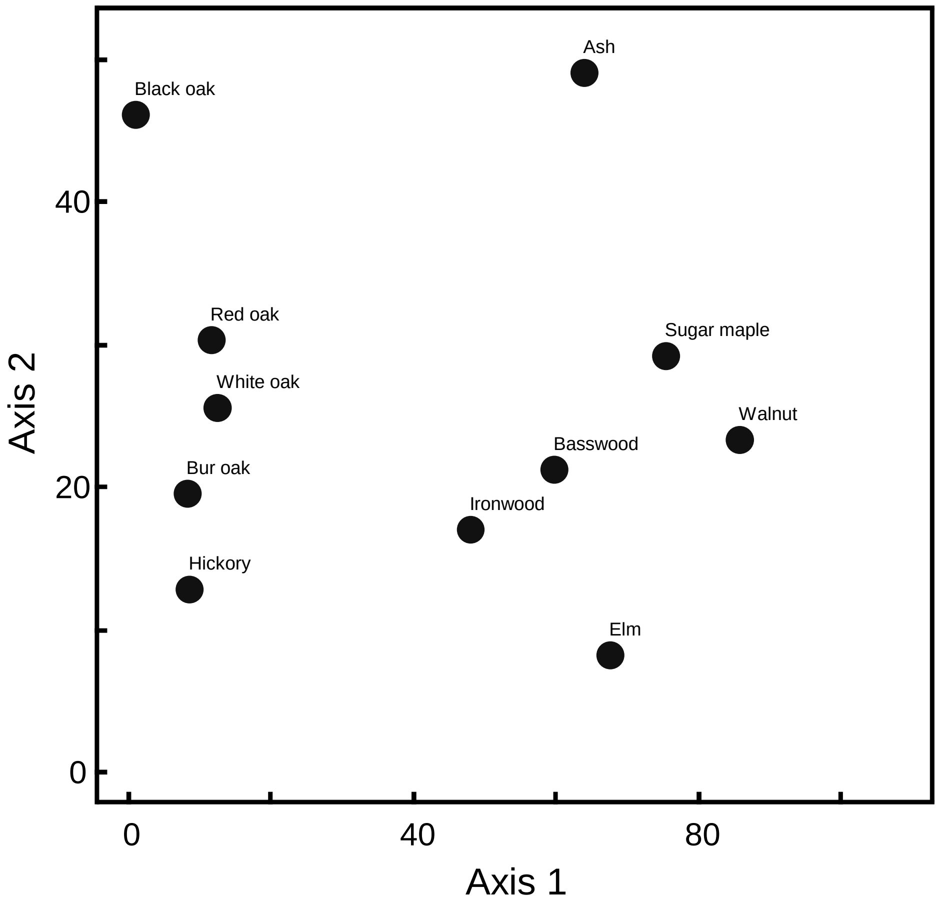


Figure 6. Distribution of maple and ash in the presettlement vegetation of DuPage County based on presence as bearing trees and line trees (solid tree symbols), and presence in section line summaries (solid lines) of the Public Land Survey of DuPage County.



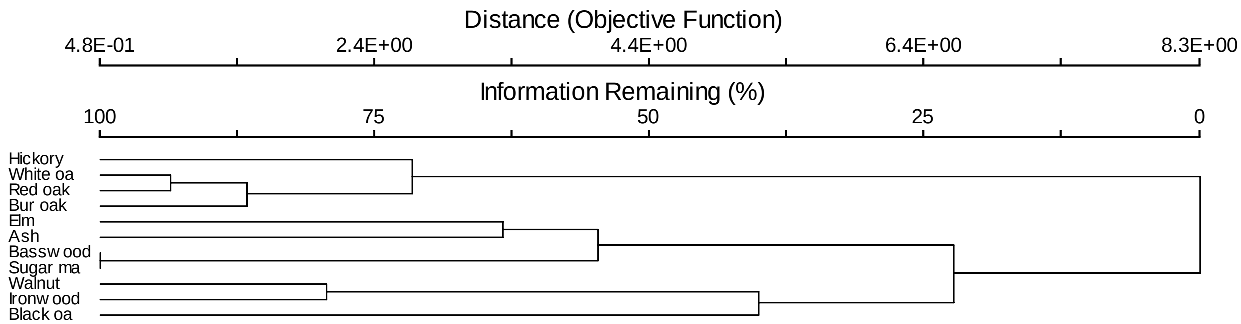


Figure 7. Decorana ordination (upper) and Ward's cluster analysis (lower) of tree species present in section line summaries of the Public Land Survey of DuPage County.

LANDSCAPE FIRE MODEL FOR
VEGETATION TYPES DESCRIBED
BY THE PUBLIC LAND SURVEY

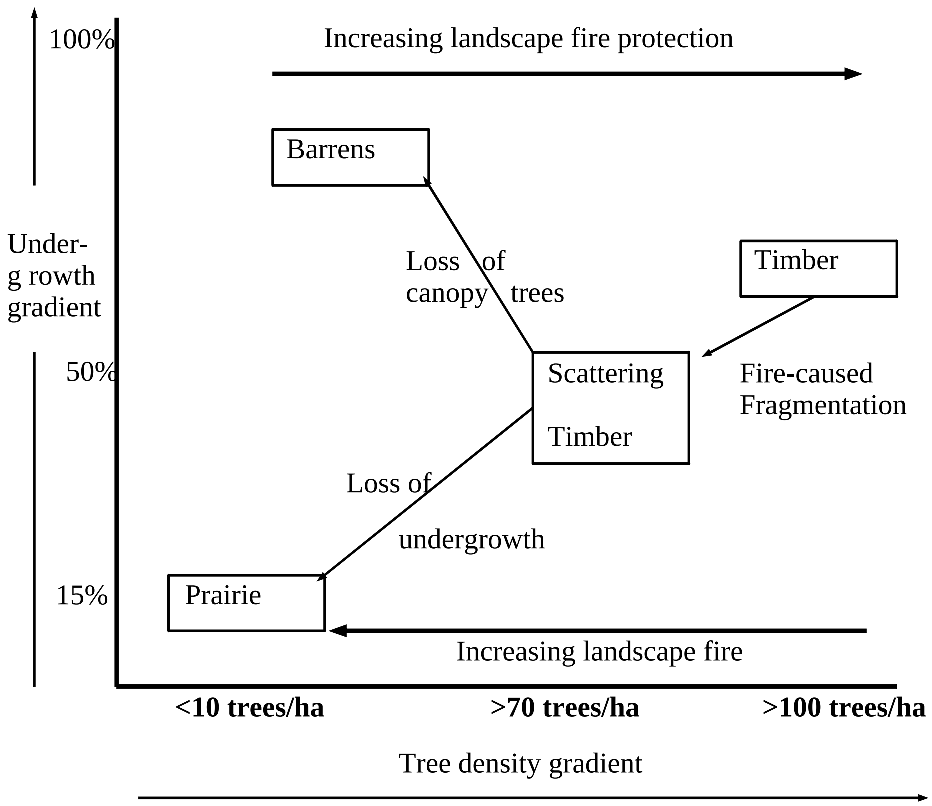


Figure 8. Ecological model for development of Presettlement Vegetation based on the Public Land Survey of DuPage County. Axis I represents increasing tree density in relation to increasing fire protection, where timber is fragmented into scattering timber by increasing fire. Axis II represents increasing percent frequency of undergrowth, where barrens develop with loss of canopy trees and prairie develops with loss of canopy trees and undergrowth.

Table 1. Area and percent of DuPage Co., Illinois landscape occupied by vegetation or wetland features described by the Public Land Survey.

Vegetation type	Area in hectares	Percent
Grassland	**69,935.5**	**80.57**
Prairie	68,541.4	78.97
Marsh	927.1	1.07
Slough	214.6	0.25
Wet marshy prairie	246.2	0.28
Grass swamp	6.6	0.01
Woody	**16,581.1**	**19.10**
Timber	11,560.0	13.32
Scattering timber	4,364.7	5.03
Barrens/Scattering Timber	581.6	0.67
Brush	38.2	0.04
Hazel thicket	8.3	0.01
Swamp	28.3	0.03
Aquatic	**279.2**	**0.32**
River/creek	253.0	0.29
Lake/pond	26.2	0.03
Total	**86,795.8**	**100.0**

Table 2. Bearing tree species density (D), basal area (BA), relative density (RD), relative basal area (RBA), and importance values (IV) in PLS vegetation types. N = No. of corners. Data recorded by the Public Land Survey of DuPage County.

TIMBER (N = 153)

Species	D	BA	RD	RBA	IV
White oak	156	21.43	43.58	50.84	47.21
Bur oak	79	8.70	22.07	20.63	21.35
Red oak	53	5.74	14.80	13.60	14.20
Hickory	24	1.40	6.70	3.32	5.01
Elm	11	2.15	3.07	5.10	4.08
Maple	8	0.58	2.23	1.38	1.81
Ash	8	0.34	2.24	0.80	1.52
Basswood	7	0.85	1.96	2.01	1.98
Black oak	5	0.63	1.40	1.50	1.45
Ironwood	3	0.09	0.84	0.21	0.52
Aspen	2	0.07	0.56	0.16	0.36
S. oak	1	0.16	0.28	0.39	0.33
Cottonwood	1	0.02	0.28	0.06	0.17
	358	42.17			100.00

SCATTERING TIMBER (N = 48)

Species	D	BA	RD	RBA	IV
White oak	37	4.00	48.05	50.08	49.07
Bur oak	31	3.35	40.26	41.90	41.08
Red oak	8	0.59	10.39	7.38	8.88
Hickory	1	0.05	1.30	0.63	0.97
	77	7.99			100.00

BARRENS (N=3)

Species	D	BA	RD	RBA	IV
Red oak	2	0.12	40.00	38.12	39.06
Hickory	2	0.10	40.00	31.25	35.62
White oak	1	0.10	20.00	30.62	25.31
	5	0.32			100.00

PRAIRIE (N=23)

Species	D	BA	RD	RBA	IV
White oak	15	1.29	44.12	32.24	44.12
Elm	4	1.39	11.76	34.57	23.17
Bur oak	8	0.87	23.53	21.76	22.65
Red oak	5	0.35	14.71	8.80	11.76
S. maple	1	0.07	2.94	1.82	2.38
Ash	1	0.03	2.94	0.81	1.87
	34	4.02			100.00

Table 3. Woody understory species section line frequencies in PLS vegetation types. N = No. of section lines. Data recorded by the Public Land Survey of DuPage County.

	Timber N = 147	Scattering Timber N = 23	Barrens N = 7
Hazel	76.19	76.28	100
Red oak	43.54	60.87	85.71
Oak	18.37	13.04	0.00
Hickory	11.56	4.35	28.57
Willow	5.44	4.35	0.00
White oak	4.08	0.00	0.00
Ash	2.72	0.00	0.00
Basswood	2.04	4.35	0.00
Briers	2.04	0.00	0.00
Vine	2.04	0.00	0.00
Dogwood	2.04	4.35	0.00
Bur oak	2.04	0.00	0.00
Witch hazel	1.36	0.00	0.00
Cherry	1.36	0.00	0.00
Walnut	0.68	0.00	0.00
Black oak	0.68	0.00	0.00
Aspen	0.68	4.35	0.00
Plum	0.68	0.00	0.00
Ironwood	0.68	0.00	0.00
Pin oak	0.00	0.00	14.29

Table 4. Species density (D), basal area (BA), relative density (RD), relative basal area (RBA), and inportance values (IV), in savanna (>0-50 trees/ha), woodland (>50-100 trees/ha), and forest (>100 trees/ha) based on DuPage County bearing tree data. Data recorded by the Public Land Survey of DuPage County.

FOREST (N = 39)

Species	D	BA	RD	RBA	IV
White oak	27	4.42	32.14	46.63	39.39
Bur oak	13	1.36	15.48	14.36	14.92
Red oak	13	1.17	15.48	12.33	13.90
Hickory	9	0.57	10.71	5.97	8.34
Elm	5	0.96	5.95	10.11	8.03
Sugar maple	5	0.32	5.95	3.38	4.67
Basswood	4	0.41	4.76	4.32	4.54
Ash	5	0.19	5.95	1.99	3.97
Aspen	2	0.07	2.38	0.73	1.55
Ironwood	1	0.02	1.19	0.19	0.69
	84	9.49		100.00	

WOODLAND (N = 40)

Species	D	BA	RD	RBA	IV
White oak	33	4.72	39.29	48.20	43.74
Bur oak	13	1.97	15.48	20.08	17.78
Red oak	12	1.42	14.29	14.46	14.38
Hickory	11	0.61	13.10	6.21	9.65
Sugar maple	4	0.31	4.76	3.17	3.97
Black oak	2	0.21	2.38	2.20	2.29
Elm	2	0.13	2.38	1.35	1.86
Ironwood	2	0.07	2.38	0.70	1.54
Ash	2	0.05	2.38	0.52	1.45
Scarlet oak	1	0.16	1.19	1.68	1.43
White Ash	1	0.11	1.19	1.17	1.18
Cottonwood	1	0.02	1.19	0.25	0.72
	84	9.78		100.00	

SAVANNA (N = 149 corners)

Species	D	BA	RD	RBA	IV
White oak	136	16.50	48.23	51.20	49.71
Bur oak	86	9.00	30.50	27.92	29.21
Red oak	38	3.87	13.48	11.99	12.73
Elm	6	1.46	2.13	4.54	3.34
Hickory	7	0.38	2.48	1.17	1.83
Basswood	3	0.44	1.06	1.36	1.21
Black oak	3	0.42	1.06	1.30	1.18
Ash	2	0.09	0.71	0.28	0.50
Sugar Maple	1	0.07	0.35	0.23	0.29
	282	32.23		100.00	

Table 5. Percent cover of Public Land Survey vegetation types associated with soils associations in DuPage County, Illinois.

Soil group & association	Prairie	Barrens/ Scattering Timber	Scattering Timber	Timber
Silty & Clayey-Uuplands	**79.2**	**28.43**	**80.7**	**74.65**
Morley-Ashkum	7.96	25.41	73.32	41.97
Markham-Ashkum	71.24	3.02	7.38	32.68
Silty-Uplands	**13.92**	**69.03**	**2.47**	**7.16**
Drummer-Lisbon-Saybrook	6.14	11.01	0	0.96
Drummer-Mundeline-Barrington	5.33	52.19	2.16	3.39
Warsaw-Fox-Will	2.45	5.83	0.31	2.81
Silty & Loamy-Terraces and bottoms	**6.88**	**2.56**	**16.83**	**18.19**
Fox-Wauconda-Sawmill	6.53	2.56	13.81	14.53
Faxon-Kankakee Rockton	0.35	0	3.02	3.66

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Appendix I. Township, deputy surveyor, and date of the Public Land Survey for DuPage County, Illinois.

Township Name	Township Location	Deputy Surveyor	Month & Year of Survey
Downers Grove	T37N R11E (fractional)	J. Walls	Aug., Sept., Oct., 1821
	T38N R11E	J. Walls	Aug., Sept., Oct., 1821
	(Indian boundary)	J. H. Rees	Sept., 1837
		W. L. D. Ewing	May, 1840
Naperville	T38N R9E	E. L. Prescott	Oct., 1837
		E. L. Prescott	Nov., 1838
		None listed	Nov., 1839
		W. L. D. Ewing	May, June, 1840
Lisle	T38N R10E	D. Miller	Oct., 1821
		J. Walls	Sept., 1821
		E. L. Prescott	Oct., 1837
	(Indian boundary)	J. H. Rees	Sept., 1837
		W. L. D. Ewing	May, June, 1840
Winfield	T39N R9E	W. L. D. Ewing	May, June, 1840
Milton	T39N R10E	W. L. D. Ewing	May, July 1840
York	T39N R11E	J. Walls	Sept., Oct., 1821
	(Indian boundary)	J. H. Rees	Sept., 1837
		G. Harrison	Oct., 1839
		W. L. D. Ewing	May, Aug., 1840
Wayne	T40N R9E	J. Thompson	Nov., Dec., 1839
		W. L. D. Ewing	May, June, 1840
Bloomingdale	T40N R10E	W. L. D. Ewing	May, July, 1840
Addison	T40N R11E	W. L. D. Ewing	May, Aug., 1840

Appendix II. Translation of oak species identifications (including original spellings & abbreviations) used by deputy surveyors for the DuPage Co., Illinois Public Land Survey. Witness trees identified as "B oak" by J. Walls in 1821 in T37N R11E and in T38N R11E were treated as Bur oak (*Quercus macrocarpa*) based on identification of this species in witness tree locations by Pierre (1962). "S oak" refers to Spanish oak, which was most likely Hill's oak (*Q. ellipsoidalis*).

Date	*Surveyor*	Black oak Q. velutina	Bur oak Q. macrocarpa	Red oak Q. rubra	White oak Q. alba	Hills oak Q. ellipsoidalis
1821	J. Walls	-----------	B oak		W oak	-----------
1821	D. Miller	-----------	B oak	-----------	W oak	S oak
1837	J. H. Rees	black oak	burr oak	-----------	white oak	-----------
1837	E. L. Prescott	black oak	burr oak	-----------	white oak	-----------
1839	G. Harrison	-----------	-----------	-----------	-----------	-----------
1839	J. Thompson	black oak	bur oak	red oak	white oak	-----------
1840	W. L. D. Ewing	-----------	burr oak	red oak	white oak	-----------