Grassland-Forest Transition in the Prairie Peninsula Region of Northwest Indiana as Recorded by the U. S. Public Land Survey (1829-1835)

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SUMMARY

Tallgrass prairie extends eastward in a narrowing peninsula across northern Illinois into adjacent Indiana. This vegetation reflects a longitudinal gradient of decreasing drought severity, and local vegetation patterned by interactions between fire and landscape firebreaks. Understanding how these processes shaped vegetation provides an ecological context for restoration management as well as a baseline for projecting effects of ongoing climate change on vegetation. We analyzed vegetation across this region using maps, notes and witness tree data from the Government Land Office Public Land Survey (PLS) of Lake, Porter, and LaPorte counties, Indiana, which was conducted in 1829-1835. We examined how topography, landscape firebreaks and proximity to Lake Michigan interact to mediate the transition from grassland to forest across this region and compared it to vegetation pattern in adjacent Illinois.

This region displayed an abrupt longitudinal (west to east) gradient of decreasing proportional abundance of prairie and increasing abundance of woody vegetation. Over a 5-10 km distance near the Illinois-Indiana border, prairie decreased from 80% to 20% cover, while barrens increased from 20% to 50% and timber from 25% to 50% cover. These changes appear to have been controlled by interactions between fire and local landscape features including water bodies, shifting alignment of the Valparaiso Moraine and the presence of Lake Michigan. Barrens were transitional between prairie and timber, and occupied habitats with intermediate topographic characteristics and had greater abundance of fire-adapted species. A tree density gradient across NW Indiana comprised increasing density of forest (>100 trees/ha) and decreasing abundance of savanna (<50 trees/ha). Oaks, which are fire-tolerant and shade-intolerant, remained dominant across this gradient. Fire-intolerant shade-tolerant species, including American beech and sugar maple increased in abundance across the gradient, reaching co-dominance in forest conditions in the eastern part of the study area. These effects varied among physiographic regions and proximity to Lake Michigan, which had greater abundance of coniferous species. Abundance of woody undergrowth data suggest that woody undergrowth dominated by American hazelnut was frequent throughout the region, especially in barrens. Managing and restoring the region's fire-dependent prairie and savanna vegetation should take into account evidence that this vegetation was strongly transitional and that woody plants (trees and shrubs) were a natural component. Management to restore this feature may be challenging in preserves that are smaller than the scale of original landscape processes.

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TABLE OF CONTENTS

TABLES

APPENDICES

INTRODUCTION

The Prairie Peninsula

At the time of European settlement, tallgrass prairie extended eastward in a narrowing peninsula across northern Illinois and adjacent Wisconsin into northwest Indiana, with small outliers in Michigan, Ohio and western Pennsylvania (Figure 1, Transeau 1935, Stuckey 1981). This distribution is well known for its longitudinal climatic gradient corresponding to decreasing drought severity caused by the moderating effect of northern and southern air masses on the eastward extension of the rain shadow of the Rocky Mountains (Borchert 1950, Changnon et al. 2003). At local scales, climate-driven interactions between fire and landscape features such as firebreaks controlled the distribution of prairie and forest, thereby structuring vegetation pattern (Gleason 1913, Anderson 1991, Grimm 1983, Grimm 1984, Leitner *et al.* 1991, Bowles et al 1994, Danz 2011, Danz 2012). As a result, landscape fire breaks determined the distribution of woody vegetation in this region (Curtis 1959, Davis 1977, Anderson 1983, Anderson & Bowles 1999). Understanding how such processes controlled vegetation in the northeastern border of the prairie peninsula is critical for guiding restoration and management for a large number of preserves and restoration projects in the Chicago region, as well as for and providing a baseline context to interpret and project effects of climate change (Fahey et al. 2014).

Analysis of data collected by the US Public Land Survey (PLS) in the early 1800s indicates that in the Chicago region of the Prairie Peninsula, vegetation comprised a mosaic of prairie and oak (*Quercus*)-dominated savanna, woodland and forest (McBride & Bowles 2007, http://www.plantconservation.us/INILPLSMAP.phtml). This pattern was found to fit an expected landscape fire model where greater landscape cover of prairie and savanna occurred in areas with little landscape fire protection, and higher tree densities and greater abundance of fire-intolerant trees occurred in more fire-protected landscape positions (Bowles et al. 1994). Grassland dominated 20-80% of the landscape, with a latitudinal gradient of increasing woody vegetation but decreasing tree density. The surveyors categorized woody vegetation as timber, scattering timber or barrens, which appear to represent a gradient of increasing fire-caused conversion to grassland. Timber was most wide spread, while scattering timber had lower tree densities and tended to form a transition between areas of timber and grassland. Barrens were uncommon, but tended to form an additional transition between scattering timber and grassland. They also tended to have low tree density and presence of woody undergrowth and oak sprouts.

In the northern part of the Chicago region, woody vegetation dominated by bur oak (*Quercus macrocarpa*) was widespread, and had tree densities of < 50 trees/ha, representing savanna conditions (Bowles & McBride 2005a, 2005b). Savanna dominated by black oak (*Quercus velutina*) also occurred in sand substrates associated with glacial outwash in the south, sand dunes along Lake Michigan, and the former lakebed of glacial lake Chicago (Bowles & McBride 2001, 2002). In the southern part of this region, vegetation reflected a species trait-group model (e.g., Will-Wolf & Roberts 1993). In this model, fire-intolerant shade-tolerant non-oak species (e.g. maple, ash, basswood) occupy fire-protected forest habitats, while oaks occupy fire-structured habitats. For example, woody vegetation dominated by white oak (*Quercus alba*) tended to be restricted to landscape firebreaks with tree densities exceeding 50 trees/ha (e.g, Bowles et al 1998, 2003, 2005). However, on the east sides of larger waterways, forest conditions (>100 trees/ha) developed, where white oak remained dominant, but sugar maple (*Acer saccharum*), ash (*Fraxinus* sp) and basswood (*Tilia americana*) became sub-dominant to oaks.

The vegetation of northeastern Illinois is presumed to have developed from Holocene (post glacial) deciduous forests during the eastward extension of the prairie peninsula (Gleason 1922, Transeau 1935, Curtis 1959), which occurred 6,000-8,000 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, and burning from lightning strikes and from indigenous people apparently maintained a prairie-oak ecosystem mosaic (Taft 1997, Anderson & Bowles 1999, Changnon et al. 2003). Much of this vegetation may have been successionally dynamic, with forest advancing into prairie during moist climatic conditions that reduced fire and prairie advancing into forest when greater aridity favored fire (e.g., Grimm 1983, 1984).

The eastward extension of the prairie peninsula into northwest Indiana provides the setting for the eastern transition from grassland to forest (Roher and Potzger 1951), and the opportunity for examining vegetation pattern in this eastern transition area. The nature of this transition is not well understood, as the vegetation has not been quantified with a standardized classification system across a longitudinal gradient. Meyer (1950) reconstructed and mapped the vegetation described by the PLS north of the Lake Michigan watershed in Lake, Porter, and LaPorte counties. Meyer mapped most wooded areas as "woodland", and described "broadleaved forest" as well as "coniferous"forest" along the Lake Michigan shoreline. He also referenced the common use of the term "barrens" as a modifier for oak, hickory and pine vegetation, indicating it was usually thinly stocked and brushy or scrubby. Although his map also illustrates a longitudinal gradient of declining area of prairie from Illinois into Indiana, Meyer did not discuss nor quantify this gradient. Roher and Potzger (1951) mapped prairie and oak openings in Lake Co., and a transition to forest to the south in Jasper Co. They referred to an increase in tree cover due to increasing number and diameter of stems as well as presence of *Fagus* and *Acer* as evidence for this shift. Lindsey (1961) and Lindsey et al. (1965) mapped dry prairie, wetlands, oak hickory and beach maple forest based on the PLS map, and used soils data to refine differences in dry vs wet prairie. Bacone et al. (1980) used contemporary floristic data to describe PLS vegetation for the Indiana Dunes National Lakeshore. Bacone & Campbell (1983) also used floristic data to refine a classification of upland forest, savanna and swamp forests mapped by the PLS for Lake Co. The PLS corner distance, bearing tree species, and notes were used to make this classification. White (2005) also combined historical and modern descriptions to classify and map the PLS vegetation for Lake, Porter and LaPorte counties. He used PLS notes to describe similarities and differences among forest, savanna, barrens and oak openings.

The Public Land Survey

A powerful 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 witness tree data, which were recorded in the early 1800s in Illinois and Indiana (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 the identity and diameter of trees intercepted by section lines, as well as section line vegetation summaries, other notes, and township plats distinguishing timber, prairie, and other important landscape features.

Despite bias in tree selection (Bourdo, 1956, Liu et al. 2011), the bearing tree data represent a large-scale 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 1998b). These data also can provide important ecological information when landscape ecological features, such as soils, topography, or fire barriers, are used to interpret the distribution pattern of different vegetation types based on their composition and structure (Leitner *et al*. 1991, Anderson & Anderson 1975, Moran 1978, 1980, Rogers & Anderson 1979, Bowles *et al.* 1994, 1999, and Edgin & Ebinger 1997).

Study objectives

In this study, we provide a standardized approach to classification and mapping of the PLS vegetation of northwest Indiana, including Lake, Porter, and LaPorte counties. We use methods applied to analysis of PLS data in northeastern Illinois (e.g., Bowles et al. 1998b). This procedure uses GIS mapping of vegetation plats provided by the PLS, and analysis of PLS vegetation types based on corner tree data. We use point center quarter (PCQ) analysis of bearing tree data to quantify corner tree density and discriminate among PLS vegetation types and modern vegetation types based on forest (>100 trees/ha), woodland (>50-100 trees/ha), savanna (>10-50 trees/ha) and open savanna (>0-10 trees/ha) tree density classes.

Research objectives were to 1) map and describe vegetation types identified by the PLS, 2) describe vegetation types based on a modern tree density classification, 3) analyze variation in this vegetation across the longitudinal gradient of the study area, and 4) analyze, to the extent possible, undergrowth data from section line summaries. In a general model, we expected that areal cover of prairie would decrease from west to east, and that it would be replaced by increasing cover and density of woody vegetation merging into forest. We also expected expression of a species trait-group model, with greater abundance of fire-intolerant shade tolerant species associated with forest conditions. To understand physiographic effects, we examine how topography, substrate, landscape firebreaks and proximity to Lake Michigan interact to mediate this transition. Based on Illinois, we expected landscape firebreaks to allow greater tree density. We also expected that proximity to Lake Michigan would ameliorate climatic effects in relation to substrate. We also sought to determine whether the transition from grassland to forest would go through intermediate vegetation stages such as savanna or barrens, and whether presence of woody undergrowth characterized this vegetation.

STUDY AREA

Lake, Porter and LaPorte counties comprise the northwestern portion of Indiana bordering Lake Michigan (Figure 2). They include about 65 km of the Lake Michigan shoreline, and LaPorte Co. extends an additional 30 km along the Michigan border. This area extends from about -86.5^o to -87.5^o longitude. This area also comprises about 465,100 hectares; it includes the Valparaiso Moraine, which forms the watershed divide between drainage north into Lake Michigan (Great Lakes/St. Lawrence drainage) and south into the Kankakee River (Mississippi River drainage) (Figure 3, Figure 4). It comprises three physiographic regions based on glacial stratigraphy: the Lake Michigan Border, the Valparaiso Morainal Complex, and Kankakee Drainageways (Figure 3). These areas represent four Natural Divisions (ND), which are divided into sections corresponding to modern vegetation and landforms (Figure 5). The following *italicized* text is paraphrased from Swink & Wilhelm (1994) and Homoya et al. (1985).

The Lake Plain ND includes the near shore sand and lacustrine deposits of the Lake Michigan border (see Figure 3). Its Chicago Lake Plain section consists of nearly level lacustrine silt and clay deposited by former glacial Lake Chicago; it supported prairie and wetland vegetation. The Gary Lake Plain Section includes former beach ridges and swales (dune and swale topography), and supported sand savanna, sand prairie, and wetlands. The Ridge and Swale Section comprises recent sand ridge and swales that supported sand prairie, sand savanna and alkaline vegetation. The High Dunes Section includes high lakeshore dunes that supported oak and conifer savanna and forest. The Benton Harbor Lake Plain Section is adjacent to the east, and has similar physiography, but tended to be more wooded.

The Morainal ND includes the Valparaiso Moraine and associated glacial deposits (see Figure 3). The Western Morainal Section supported primarily prairie and savanna, as well as isolated woodland and forest. The Eastern Morainal Section is adjacent to the east, and similar topography and vegetation, but with greater tree cover.

The Grand Prairie ND represents an extension of the Illinois Grand Prairie. In Indiana it includes primarily the Kankakee Marsh Section, which was marsh, wet prairie, and wooded wetlands associated with sands of the floodplain of the Kankakee River. The Grand Prairie section, enters the eastern edge of the study area, was excluded because it contained only two section corners with trees.

The Glacial Lakes ND is represented by the Glacial Lakes Section. It comprises ice-contact glacial landforms including moraines, kames, kettle holes, and outwash plains. Vegetation included forest and savanna, bogs fens, marshes and swamps. This area is also included with the Valparaiso Moraine complex (Figure 3)

For some analyses, we combine the four NDs into three physiographic regions (Figure 3): 1) the <u>Lake Plain</u>, 2) <u>Glacial Till</u>, including both till and outwash features comprising the Morainal and Glacial Lakes sections, which constitute the Valparaiso Moraine complex, and 3) <u>Outwash</u> of the Kankakee Marsh section, north of the Kankakee River.

The adjacent Illinois portion of the study area extends about 125 km from -87.5^o to -88.5^o longitude across Will, southern Cook, and Kendal counties. This area includes the Chicago Lake Plain, Grand Prairie, Kankakee Sands, and Bedrock Valley natural division (Figure 5). Only the Bedrock Valley section is not represented in Indiana. This section comprises the floodplain and valley walls of the DesPlaines River valley.

METHODS

PLS methods

The PLS of Lake, Porter and LaPorte counties was completed between 1829 and 1835 by at least 11 deputy or junior deputy surveyors (Table 1). After completion of a township survey, the principal vegetation was mapped (primarily prairie, timber, scattering timber and barrens, watercourses, and settlement features. The PLS also described about 20 additional vegetation types that were not large enough in area to map, but were indicated in section line summaries. The PLS indicated distances along section lines for transitions between these vegetation types, which facilitated mapping precision. The primary data collected by the PLS in Indiana were the identity, diameter, distance, and direction for up to two bearing trees, each in different quadrants at each quarter corner and at river crossings. In Illinois, up to four trees were sampled. The PLS also recorded the identity and diameter of "line trees" intercepted by section lines and summarized tree species present along section lines. However, line tree data tend to be more biased than corner data (Liu et al. 2011). Some surveyors also recorded the distances along section lines in which woody undergrowth was present, and summarized the species present in undergrowth along each section line.

The surveyors recorded useable data from 3,646 corners. They identified about 30 witness tree species by common name or by abbreviation, including most of the dominant native tree species (Table 2). We followed White (2005) in determining species identities and placing them in modern species analogs. At least nine trees were identified by common names that did not allow species-specific identification.

Data analysis
Research objectives were to 1) map and describe vegetation types identified by the PLS, 2) describe vegetation types based on modern tree density classes, 3) analyze variation in this vegetation across the longitudinal gradient of the study area and 4) analyze, to the extent possible, undergrowth data from section line summaries. We also analyze these differences among NDs and in relation to landscape ecological factors.

PLS vegetation mapping and analysis
We used ARC/INFO Geographical Information System (GIS) software (http://esri.com/) to digitize original vegetation plats drawn by the PLS. All maps and data were obtained from microfilm copies of the original notes. Recorded distances along section lines for transitions between vegetation types were then used to refine the digitized plat maps. Basal area (in m^2) was calculated for all bearing trees using the diameter provided (converted from inches to meters) by the PLS, where BA = $\pi * r^2$. Tree density per ha at each corner was calculated for each corner using the modified point-center-quarter (PCQ) sampling method, where trees/hectare = 10,000 m^2 / d^2, and d = the mean distance (in m) of up to four witness trees at each corner adjusted for the number of trees present (Cottam & Curtis 1956). GIS was also used to add layers for section lines, bearing trees, as well as section and quarter-corner tree densities. Features of European settlement, such as fields and roads, were not included in the GIS maps.

The surveyors described 22 vegetation types that could be mapped with corners (n = 3584 corners). Three were aquatic (lakes, rivers, ponds), and one could not be identified; the remaining 18 were analyzed. Dominance (relative basal area) was calculated using the closest (Q1) tree for all species in each of these vegetation types. Mean density per ha was also calculated based on the number of corners sampled in the dominant woody vegetation types (prairie, barrens, and timber) in each physiographic region. As noted by White (2005), the PLS had quite similar references to both barrens and oak openings. About 90% of these references were to barrens, and section line references to entering or leaving oak openings was less distinct than for barrens. As a result, we pooled these data into one term, barrens.

We used Analysis of Variance (ANOVA) in a general linear model (GLM) to test how the dominant PLS vegetation types (barrens, prairie, scattering timber, and timber differed in structure among physiographic regions. These tests used factorial models, in which individual tree size (expressed as BA of the Q1 tree), tree density/ha (measured at each corner), and BA/ha (tree size * tree density) were tested in relation to three physiographic regions. These regions included 1) "**Lake Plain"** (comprising the Lake Michigan Border, or Lake Plain ND); 2 **"Till Plain"** (comprising the Valparaiso Morainal Complex, including the Western and Eastern Morainal and Glacial Lakes ND sections); and 3) **"Outwash"** region (comprising Kankakee Drainageways or Kankakee Marsh ND section). For these tests, and those below, analyses of prairie data include only corner data with trees present, and thus a subset of information about prairie. As a result, they are probably biased toward factors that selected for presence of trees.

We also used ANOVA in a GLM to test how dominant PLS vegetation differ in relation to variation in landscape ecological factors and physiographic region. These tests also used factorial models, in which each of five ecological factors (slope, elevation, topographic variability and hillshade) were tested in relation to the three physiographic regions. Topographic variability was based on a running 10-cell calculation of the variance/mean ratio (standard error of the mean) of elevation, which thus reflects the degree of heterogeneity or variability within each category.

To further define refine differences among dominant vegetation types, Nonmetric Multidimensional Scaling ordination (NMS) was used to compare shifts in species composition (using species relative frequency as a metric) between barrens and timber in different ND sections. Results were tested with Multi Response Permutation Procedures (MRPP), and with correlations of elevation, density, and distance and azimuth to Lake Michigan with the ordination axes. These tests were conducted on PCORD software (McCune & Mefford 1995).

Tree density classes

To partition effects of forest structure on vegetation, we developed synthetic vegetation classes based on tree density. Corner tree densities were placed into four categories following Anderson & Anderson (1975) and Bowles *et al*. (1994): ***open savanna*** (> 0-10 trees/ha), ***savanna*** (> 10-50 trees/ha), ***woodland*** (> 50-100 trees/ha) and ***forest*** (> 100 trees/ha). These categories were then partitioned among ND sections, in which species relative frequency and dominance (relative BA) were calculated. Six divisions were represented by all classes, others were incomplete, resulting in 26 synthetic communities.

We calculated stand tables based on dominance (relative BA of the Q1 tree) for the Lake Plain ND, and for the Morainal, Kankakee Marsh, and Glacial Lakes Sections. Relationships between species dominance and tree density class were also compared graphically in the Lake Plain ND and the Western and Easter Morainal ND sections. We expected that shade-tolerant fire-intolerant species (e.g., American beech, ash, basswood, sugar maple and tulip tree) would be sub-dominant and more abundant in forest and woodland than in savanna conditions. We also expected that oaks, which tend to be shade-intolerant and fire tolerant would be more dominant in savanna conditions.

We used Analysis of Variance (ANOVA) in a general linear model (GLM) to test how the tree density classes differ in relation to variation in landscape ecological factors and physiographic region. These tests used factorial models, in which each of five ecological factors (slope, elevation, topographic variability and hillshade) were tested in relation to the Lake Plain, Till Plain, and Outwash physiographic regions.

To further refine species-habitat relations, we ordinated all of the tree density class communities by NDs with NMS using species relative abundance as a metric. To understand ecological effects on these communities, we correlated 10 measures with the first and second axis of the ordination: distance and azimuth to the nearest water body (a proxy for fire break); distance and azimuth to Lake Michigan; slope, aspect, elevation, hill shade; and soil saturation class and % sand.

Longitudinal gradient

We used direct gradient analysis of the PLS vegetation types and synthetic communities based on tree density classes to understand how vegetation changed across the longitudinal gradient of the study area. Changes in relative abundance of prairie, barrens, timber, and scattering were calculated using a running 20-cell average across the longitudinal gradient of both Illinois and adjacent Indiana. Illinois data were included for an area south of an extension of the lower edge of Lake Michigan into Illinois. For this test, only the Valparaiso Morainal physiographic region was used, as prairie tended to be restricted or absent from areas developed in sand. Each cell represented the relative abundance of each vegetation type for each latitudinal section line. We also calculated overall mean tree density (from bearing tree corner calculations) at ~1.75 km intervals across this gradient for the two dominant physiographic provinces: a combined lake plain and glacial till group, and an outwash group. We examined change in tree density classes across the Indiana portion of the study area gradient in both the Lake Plain ND and the combined Western and Eastern Morainal sections of the Morainal ND. This gradient was calculated based on running 100-cell sums of the relative abundance of corners in each of the four tree density classes.

To better understand the extent of severe drought across the Prairie Peninsula, we accessed Palmer Drought Severity (PDSI) Index data from the NOAA National Climatic Data Center (: http://ncdc.noaa.gov/paleo/). We plotted the 1934 instrumental PDSI data at from 39^{O} and 41^{O} latitude at 3^{O} (256 km) longitude intervals for approximately -100 to -70 degrees longitude through the longitudinal axis of the Prairie Peninsula. We used 1934 because it represented the most extreme negative deviation of drought available for instrumental climatic data. Such data are most likely to register the drought effect of the Prairie Peninsula (Borchert 1950).

Vegetation undergrowth

Vegetation undergrowth was rarely recorded in the Indiana PLS (e.g. White 2005) in contrast to Illinois where more undergrowth was recorded (e.g., Bowles et al. 1998b). We analyzed section lines for under growth only in Lake Co., where it was recorded as present or absent from < 1% of the section lines. The length of each section line for which a species was recorded was partitioned by natural division and by vegetation types. Percent total cover of section lines was calculated for the predominant vegetation types (timber and scattering timber), and relative abundance of each species was calculated for each vegetation type and natural division.

Species level habitat modeling

We used nonparametric multiplicative regression (NMR) to further understand how species responded within trait groups and individualistically to physiographic factors. In this analysis we used NMR on Hyperniche (McCune & Mefford 2004) to model multiple effects of longitude, aspect, slope, elevation, hill shade and topographic variability on tree species basal area/ha. This metric was calculated using corner tree density and basal area of the Q1 tree (e.g., Lindsey 1961). Among oaks, we tested black oak, bur oak, red oak and white oak. Among non-oaks, we tested American beech, basswood, elm, and sugar maple. We chose these species because of their relatively large sample sizes and their equal representation of oak and non-oak groups. We used a local mean (Gaussian) model and aggressive small neighborhood size to conduct the tests, and tested the models with 20-50 random bootstrap runs. These tests were made within the Valparaiso Morainal Physiographic complex because we presumed it is buffered by distance from a strong climatic effect of Lake Michigan.

RESULTS

PLS vegetation mapping and analysis

Vegetation mapped by the PLS in northwest Indiana represented an eastward extension of the prairie and woody vegetation from adjacent Illinois (Figure 6). In Indiana, the dominant vegetation comprised a variable mosaic in which timber accounted for about 29% of the landscape, prairie 24%, marsh 20%, barrens about 17% and scattering timber about 2% (Table 3). Timber, prairie and barrens occurred primarily on fine textured glacial soils, while marsh predominated on glacial outwash in the Kankakee Marsh ND section. A large number of small wetland types or sand dune-associated vegetation types comprised most of the remaining cover (Table 3). Among vegetation types represented by corners with bearing trees, timber accounted for 41.5%, barrens 23%, sand banks about 2.9%, and scattering timber about 2.3% of the corners (Table 3).

Species dominance by PLS vegetation type is provided in the Appendices. Areas mapped as timber were co-dominated by black and white oak in all NDs except for the Morainal ND sections, where American beech replaced black oak. Barrens were also dominated by black and white oak. Burr oak and hickory tended to be sub-dominant in barrens, but were replaced by pine in the Lake Plain ND. Scattering timber was also dominated by black oak and white oak, with sub-dominance by burr oak.

Basal area differed significantly among vegetation types, with higher BA in timber and intermediate values in barrens and scattering timber on glacial till; it did not differ among physiographic regions (Figure 7). Tree density also differed among vegetation types, with usually about 40 trees/ha in scattering timber, 80 trees/ha in barrens and 100 trees/ha in timber; however, these measures were lower in outwash habitat (Figure 7). Basal area/ha on till was higher in timber, intermediate in barrens and lower in scattering timber. Other regions were more variable (Figure 7).

Aspect did not differ among vegetation types or regions (data not shown). However, slope and elevation differed significantly among vegetation types and regions (Figure 8). Prairie and scattering timber had lower slopes and occurred at lower elevations than did barrens or timber on both till and lake plain habitat. Topographic variability differed significantly among regions, and had a significant interaction with vegetation type (Figure 8). It was greater in timber than in barrens or prairie on glacial till. Topographic variability was lowest in scattering timber in till and lake plain habitat. Prairie and barrens had greater topographic variability than did scattering timber or timber on outwash. Hill shade differed among regions, and except for scattering timber was lower in lake plain habitats (Figure 8) .

NMS indicated that there were compositional differences between barrens and timber depending on ND (Figure 9). In the Western Morainal and Glacial Lakes ND sections, barrens had more burr oak and timber had more white oak. In the Eastern Morainal and Benton Harbor ND sections, barrens were oak dominated whereas timber was dominated by basswood, beech, tulip tree and sugar maple. In the Gary Lake Plain ND section, barrens were dominated by white and black oak with timber having more red oak. There were two instances in the High Dunes ND where the trends were opposite of those described above. Greater representation of oaks in timber than in barrens for woodlands may represent the complexity of topography and microclimate in the High Dunes or a random effect from a natural division of small area and sample size. Timber had pine (jack and white), species that were absent in barrens, in the forested regions of the High Dunes.

Tree density classes

In a comparison among ND sections across Illinois and Indiana, proportional abundance of open savanna and savanna tree density classes exceeded 70% in all but three sections (Figure 10). However, savanna abundance was < 50% to < 20% in the High Dune, Eastern Morainal and Benton Harbor Lake Plain sections. In contrast, forest proportional abundance was < 20% in all but four ND sections; It exceeded 20% in the Glacial Lakes Section, 30% in the High Dune section, and 50% in the Eastern Morainal and Benton Harbor Lake Plain sections. Proportional abundance of Woodland was < 20% in all groups. Proportional abundance of dominant and sub-dominant species varied among tree density classes in the Lake Plain and Morainal NDs (Figure 11). White oak and black oak, both fire-tolerant shade intolerant species, tended to dominate this vegetation. Burr oak, which is strongly fire-tolerant, was subdominant in the Morainal Sections, were it tended to decrease with increasing tree density. Among fire-intolerant shade-tolerant species, only American beech and sugar maple reached co-dominance, which occurred in woodland and forest conditions in the Lake Plain and Eastern Morainal section, respectively. These species, along with basswood, ash and tulip tree, were subdominant and more abundant in woodland and forest conditions in the Lake Plain and Western Morainal Section. Red oak, which has intermediate fire-tolerance but is shade-intolerant, was also sub-dominant across most tree density classes in all NDs.

Slope, aspect and topographic variability differed significantly among regions and had significant interactions with tree density class (Figure 12). All three variables were higher and had a strong tree density gradient on glacial till, with lower values in open savanna and higher values in forest. Hill shade differed significantly among tree density classes and regions, with a significant interaction (Figure 12). It was lower in lake plain habitats, and higher in woodland on glacial till.

NMS ordination indicated a decreasing tree density gradient associated with the first ordination axis (Figure 13). Forest conditions were also associated with decreasing distance and increasing azimuth to Lake Michigan. Forest-associated species (e.g., Sugar maple and beech) were also associated with increasing slope, aspect and azimuth to water courses, and with decreasing hill shade (Figure 14).

Longitudinal gradient

The longitudinal gradient in vegetation described by the PLS shifted from about 60% to 20% prairie cover in a 10km distance between -87.6677^{O} and -87.543^{O} longitude, ending about 2km west of the Illinois-Indiana border.(Figure 15). At that point, barrens shifted from minor representation to about

20% cover, and climbed to almost 50% cover over a distance of about 5 km. Timber also shifted from about 25% cover to 50% cover in the same distance. A shift in tree density in the Chicago Lake Plain and adjacent Morainal ND occurred further eastward, increasing from about 50 trees/ha to 100 trees/ha in a 17.5km distance between -86.9074 ^{O} to -87.1417^{O} (Figure 16). This transition to forest tree density (>100 trees/ha) was completed at about the eastern extent of the Indiana-Lake Michigan border, but tree density continued to increase eastward, eventually reaching about 200 trees/ha (Figure 16). In contrast, tree density did not increase in the Kankakee Marsh Section, remaining at < 50 trees/ha. A longitudinal shift in relative abundance of tree density classes also occurred eastward from the Illinois-Indiana boundary (Figure 17). In the Chicago Lake Plain and Morainal ND, forest tree density accounted for about 20% relative abundance west of about -87^{O}. Eastward, it shifted to over 50% forest abundance over a 10km distance, reaching over 60% by about 86.6664^{O} Longitude. This transition also represents the shift from the western to eastern Morainal sections. From this point eastward, forest abundance declined and then increased to almost 80%. Relative abundance of open savanna, savanna and woodland decreased across this gradient, reaching about 10% representation at about -86.6^{O} Longitude, a point about 10 km east of the eastern extent of the Indiana-Lake Michigan.

Analysis of summer 1934 PDSI data revealed a non-linear relationship between drought and longitude across the longitudinal axis of the Prairie Peninsula (Figure 18). PDSI ranged from about - 7.5 (extreme drought) to 0 (normal) across the entire central U.S. gradient. A quadratic equation projected about 6.041 - 4.4 PDSI across the Prairie Peninsula (from Mississippi River to east central Indiana). In our study area (-88.5^{0} to -86.5^{0} longitude), the projected PDSI ranged from about 5.435 to 4.871, a difference of 0.564 PDSI.

Vegetation undergrowth

As indicated, < 1% of the section lines in Lake Co. could be analyzed for undergrowth. Most of the undergrowth recorded in those lines was woody (Table 5), and this vegetation had 60-80% coverage of timber and scattering timber in the Kankakee Marsh, Chicago Lake Plain and on the Valparaiso Moraine (Figure 19). Of the 26 species, only grass, rosinweed, cranberry, bamboo and weeds were non-woody species. American hazelnut was the dominant species in almost all vegetation types, especially on the Valparaiso Moraine. Exceptions included whortleberry (*Vaccinium* sp), willow and alder in Lake Plain habitats. On the Valparaiso Moraine, recorded species (in declining abundance) in prairie were rosinweed (*Silphium* sp) "grass", hazel and "weeds"; in barrens they were, hazel , redroot (*Ceanothus* sp.) and willow; and in scattering timber they were, hazel, burr oak, hickory, and sumac.

Species level habitat modeling

NMR models were not significant (P > 0.05) for basswood, elm and bur oak (Figure 20). Tolerances were extremely high for longitude, intermediate for aspect, and lower for other variables. Sensitivities were highest for slope, elevation and topographic variability, which were the best predictors of habitat niches (Figure 20). BA/ha tended to be unimodal and intermediate with respect to slope and increasing elevation for bur oak, and for slope and increasing topographic variation for black oak. White oak BA/ha was unimodal for topographic variation, becoming steeper with increasing slope. Red oak BA/ha appeared to have a truncated unimodal or non-linear distribution, increasing with increasing slope and hillshade. Among non-oaks, basswood and elm BA/ha had a negative linear response to topographic variation, with greater responses for slope and elevation, respectively. Sugar maple had a non-linear response that increased with decreasing topographic variation. In contrast, American beech had a strongly unimodal response to topographic variation. In all cases, there was little evidence of interactions among variables, suggesting strongest responses to a single variables.

DISCUSSION

The forest-prairie transition in northwest Indiana

Our analysis of PLS data indicates that the vegetation of northwest Indiana represented an abrupt transitional between prairie and forest, and that this transition was patterned by interactions between landscape stratigraphy and fire along a longitudinal gradient. This is evidenced by region-wide gradients among vegetation types, and by structural and species level gradients within vegetation, as well as ecological responses that indicate fire effects. Climate effects are less understood. As shown by Borchert (1950), our analysis of summer PDSI data from 1934 (a major drought year) suggests a longitudinal gradient in drought severity, and projects an 0.56 difference in PDSI across our study area. Our data also suggest that proximity to Lake Michigan had a moderating effect on vegetation, and therefore may have also affected a longitudinal climatic gradient. The absence of local climate data prevents a more direct linkage between vegetation and climate within our study area.

Local stratigraphy appears to have been important in structuring the vegetation gradient. The abrupt transition from about 60% to 20% grassland cover near the Illinois-Indiana border probably resulted from a shift in the axis of the Valparaiso Moraine that reduced prairie habitat, as well as the proximity of Lake Michigan. In Illinois, this moraine has a northwest-southeast axis, with an extensive outwash-till plain to the south and west, most of which was occupied by grassland. Eastward into Lake Co., Indiana, the Valparaiso Moraine assumes a longitudinal axis, and it is truncated by the Lake Michigan sand plain on the north and by the Kankakee River outwash plain on the south. This transition apparently restricted prairie to available habitat on morainic uplands, where it was the predominant vegetation. Woody vegetation identified by the PLS as timber was associated with landscape firebreaks provided by north-south aligned tributaries of the Kankakee River, a pattern typical of vegetation in adjacent Illinois. Barrens were least abundant and occupied contact zones between prairie and timber vegetation types.

Eastward in Porter and LaPorte counties, the orientation of the Valparaiso Moraine shifts to a southwest to northeast axis and the proportional abundance of prairie, timber and barrens changed. Prairie became more restricted to south of the Lake Michigan drainage divide on morainic uplands and on outwash fan terraces above the Kankakee river outwash plain. Timber, barrens and prairie occurred in equal proportions south of the drainage divide, forming a mosaic in relation to physiographic features. Timber predominated north of the drainage divide, with secondary abundance of barrens and only minor representation of prairie.

Our PLS vegetation map differs from Transeau's Prairie Peninsula map by having reduced distribution of prairie. His map included only forest and prairie; marsh may have been represented by prairie, and barrens may have been represented by either forest or prairie. In Lake Co., the Prairie Peninsula map shows prairie extending south to the Kankakee river, with forest isolated on the west and east sides of the county. Our map indicates that marsh vegetation predominated in the Kankakee watershed, and that forest tended to be isolated in central Lake Co. Likewise, the Prairie

Peninsula map indicates that prairie occurred eastward in the Kankakee River watershed of Porter and LaPorte counties, where our PLS map indicates marsh vegetation was present. The prairie Peninsula map also indicates areas of prairie in northern and northeastern LaPorte Co. that were described by the PLS as barrens.

Ecological effects on vegetation types and classes

Our analysis of physiographic data suggest fire-caused ecological differences among prairie, barrens, timber and scattering timber. For example, slope, elevation and topographic variability tended to be lower in prairie and scattering timber, intermediate in barrens and higher in timber, but variable among physiographic regions. Low values for these factors would facilitate movement of fire and maintenance of grassland while high values increase probability of persistence of forest (Anderson 1991, Danz et al. 2011). Midwest barrens vegetation was apparently intermediate between grassland and forest, where reduced fire effects prevent complete conversion of forest to grassland resulting in post-fire sprouting woody vegetation (Bowles & McBride 1994, Anderson & Bowles 1999). Scattering timber is also apparently transitional to timber but different from barrens. On glacial till, the extremely low topographic variability of scattering timber suggests a low level of fire protection for this vegetation. However, significant interactions indicate that these effects vary among physiographic regions. In the Lake Plain, the proximity of Lake Michigan as well as wetland sand soils may reduce fire effects. Upland habitats in the Kankakee outwash Plain may have more extreme fire conditions, while wetland tended to support marsh conditions that may be seasonally fire-dependent.

Measures of vegetation structure by BA, tree density/ha and BA/ha also support fire-caused differences among barrens, scattering timber and timber. These values were greater for timber and intermediate for barrens and lower for scattering timber. This suggests that fire reduced the volume and density of woody vegetation most in scattering timber least in timber, and intermediately in barrens. Barrens and scattering timber may have represented successional zones between prairie and forest, where forest advanced during moist climatic conditions that reduced fire and prairie advanced when drier conditions favored fire (e.g., Grimm 1983, 1984). However, structural and physiographic habitat differences indicate that these processes may have differed between these vegetation types.

Ecological responses among tree density classes also support a fire-caused vegetation gradient hypothesis. On glacial till, the decreasing gradients of slope, elevation and topographic variability across a decreasing tree density gradient suggest increasing potential for a stronger influence of fire across this gradient. These results also suggest that open savanna and scattering timber, as well as prairie shared similar fire processes, as tree densities of < 10 trees/ha approach grassland conditions. The lack of a strong gradient response in Lake Plain and Outwash physiographic regions parallels results for the PLS vegetation types, indicating that these conditions vary among habitats. Reversed and somewhat paradoxical effects have been observed in modern studies of sand savanna vegetation gradients, where more well drained uplands are more fire sensitive, and lower areas with higher water tables are more fire-protected (Haney et al., 2008, Bowles et al., 2011). Nevertheless, lower areas may be more fire-dependent but burn only during seasonal draw-downs of the water table.

Species responses

The PLS data supported the species trait-group fire and habitat model, where fire-intolerant shade-tolerant non-oak species occupy fire-protected forest habitats, while oaks tend to occupy fire-structured habitats (e.g., Will-Wolf & Roberts 1993). Our analysis indicated that non-oaks increased along a gradient of increasing tree density, which would favor shade-tolerant species. Non-oak species also increased with increasing ecological factors that indicate greater fire protection, with opposite responses from oaks.

Among PLS vegetation types, non-oak species were either co-dominant or subdominant to oaks in timber, less frequent in barrens, and absent from prairie. In contrast, burr oak, the most fire-tolerant oak species, tended to be co-dominant with black oak in prairie and barrens, but rare in timber. Scattering timber also lacked presence of non-oak species and had greater representation of burr oak. There were minor species differences among natural division sections, such as greater abundance of white oak, tulip tree and beech on till, presence of pine in the Lake Plain, and greater abundance of black oak in the Lake Plain and Kankakee Outwash plain.

The species-trait model was also supported among tree density classes, particularly with greater abundance of burr oak in savanna and greater abundance of non-oak species in forest and woodland. In support of a longitudinal gradient hypothesis, the comparison between the western and eastern Morainal ND sections indicated that non-oak species, including beech and sugar maple reached co-dominance in the forest tree density class only in the eastern Morainal section. Sugar maple was also a co-dominant in forest in the Glacial Lakes Natural division section as well. The co-dominance of beech and maple in these natural divisions indicates the strong trend in the longitudinal gradient toward development of late-successional beech-maple forest (e.g., Potzger et al. 1956). Oaks and non-oaks also tended to respond differently to ecological factors, suggesting some unifying characteristics within trait groups. The trend toward unimodal responses among oaks indicates a narrow gradient response to habitat variation, a well known characteristic of oaks (Curtis 1959). The negative linear response of basswood, sugar maple and elm to topographic variability suggests that these species prefer habitats with low topographic variability, which also tend to have less drainage at lower elevations. Our data indicate that such habitats are more vulnerable to fire effects, which may help explain the more limited distribution of these species to fire-protected habitats. The unimodal response of American beech to topographic variation suggests that this species has a more narrow habitat niche in our study area. Overall, these differing responses support a continuum approach to interpreting development of this vegetation, with overlapping responses among species contributing to vegetation types.

Undergrowth

Although undergrowth was recorded and analyzed in only a few section lines in Lake Co., the results appear to be meaningful because they parallel findings from northeast Illinois where data were more robust (e.g., Bowles et al. 1998b). The high (60-80% cover) of primarily woody undergrowth in both timber and scattering timber suggests that woody vegetation was abundant in most vegetation types. The greater proportional abundance of hazel in barrens, scattering timber and in timber on glacial till indicates that this species dominated the woody understory of this natural division. Its high relative abundance in prairie also indicates that grasslands may have had high cover of woody vegetation. Hazel also tended to be abundant in other natural divisions, except when replaced by more specialized species such as *Vaccinium* sp. or willow in the Lake Plain or by alder in the Kankakee Marsh.

Interpreting PLS vegetation types

The PLS identification of vegetation types appears to have been based primarily on observations of landscape-scale vegetation pattern and tree density, and limited ecological knowledge. With some limitations, they have been compared to modern community types based on landscape position, tree density classes and presumed fire processes. For a detailed interpretation of PLS vegetation types, see White (2005). For a floristic interpretation using modern information, see Bacone et al. (1980) and Bacone & Campbell (1983). Here, we discuss barrens, scattering timber and timber, the three most commonly recognized woody vegetation types.

According to Gleason (1922), barrens were characterized by post-fire sprouting shrubs and oaks representing late stages of fire-caused deterioration of forest. Fire-regime characteristics probably determine whether barrens represents a successional stage between forest and prairie, or an alternative stable state. In northeast Illinois, barrens, usually appeared along the windward margins of scattering timber and timber, and were uncommon - possibly due to the limited distribution of timber. Their widespread occurrence in Indiana may be a result of the greater amount of timber relative to prairie, and widespread interaction with fire. According to Bushnell (1917), pioneers in Indiana referred to the contact zone between prairie and forest as "hazel-brush land", with a sparse growth of forest and undergrowth of hazel bushes. Lindsey (1961) also interpreted barrens as fire-maintained brushland and scrub. This fits a general description of barrens, as well as our data, as having woody undergrowth dominated by hazel (Bowles & McBride 1994). This description also complies with use of the term savanna as a modern analog to barrens if both definitions assume presence of woody undergrowth (Anderson & Bowles 1999). Our data also indicate greater abundance of oak species in barrens relative to timber, supporting the contention that fire was a determining factor in their presence. Oak openings, a less frequent vegetation type, was pooled with barrens in our study. According to White (2005), this vegetation may have differed from barrens by absence (or less frequent) woody undergrowth.

The PLS identification of scattering timber appears most similar to a modern definition of savanna as oak openings, with scattered trees in grassland. However, our data indicate that woody understory vegetation may be present in scattering timber as well. The PLS concept of scattering timber may have relied not only on tree density but also on the amount of dispersion or “scattering” of timber fragments left by the process of fire-caused deterioration of timber. This vegetation may have been detected most easily at a large landscape scale. Although low tree densities representing savanna occurred in both scattering timber and in timber, savanna conditions within timber may have had less fragmentation of woody vegetation. In northeastern Illinois, scattering timber often occurred as an intermediate zone between barrens and timber. Scattering timber had few, if any, descriptions by settlers. Our data suggest that in Indiana, this vegetation differed from barrens by having lower slopes and elevations and less topographic variability, and thus greater similarity to prairie.

Timber appears to have been a broad category used by the PLS to represent presence of woody vegetation that did not fall into barrens or scattering timber categories, and appears to have included a range of tree densities. We suggest use of tree density classes to further define and standardize timber along a gradient of increasing fire protection provided by ecological factors including slope, elevation and topographic variability. Open savanna and savanna classes represent timber occurring in habitats with low slope, elevation and topographic variability; with low tree density and strong fire effects; and with dominance by oaks and few non-oak species. Woodland conditions have intermediate ecological factors, intermediate tree density, oak dominance and minor representation of non-oak species. Forest conditions have greater slope, elevation and topographic variability and greater fire protection. They differ primarily by sub-dominance, or rarely co-dominance in the east, of shade-tolerant fire-intolerant species, including elm, basswood, ash, beech, and sugar maple.

Management and restoration applications

Restoration baselines based on PLS vegetation are often used to guide management (e.g., Fahey (et al. 2014). However, they must take into account temporal status and variability, as well as differences in scale, between PLS data and modern ecological data (e.g, http://www.esa.org/esa/science/reports/managing-land-use/). Indeed, the landscape-scale of vegetation and ecological processes observed by the PLS were much greater than modern preserves and even preserve systems. Recent advances in understanding how fire structures forest and savanna vegetation can help guide management (e.g., Pavlovic et al. 2006, Bowles et al. 2007, Haney et al. 2008, Bowles et al. 2011).

In general, management to replicate presettlement savanna and woodland should focus on using fire-management to maintain oak dominance. More specific guidelines can be related to landscape features, remnant vegetation types, or to arbitrary objectives. For example, restoration of barrens would be most applicable in fire-prone areas of moderate topographic relief, while open savanna or scattering timber might require less topographic relief and greater scales.

Presettlement woody vegetation structure appears to have been either one- or two-layered, depending upon the presence or absence of woody undergrowth, which appears to have been frequent in Indiana. When present, it would have been an important component of biodiversity as it provides nesting habitat for many bird species (Whelan & Dilger 1992, Grundel & Pavlovic 2007a & b). Thus, removal of 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 mechanical canopy opening, which should be conducted experimentally.

Developing management and restoration guidelines for forest habitats based on PLS information is more difficult and challenging, and their management also may benefit from experimentation (Bowles *et al*. 2007). Many of these habitats have undergone dramatic loss of canopy oaks and increased numbers of maples in smaller size classes in the last 20 years, after a series of post-settlement disturbances including fire-protection, burning, logging, and grazing. Here, management goals should take into account available historic conditions, such as provided by PLS data, recent successional changes, and the effects of fire on forest groundlayer vegetation (Bowles *et al*. 2007).

Little information is available from the PLS on the composition and structure of presettlement ground layer herbaceous vegetation. Studies of few remaining savanna remnants have illustrated an expected strong negative relationship between canopy cover and tree density, and a positive relationship between available light and ground layer species richness and diversity (Pavlovic et al. 2006, Bowles et al. 2007, Bowles et al. 2011). Management that reduces overstory tree density should help maximize groundlayer species diversity in savannas, and may require high intensity fires (Haney et al. 2008); however, high intensity fires may destroy the canopy and result in proliferation of oak resprouts (Pavlovic pers. Obs., Haney et al., 2008). This may represent one process by which barrens developed. This would also represent a new stable state from which it would be difficult to restore the canopy with frequent applications of fire. Because savanna, woodland, and forest species are adapted to a range of light conditions that help define these habitats, managing for a continuum of tree densities maximizes ground layer species richness across vegetation types (Bowles et al. 2011). The PLS vegetation data also have limited application to prairie management, where control or elimination of woody vegetation in smaller remnants is often a goal. Nevertheless, the abundance of hazel in the limited sample from Lake Co. suggests that woody vegetation may have been an important component of Indiana prairies. Curtis (1959) described brush prairies as a type of prairie in Wisconsin, and they were also described by the PLS in northern Illinois (Bowles & McBride 2005). Brush prairie may represent a more advanced stage of conversion of barrens to prairie, or woody invasion of prairie, and could have been most common in proximity to timber or barrens.

LITERATURE CITED

Anderson, R.C. 1983. The eastern prairie-forest transition - an overview. Pages 86-92 in: Proceedings of the Eighth North American Prairie Conference. R. Brewer, ed. Western Michigan University, Kalamazoo.

Anderson. R.C. 1991. Presettlement forests of Illinois. Pages 9-19 in: Proceedings of the Oak Woods Management Workshop. G.V. Burger, J.E. Ebinger, & G.S. Wilhelm, eds. Eastern Illinois University, Charleston.

Anderson, R.C., & M.R. Anderson. 1975. The presettlement vegetation of Williamson County, Illinois. Castanea 40:345-363.

Anderson, R.C, & M.L. Bowles. 1999. Deep soil savannas and barrens of the midwestern United States. Pages 55-70 in: The savanna, barren, and rock outcrop communities of North America. R.C. Anderson, J.S. Fralish, & J. Baskin, eds., Cambridge University Press.

Bacone, J.A., R.K. Campbell, & G.S. Wilhelm. 1980. Presettlement vegetation of the Indiana Dunes National Lakeshore. pages 156-191 *in*: Proceedings of the Second Conference on Scientific Research in the National Parks, V.4: Resource Analysis and Mapping. National Park Service, U.S. Dept. of the Interior, Washington, D.C.

Bacone, J.A. & R.K. Campbell. 1983. Presettlement vegetation of Lake County, Indiana. Pages 27-37 *in:* C.L. Kucera (editor), Proceedings of the Seventh North American Prairie conference. Southwest Missouri State University, Springfield.

Baker, R.G., L.J. Maher, C.A. Chumbley & K.L. Van Zant. 1992. Patterns of Holocene environmental change in the Midwestern United States. Quaternary Research 37:379-389.

Bourdo, E.A., 1956. A review of the General Land Office Survey and of its use in quantitative studies of former forests. Ecology 37:754-768.

Bowles, M., S. Apfelbaum, A. Haney, S.Lehnhardt and T.Post. 2011. Canopy Cover and Groundlayer Vegetation Dynamics in a Fire Managed Eastern Sand Savanna. Forest Ecology and Management 262:1972-1982.

Bowles, M.L., M.D. Hutchison, & J.L. McBride. 1994. Landscape pattern and structure of oak savanna, woodland, and barrens in northeastern Illinois at the time of European settlement. Pages 65-73 in: Proceedings of the North American Conference on Savannas and Barrens. J.S. Fralish, R.C. Anderson, J.E. Ebinger, & R. Szafoni, eds. Environmental Protection Agency, Great Lakes National Program Office, Chicago.

Bowles, M.L, K.A. Jacobs, & J. Mengler. 2007. Long-term changes in an oak forest's woody understory and groundlayer with repeated burning. Journal of the Torrey Botanical Society 134:223-237.

Bowles, M., J. McBride, & L. Bell. 1998a. Landscape Vegetation Pattern, Composition & Structure of DuPage County, Illinois, as Recorded by the U.S. Public Land Survey (1821-1840). Report to the DuPage County Forest Preserve District, Chicago Wilderness, Fish & Wildlife Service & Max McGraw Wildlife Foundation. The Morton Arboretum, Lisle, Ill.

Bowles, M.L. & J.L. McBride. 1998b. Vegetation composition, structure, and chronological change in a decadent midwestern North American savanna remnant. Natural Areas Journal 18:14-27.

Bowles, M.L., & J.L. McBride. 1994. Presettlement barrens in the glaciated prairie region of Illinois. Pages 75-85 in: Proceedings of the North American Conference on Savannas and Barrens. J.S. Fralish, R.C. Anderson, J.E. Ebinger, & R. Szafoni, eds. Environmental Protection Agency, Great Lakes National Program Office, Chicago.

Bowles, M., J. McBride. 2001. Historic Landscape Vegetation Pattern, Composition & Structure of Will County, Illinois. Report to the Forest Preserve District of Will County, Chicago Wilderness, USDA Forest Service & US Fish & Wildlife Service. The Morton Arboretum, Lisle, Ill.

Bowles, M. & J. McBride. 2002. Pre-European Settlement Vegetation of Cook County, Illinois. Report to The Cook County Forest Preserve District, Corlands & The Nature Conservancy. The Morton Arboretum, Lisle, Ill.

Bowles, M. & J. McBride. 2003. Pre-European Settlement Vegetation of Kane Co., Illinois. Report to The Kane County Forest Preserve District, Chicago Wilderness, USDA Forest Service, US Fish & Wildlife Service, & Illinois Conservation Foundation. The Morton Arboretum, Lisle, Ill.

Bowles, M. & J. McBride. 2004. Pre-European Settlement Vegetation of Kendall Co, Illinois. Report to the Kendall County Forest Preserve District, Chicago Wilderness, USDA Forest Service, US Fish & Wildlife Service, & Illinois Conservation Foundation. The Morton Arboretum, Lisle, Ill.

Bowles, M. & J. McBride. 2005a. Presettlement vegetation of Lake County, Illinois. Report to Forest Preserve District of Lake, Chicago Wilderness, USDA Forest Service, US Fish & Wildlife Service, & Illinois Conservation Foundation. The Morton Arboretum, Lisle, Ill.

Bowles, M. & J. McBride. 2005b. Presettlement vegetation of McHenry County, Illinois. Report to the McHenry County Conservation District, Chicago Wilderness, USDA Forest Service, US Fish & Wildlife Service, & Illinois Conservation Foundation. The Morton Arboretum, Lisle, Ill.

Brugman, R.B. & M.J. Patterson. 1996. Application of a geographic information system to mapping presettlement vegetation in southwestern Illinois. Transactions of the Illinois Academy Science 89:125-141

Changnon, S.A., K.A. Kunkel, & D, Winstanley. 2003. Quantification of climatic conditions important to the tallgrass prairie. Transactions of the Illinois Academy of Science 96:4154.

Cottam, G. & J.T. Curtis. 1956. The use of distance measures in phytosociological sampling. Ecology 37:451-460.

Curtis, J.T. 1959. The vegetation of Wisconsin - an ordination of plant communities. The University of Wisconsin Press, Madison.

Danz, N.P., P.B Reich, L.E. Frelich & G. Niemi. 2011. Vegetation controls vary across space and spatial scale in a historic grassland-forest biome boundary. Ecography 34:402-414.

Danz, N.P., L.E. Frelich, P.B Reich, & G. Niemi. 2012. Do vegetation boundaries display smooth or abrupt spatial transitions along environmental gradients? Evidence from the prairie-forest biome boundary of historic Minnesota, USA. Journal of Vegetation Science doi 10.1111/jvs.12028.

Davis, A.M. 1977. The prairie-deciduous forest ecotone in the upper middle west. Annals of the Association of American Geographers 67:204-213.

Donnelley, G.T. & P.B. Murphy. 1987. Warren Woods as a forest primeval: a comparison of forest composition with pre-settlement beech-sugar maple forest of Berrien County, Michigan. Michigan Botanist 26: 17-24.

Ebinger, J.W. 1997. Forest communities of the Midwestern United States. Pages 3-23 in: Conservation in highly fragmented landscapes, M.W. Schwartz, ed. Chapman & Hall, New York.

Edgin, B.R. & J.E. Ebinger. 1997. Barrens and the forest-prairie interface in presettlement Crawford County, Illinois. Castanea 62:260-267.

Fahey, R.T. D. Maurer, M. Bowles, and J. McBride. 2014. Evaluating restoration baselines for historically fire-protected woodlands within a Northeastern Illinois Prairie Peninsula landscape. *Natural Areas Journal.* 34(2): 166-177.

Geis, J.W. & W.R. Boggess. 1967. The prairie peninsula: its origin and significance in the vegetation history of central Illinois. Pages 89-95 in: The Quaternary of Illinois: a symposium in observance of the centennial of the University of Illinois. R.E. Bergstrom, ed. University of Illinois College of Agriculture, Special Publication No. 14, Urbana.

Gleason, H.A. 1913. The relation of forest distribution and prairie fires in the middle west. Torreya 13:173-181.

Gleason. H.A. 1922. Vegetational history of the Middle West. Association of American Geographers Annals 12:39-85.

Grimm. E.C. 1983. Chronology and dynamics of vegetation change in the prairie-woodland region of southern Minnesota, U.S.A. New Phytologist 93:311-350.

Grimm, E.C. 1984. Fire and other factors controlling the Big Woods vegetation of Minnesota in the mid-nineteenth century. Ecological Monographs 54:291-311.

Grundel, R. and N. B. Pavlovic (2007a). Response of bird species densities to habitat structure and fire history along a Midwestern oak-forest gradient. Condor 109: 734-749.

Grundel, R. and N. B. Pavlovic (2007b). Distinctiveness, use and value of midwestern oak savannas and woodlands as avian habitats. Auk 124: 969-985.

Haney, A., M. Bowles, S. Apfelbaum & E. Lain. 2008. Gradient analysis of an eastern sand savanna's woody vegetation, and its long-term responses to restored fire processes. Forest Ecology and Management(266)1560-1571

Hutchison, M.D. 1988. A guide to using the Public Land Survey Notes in Illinois. Natural Areas Journal 8:245-255.

King, J.E. 1981. Late Quaternary vegetational history of Illinois. Ecological Monographs. 51:43-62.

Leitner, L.A., C.P. Dunn, G.R. Guntenspergen, F. Stearns, & D.M. Sharpe. 1991. Effects of site, landscape features, and fire regime on vegetation patterns in presettlement southern Wisconsin. Landscape Ecology 5:203-217.

Lindsey, A.A. 1961. Vegetation of the drainage-aeration classes of northern Indiana soils in 1830. Ecology 42:432-436.

Lindsey, A.A., W.B. Crankshaw & S.A. Qadir. 1965. Soil relations and distribution map of the vegetation of presettlement Indiana. Botanical Gazette 126:155-163.

Liu, F., D.L. Mladenoff, N.S. Keuler & L. Schulte-Moore. 2011. Broadscale variability in tre data of the historic Public land Survey and its consequences for ecological studies. Ecological Monographs 81:259-275.

McBride, J. & Bowles, M. 2007a. Pre-European Settlement Vegetation of the Chicago Region. Interactive Maps and Reports. interactive map (http://www.plantconservation.us/INILPLSMAP.phtml)

McBride, J. & M. Bowles. 2007b. Searching the Public Land Survey for Illinois Natural History. Report to Chicago Wilderness and Illinois Conservation Foundation. The Morton Arboretum, Lisle, Ill.

McCune, B. & M.J. Mefford. 1995. PC-ORD. Multivariate analysis of ecological data, Version 2.0. MjM Software Design, Gleneden Beach, Oregon, USA.

McCune, B. & M.J. Mefford. 2004. HyperNiche. Multiplicative habitat modeling. Version 2.0. MjM Software Design, Gleneden Beach, Oregon, USA.

Meyer, A.H. 1950. Fundament vegetatin of the Calumet region, northwest Indiana - northeast Illinois. Papers of the Michigan Academy of science, Arts and Letters 36:177-182.

Moran, R.C.1978. Presettlement vegetation of Lake County, Illinois. Pages 12-18 in: D.C. Glenn-Lewin & R.Q. Landers, Jr. (editors), Fifth Midwest Prairie conference Proceedings. Iowa State University.

Pavlovic, N. B., R. Grundel, and W. Sluis. 2006. Groundlayer vegetation gradients across oak woodland canopy gaps. Journal of the Torrey Botanical Club. 133(2): 225-239.

Potzger, J.E., M.E. Esther, & J. McCormick. 1956. The forest primeval of Indiana as recorded in the original U.S. land surverys and an evaluation of previous interpretations of Indiana vegetation. Butler University Botanical Studies 13(12):95-111.

Rogers, C.S. & R.C. Anderson. 1979. Presettlement vegetation of two prairie peninsula counties. Botanical Gazette 140 (2):232-240.

Rohr, F.W. & J.E. Potzger. 1951. Forest and prairie in three northwestern Indiana counties. Butler University Botanical Studies 10:61-70.

Stuckey, R.L. 1981. Origin and development of the concept of The Prairie Peninsula. Pages 4-23 in: Proceedings of the sixth North American Prairie conference. R.L. Stuckey & K.J. Reese (editors). Ohio Biological Survey Notes Number 15.

Transeau, E.N. 1935. The prairie peninsula. Ecology 16:423-437.

Webb, T., E.J. Cushing, & H.E. Wright. 1983. Holocene vegetation changes of the Midwest. in: Late Quaternary environments of the United States, Volume 2, The Holocene, H.E. Wright, Jr. ed. University of Minnesota press, Minneapolis.

Whelan, C.J. & M.L. Dilger. 1992. Invasive, exotic shrubs: a paradox for natural area managers? Natural Areas Journal 12:109-110.

White, J. 1994. How the terms *savanna, barrens,*and *oak openings* were used in early Illinois. Pages 25-63 in: Proceedings of the North American Conference on Savannas and Barrens. J.S. Fralish, R.C. Anderson, J.E. Ebinger, & R. Szafoni (editors), Environmental Protection Agency, Great Lakes.

White, J. 2005. Land cover of the Indiana coastal zone about 1830. Report ot the Indiana Department of Natural Resources. Ecological Services, Urbana, Illinois.

Will-Wolf, S. & D.W. Roberts. 1993. Fire and succession in oak-maple upland forests: a model approach based on vital attributes. Pages 217-236 in: J.S. Fralish, R.P. McIntosh, & O.L. Loucks (editors), John T. Curtis - Fifty Years of Wisconsin Plant Ecology. University of Wisconsin Press, Madison.

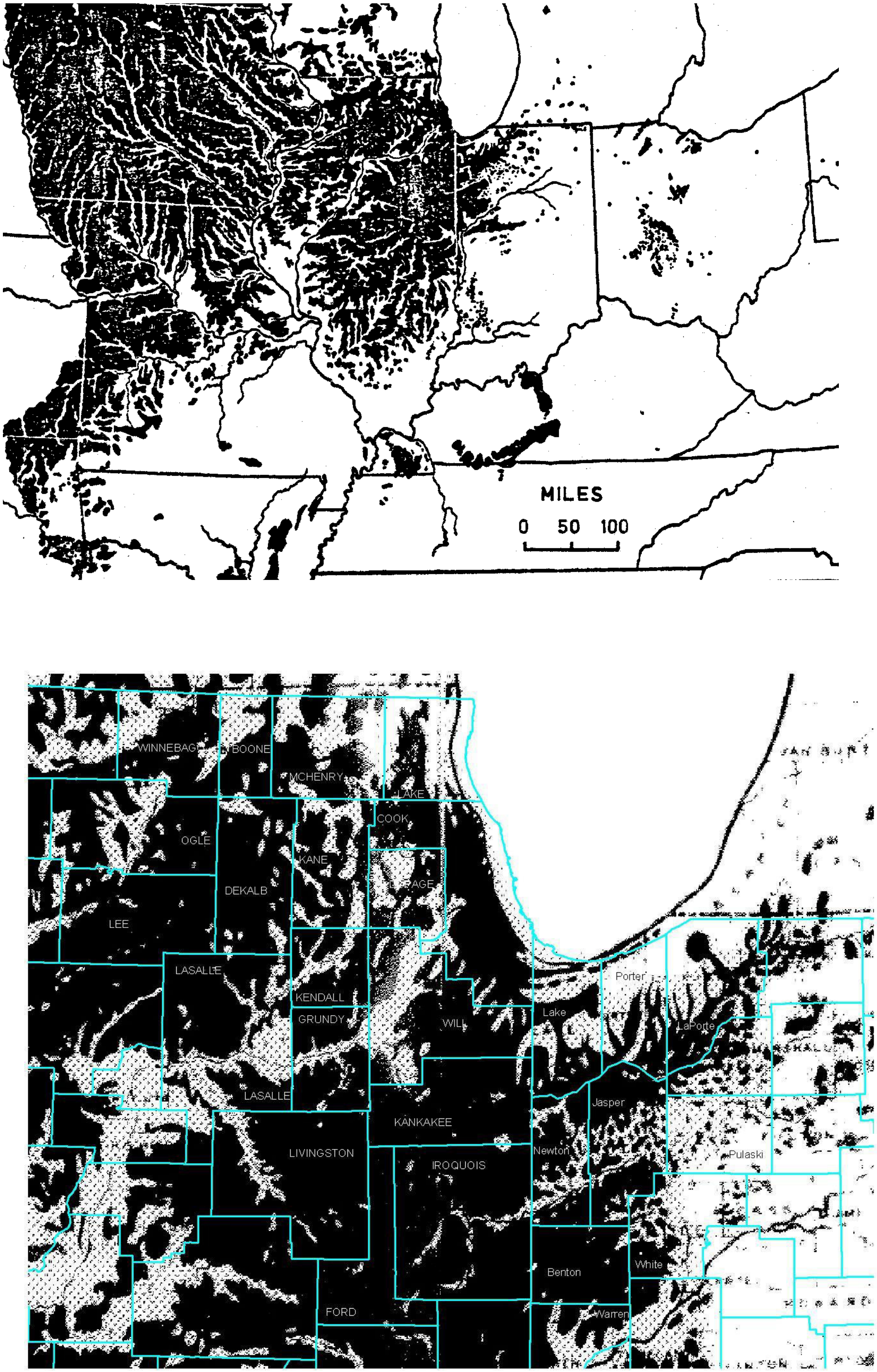


Figure 1. The Prairie Peninsula (Transeau 1935). Upper panel: full extension. Lower panel: detail of northeast Illinois and northwest Indiana with county overlay.

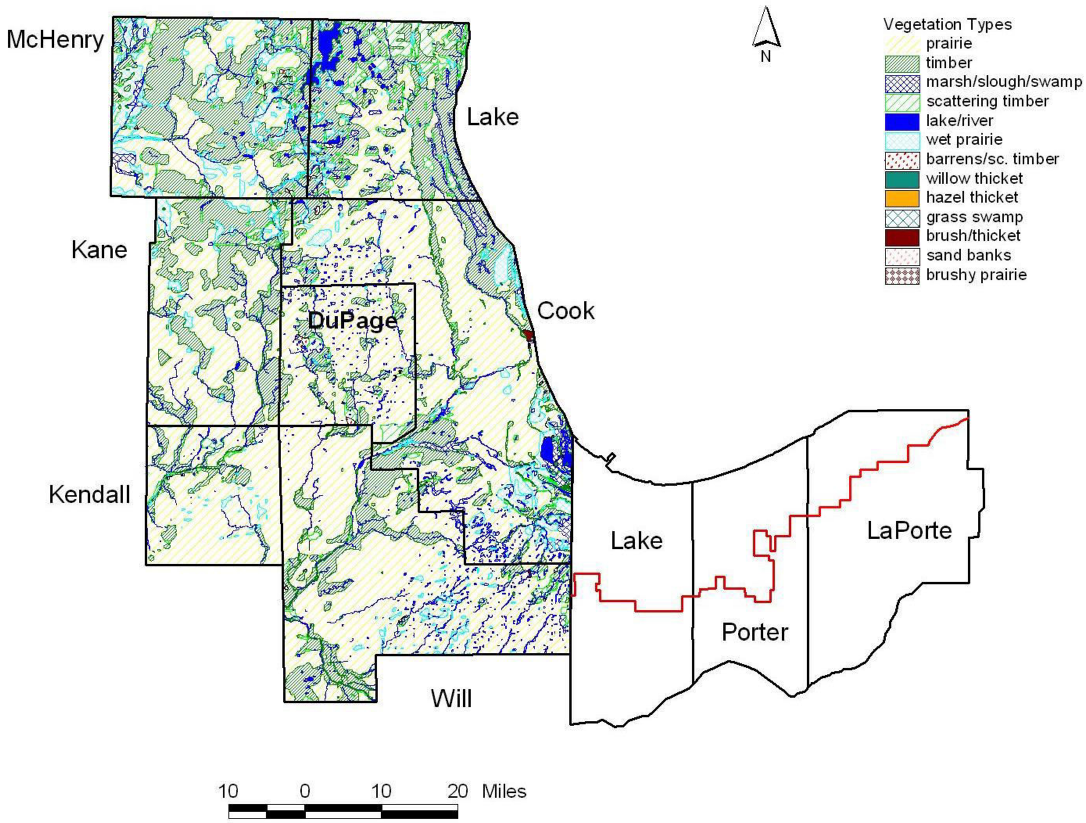


Figure 2: Three-county Study area shown as extension from mapped region of northeast Illinois. Red line indicates Lake Michigan watershed divide.

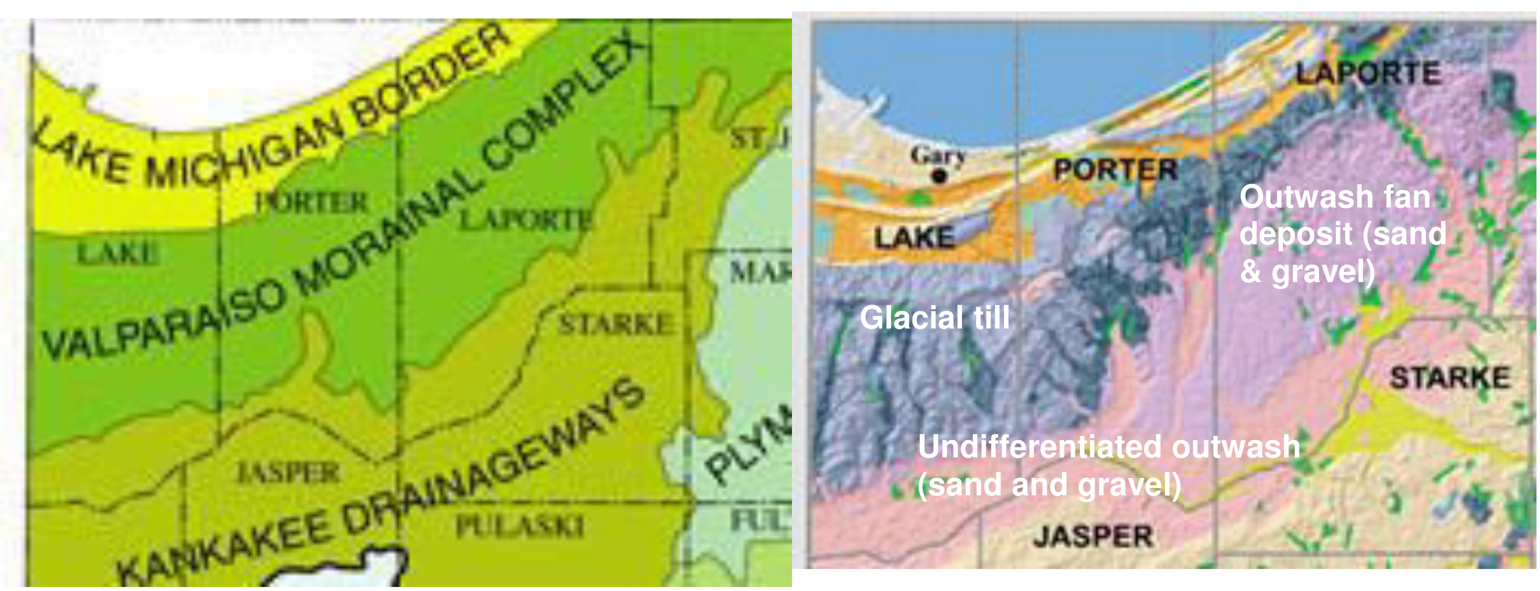


Figure 3. Left: Physiographic regions of northwest Indiana. Modified from Gray, A.H. 2000. Physiographic Divisions of Indiana. Indiana Geological Survey Special Report 61, Plate I. Digital compilation by Kimberly H. Sowder. Right: Detail of Valparaiso Morainal Complex and Kankakee Drainageways. Source: DEM overlay of Gray, A.H. 1989. Quaternary Geologic Map of Indiana Miscellaneous Map 49.

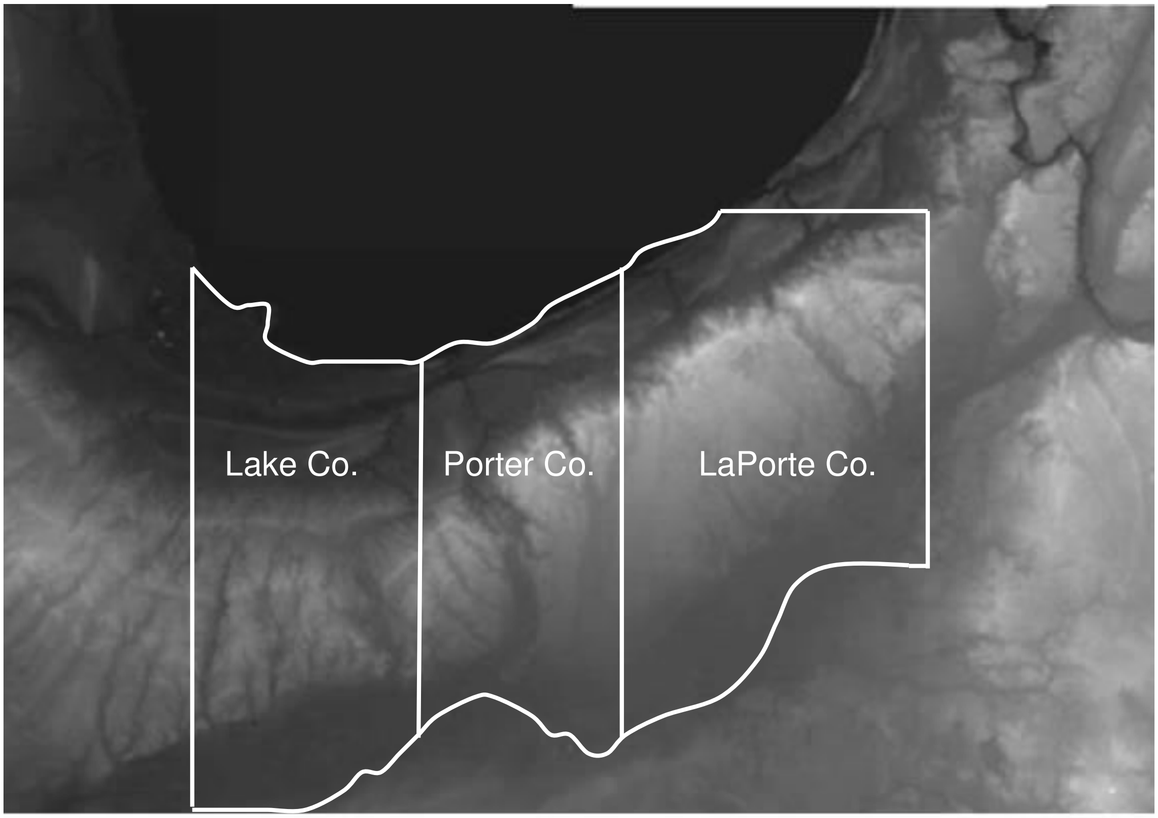


Figure 4. Digital elevation model of northwest Indiana and adjacent Illinois and Michigan. Dark to light elevation gradient.

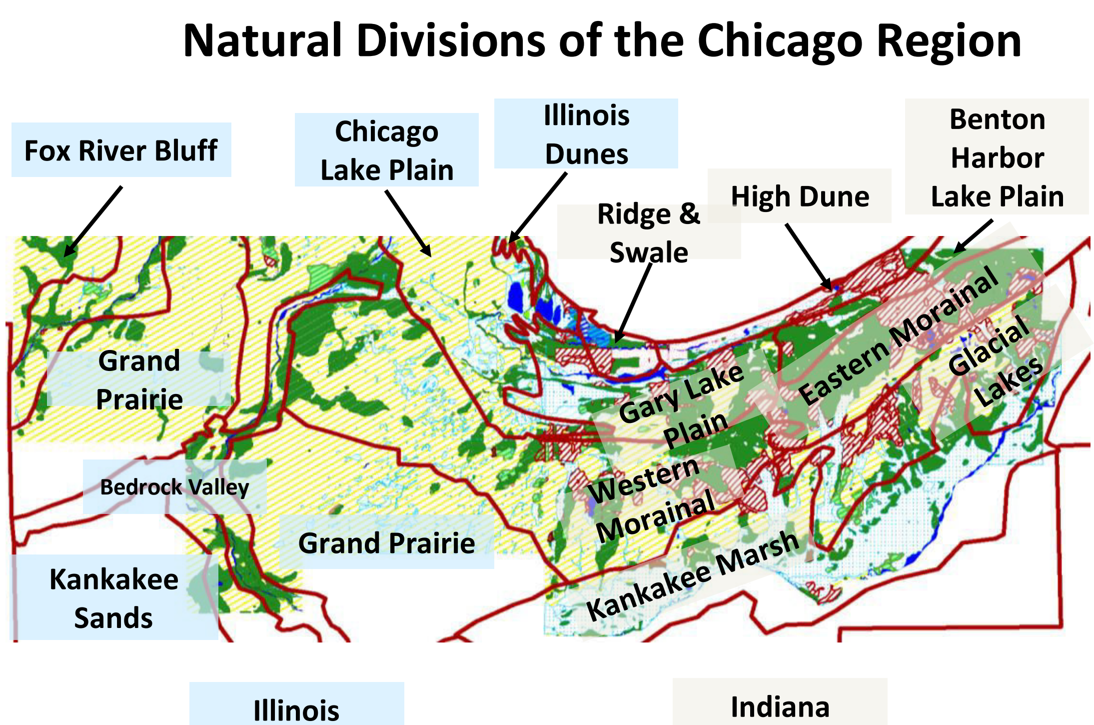
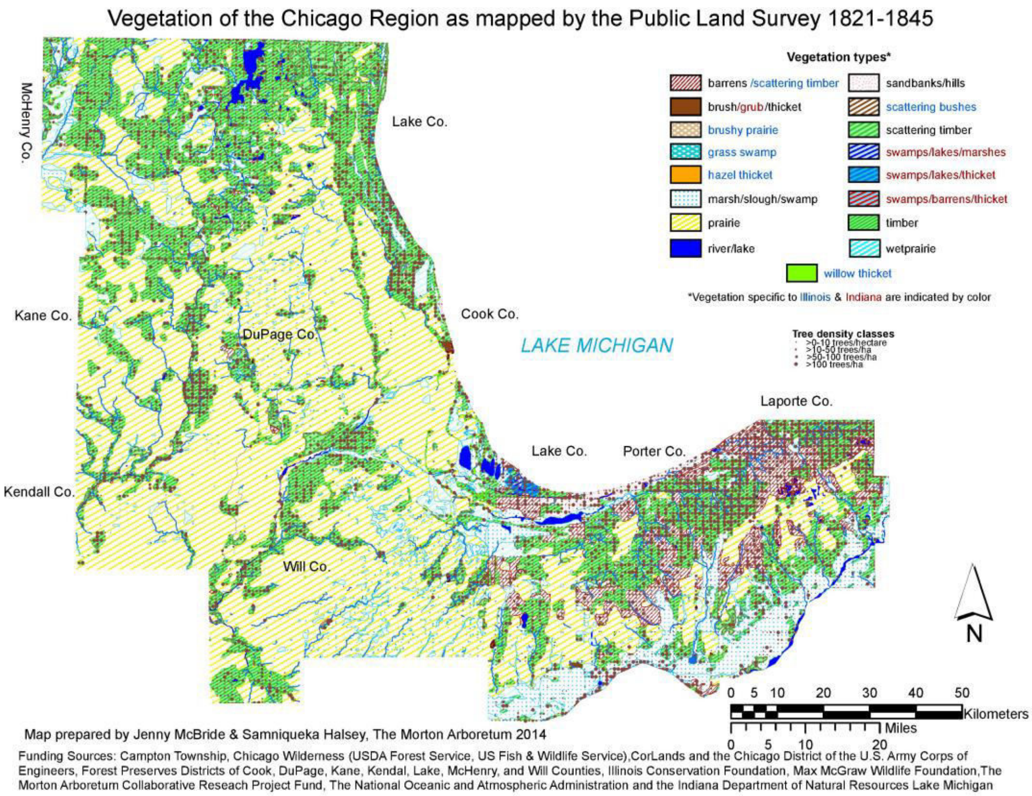


Figure 5 , Natural Divisions of the Chicago Region (from Swink & Wilhelm 1994). Coverage of northwest Indiana study area and adjacent Illinois with natural vegetation overlay (see Figure 6).



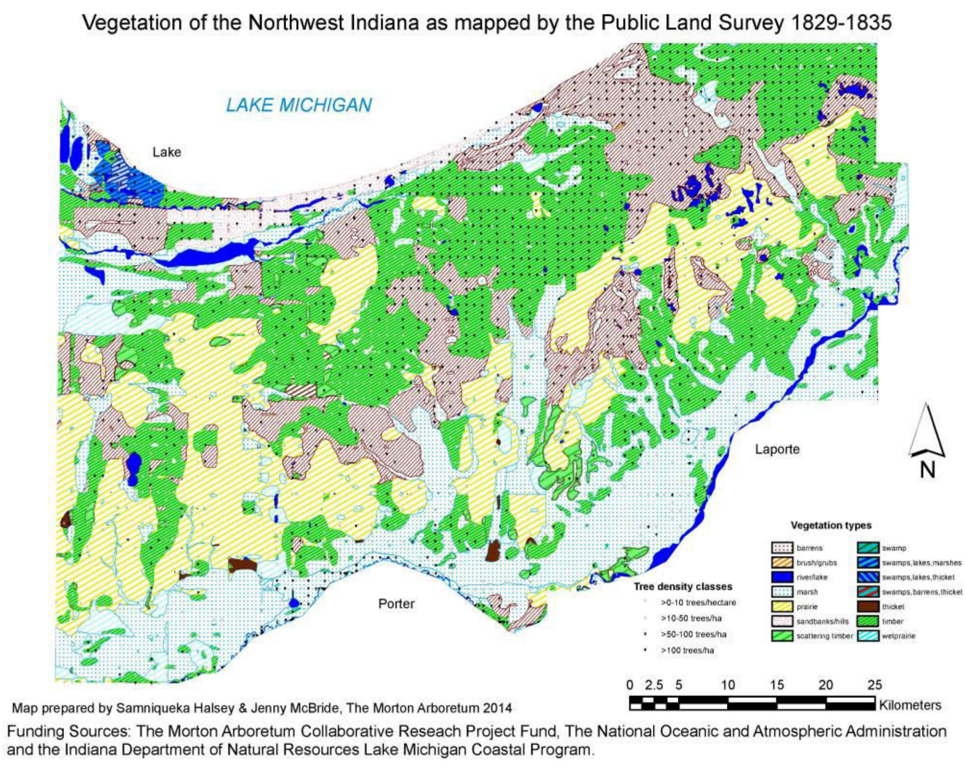


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Figure 6. Vegetation mapped by the PLS in the Chicago region (upper panel) and northwest Indiana (lower panel).

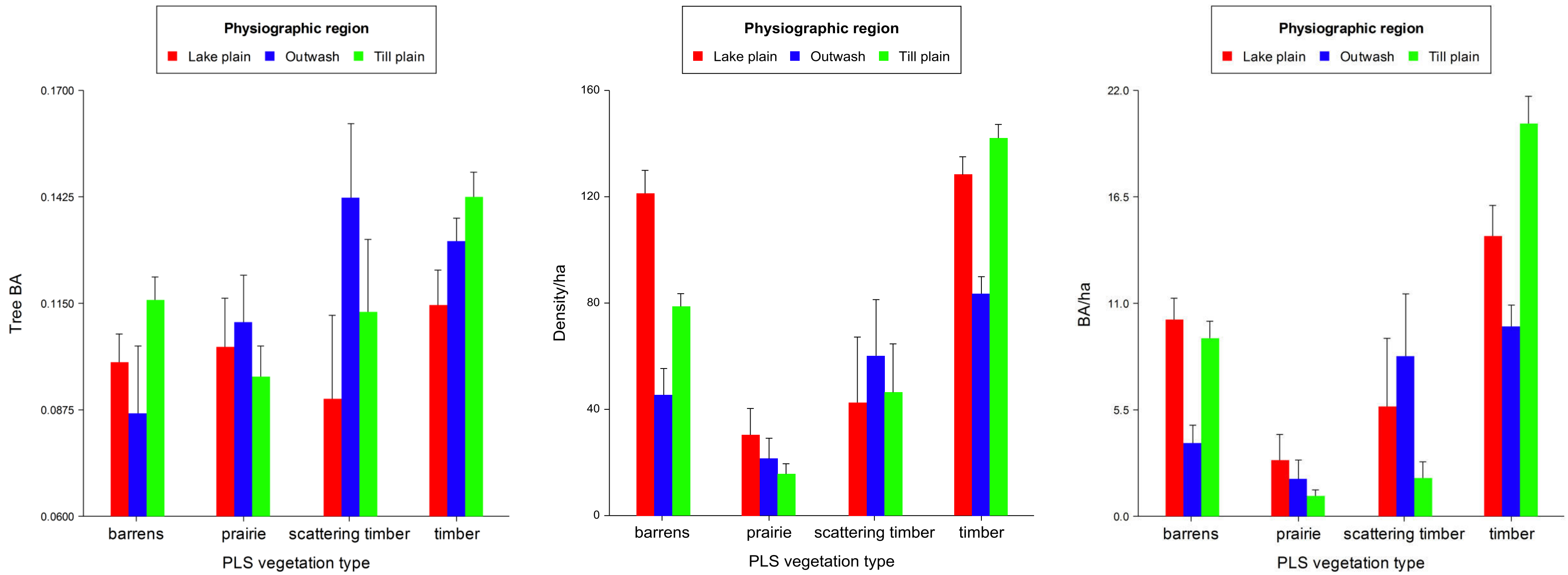


Figure 7. Variation in mean BA, tree density/ha, and BA/ha in relation to PLS vegetation type and physiographic region

Analysis of Variance Table

Source Tree BA	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
A: PLS Veg	3	0.2943977	0.09813257	4.33	0.004743*	0.869670
B: PhysReg	2	0.03136337	0.01568169	0.69	0.500954	0.167332
AB	6	0.1117374	0.01862291	0.82	0.553372	0.330491
Density/ha						
A: PLS Veg	3	2305997	768665.6	50.50	0.000000*	1.000000
B: PhysReg	2	82711.85	41355.93	2.72	0.066263	0.539089
AB	6	540908.5	90151.41	5.92	0.000004*	0.998406
BA/ha						
A: PLS Veg	3	46007.09	15335.7	18.91	0.000000*	1.000000
B: PhysReg	2	798.392	399.196	0.49	0.611319	0.131229
AB	6	12568.21	2094.701	2.58	0.016937*	0.855530

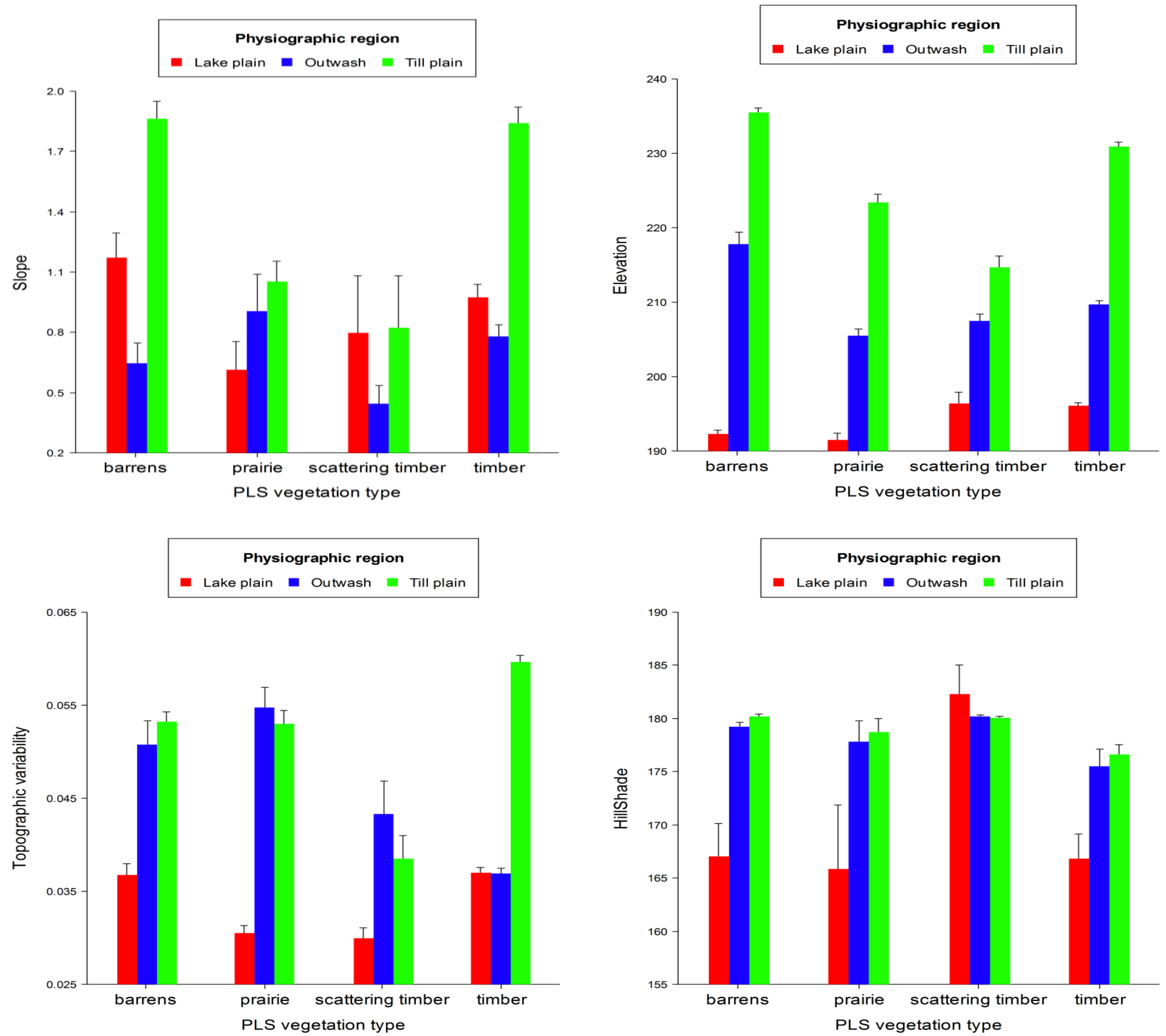


Figure 8. Variation in landscape ecological factors (slope, elevation, topographic variability and hillshade) in relation to PLS vegetation type and physiographic region.

Analysis of Variance Table

Source		**Sum of**	**Mean**		**Prob**	**Power**
Slope	**DF**	**Squares**	**Square**	**F-Ratio**	**Level**	**(Alpha=0.05)**
A: MajorVeg	3	42.86536	14.28845	4.46	0.003915*	0.880788
B: PhysReg	2	80.74609	40.37304	12.61	0.000004*	0.996676
AB	6	51.49212	8.58202	2.68	0.013476*	0.870398
Elevation						
A: MajorVeg	3	12586.91	4195.638	24.71	0.000000*	1.000000
B: PhysReg	2	137190.8	68595.38	404.02	0.000000*	1.000000
AB	6	15065.14	2510.857	14.79	0.000000*	1.000000
Topographic variabiltiy						
A: MajorVeg	3	0.005771824	0.001923941	5.63	0.000766*	0.946111
B: PhysReg	2	0.03919653	0.01959827	57.32	0.000000*	1.000000
AB	6	0.04597146	0.00766191	22.41	0.000000*	1.000000
Hillshade						
A: MajorVeg	3	5203.972	1734.657	1.95	0.118932	0.506860
B: PhysReg	2	9469.39	4734.695	5.33	0.004891*	0.840397
AB	6	3420.367	570.0611	0.64	0.696805	0.259474

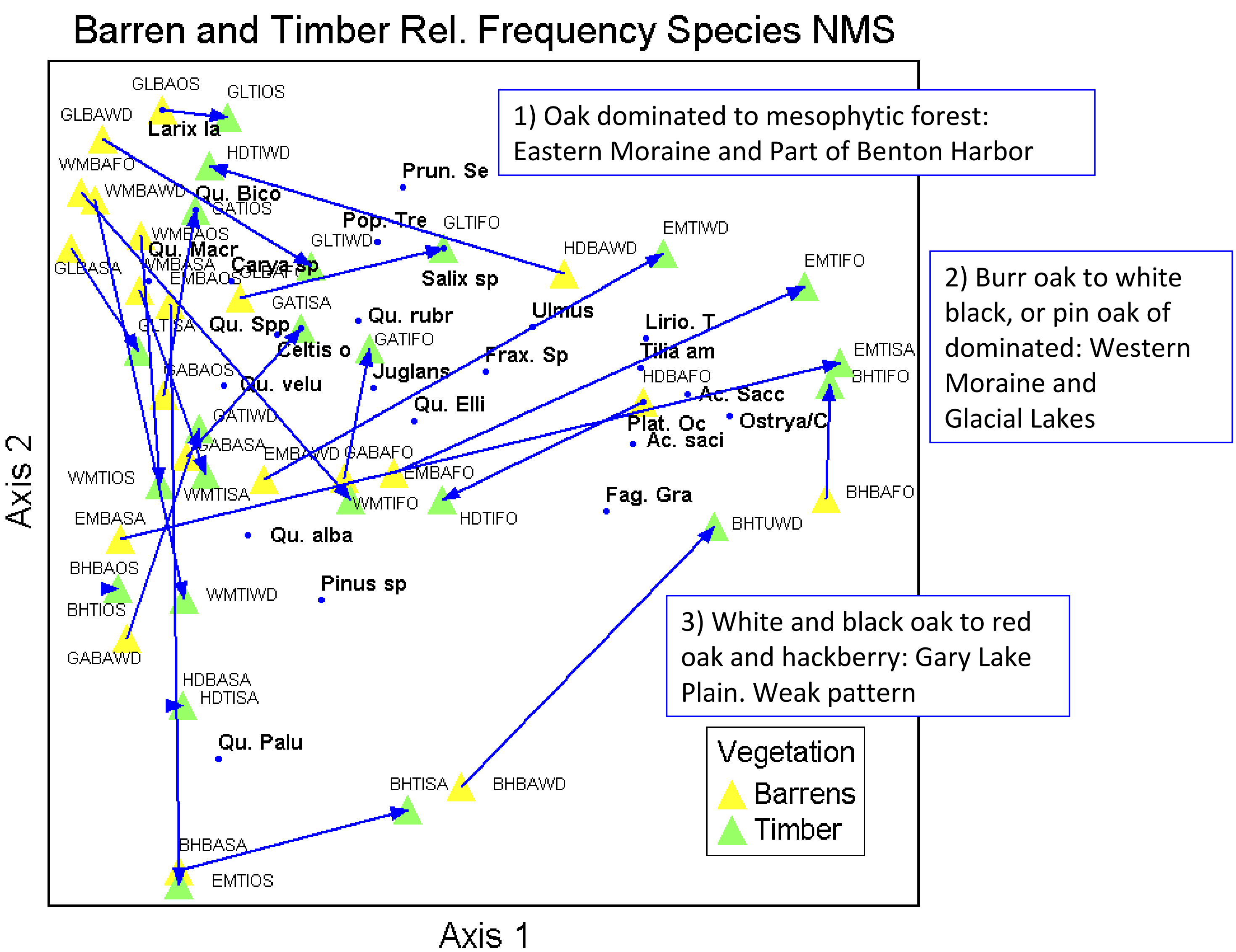


Figure 9. NMS ordination showing vegetation shifts between barrens and timber vegetation in northwest Indiana. MRPP: A = 0.016, P = 0.071.

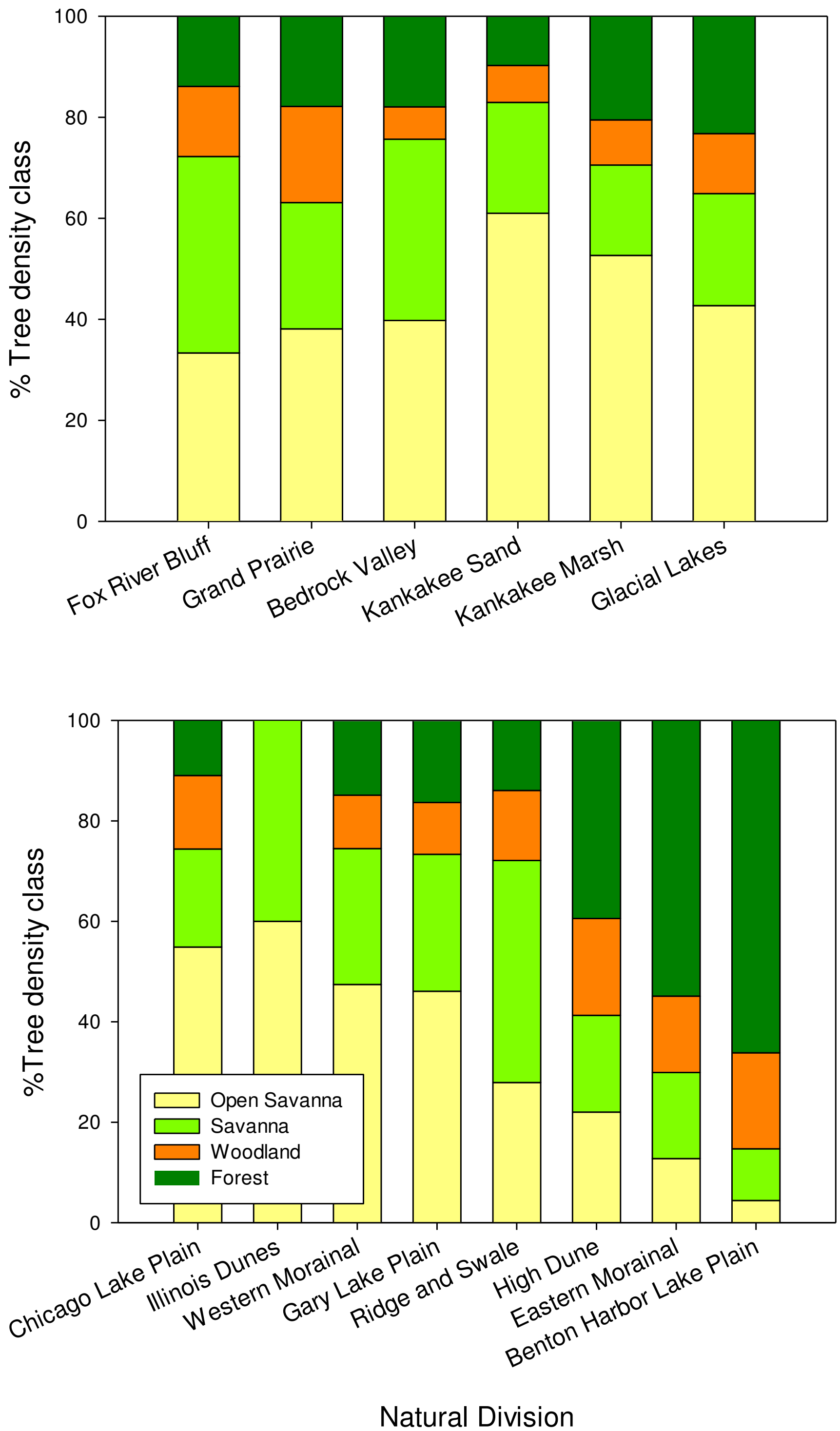


Figure 10. Proportional differences in abundances of tree density classes by natural division in the Chicago region. Upper panel: outwash and till plain sections; lower panel: dunes and morainal sections.

Figure 11. Dominance (relative BA) of co-dominant (left panels) and sub-dominant (right panels) tree species in the Lake Plain, Morainal, Glacial Lakes and Kankakee Marsh Natural Divisions of northwest Indiana. Note differences in scale between left and right panels.

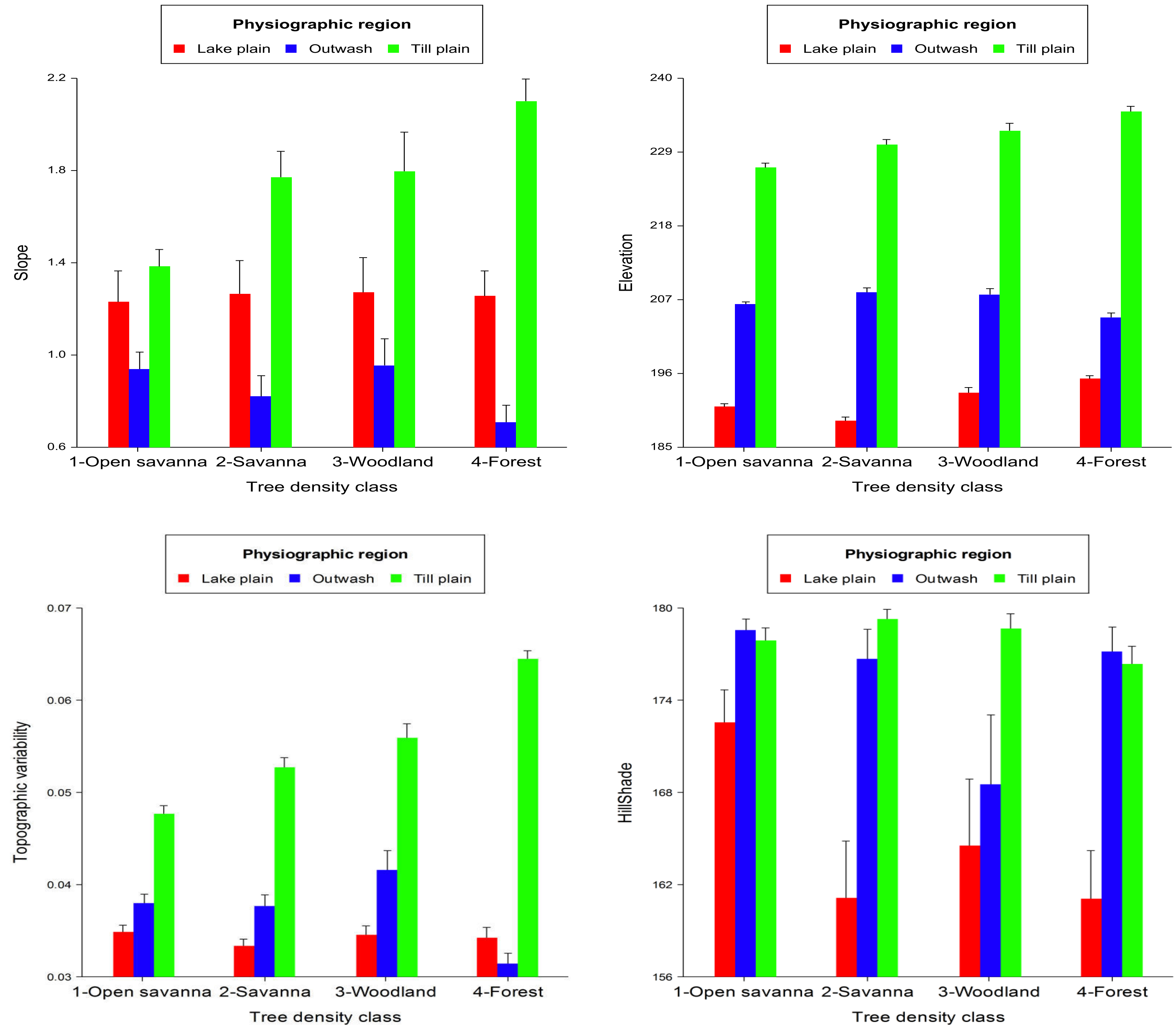


Figure 12. Variation in landscape ecological factors (slope, elevation, topographic variability and hillshade) in relation to Tree Density Class and physiographic region.

ANOVA table:

Slope	**DF**	**Sum of Squares**	**Mean Square**	**F-Ratio**	**Prob Level**	**Power (Alpha=0.05)**
A: TIMBERType	3	18.19536	6.065121	1.56	0.196471	0.414747
B: PhysReg	2	408.41	204.205	52.59	0.000000*	1.000000
AB	6	101.5005	16.91675	4.36	0.000217*	0.984230
Elevation						
A: TIMBERType	3	7646.378	2548.793	16.39	0.000000*	0.999995
B: PhysReg	2	890402	445201	2862.81	0.000000*	1.000000
AB	6	12244.84	2040.806	13.12	0.000000*	1.000000
A: TIMBERType	3	0.00777043	0.002590144	7.25	0.000076*	0.983997
Topographic variability						
A: TIMBERType	3	0.00777043	0.002590144	7.25	0.000076*	0.983997
B: PhysReg	2	0.2960986	0.1480493	414.50	0.000000*	1.000000
AB	6	0.06405088	0.01067515	29.89	0.000000*	1.000000
Hillshade						
A: TIMBERType	3	17984.04	5994.68	5.88	0.000531*	0.955191
B: PhysReg	2	99688.38	49844.19	48.90	0.000000*	1.000000
AB	6	23337.04	3889.507	3.82	0.000853*	0.967400

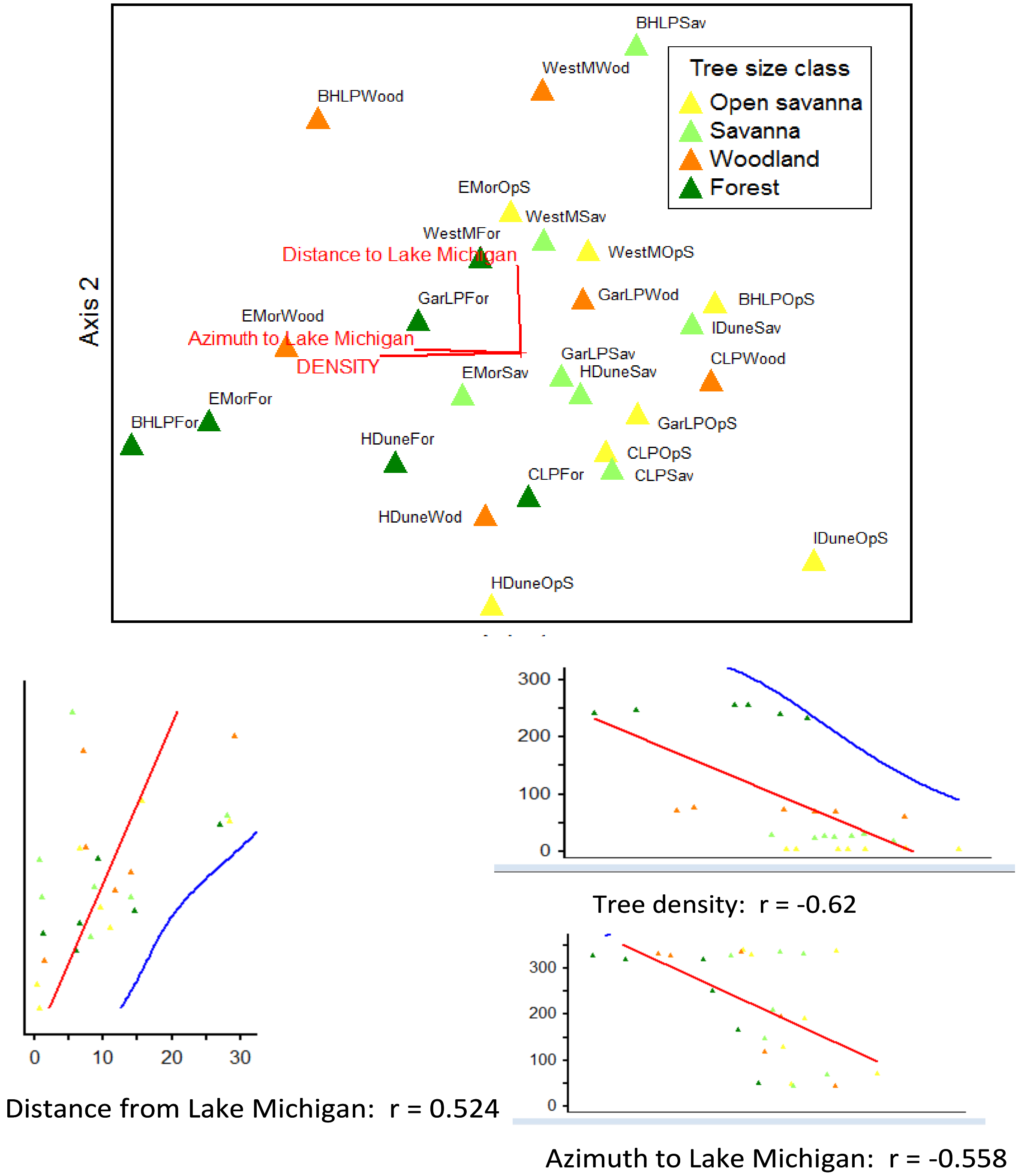


Figure 13. Upper panel: NMS ordination of natural divisions and tree density classes. Lower panels: significant ecological overlay correlations for first axis (distance from Lake Michigan) and second axis (tree density and azimuth to Lake Michigan).

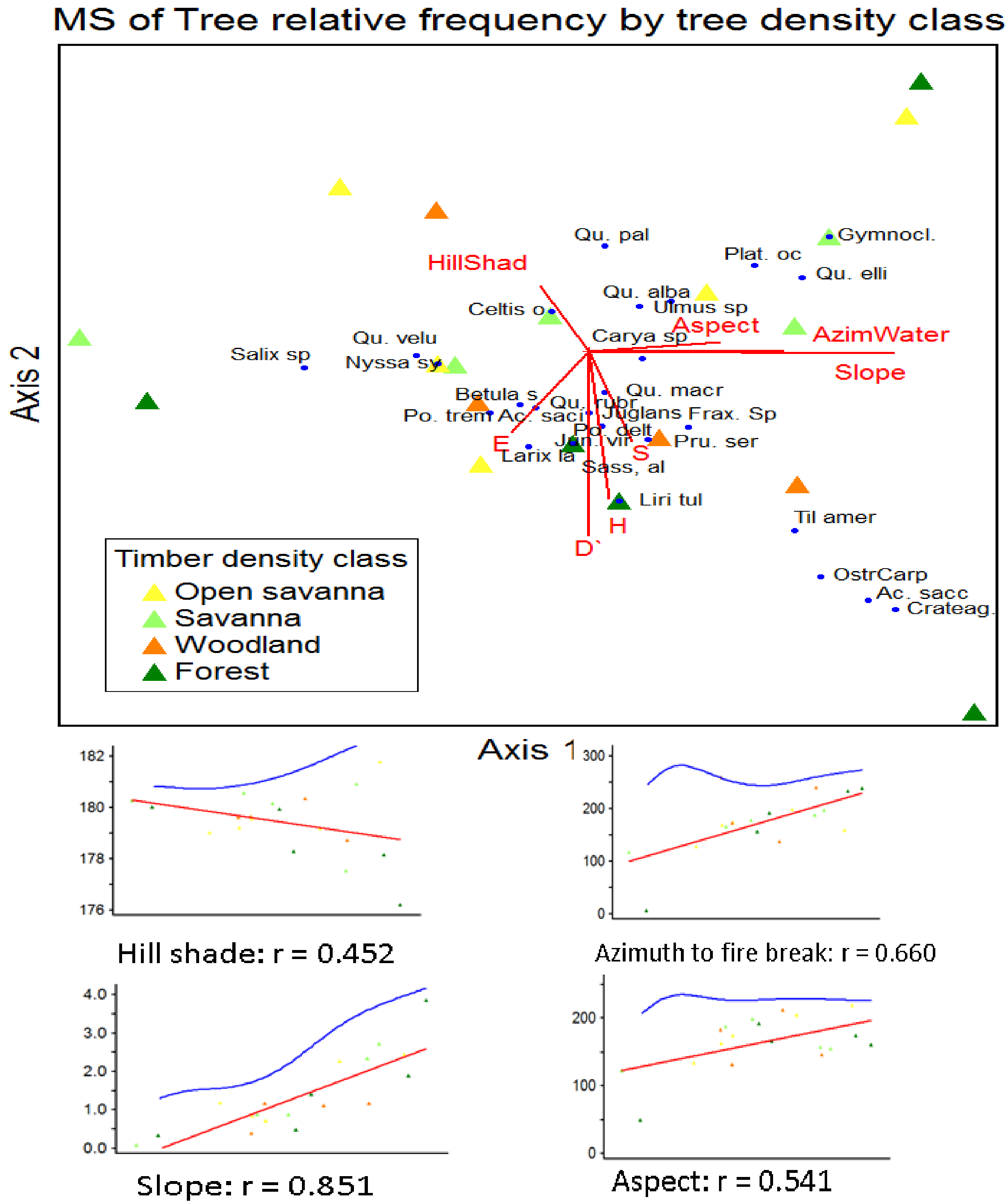


Figure 14. Upper panel: NMS ordination of tree species by tree density classes. Lower panels: significant ecological overly correlations for first axis (aspect, hill shade, slope and azimuth to fire break).

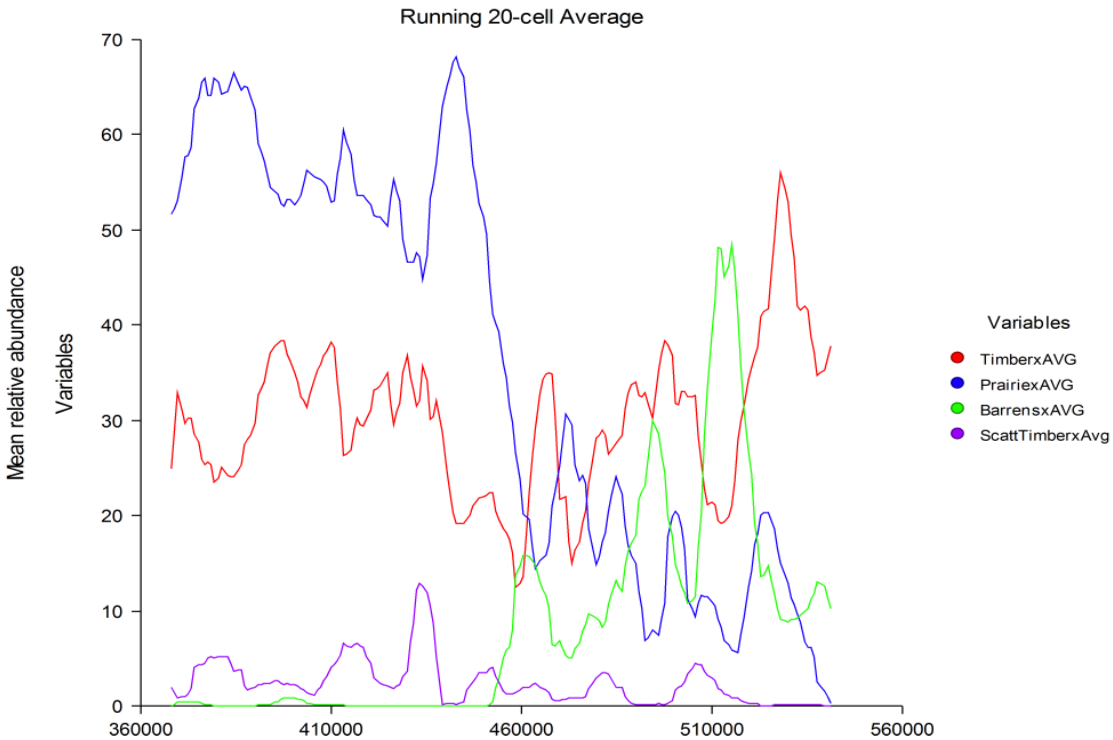


Figure 15. Longitudinal gradient of dominant vegetation described by the PLS across northeast Illinois and adjacent northwest Indiana. Data are running 20-cell average; gradient represents meters in NAD 83 UTM zone 16.

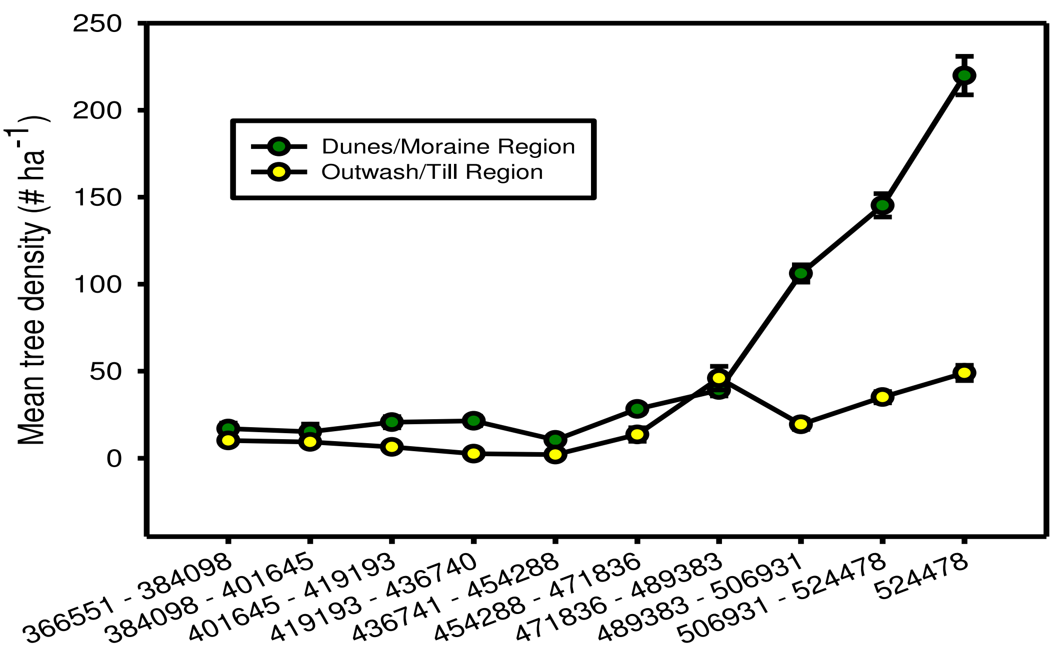


Figure 16. Mean tree density across northeast Illinois and adjacent northwest Indiana by the two dominant physiographic provinces (Dunes/moraine and outwash/till regions). Gradient represents meters in NAD 83 UTM zone 16.

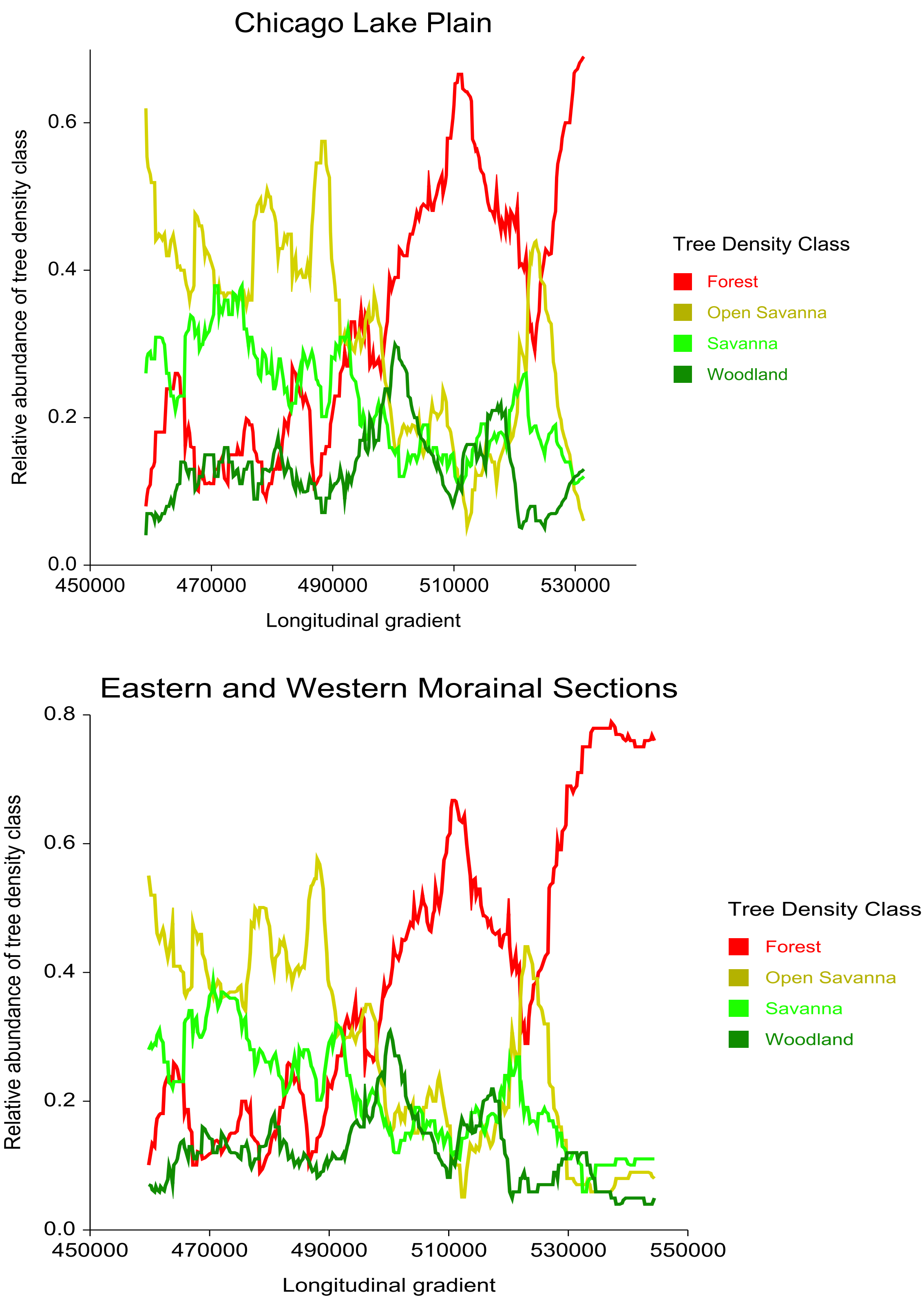


Figure17. Longitudinal tree density class gradient across the Chicago Lake Plain (upper panel) and Morainal sections (lower panel) of northwest Indiana. Data are running 100-cell relative abundance; gradient represents meters in NAD 83 UTM zone 16.

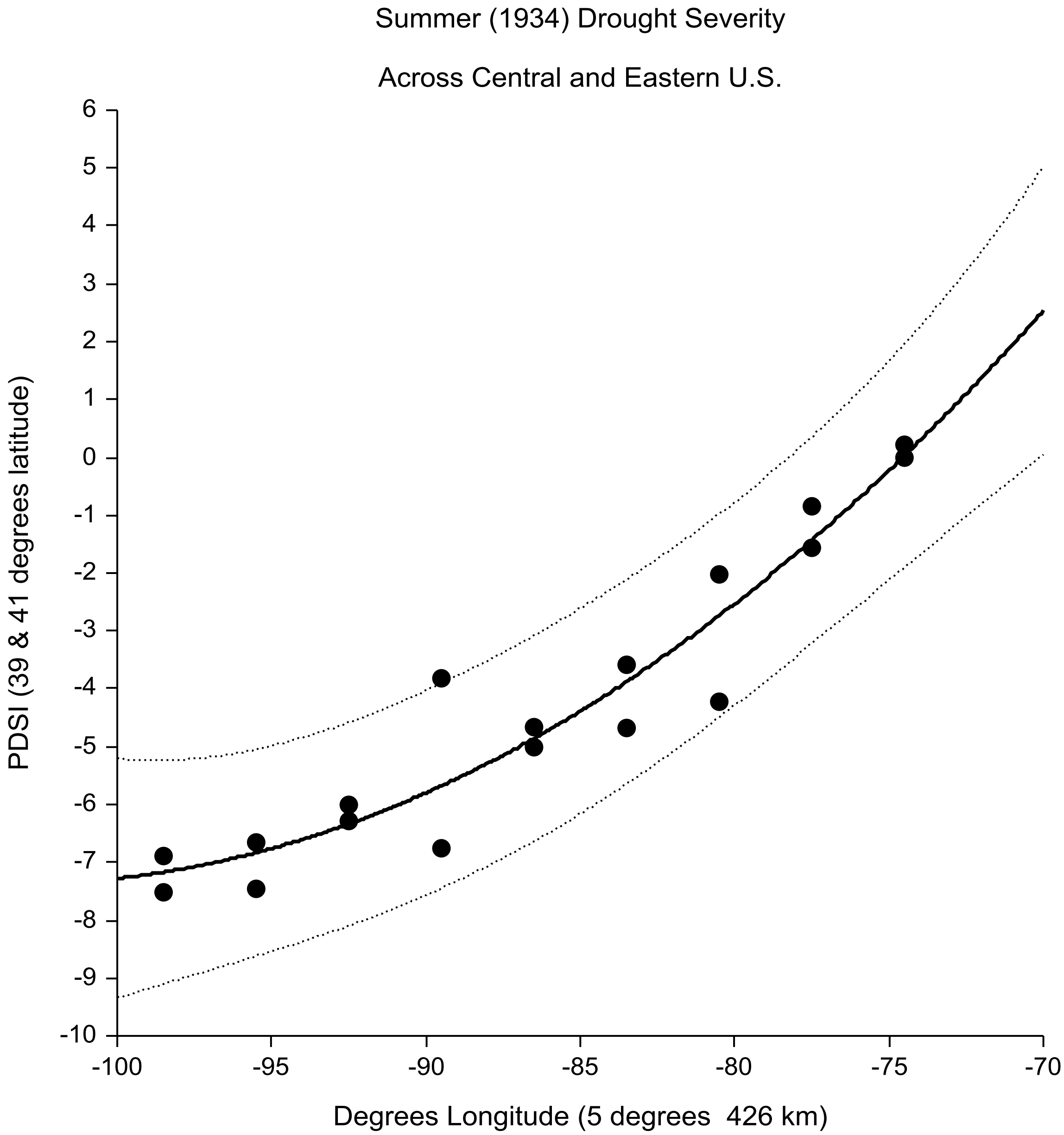
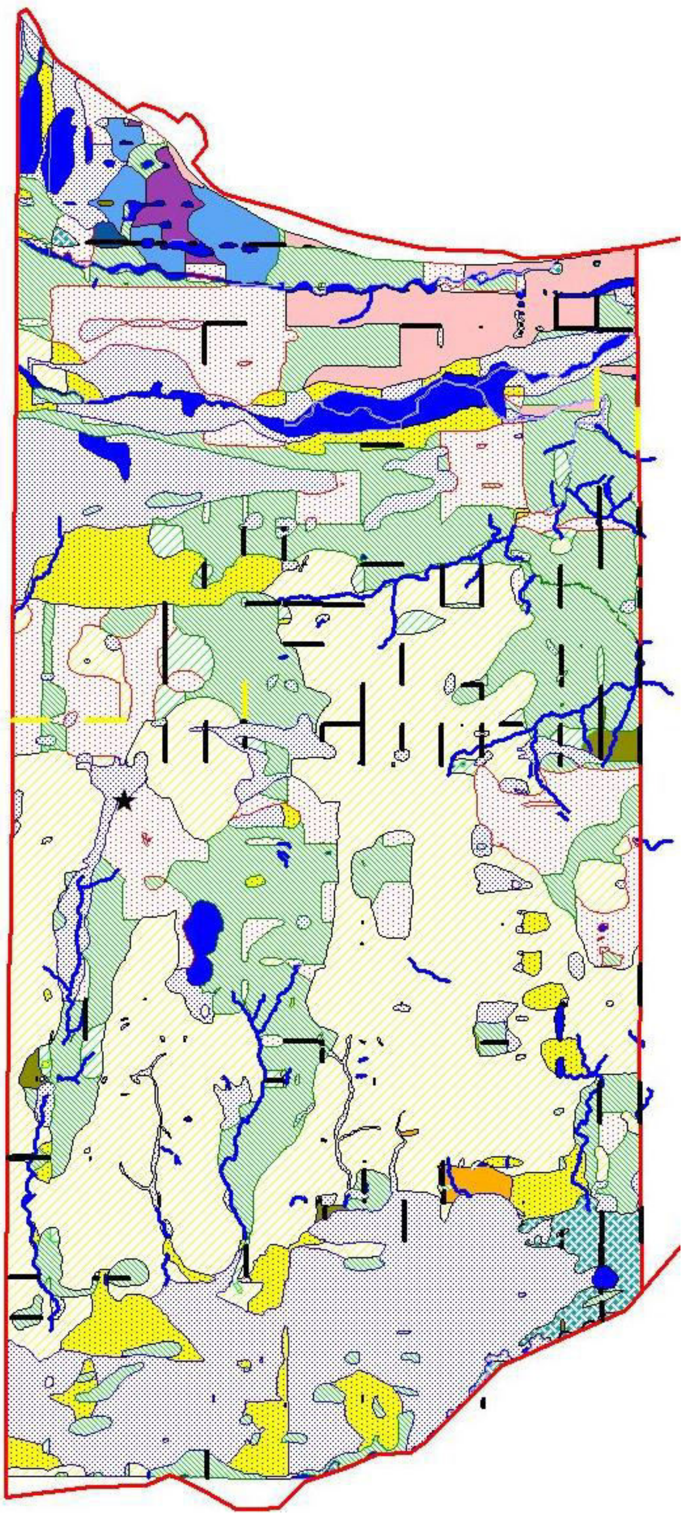


Figure 18. Relationship between PDSI and longitude in summer, 1934. PDSI = 88.0723 + 1.84875 + (0.00895*longitude^2); R-sq = 0.9162. Points represent paired PDSI values from 39^{O} and 41^{O} latitude at 3^{O} (256 km) longitude intervals. Upper values represent 41^{O} in each pair. Dotted lines are 95% CI's. Data source: http://ncdc.noaa.gov/paleo/



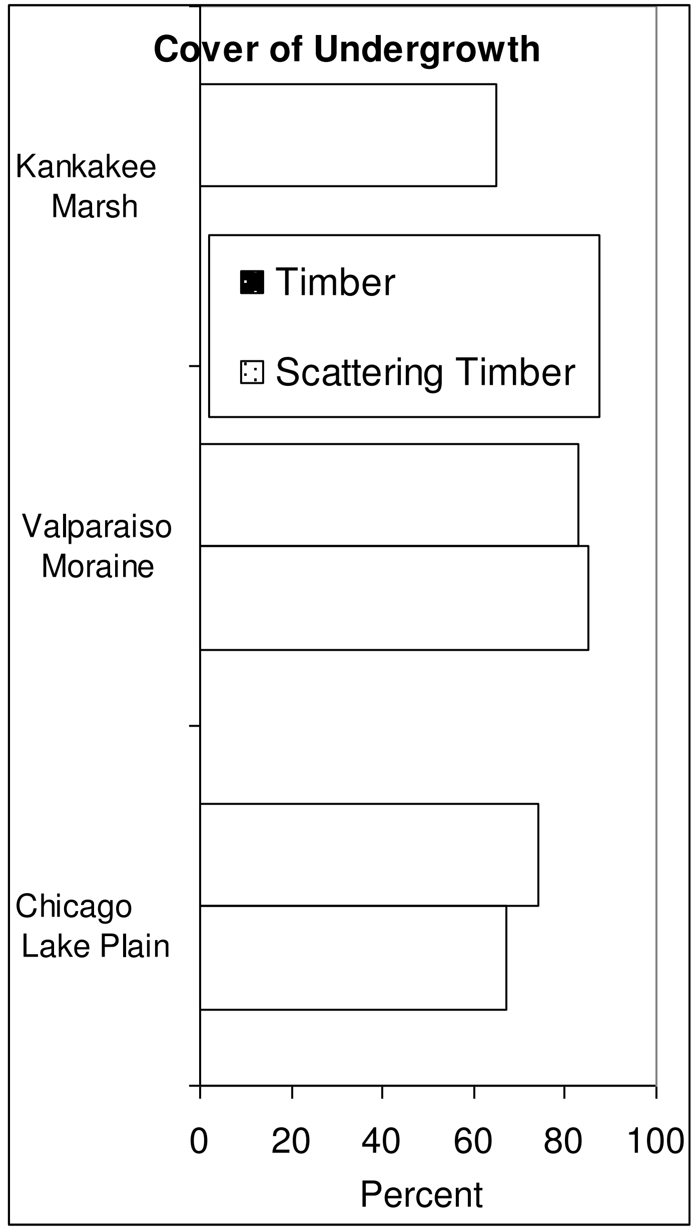


Figure 19. Left: distribution of section lines in which undergrowth was recorded (shown as solid line) as present or absent in Lake Co., Indiana. Right: Proportional linear cover of undergrowth by natural division and vegetation type along section lines in Lake Co.. See Table 5 for individual species relative abundance.

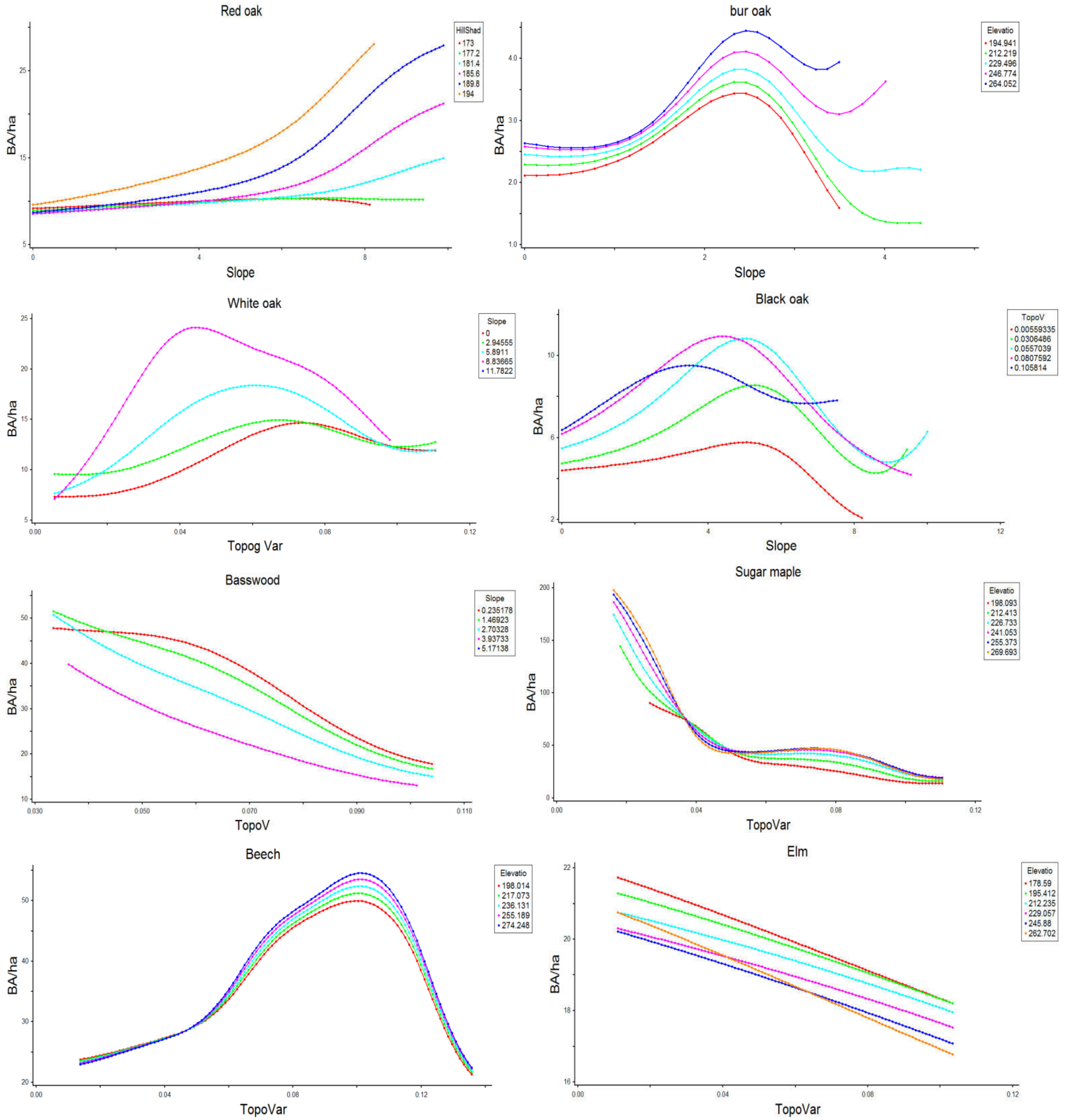


Figure 20. Responses of oak (upper panels) and non-oak (lower panels) species to variation in slope, elevation and topographic variation in the Valparaiso Morainal Complex Physiographic Region. Non Parametric Multiplicative Modeling: Red oak (N = 77, P = 0.039, R-sq = 0.5073), Bur oak (N = 257, P = 1.00, R-sq = 0.04433), White oak (N = 407, P = 0.048, R-sq = 0.0798), Black oak (N = 318, P = 0.02, R-sq = 0.1052), Basswood (N = 48, P = 0.490, R-sq = -0.0143), Sugar maple (N = 81, P = 0.048, R-sq = 0.4066), American Beech (N = 119, P = 0.048, R-sq = 0.1630), Elm (N = 74, P = 0.235, R-sq = 0.0666).

Table 1. Public Land Surveyors, county, township, date and type (exterior vs interior) of Lake, Porter, and LaPorte counties in northwest Indiana.

Surveyor Name	Title	County	Township	Survey date	Type
A. Barnside	DS	Porter	T36NR5W	06/1/1834	Int
Andrew Barnside	DS	Porter	T34NR6W	07/7/1834	Int
Barnside	DS	Porter	T35NR5W	10/23/1834	Int
Calvin Britain	Jr. DS	Laporte	T37NR4W	4/1/1830	Int
Calvin Britain	Jr. DS	Porter	T37NR5W	04/21/1830	Int
Calvin Britain	Jr. DS	Porter	T37NR5W	04/10/1830	Ext
D. Hills	DS	Laporte	T36NR1W	12-May	Ext
D. Hills	DS	Laporte	T37NR1W	05/15/1839	Ext
David Hillis	DS	Laporte	T35NR1W	12/15/1834	Ext
David Hillis	DS	Laporte	T38NR1W	08/12/1829	Ext
J. Smith	DS	Laporte	T33NR4W	01/16/1835	Int
Jermiah Smith	DS	Laporte	T33NR3W	01/4/1835	Int
Jermiah Smith	DS	Porter	T33NR5W	07/3/1834	int
Jermiah Smith	DS	Porter	T33NR5W	01/31/0835	int
Jermiah Smith	DS	Laporte	T34NR3W	01/7/1835	Int
Jermiah Smith	DS	Laporte	T34NR4W	07/18/18334	Int
Jermiah Smith	DS	Porter	T34NR5W	7/3/1834	Int
Jermiah Smith	DS	Laporte	T35NR2W	10/18/1834	Int
Rob Clark	Jr. DS	Porter	T33NR6W	01/24/1834	Ext
Rob Clark	Jr. DS	Porter	T33NR6W	04/4/1834	Ext
Rob Clark	Jr. DS	Laporte	T34NR2W	12/12/1833	Int
Rob Clark	Jr. DS	Laporte	T34NR2W	01/31/1835	Int
Rob Clark	Jr. DS	Laporte	T34NR4W	02/11/1834	Ext
Rob Clark	Jr. DS	Porter	T34NR5W	02/11/1833	ext
Rob Clark	Jr. DS	Porter	T34NR6W	12/4/1834	
Rob Clark	Jr. DS	Porter	T34NR6W	02/15/1834	Ext
Rob Clark	Jr. DS	Laporte	T35NR1W	12/16/1833	Ext
Rob Clark	Jr. DS	Laporte	T35NR1W	10/1/1834	Int
Rob Clark	Jr. DS	Laporte	T35NR2W	12/16/1833	Ext
Rob Clark	Jr. DS	Laporte	T35NR4W	Feb 1834	Ext
Rob Clark	Jr. DS	Porter	T35NR5W	02/11-13/1833	Ext
Rob Clark	Jr. DS	Laporte	T36NR1W	12/18/1834	Ext
Rob Clark	Jr. DS	Laporte	T36NR1W	06/03/1834	Int
Rob Clark	Jr. DS	Laporte	T36NR2W	12/17/1833	Ext
Rob Clark	Jr. DS	Laporte	T36NR3W	02/20/1833	Ext
Rob Clark	Jr. DS	Laporte	T36NR4W	2/20/1834	Ext
Rob Clark	Jr. DS	Porter	T36NR5W	02/28/1834	Ext
Rob Clark	Jr. DS	Laporte	T37NR2W	12/19/2015	Ext
Rob Clark	Jr. DS	Laporte	T37NR2W	12/20/1835	Ext
Rob Clark	Jr. DS	Laporte	T37NR4W	03/9/1833	Ext
Rob Clark	Jr. DS	Porter	T37NR5W	03/9/1834	Ext
Robert Clark	Jr. DS	Porter	T35NR6W	?	ext
Robert Clark	Jr. DS	Porter	T36NR6W	3/7/1834	ext
Robert Clark	Jr. DS	Laporte	T37NR1W	12/18/1835	Ext
Robert Clark	Jr. DS	Porter	T37NR5W	2/28/1837	Ext
S. Sibley	DS	Laporte	T33NR3W	01/10/1834	Ext
S. Sibley	DS	Porter	T33NR5W	1/18/1834	Ext
S. Sibley	DS	Laporte	T34NR4W	01//15/1834	Ext
S. Sibley	DS	Porter	T34NR5W	01/17/1834	ext
S. Sibley	DS	Porter	T34NR5W	01/18/1834	ext
S. Sibley	DS	Laporte	T35NR2W	01/23/1834	Ext
S. Sibley	DS	Laporte	T36NR2W	01/25/1834	Ext
S. Sibley;R. Clark	DS	Laporte	T35NR3W	July 1834	Ext
Sylvester Sibley	DS	Laporte	T33NR4W	01/4/1834	Ext
Sylvester Sibley	DS	Porter	T33NR6W	1/8/1834	Ext
Sylvester Sibley	DS	Laporte	T34NR2W	01/13/1834	Ext
Sylvester Sibley	DS	Laporte	T34NR3W	01/14/1834	Ext
Sylvester Sibley	DS	Porter	T34NR6W	01/18/1834	
Sylvester Sibley	DS	Porter	T35NR6W	05/20/1834	Int
Sylvester Sibley	DS	Porter	T36NR6W	3/15/1834	Int
S. Sibley; R. Clark	JR DS	Laporte	T35NR4W	03/19/1834	Int
Tho Brown	DS	Laporte	T37NR1W	06/17/1829	Ext
Tho Brown	DS	Laporte	T37NR2W	06/18/1829	Ext
Tho Brown	DS	Laporte	T37NR3W	06/25/1829	Ext
Tho Brown	DS	Laporte	T37NR4W	06/27/1829	Ext
Tho Brown	DS	Porter	T37NR5W	06/29-30/1829	Ext
Tho Brown	DS	Laporte	T38NR1W	06/18-19/1829	Ext
Tho Brown	DS	Laporte	T38NR3W	06/24/1829	Ext
Tho Henderson	DS	Laporte	T38NR3W	July 1830	Int
Thomas Brown	DS	Porter	T37NR5W	06/29/1829	Ext
Thomas Henderson	DS	Laporte	T37NR1W	11/21/1829	Int
Thomas Henderson	DS	Laporte	T37NR2W	Feb 1830	Int
Thomas Henderson	DS	Laporte	T37NR3W	12/17/1829	Int
Thomas Henderson	DS	Laporte	T38NR4W	11/2/1829	Ext
Thomas Henderson	DS	Laporte	T38NR4W	11/8/1829	Int
Thomas Hudson	DS	Laporte	T38NR1W	07/04/1830	Int
Uriah Biggs	DS	Porter	T33NR6W	01/5/1830	Int
W. Clark	DS	Laporte	T36NR2W	05/30/1834	Int
W. Polke	DS	Laporte	T36NR3W	07/10/1832	Int
W. Polke	DS	Laporte	T36NR4W	Sept 1831	Int
W. Polke	DS	Laporte	T37NR2W	09/23/1831	Int
W. Polke	DS	Laporte	T37NR3W	09/19/1831	Int
W. Polke	DS	Laporte	T37NR4W	9/18/1831	Int
William Clark	DS	Laporte	T35NR1W	10/15/1834	Int
William Clark	DS	Laporte	T35NR3W	July 1834	Int
William Clark	DS	Laporte	T36NR2W	05/27/1834	Ext
William Clark	DS	Laporte	T37NR2W	12/19/1834	Int
William Clark	DS	Laporte	T37NR4W	12/15/1834	Int
William Clark	DS	Porter	T37NR5W	07/24/1834	Int

Table 2. Woody plant bearing trees identified by the PLS in northwest Indiana.

Surveyor name	Common name	Scientific name	Surveyor name	Common name	Scientific name
Maple	Maple	*Acer saccharinum*	Sycamore	Sycamore	*Platanus occidentalis*
Sugar	Sugar maple	*Acer saccharum*	cottonwood	Eastern cottonwood	*Populus deltoides*
B alder	Alder	*Alnus rugosa*	Aspen	Quaking aspen	*Populus grandidentata*
w birch	Paper birch	*Betula papyrifera*	cherry	Black cherry	*Prunus serotina*
bastard birch	birch	*Betula sp.*	W Oak	White oak	*Quercus alba*
birch	birch	*Betula sp.*	white oak	White oak	*Quercus alba*
Ironwood	Blue beech	*Carpinus caroliniana*	swamp oak	Swamp white oak	*Quercus bicolor*
hickory	Hickory	*Carya sp.*	Br Oak	Burr oak	*Quercus macrocarpa*
hackberry	hackberry	*Celtis sp.*	bur oak	Burr oak	*Quercus macrocarpa*
beech	American beech	*Fagus grandifolia*	p oak	Pin oak	*Quercus palustris*
Ash	Ash	*Fraxinus sp.*	Pin	Pin oak	*Quercus palustris*
S Ash	Ash	*Fraxinus sp.*	Pin Oak	Pin oak	*Quercus palustris*
Y Ash	Ash	*Fraxinus sp.*	R Oak	Red oak	*Quercus rubra*
w ash	White ash	*Fraxinus americana*	red oak	Red oak	*Quercus rubra*
white ash	White ash	*Fraxinus americana*	Oak	Oak	*Quercus spp.*
B Ash	Black ash	*Fraxinus nigra*	Scrub Oak	Oak	*Quercus spp.*
Blue Ash	Blue Ash	*Fraxinus quadrangulata*	B Oak	Black oak	*Quercus velutina*
j oak	jack oak	*jack oak*	Blk Oak	Black oak	*Quercus velutina*
jack oak	jack oak	*jack oak*	Y Oak	Black oak	*Quercus velutina*
butternut	Butternut	*Juglans cinerea*	yellow oak	Black oak	*Quercus velutina*
B Walnut	Black walnut	*Juglans nigra*	willow	Willow	*Salix spp.*
black walnut	Black walnut	*Juglans nigra*	Sassafras	Sassafras	*Sassafras albidum*
walnut	Walnut	*Juglans nigra*	S Oak	Spanish oak	*Spanish oak*
cedar	Eastern red cedar	*Juniperus virginianus*	basswood	Basswood	*Tilia americana*
tamerac	Tamarack	*Larix laciniata*	lynn	Basswood	*Tilia americana*
Poplar	Tulip tree	*Liriodendron tulipifera*	Elm	Elm	*Ulmus americana*
B Gum	Black gum	*Nyssa sylvatica*	W Elm	American elm	*Ulmus americana*
B Gum	Black gum	*Nyssa sylvatica*	W Beech	unknown	*unknown*
gum	Black gum	*Nyssa sylvatica*			
Pepperage	Black gum	*Nyssa sylvatica*			
nine bark	Ninebark	*Physocarpus opulifolius*			
y pine	Jack pine	*Pinus banksiana*			
Pine	Pine	*Pinus sp.*			
w pine	White pine	*Pinus strobus*			
white pine	White pine	*Pinus strobus*			

Table 3. Number of section corners sampled by the PLS, and total area in hectares, by Natural Division, Tree Density Class and PLS Vegetation Type in northwest Indiana.

Natural Division	Section	No. corners	% corners	Hectares	% hectares
Glacial Lakes	Glacial Lakes Section	590	16.22	1805416.29	6.76
Grand Prairie	Kankakee Sand Section	54	1.48	8377.22	0.03
Grand Prairie	Grand Prairie Section	2	0.05	102069.01	0.38
Grand Prairie	Kankakee Marsh Section	841	23.12	5132504.51	19.20
Lake Plain	Ridge and Swale Section	105	2.89	100050.02	0.37
Lake Plain	Chicago Lake Plain Section	47	1.29	110877.57	0.41
Lake Plain	High Dune Section	223	6.13	802691.73	3.00
Lake Plain	Benton Harbor Lake Plain Section	207	5.69	2151040.86	8.05
Lake Plain	Gary Lake Plain Section	421	11.57	7113916.97	26.62
Morainal	Eastern Morainal Section	678	18.64	3480943.74	13.02
Morainal	Western Morainal Section	470	12.92	5918139.11	22.14
Total		3638	100.00	26726027.03	100.00

Tree Density Class	Tree Density	No. corners	% corners
Open Savanna	>0-10 trees/ha	1348	37.05
Savanna	>10-50 trees/ha	776	21.33
Woodland	>50-100 trees/ha	441	12.12
Forest	>100 trees/ha	1073	29.49
		3638	100.00

PLS vegetation type	No. corners	% corners	Hectares	% hectares
timber	1504	41.49	120976.57	28.95
marsh	412	11.05	83097.42	19.89
prairie	191	5.33	82971.72	19.86
barrens	822	22.94	69909.19	16.73
wet prairie	115	3.01	16299.63	3.90
scattering timber	81	2.26	8005.10	1.92
swamp	175	4.88	7944.07	1.90
marsh wetprairie	41	1.14	6775.33	1.62
sandbank	103	2.87	6641.90	1.59
lake	75	2.09	6621.57	1.58
river	68	1.90	3667.72	0.88
lakes,marshes,swamps	2	0.06	1180.95	0.28
thicket	5	0.14	1071.63	0.26
scattering bushes	5	0.14	902.37	0.22
pond	4	0.11	595.80	0.14
swamp marsh	6	0.17	366.03	0.09
brush	2	0.06	250.75	0.06
sandy barrens	5	0.14	243.86	0.06
sandhills	3	0.08	221.50	0.05
grubs	1	0.03	48.78	0.01
slough	1	0.03	38.03	0.01
unknown	15	0.03	13.96	0.00
swamp prairie	2	0.06	10.06	0.00
	3638	100.00	417853.94	100.00

Table 4. Spearman rank correlation matrix among landscape variables, basal area and tree density. Partitioned by Physiographic region. Lake Plain = Lake Plain natural division, Outwash = Kankakee Marsh, Till Plain = Morainal and Glacial Lakes natural division sections.

Lake Plain	**Basal area**	**Tree density**	**Aspect**	**Slope**	**Elevation**	**Hill shade**	**Topographic Variability**
Basal area	1.0000						
Tree density	-0.0563	1.0000					
Aspect	0.0043	0.0901	1.0000				
Slope	-0.0060	0.1349	0.2948	1.0000			
Elevation	0.2152	0.2011	0.0676	0.1136	1.0000		
Hill shade	0.0526	-0.0114	0.2719	0.1330	0.0756	1.0000	
Topographic variability	-0.1403	-0.0811	-0.0721	-0.0506	0.0898	-0.0961	1.0000

Outwash	**Basal area**	**Tree density**	**Aspect**	**Slope**	**Elevation**	**Hill shade**	**Topographic Variability**
Basal area	1.0000						
Tree density	-0.1097	1.0000					
Aspect	0.0048	-0.0016	1.0000				
Slope	0.0355	-0.0672	0.1466	1.0000			
Elevation	0.0907	-0.0184	-0.0087	0.1788	1.0000		
Hill shade	0.0209	0.0416	0.1666	0.0394	-0.0304	1.0000	
Topographic variability	-0.3225	-0.0200	0.0494	0.0911	0.1308	-0.0125	1.0000

Till Plain	**Basal area**	**Tree density**	**Aspect**	**Slope**	**Elevation**	**Hill shade**	**Topographic variability**
Basal area	1.0000						
Tree density	0.0171	1.0000					
Aspect	-0.0015	-0.0175	1.0000				
Slope	0.0481	0.1890	0.0391	1.0000			
Elevation	0.1243	0.2317	-0.0538	0.1993	1.0000		
Hill shade	0.0002	0.0114	0.3321	0.1068	-0.0288	1.0000	
Topographic variability	-0.1664	0.3262	0.0383	0.1829	0.1606	0.0686	1.0000

Table 5. Relative abundance within natural division and vegetation type of plant species identified as undergrowth by the US Public Land Survey of lake County, Indiana. Species ranked by average abundance.

Vegetation	**Prairie**			**Barrens**		**Scattering Timber**			**Timber**			**Sandbanks**	**Lakes, Marshes, Swamps, Thickets**		
Natural Division	Chicago Lake Plain	Valparaiso Moraine	Kankakee Marsh	Chicago Lake Plain	Valparaiso Moraine	Chicago Lake Plain	Valparaiso Moraine	Kankakee Marsh	Chicago Lake Plain	Valparaiso Moraine	Kankakee Marsh	Chicago Lake Plain	Chicago Lake Plain	Valparaiso Moraine	Kankakee Marsh
Hazel	37.27	20.11			63.08		60.96		9.47	46.33	27.67	21.45		30.65	29.54
Grass	12.58	34.29	100.00												
Willow	25.10				16.29	21.57			5.02	17.29			25.01	1.95	15.64
Whortleberry						28.52			19.51			78.55			
Black alder				100.00									13.92		
Redroot					20.63	28.34			20.78	11.67					
Hickory						21.57	13.46		14.05					30.16	
Oak									22.17		23.15			15.99	
Rosinweed		36.95													
Sumac							11.17				23.15				
Sassafras									2.83	7.42	23.15				
Alder													12.80		17.91
B oak	12.53													14.17	
Bur oak							14.41			11.71					
Swamp alder															25.07
Aspen									2.83				13.92	7.07	
Prickly ash													21.91		
Rose													3.98		11.84
Cranberry	12.52														
Weeds		8.64													
Bushes										5.58					
Bamboo													3.98		
Huckleberry									3.33						
Pawpaw											2.89				
Juniper													2.24		
Cedar													2.24		
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Appendix I. Dominance (relative BA) of bearing trees in the Lake Plain Natural Division in northwest Indiana. Arranged by tree density class and ranked by abundance among classes.

	Tree Density Classification			
Common name	**Open Savanna** >0-10 trees/ha	**Savanna** >10-50 trees/ha	**Woodland** >50-100 trees/ha	**Forest** >100 trees/ha
White oak	0.33	0.35	0.50	0.28
Black oak	0.42	0.31	0.15	0.12
American beech	0.01	0.00	0.11	0.19
Pine	0.05	0.13	0.04	0.06
Elm	0.01	0.06	0.05	0.03
Red oak	0.06	0.01	0.00	0.03
Burr oak	0.06	0.02	0.00	0.00
Maple	0.00	0.04	0.02	0.03
Quaking aspen	0.03	0.01	0.01	0.02
Hickory	0.02	0.01	0.02	0.02
Sugar maple	0.00	0.01	0.02	0.04
Tulip tree	0.00	0.00	0.04	0.03
Black ash	0.00	0.00	0.00	0.03
Basswood	0.00	0.00	0.00	0.02
White ash	0.00	0.01	0.00	0.02
Sycamore	0.00	0.01	0.00	0.02
Black walnut	0.00	0.02	0.00	0.00
Swamp white oak	0.00	0.00	0.02	0.00
Black gum	0.00	0.00	0.01	0.01
Spanish oak	0.00	0.00	0.00	0.01
Blue beech	0.00	0.00	0.00	0.01
Black cherry	0.00	0.00	0.00	0.01
Ash	0.00	0.00	0.00	0.00
Tamarack	0.00	0.00	0.00	0.01
Eastern red cedar	0.00	0.01	0.00	0.00
Birch	0.00	0.00	0.00	0.00
Jack pine	0.00	0.00	0.00	0.00
Butternut	0.00	0.00	0.00	0.00
Pin oak	0.00	0.00	0.00	0.00
Sassafras	0.00	0.00	0.00	0.00
White pine	0.00	0.00	0.00	0.00
Paper birch	0.00	0.00	0.00	0.00
jack oak	0.00	0.00	0.00	0.00
Willow	0.00	0.00	0.00	0.00
American elm	0.00	0.00	0.00	0.00
Alder	0.00	0.00	0.00	0.00
Total	1.00	1.00	1.00	1.00

Appendix II. Dominance (relative BA) of bearing trees in the Western Morainal Section in northwest Indiana. Arranged by tree density class and ranked by abundance among classes.

	Tree Density Classification			
	Open Savanna	**Savanna**	**Woodland**	**Forest**
Common name	>0-10 trees/ha	>10-50 trees/ha	>50-100 trees/ha	>100 trees/ha
White oak	0.31	0.40	0.76	0.42
Black oak	0.31	0.19	0.08	0.21
Burr oak	0.25	0.27	0.09	0.09
Hickory	0.11	0.11	0.07	0.14
Red oak	0.01	0.02	0.00	0.06
Black ash	0.00	0.00	0.00	0.06
Pin oak	0.01	0.00	0.00	0.00
American beech	0.00	0.00	0.00	0.01
Quaking aspen	0.00	0.01	0.00	0.00
Black walnut	0.00	0.00	0.00	0.01
jack oak	0.00	0.00	0.00	0.00
Basswood	0.00	0.00	0.00	0.00
Black cherry	0.00	0.00	0.00	0.00
Blue beech	0.00	0.00	0.00	0.00
Willow	0.00	0.00	0.00	0.00
Total	1.00	1.00	1.00	1.00

Appendix III. Dominance (relative BA) of bearing trees in the Eastern Morainal Section in northwest Indiana. Arranged by tree density class and ranked by abundance among classes.

	Tree Density Classification			
	Open Savanna	**Savanna**	**Woodland**	**Forest**
Common name	>0-10 trees/ha	>10-50 trees/ha	>50-100 trees/ha	>100 trees/ha
White oak	0.44	0.45	0.37	0.19
American beech	0.05	0.11	0.15	0.25
Black oak	0.20	0.14	0.16	0.05
Sugar maple	0.02	0.04	0.12	0.16
Basswood	0.06	0.01	0.02	0.09
Red oak	0.04	0.08	0.06	0.04
Burr oak	0.10	0.05	0.03	0.00
Elm	0.00	0.05	0.04	0.02
Tulip tree	0.04	0.00	0.00	0.03
Oak	0.00	0.03	0.00	0.02
Ash	0.00	0.00	0.03	0.02
Hickory	0.02	0.01	0.01	0.02
Maple	0.00	0.01	0.00	0.01
American elm	0.00	0.00	0.00	0.02
Quaking aspen	0.02	0.00	0.00	0.00
Walnut	0.00	0.00	0.00	0.01
Black walnut	0.00	0.00	0.00	0.01
Black ash	0.00	0.01	0.00	0.01
Blue beech	0.00	0.00	0.01	0.01
Slippery elm	0.00	0.00	0.00	0.01
Butternut	0.00	0.00	0.00	0.01
Black cherry	0.00	0.00	0.00	0.01
Birch	0.00	0.00	0.00	0.00
jack oak	0.01	0.00	0.00	0.00
Spanish oak	0.00	0.00	0.00	0.00
Pine	0.00	0.00	0.00	0.00
Pin oak	0.00	0.00	0.00	0.00
Tamarack	0.00	0.00	0.00	0.00
Total	1.00	1.00	1.00	1.00

Appendix IV. Dominance (relative BA) of bearing trees in the Glacial Lakes Section in northwest Indiana. Arranged by tree density class and ranked by abundance among classes.

	Tree Density Classification			
	Open Savanna	**Savanna**	**Woodland**	**Forest**
Common name	>0-10 trees/ha	>10-50 trees/ha	>50-100 trees/ha	>100 trees/ha
Black oak	0.32	0.38	0.26	0.12
White oak	0.26	0.27	0.19	0.22
Burr oak	0.13	0.14	0.17	0.03
Hickory	0.06	0.09	0.10	0.08
Red oak	0.14	0.08	0.03	0.00
Sugar maple	0.00	0.01	0.06	0.21
American beech	0.00	0.00	0.11	0.09
Black walnut	0.00	0.00	0.00	0.10
Basswood	0.01	0.01	0.00	0.04
Oak	0.00	0.00	0.07	0.01
Black cherry	0.02	0.00	0.00	0.00
Quaking aspen	0.02	0.00	0.00	0.00
Elm	0.00	0.00	0.00	0.03
Ash	0.00	0.00	0.00	0.02
Tamarack	0.01	0.00	0.00	0.00
jack oak	0.01	0.00	0.00	0.00
Pin oak	0.01	0.00	0.00	0.00
Blue beech	0.00	0.00	0.00	0.01
Tulip tree	0.00	0.00	0.00	0.01
Spanish oak	0.00	0.01	0.00	0.00
Butternut	0.00	0.00	0.01	0.00
Black ash	0.00	0.00	0.00	0.00
White ash	0.00	0.00	0.01	0.00
Maple	0.00	0.00	0.00	0.00
Willow	0.00	0.00	0.00	0.00
Total	1.00	1.00	1.00	1.00

Appendix V. Dominance (relative BA) of bearing trees in the Kankakee Marsh Section in northwest Indiana. Arranged by tree density class and ranked by abundance among classes.

	Tree Density Classification			
	Open Savanna	**Savanna**	**Woodland**	**Forest**
Common name	>0-10 trees/ha	>10-50 trees/ha	>50-100 trees/ha	>100 trees/ha
Black oak	0.42	0.34	0.34	0.22
White oak	0.15	0.35	0.33	0.26
Red oak	0.19	0.08	0.03	0.03
Burr oak	0.06	0.07	0.03	0.04
Hickory	0.03	0.03	0.03	0.02
Pin oak	0.04	0.04	0.00	0.01
White ash	0.01	0.01	0.04	0.10
Maple	0.01	0.03	0.01	0.06
Elm	0.01	0.00	0.03	0.09
Birch	0.01	0.02	0.03	0.04
Quaking aspen	0.02	0.01	0.03	0.00
Sycamore	0.01	0.00	0.00	0.07
Ash	0.01	0.01	0.00	0.03
Willow	0.01	0.01	0.01	0.01
Spanish oak	0.00	0.00	0.06	0.00
Black ash	0.00	0.00	0.02	0.01
Black gum	0.01	0.00	0.01	0.00
Oak	0.00	0.01	0.00	0.00
Black cherry	0.00	0.00	0.00	0.00
Tamarack	0.00	0.00	0.00	0.01
Ninebark	0.00	0.00	0.01	0.00
American elm	0.00	0.00	0.00	0.00
blackjack oak	0.00	0.00	0.00	0.00
Eastern cottonwood	0.00	0.00	0.00	0.00
Blue beech	0.00	0.00	0.00	0.00
Sassafras	0.00	0.00	0.00	0.00

Appendix VI. Dominance (relative BA) of bearing trees in Lake Plain Natural Division vegetation types described by the PLS in northwest Indiana. Ranked by abundance among types.

						PLS Vegetation Types						
Common name	**timber**	**barrens**	**swamp**	**Marsh**	**sandbank**	**wet prairie**	**prairie**	**sandy barrens**	**swamp marsh**	**marsh swamp**	**sandhills**	**scatt. Timber**
Black oak	0.1805	0.2558	0.1539	0.4892	0.4601	0.2725	0.3355	0.7092	0.5432		0.2000	0.5792
White oak	0.4255	0.4044	0.0724	0.3088	0.1812	0.1150	0.3263	0.0976	0.3699		0.8000	0.4208
Pine	0.0355	0.0745	0.2315	0.0681	0.2551			0.1614				
Eastern red cedar				0.0037	0.0187					0.6098		
White pine			0.0020		0.0075					0.3902		
Maple	0.0105	0.0048	0.1001	0.0016		0.2671						
Burr oak	0.0213	0.0100		0.0520		0.1217	0.1685					
American beech	0.1116	0.1184	0.0618									
Red oak	0.0259	0.0287	0.0000	0.0260		0.1589						
Quaking aspen	0.0113	0.0107	0.1181	0.0037	0.0337	0.0376						
Hickory	0.0304	0.0046	0.0195				0.0522		0.0869			
Elm	0.0196	0.0208	0.0118				0.1106					
Black ash	0.0145		0.0576									
Tulip tree	0.0266	0.0111			0.0108	0.0230						
Tamarack	0.0002		0.0385	0.0082								
Sycamore		0.0188	0.0239									
Spanish oak	0.0056	0.0041						0.0319				
Sugar maple	0.0346	0.0069										
White ash	0.0102	0.0031	0.0122	0.0123								
Black gum	0.0035		0.0313									
Basswood	0.0087	0.0115			0.0048		0.0069					
Birch			0.0153	0.0138								
Ash	0.0003	0.0060	0.0153									
Black cherry	0.0035		0.0177									
Jack pine	0.0007		0.0153		0.0039							
Pin oak					0.0168							
Paper birch				0.0118								
Swamp white oak	0.0098											
jack oak					0.0075							
Blue beech	0.0040	0.0025										
Willow	0.0000	0.0008	0.0020	0.0009								
Butternut	0.0021	0.0008										
Sassafras	0.0022											
American elm		0.0015										
Black walnut	0.0013											
Alder		0.0003										
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Appendix VII. Dominance (relative BA) of bearing trees in Morainal Natural Division vegetation types described by the PLS in northwest Indiana. Ranked by abundance among types. Data rounded to three digits.

	PLS Vegetation Types										
Common name	**timber**	**barrens**	**prairie**	**marsh**	**lake**	**wet prairie**	**scattering timber**	**swamp**	**scattering bushes**	**marsh wet prairie**	**brush**
White oak	0.275	0.448	0.171	0.149	0.581	0.510	0.212	0.056		0.000	1.000
Black oak	0.053	0.236	0.309	0.559	0.227	0.216	0.551		0.971	0.137	
Burr oak	0.051	0.123	0.288	0.207		0.211	0.094			0.683	
American beech	0.204	0.024			0.057			0.322			
Hickory	0.033	0.059	0.051	0.039	0.011	0.028	0.124		0.029		
Red oak	0.054	0.028	0.000	0.036	0.041			0.143			
Basswood	0.067	0.012								0.179	
Birch								0.223			
Quaking aspen	0.004	0.003	0.031	0.008				0.161			
Elm	0.029		0.099			0.033		0.045			
Sugar maple	0.117	0.029			0.018						
Maple	0.006	0.002			0.054			0.020			
Pin oak	0.001		0.036				0.019				
Oak	0.021		0.011								
Tulip tree	0.029										
Ash	0.014	0.008									
Pine								0.020			
Blue beech	0.005	0.001			0.010						
Black walnut		0.012									
American elm	0.004	0.008									
Black ash	0.008	0.004									
Tamarack								0.009			
Walnut	0.008										
Black cherry	0.003		0.004								
Butternut	0.006										
Slippery elm	0.006										
jack oak		0.004									
Willow				0.002		0.002					
Spanish oak	0.001										

Appendix VIII. Dominance (relative BA) of bearing trees in Kankakee Marsh Natural Division vegetation types described by the PLS in northwest Indiana. Ranked by abundance among types. Data rounded to three digits.

	PLS Vegetation Types										
Common name	**timber**	**marsh**	**swamp**	**prairie**	**scattering timber**	**barrens**	**wet prairie**	**Marsh wet prairie**	**thicket**	**grubs**	**brush**
Black oak	0.428	0.426	0.009	0.406	0.238	0.234	0.578	0.244	0.417		
White oak	0.355	0.181	0.048		0.271	0.491	0.146	0.353		1.000	
White ash	0.001	0.007	0.295					0.086			1.000
Red oak	0.084	0.181		0.131	0.340		0.076	0.221			
Burr oak	0.047	0.036		0.223	0.152	0.166	0.076				
Quaking aspen	0.001	0.037		0.009			0.037		0.371		
Hickory	0.036	0.017		0.161		0.036					
Elm	0.001	0.008	0.229								
Black cherry									0.186		
Willow	0.002	0.014	0.027	0.011			0.035	0.062	0.026		
Maple	0.011	0.008	0.153								
Pin oak	0.017	0.042	0.065				0.037				
Birch		0.008	0.055	0.020			0.007	0.034			
Spanish oak	0.001	0.008	0.072								
Oak				0.010		0.053					
Ash	0.010	0.011		0.029							
Black ash	0.003	0.009	0.029								
Black gum		0.001				0.021					
Tamarack			0.012								
Blue beech							0.007				
Eastern cottonwood			0.006								
Sycamore		0.004									
American elm		0.003									
blackjack oak	0.002										
Ninebark	0.001										
Sassafras	0.001										
Total	1	1	1	1	1	1	1	1	1	1	1

Appendix IX. Dominance (relative BA) of bearing trees in Glacial Lakes Natural Division vegetation types described by the PLS in northwest Indiana. Ranked by abundance among types. Data rounded to three digits.

Common name	PLS Vegetation Types										
	timber	barrens	marsh	prairie	lake	wet prairie	marsh wet prairie	scattering timber	Swamp Prairie	swamp	slough
Black oak	0.243	0.307	0.412	0.234	0.096	0.299	0.489	0.116			1.000
White oak	0.251	0.163	0.299	0.199	0.404	0.447	0.017	0.226	0.999		
Burr oak	0.051	0.309	0.005	0.295	0.033	0.069	0.019	0.082			
Hickory	0.064	0.166	0.050	0.078		0.036	0.014	0.063			
Red oak	0.035	0.012	0.183	0.067	0.081	0.131	0.294	0.513			
Sugar maple	0.135										
American beech	0.077	0.005									
Black walnut	0.055			0.005							
Basswood	0.024			0.041	0.081						
Oak	0.006	0.002		0.023	0.264						
Black cherry	0.011			0.059							
Quaking aspen	0.010		0.017				0.070				
Elm	0.013	0.006			0.013						
Ash	0.014				0.007						
Tamarack		0.003	0.029			0.017				0.752	
jack oak							0.093				
Pin oak		0.012	0.005								
Blue beech	0.003	0.005									
Tulip tree	0.003				0.020						
Spanish oak		0.009									
Butternut	0.002										
Black ash	0.001										
White ash	0.001										
Maple										0.248	
Willow							0.004				
Total	1	1	1	1	1	1	1	1	1	1	1