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FOREST VEGETATION IN THE NATIONAL PARKS
AND U.S. GREAT LAKES REGION: 1800-1900
AND DISRUPTANCE

ECOLOGICAL FACTORS CONTROLLING NINETEENTH-CENTURY
FOREST VEGETATION IN THE GREAT LAKES BASIN REGION
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ABSTRACT

The Great Lakes basin is a major ecotone. Plant distribution is determined by climate while local variation is due to edaphic factors. Actual species occurrence is a function of site factors such as microclimate, plant dispersal, chance, symbionts, and competition. The objective of this study is to quantify the extent of major forest species during presettlement time (before 1850), and to identify the major ecological factors responsible for their distribution. Methods which have traditionally been employed to assess this question include General Land Office surveys, lake/bog sediment analyses, intensive quantification of living and dead plant matter, historical records, and combinations of these methods. The use of General Land Office survey data to quantitatively assess historical vegetation patterns has been minimal, but if combined with climate and soils data it could yield potentially valuable regional results. Definitive results from paleoecological study remain limited by the relatively low number of sites assessed and what can be interpreted from the results. The study of mechanisms operating over time at the local level has been minimal. Such study, especially if integrated with climate and soils data, probably has the most potential in explaining present and past plant occurrences in national parks. Several

additional potentially valuable study proposals are outlined.

INTRODUCTION

The Great Lakes basin is a major ecotone. The primary factors responsible are relatively recent glaciation, the considerable variation in soil development following deglaciation, biotic invasion and range expansion, climate (especially as modified by the Great Lakes), and possibly geological substrate. In general, plant distributions are determined primarily by climate whereas local variations are likely due to edaphic conditions (Spurr and Barnes 1980). In this region many plant species occur at or near the edge of their range. Under such circumstances limiting factors can vary widely from site to site (Steenburgh and Lowe 1976). Actual site occurrence of the species will be determined by microclimate, edaphic conditions, site disturbances such as fires or windthrows, plant migration patterns, occurrence of symbionts, and competition (Denton and Barnes 1987b).

There are strong meteorologic gradients within the region some of which are correlated to vegetation distribution (Denton and Barnes 1987b). Precipitation amounts and deposition of ionic species are closely related to latitude and longitude. Length of the growing season is a major factor determining the northern extension of species found only in the southern portion of the region, while multiple climatic factors are correlated with the distribution of northern species. Regionwide gradients in

surface water chemistry occur which reflect primarily soil and bedrock character (Gorham et al. 1983)^{OK} but which may be now modified by the gradient of atmospheric inputs.

The occurrence of fire has been a topic of considerable interest in the region, but now can be put into a wider context. Major anthropic-induced holocausts of the late 19th century, associated with logging, drew attention to this ecological factor. But the range and general occurrence of species generally associated only with fire probably are the result of climate variation (Wright 1986), while the species' actual site occurrence may be due to a history of disturbance, soil conditions, migration patterns, and chance, such as location relative to a large lake (Heinselman 1973, Swain 1980).

This study is being undertaken to 1) estimate species composition (pattern) of presettlement forests (before 1850); 2) estimate their successional status, and the frequency and type of episodic events; and 3) to provide park managers within the Great Lakes basin a context within which strategic decisions can be made on activities that affect perpetuation or re-establishment of natural vegetation communities. In particular, it is our objective to show the likely links among ecological factors in determining the spatial vegetation patterns, and also to introduce into the equation the potential for chance and episodic events to be major factors. These factors are very rarely considered in park management because of their

purpose

regarding

it is necessary that management and policy makers appreciate the fact that the resources we see today are the products of a long-term imposition and accommodation of episodic events as modified by concurrent multi-factor interaction. Together these will determine future vegetation composition and pattern in the Great Lake basin national parks.

Our working hypotheses are:

- 1.) Species distribution is determined by climate.
- 2.) Species occurrence is a function of edaphic factors, microclimate, fire, symbionts, chance, and competition.
- 3.) The establishment of white pine (Pinus strobus), red pine (Pinus resinosa) and jack pine (Pinus banksiana) in the northern half of this region is fire-dependent.
- 4.) In the southern and central portions of our study area, the widespread occurrence of white pine and hemlock during the 15th and 16th centuries resulted from climatic change (cooling).
- 5.) In the northern portion of the range of red and white pine, the absence of fire leads to a spruce-fir forest.

6.) Occurrence of spruce (Picea glauca and mariana)

and fir (Abies balsamea) is ~~not~~ determined by the lack of recent fire, ^{disturbance} but is based upon a combination of factors, ^{and additional} particularly seed source availability and herbivory.

7.) In the southern portion of the study area, the establishment of yellow birch (Betula alleghaniensis), paper birch (Betula papyrifera) and trembling aspen (Populus tremuloides) is primarily determined by fire, especially on drier sites.

8.) In the northern portion of the study area, the establishment of birch and aspen is primarily determined by an array of factors that lead to patch dynamics in spruce-fir forests.

9.) Occurrence of sugar maple (Acer saccharum), ^{much of} the dominant species throughout the region, is primarily a function of change in climate. Its range and density (frequency) has been increasing for three centuries.

DESCRIPTION OF THE ENVIRONMENT

Geology

Intrusives dominate the geological substrate of the region. In northern Minnesota and north-central Wisconsin the substrate is very resistant Precambrian metamorphosed and igneous rock. In Minnesota's Arrowhead region, northern Wisconsin, and Isle Royale, the substrate is made up of younger (middle) Precambrian intrusives. To the east and south the substrate is considerably younger. In the northern Upper Peninsula of Michigan and in southern Wisconsin, the bedrock is lower Paleozoic (Ordovician and Cambrian). Underlying the Lake Michigan basin, northwest Indiana, and Ohio is middle Paleozoic (Devonian and Silurian) bedrock, while lower Michigan is underlain by still younger upper Paleozoic (Permian, Pennsylvanian, and Mississippian) substrates. The non-Precambrian materials, in general, are much less resistant to erosion.

Glaciation

Except for central Wisconsin, the entire region was subjected to Pleistocene glaciation. At the same time and afterwards, there was considerable change in the level and extent of what are now the Great Lakes. Central portions of Wisconsin were influenced by the earlier Kansan and Nebraskan glacial periods.

Climate

Mean annual precipitation is 60 cm in the western and north-central portions of the region, and 81 to 102 cm near the south shore of Lake Superior and in southern Michigan and northern Indiana and Ohio. Snowfall in western Minnesota averages about 80 cm/yr, over 400 cm along the south shore of Lake Superior, 150 cm along the eastern shore of Lake Michigan, and about 50 cm/year in southern portions of the region.

Mean minimum January temperatures range from -18°C in northwest Minnesota to -5°C in southern Michigan, and maximum July temperatures range from 21°C near Lake Superior to 26°C in southern Michigan.

Soils

Glacial advances and retreats, and the occurrence of glacial outwash, moraines, and till were and still are major factors in determining edaphic conditions throughout the region. For example, the physical and especially chemical characteristics of soil rarely reflect the character of the local bedrock because the soils were brought in by glacial advances. In many portions of upper Minnesota and its Arrowhead region, soils are thin and scattered and the bedrock is low in carbonates and very resistant to erosion. But the soils are often alkaline. This is due to carbonate materials picked up by the glaciers as they advanced over surface limestone and dolomite immediately south of James

Bay. Conversely, in northern Wisconsin and especially the eastern portions of Michigan's Upper Peninsula, the soils are poorly buffered, nutrient-poor, deep glacial outwash covering carbonate-containing lower Paleozoic sedimentary bedrock.

Throughout northern Minnesota, Wisconsin, and Michigan's western Upper Peninsula the soils are cool, moist Boralfs with mean annual soil temperature $< 7^{\circ}$ C. South of here and including the central portion of Michigan's Lower Peninsula the soils are warmer Orthods. In central Wisconsin, southern Michigan, northern Indiana, and Ohio, the soils are all warmer but still moist Udulfs characteristic of warm humid climates.

Vegetation

Before significant human manipulation ^{started} during the second half of the 19th century, regional vegetation was apparently patchy, probably because of the influence of glaciation on soil quality and local topography, ^{and frequent disturbance by fire.} In northern Minnesota, the pine forests (Pinus) were mixed with spruce-fir (Picea-Abies) and their hardwood associates (Populus-Betula). In major portions of northern Wisconsin and in most of Michigan's Upper Peninsula, the pine forest was mixed with northern hardwoods (Acer-Betula, some Abies-Tsuga) which extended well into Michigan's Lower Peninsula. At the "tension zone" in lower central Michigan, southern forest species (Quercus-Carya) began to prevail, mixed with beech-

maple (Fagus-Acer). In southern Michigan and northern Indiana and Ohio, Fagus-Acer became mixed with elm and ash (Ulmus-Fraxinus).

Wildlife

It might be appropriate to describe the region's wildlife as influenced by vegetation patterns, especially since herbivory by insects, birds, small mammals, beaver, ungulates and bears influences that pattern and significantly contributes to vegetation dispersal.

Pre-European ~~Man~~ influences

Describe role of prehistoric & historic cultures in shaping vegetation pattern, especially by the use of fire for a variety of purposes.

METHODS *- refer to Appendix 2*

A review of the literature reveals numerous studies designed to determine presettlement vegetation (that is, the vegetation present before major influence by European settlers). Some of the studies have focused principally on characterizing the presettlement vegetation of an area. Others have focused not only on pattern but on process as well, relating environmental factors (such as climate or soil type) and disturbance regimes to presettlement conditions. These studies take a variety of approaches, many of which have been reviewed by Noss (1985).

This section describes and assesses the methods used by various investigators in the Great Lakes region. The findings of these studies are detailed in the "Results" section. Studies that took place entirely within a park unit, as well as others that provide relevant information, are included. Studies will be described on the basis of methodology in the following order:

1. General Land Office surveys
2. Sediment analysis
3. Live and dead plant matter
4. Historical records
5. Integrated approaches

General Land Office Surveys

A significant number of presettlement vegetation reconstructions have relied in part on the General Land Office (GLO) surveys. The rectangular system of surveying public lands based on running township (tier and range lines) was authorized by Congress in 1785. The Great Lakes region was surveyed by the GLO from the early 1800's to the 1850's. As the system was used, changes and refinements were made, none of which greatly modified the basic surveying procedure (Stewart 1935).^{TP} Instructions for surveys in different areas of the country were periodically published. The first standardized manual of instructions for use by all surveyors was not published until 1855. These instructions specified "objects and data required to be noted," including the type and diameter of all bearing or witness trees, those closest to section and quarter-section corners. Bearing trees were also noted at meander corners where streams or other bodies of water intersected the line. In the absence of trees at these corners, posts were set. Trees on lines between corners were noted in the order of abundance. Points where the lines were intersected by windfalls, prairies, marshes, swamps, rivers, or lakes were also noted. Additionally, soil type and topographic and geologic features were recorded. Though not required to do so, surveyors usually also noted the occurrence of burnt-over land. The instructions stated that these notes "must

always be written down on the spot, leaving nothing to be supplied by memory" (White 1984).

When completed according to the instructions, the GLO surveys provide a wealth of quantitative and qualitative information regarding conditions at the time of these early surveys. However, limitations in the form of fraud, surveyor bias, inadvertent errors, and variable quality of recorded data should be recognized. In their reviews of the public land surveys, Stewart (1935) cites several cases of fraud, while Bourdo (1956) attempts to statistically analyze for surveyor bias. According to Grimm (1984), however, statistical testing of surveyor bias in the choice of bearing or witness trees is invalid since the assumption that trees were randomly arranged is unrealistic. Grimm further states that to facilitate their relocation, surveyors were inevitably biased for or against certain sizes and species of trees. In spite of these limitations, however, the General Land Office surveys provide valuable information on the condition of presettlement forests of the Great Lakes (Curtis 1959).

Meyer (1950) used original survey records of 1829 to 1834 to construct a map of dominant vegetation types of the Lake Michigan shoreline in northwestern Indiana and northeastern Illinois. Meyer's map encompassed 41 townships. The types and sizes of trees were transcribed from surveyor's notes to a base map along every third north-south section line and along "most" of the east-west

township lines. Common names of tree species and topographic features of each vegetation type were given. Maps generated by this straightforward method can vary greatly in detail and extent.

The presettlement vegetation of a smaller area in northwest Indiana was reconstructed by Bacone et al. (1979) using the original survey records. The investigators did not describe their use of the records in detail, only noting that "information was transferred to a base map of the region." Relative frequency, relative density, relative dominance, and importance values were determined for species in some areas, though these values were not presented. Additional information from early floristic studies of the area and current soil and topography maps were also used. Both a general community type map of the local Lake Michigan watershed and a more detailed map delineating presettlement vegetation of a small portion of Indiana Dunes National Lakeshore were created. A contemporary map illustrating remaining natural lands was also prepared. Major disturbances, the most profound of which were anthropogenic, were discussed.

Also within the region, Potzger and Keller (1952) used the land survey records to determine presettlement distribution of beech (Fagus grandifolia). They prepared a map-graph of percentages of beech based on the total number of stems listed as witness trees in 21 counties.

Rohr and Potzger (1950) relied on witness tree and post data to delineate forest and prairie distribution in the area. They recorded numbers of stems by species or genera within townships of three counties.

Continuing around the tip of Lake Michigan, Brewer et al. (1984) prepared a 1:250,000-scale color map of 10 counties in southwestern Michigan. Witness tree data and information from descriptions of the original surveys (1825-1832) were transferred to 7.5- and 15-minute U.S. Geological Survey topographic maps. Approximately 55,000 individual trees were recorded in this way. Vegetation boundaries were delineated by comparing trees in the same vicinity.

Donnelly and Murphy (1987) compared survey records from 1825 to 1832 with data from Warren Woods, a remnant beech-maple stand, within the area mapped by Brewer et al. (1984). Diameter at breast height was recorded for stems > 2.5 cm within 25-100 m² plots. From these data and from the GLO data, relative density, relative dominance (in terms of basal area), relative frequency, importance values, and importance percentages were calculated for each species.

Frederick et al. (1977) used original records to draft a vegetation map of Pictured Rocks National Lakeshore. These data were compared with vegetation cover at the time of the study, which was determined by ground reconnaissance, aerial photographs, and timber maps. The authors stated that importance values were computed for all species recorded by the surveyors, although these are not presented

in the article. All comparisons of vegetation are descriptive.

Janke et al. (1978) sampled the boreal forest of Isle Royale National Park. Data were randomly collected along alternate section lines below 244 m elevation using the random pairs method of forest sampling (Cottam and Curtis 1956). Tree counts, relative densities, and diameters at breast height were compared with the surveys of 1847-1848. This method allowed for quantitative comparisons of presettlement and current vegetation over a fairly large area.

Also working on Isle Royale, McKaig (1978) compared original survey data with three vegetation surveys conducted between 1973 and 1976 using basically the same measurements noted for Janke et al. ⁽¹⁹⁷⁸⁾ Comparisons were made within the boreal forest and also within the sugar maple-yellow birch association. McKaig prepared two maps of the entire island at a scale of 1:63,360 -- a presettlement vegetation map (using the GLO surveys) and a contemporary vegetation map (using 1956 aerial photographs and data from ground sampling).

Whitney (1986) reconstructed the composition and disturbance history of the pine forest of two counties in northern lower Michigan using records of 1836-1839 and 1849-1859. The study site encompassed 32 townships, an area of approximately 278,000 ha. Bearing tree data were transcribed for section and quarter-section points. For

each of these points, a coding system for various site factors (geology, soil, topography) was derived from early soil surveys and current topographic maps. Species-site factor relationships were determined using standard contingency table analysis procedures. Section line descriptions, noting species abundances and disturbance events, were used to determine forest types and incidence of disturbances.

Stearns (1949) made comparisons between surveyors' notes from Forest County, Wisconsin taken in 1857-1859 to quadrat studies made within the area in 1946. Thirty-five quadrats, 100 m^2 were established by use of a grid system within two sections containing undisturbed hardwood-conifer stands. Comparisons of density and size classes of the major tree species were made. Because of the limited existence of undisturbed remnant forest stands, direct comparisons with surveyors' notes are obviously limited.

Utilizing the original land survey records of 1847-1850, Grimm (1984) reconstructed vegetation of the Big Woods and adjacent areas along the prairie-woodland border in south-central Minnesota. A second objective of the study was to examine environmental factors that controlled vegetation distribution, including fire, soils, and climate. Bearing trees were plotted on 1:250,000-scale maps which were overlaid with maps of water bodies and physiography. Associations between the bearing trees and soils were statistically analyzed. A non-metric analysis of

associations between bearing trees was also made. Isotherms indicating mean annual temperature (from 1931-1960) and isohyets indicating mean annual precipitation (from 1941-1970) were drawn on a map of the study region. A large area, encompassing all or parts of 193 townships and totalling 16,900 km², was covered.

Sediment Analysis

The analysis of bottom sediments from lakes and ponds and of peat from bogs is another tool widely used for reconstructing vegetation history. This technique involves the collection of cores which can be analyzed for types and amounts of pollen, and also for plant fragments and charcoal. These particles, deposited within a water body or within peat, settle in layers. Segments of the core can be radiocarbon-dated to obtain estimates of the rate of sedimentation. Layers then provide a time scale of vegetation changes. Pollen and plant fragments, such as fossil leaves or seeds, provide information on vegetation composition. (Some pollen can be identified to the species level, some only to the genus or family level.) Fire frequencies can be determined from varying amounts of charcoal in the layers. Results are usually presented as diagrams which show changes in abundances of pollen or charcoal with depth in the deposit. These stratigraphies have been extensively used for reconstructing paleoenvironments as well as those of the more recent past,

including changes in vegetation since European settlement. Spatial scales range from entire continents to individual vegetation plots.

Biases inherent in the analysis of pollen data are widely recognized. These include, primarily, interspecific differences in pollen production and dispersal rates (Noss 1985). The use of correction coefficients to account for differences in production, dispersal, deterioration, and sampling of various pollen types can reduce these biases (Davis 1963; Webb et al. 1978).

Caution should be used when interpreting results based on pollen percentages within layers. These percentages reflect relative frequencies and are based upon the relative abundance of all pollen in a sample. A change in percentage of one taxon may actually be the result of an increase or decrease of pollen contributed by other taxa. A more accurate assessment of vegetation composition can be gained by determining absolute pollen frequencies, such as pollen influx (numbers of grains from a certain taxon accumulated on a given area during a given time period, usually expressed as cm^2/yr) (Davis 1981).

Sediment analysis has been used by many investigators in the Great Lakes region (particularly in the northern area) for reconstructions of varying spatial and temporal scales. Of primary interest here are those studies focusing on presettlement vegetation and disturbance histories. The techniques and presentations of results of investigators

analyzing sediments are all basically similar (in contrast to the varied uses of the GLO surveys).

Swain (1973) described a history of vegetation and fire in northeastern Minnesota. He analyzed pollen and charcoal from sediments of Lake of the Clouds within the Boundary Waters Canoe Area (BWCA) ^{Wilderness}. The age of layers was established by analyzing varves (annual deposits which are distinguishable because each consists of a light and dark layer). Swain also determined the ratio of conifers to sprouters and the ratio of charcoal to pollen. These are more sensitive indicators of species change than pollen influx values alone. Results for the last 1000 years were presented, along with a general comparison of presettlement with contemporary vegetation.

In another BWCA study, Swain (1980) analyzed pollen and charcoal from sediments of Hug Lake and made comparisons with his findings from Lake of the Clouds. The local environments of these two lakes differ. Hug Lake is surrounded by gradual sloping shores in an area dominated by deciduous trees, a relatively uncommon occurrence in the BWCA. Lake of the Clouds is located in a more rugged topography, with large lakes and a forest dominated by conifers. Swain hypothesized that because of these differences in local landscape patterns, the effects of fires at the sites were different, accounting for the difference in the forest types. He compared pollen and

charcoal concentrations, charcoal-to-pollen ratios and conifer-to-sprouter ratios between the sites.

Futyma (1985) examined pollen and charcoal stratigraphies from three sites within Indiana Dunes National Lakeshore; Pinhook Bog (a Sphagnum bog), Cowles Bog (a wetland complex consisting of conifer and hardwood swamps and a fen), and Miller Woods (an area of dunes and ridges covered by oak).

An early pollen analysis was conducted at Isle Royale National Park by Potzger (1954). Nine bogs at varying elevations were core-sampled. All of the bogs were submerged during the Algonquin high-water stage of Lake Superior. Some were still submerged during the following Nipissing stage. Pollen percentages at varying depths were presented for 15 genera.

Also on Isle Royale, in an attempt to document the occurrence of fire before the 1847 ^{shovel core & pollen} GLO survey, charcoal influxes in cores from eight lakes and three bogs were analyzed by Raymond (1975).

Live and Dead Plant Matter

This method typically involves collecting data from small undisturbed or least-disturbed sites. For example, Henry and Swan (1974) reconstructed the forest history of a 0.04-ha plot by examining living trees, along with unburied and buried dead plant fragments. This method of intensively examining live and dead plant matter can provide detailed,

site-specific data. However, it does ~~not~~^{not} provide regional information since data can^{not} be easily extrapolated.

A pertinent example of the use of live and dead plant matter is Cooper's (1913) classic study of the boreal forest of Isle Royale, conducted during the summers of 1909 and 1910. His interest in studying a climax community led him to locate quadrats on Smithwick Island (a small offshore island) which appeared to have been the "least disturbed by accidental conditions such as fire." Cooper seemed to have been interested not only in avoiding an area affected by human-caused fires but sought to exclude fire of any origin from his study plots. To compensate for exposure to strong lake winds on Smithwick, quadrats on the main island, which were sheltered from wind, were also sampled.

The position, type, and diameter of every tree within 10 m² quadrats was noted. Using an ax, large trees were cut to the center and smaller ones felled. Age was determined by counting annual rings; periods of growth suppression based on ring width were also noted. Results were presented in a diagram showing species, distribution, and approximate age. Descriptions of the prominent tree species, along with a graphic representation of species by percentage (according to size and age) within the climax forest were presented.

Cooper had the advantage of working in an environment relatively undisturbed by humans. This afforded a better view of natural disturbances and their effects on forest vegetation. The same advantage still exists on Isle Royale.

Obviously, the destructive methods Cooper employed would not be allowed in natural areas today. Interestingly, he felt the need to justify his methods by equating the effect of chopping down trees with windfalls and emphasizing the possibility of the growth of "a new crop" of trees within the cleared areas.

Historical Records

Historical accounts, such as those of early travelers and explorers, provide another source of information on presettlement conditions. One of the first such studies, Bromley's (1935) reconstruction of southern New England forests, used historical writings as a major source. However, the credibility of early accounts should first be established. Forman and Russell (1983) stated that early written accounts are too often believed to be factual simply because information is scarce and the statement is old. Forman and Russell presented a standard technique used by historians for evaluating the validity of historical statements: was the observation first- or second-hand? Did a bias color the statement? In what context was the statement made? Did the author have the necessary knowledge about the subject?

Once the reliability of an account of early vegetation has been established, the purely descriptive nature of most accounts precludes detailed comparisons with current conditions. However, qualitative descriptions can provide

useful information on prevailing conditions at the time, or can be used to corroborate data from other sources.

Integrated Approaches

Thorough studies of presettlement conditions should involve an integrated approach, using information from more than one source. Because of the limits of any one method, Noss (1985) thought that the best approach was an eclectic one, consulting as many sources as possible and integrating both quantitative and qualitative information. Several studies already described used integrated approaches.

Heinselman (1973) also employed an integrated approach in studies of the fire history of the BWCA conducted from 1966-1972. He used ^{ground level data} GLO surveys, historical sources, tree ring counts from fire-scarred trees, aerial photos, and forest type maps to prepare stand origin maps covering 1,300,000 acres. He also drew "fire year maps" delineating areas covered by significant fires from 1610-1972. The extent of fires before 1700 was conservatively estimated because most evidence of earlier fires was obliterated by succeeding fires.

Additional information concerning forests and environmental factors (both past and present) which may be useful as part of an integrated approach can be gained from the Continuous Forest Inventory (CFI) and also from climatological data. CFI surveys, conducted by the U. S. Forest Service, were begun in 1928 to maintain current

inventories of the country's timber supply. Since that time, two or four inventories have been conducted in each of the Great Lakes States. These surveys provide data on forest area, growth, mortality, and other forest industry statistics.

One source of climate data, The Monthly Weather Review, has been published since 1872. It contains climatological tables and maps of temperature and precipitation data from various weather stations throughout the region.

Denton and Barnes (1987b) combined climatological statistics and Continuous Forest Inventory data to determine the spatial relationships of climate and tree species distribution throughout Michigan. Twelve climatic variables were computed for the entire state using 30 years (1951-1980) of data obtained from 125 National Weather Service stations (Denton and Barnes 1987a). Relationships between individual species and climate data were determined using appropriate statistics. Distribution maps and corresponding climate-variable histograms were presented for ten species.

RESULTS

General Land Office Surveys

Meyer (1950) mapped and described six vegetation types as they appeared in 1830 along the southern shoreline of Lake Michigan. These included three forest types (broadleaved forests, mixed broadleaved-coniferous forests, and swamps), and three grassland types (prairies, wet prairies, and marshes). The work is strictly descriptive; no attempt to quantify information from the surveyors's notes was made. If any types of disturbances were noted by the surveyors, Meyer did not mention them. His only acknowledgment of disturbance was to state that prairie fires had "often been held responsible for the total absence or the limited occurrence of forests in the humid prairie country."

Eight general community types representing the presettlement condition of three Indiana counties within the area mapped by Meyer were delineated by Bacone et al. (1979) principally from GLO records. These types were: 1) dune complex, 2) savanna, 3) forest, 4) wet prairie, 5) marsh, 6) swamp, 7) open water, and 8) prairie. These were further divided into 22 more specific community types, including descriptions of physiographic features and fairly extensive lists of dominant species (from both GLO records and contemporary vegetation surveys).

The investigators thought that at least five major factors had a role in the formation and maintenance of this presettlement scenario:

- 1) the geographic position of northwestern Indiana at the southern tip of Lake Michigan;
- 2) the effects of regular, probably annual, fires;
- 3) the predominantly sandy substrates composing all of the area north of the Valparaiso moraine;
- 4) the physiographic position of northwestern Indiana and southern Lake Michigan within the eastern prairie province;
- 5) the level of the local water table and the degree to which it fluctuates.

Bacone et al. ⁽¹⁹⁷⁹⁾ considered fire the principal force in maintaining the community structure of savannas, prairies, and marshes. However, no fire frequencies (as derived from surveyors's records) were reported. The investigators stated that "fires, moving eastward under the influence of the prevailing westerlies, were very influential in maintaining these communities, especially in the western portion of the watershed. Fires had diminishing influence as they moved east, in part because of the moisture-laden winds coming off Lake Michigan."

As a result of agriculture, urbanization, and industrialization, only isolated remnants maintaining presettlement conditions persist ^{in Indiana}. These remaining areas continue to be affected by the suppression of fire and

alteration of water table levels. ↓ According to Bacone et al. (1979), these factors were responsible for maintaining treeless communities; in their absence, an increase in woody species occurs.

The (Bacone) study concluded with the following management recommendations: "In order to responsibly manage or maintain areas which have retained or are capable of reassuming a high degree of presettlement integrity, the probable presettlement nature of each community must be considered, the forces or lack of forces which resulted in its present condition must be analyzed, and the methods by which the presettlement conditions can be maintained or restored must be devised."

Potzger and Keller (1952), studying the presettlement distribution of beech (Fagus grandifolia) at the edge of the prairie peninsula in northwest Indiana, described the progressive westward decrease in abundance of beech, sugar maple, (Acer saccharum) upland ash (Fraxinus americana and F. quadrangulata) and other mesophytes as a striking example of increasingly less favorable habitat conditions for forest development. Species of oak (Quercus) and hickory (Carya) increased in abundance nearing the prairie border, with oaks thriving in the more xeric habitats.

Noting that beech was found along the southeast (windward) shoreline of Lake Michigan but not along the southwest shoreline, they speculated that prevailing winds

crossing the lower tip of the lake created conditions favorable for beech growth.

In another study of this forest-prairie ecotone, Rohr and Potzger (1950), although lacking specific data, attributed the vegetation patterns of the area to climatic or edaphic factors. They mapped three northwestern counties as dry prairie, wet prairie, and oak openings dominated by white oak (Quercus alba), black oak (Q. velutina), and bur oak (Q. macrocarpa). They also noted that white pine (Pinus strobus), jack pine (Pinus banksiana), and northern white cedar (Thuja occidentalis) were limited to a belt about a mile inland from Lake Michigan.

The map prepared by Brewer et al. (1984) presents a continuation of vegetation patterns around the southeastern tip of Lake Michigan. Twenty-two vegetation associations were depicted. These included prairie, "low-density" woodland (bur oak opening and savanna), upland forest (oak, pine, oak-pine, beech-sugar maple, northern coniferous-hardwood), nine swamp or floodplain forests, and five additional wetland classifications. A cursory examination of the map shows the southwestern Michigan shoreline was dominated by upland forest types, while oak forests and scattered prairie occurred inland.

Within the region mapped by Brewer et al., Donnelly and Murphy (1987) compared the composition of Warren Woods, a remnant beech-maple stand, with the presettlement composition of the surrounding area. For both the

presettlement and contemporary data, importance values for beech exceeded those of sugar maple. However, the data indicated that sugar maple was more important relative to beech in Warren Woods compared with the presettlement forest. Relative density and relative frequency values for sugar maple exceeded those of beech in the Warren Woods data. This finding reflected the abundance of sugar maple in the understory.

The authors suggested three possible reasons for the apparent increase in sugar maple: a successional shift may have occurred since the time of settlement, surveyors may not have recorded trees as small as those included in current ecological studies (which would have excluded the smaller understory maples), and surveyors may have preferred marking beech trees because of their smooth bark. Despite possible surveyor bias, the authors concluded that "it is reasonable to assume that beech was more important than sugar maple in the forests of presettlement times."

The map prepared by Frederick et al. (1977), showing presettlement vegetation of Pictured Rocks National Lakeshore, included eleven forest types. These were seven mesic types: 1) sugar maple-beech-yellow birch, 2) sugar maple-beech, 3) hemlock-yellow birch, 4) sugar maple-yellow birch, 5) hemlock-yellow birch-beech, 6) hemlock-yellow birch-sugar maple, and 7) hemlock-beech-sugar maple; two xeric types: 8) white pine-hemlock, and 9) white pine-red pine; and two lowland types: 10) black spruce-tamarack, and

11) cedar. General comparisons were made between the "original" vegetation as determined by the investigators from the GLO surveys and vegetation present at the time of the study. ^{by Frederick et al.} The following statements regarding compositional changes in the forests of Pictured Rocks were made, though not quantitatively substantiated:

- 1) The greatest change in the upland mesic forests has
 - ← been a decrease in average tree size resulting
 - ← from clearcutting and selective cutting.
- 2) A major change is occurring in the wetter mesic
 - ← forest areas with the presumption that red maple
 - ← (Acer rubrum) will become an overstory dominant as
 - ← the larger elm (Ulmus americana) are eliminated
 - ← by Dutch elm disease.
- 3) There has been relatively little compositional
 - ← change in the bottomland cedar type.
- 4) The greatest change in Pictured Rocks forest has
 - ← occurred in the xeric type with reference to
 - ← cutting over of extensive white pine stands on the
 - ← Kingston Plains.

← Regarding disturbance effects, a history of logging in the area is presented with a brief mention of the occurrence of fire in logged stands.

Data collected on Isle Royale in 1978 by Janke et al., when compared with the original survey notes of 1847-1848, showed increases in relative densities of paper birch (Betula papyrifera) and quaking aspen (Populus tremuloides)

with a decrease in balsam fir (Abies balsamea) density, indicating the forest had become less mature. The authors suggested that this change was related mostly to a human-induced regime of numerous fires during the 1800's mining era, and the great fire of 1936, which started in the slash of a logging operation. The role of naturally occurring fires was not discussed. Moose browsing, windthrow, and insect infestation (as a possible cause of tamarack (Larix laricina) reduction) were discussed, although the authors concluded that human-caused fires since 1848 have been the greatest cause of change in this boreal forest.

Results of McKaig's (1978) study on Isle Royale also showed changes in species composition which indicated that the contemporary forest is successional less mature than the forest of 1847. His findings in the boreal forest corroborate those of Janke et al. ⁽¹⁹⁷⁶⁾ Additionally, McKaig noted an increase in area of the sugar maple-yellow birch association. He considered three major factors to have influenced the boreal association: fire, change in the dominant herbivore (from caribou to moose), and insect infestations. McKaig suggested that the sugar maple-yellow birch forest may have expanded as a consequence of fire, moose browsing in the boreal forest, or the recent period of global warming.

McKaig delineated the following forest associations on maps showing presettlement and contemporary vegetation distribution: balsam fir-paper birch-spruce-cedar (two types

of this designation, based on varying abundances of the species), sugar maple-yellow birch-cedar-balsam fir (also, two types of this designation), and swamp forest. Burned areas were also noted.

Using GLO surveys, Whitney (1986) determined that the presettlement forests of Roscommon and Crawford counties in northern Lower Michigan were dominated by pines. Jack pine, white pine, and red pine (Pinus resinosa) composed over 57% of the bearing trees recorded. The occurrence of these pine forests was correlated with coarse-textured soils derived from glacial outwash and ice-contact deposits. (The study area was located between lobes of the Wisconsin Laurentide ice sheet.)

Windfalls occurred on <0.7% of section line transects and were concentrated in the hemlock-white pine-northern hardwoods and swamp conifer forest types. Average return times for windfall events in these two forest types were calculated to be 1220 years and 1316 years, respectively. It was thought that the shallow root system of some swamp conifers and the irregular nature of the old-growth hemlock-white pine-northern hardwoods canopy may have contributed to blowdowns in these two forest types.

Fire occurred over 7.3% of the total area, with the highest incidence in pine forest types. Return times ranged from 83 years in the jack pine type to 1400 years in the hemlock-white pine-northern hardwoods type and 3000 years in the swamps conifer type. Whitney thought that the incidence

of fire was related more to the nature of vegetation rather than to the occurrence of firebreaks because the area was level or only gently rolling. The glacially derived, coarse-textured soils of the area favored the growth of pines which "initiated a fire regime that perpetuated the more flammable pine species." Whitney concluded that the relative importance of substrate (as opposed to disturbance) in the maintenance of this presettlement pine forest could not be ascertained; both factors were inseparably linked.

When original surveyors's notes of 1857-1859 in northeastern Wisconsin were compared with studies conducted in 1946 of undisturbed forest remnants, a decline in yellow birch (Betula alleghaniensis), hemlock (Tsuga canadensis), and white pine densities, along with a considerable increase in sugar maple density, was indicated (Stearns, 1949). Stearns suggested the forest was gradually reaching stability after a catastrophic upset--possibly a period of widespread drought and forest fires postulated to have taken place during the 16th century (Graham 1941). Increased dominance of sugar maple in this aging forest indicated to Stearns this species's ability to successfully reproduce in the understory as well as in openings, while reproduction of yellow birch, hemlock, and white pine was limited under a closed canopy.

Stearns further stated that a mixed forest type in this area was perpetuated by "an island type of replacement" in which yellow birch, hemlock, and white pine were able to

germinate on clearings (primarily wind-produced) surrounded by mature forest. Notations made by early surveyors concerning windfall were numerous, indicating windthrow was not a rare event. He stated that the role of fire ("the more spectacular agent of destruction") in the primary mixed hardwood forest had been overemphasized. Stearns concluded "windfall alone or with the other agents of mortality, fire, drought, glaze storm, insect or fungus infestation and senescence keeps the forest in a constant state of flux which results in a continuous variation in composition, both in space and in time, within the limits of the species present."

From the original survey data, Grimm (1984) determined totals and percentages of bearing trees within the Big Woods of south-central Minnesota and the surrounding area. He found elm to be most common, exceeding the sum percentages of sugar maple and basswood (Tilia americana). This is in contrast to the findings of Daubenmire's (1936) study in which the forest was considered to be dominated by sugar maple and basswood.

No correlation between contemporary climatic data and vegetation distribution was found because diverse vegetation types existed side by side in areas under the same climatic conditions. Changes in vegetation types were not gradual, but had sharp, distinctive boundaries. Grimm concluded that the major factor accounting for the occurrence of multiple stable vegetation types in this area was the fire-

probability pattern. This probability was a function of many abiotic and biotic factors which included macroclimate, physical firebreaks, topography, soil texture, size of physiographic units, flammability of vegetation, pattern of the ~~and much more~~ vegetation that develop either as a result of fire or in its absence." He concluded that the vegetation composition and fire history have been relatively stable for the last 1000 years, with only minor changes that may reflect the "Little Ice Age" of 1550-1850 (a period of cooler, moister climate).

The charcoal record indicated that fire has been a major ecological factor in the forests of this region. Fire frequency for the last 1000 years was conservatively estimated at 70-80 years, resulting in short term (20~~4~~ to ~~30~~30~~4~~ year) changes which had a positive influence on long term stability. The occasional absence of fire for over 100 years was not thought to have had a regional effect.

Swain found no evidence that the vegetation or fire regime had been significantly modified since the arrival of Europeans about 300 years ago. However, he stated that the

suppression of fire could change the forest composition by increasing the abundance of species that do not require fire for reproduction, such as spruce (Picea), northern white cedar, and balsam fir.

From comparisons of pollen and charcoal stratigraphies of Hug Lake and Lake of the Clouds (both within the BWCA), Swain (1980) concluded that the different forest types of the two sites were related to the presence or absence of firebreaks within the landscape--specifically, steep topography and large lakes.

The forest around Hug Lake is predominantly deciduous, an uncommon occurrence for the region. Swain concluded that this forest has been maintained for at least 400 years and is not the result of human-induced fires. He based these conclusions on the relatively constant influxes of major pollen types and the consistently low conifer-to-sprouter ratio since the year 1580.

The fire frequency of the Hug Lake area was determined to be 70 years, similar to that for Lake of the Clouds. Swain therefore concluded that the different forest composition of the sites could not be caused by different fire histories, but is related to landscape patterns: firebreaks are essential for conifer survival in an area where the interval between fires is shorter than the reproductive age of the trees.

Futyma (1985) examined sediment cores from three ecologically distinct sites at Indiana Dunes National

Lakeshore: a bog, a wetland, and a dune woodland dominated by oaks. The length of the pollen records and species represented varied between sites. However, vegetation changes caused by human activities over the past 150 years were evident at all three areas. Pollen percentages of trees in general, particularly of Quercus and Pinus, were found to be lowest in post-settlement times. Futyma also found evidence of several major presettlement fires with concomitant fluctuations in pollen frequencies. However, estimations of fire frequencies were not possible because of the spacing of core samples, and variability in sediment type and sedimentation rate.

From bog corings at Isle Royale National Park, Potzger (1954) established three general patterns of forest composition on the basis of pollen abundances at various depths (sediment layers were not dated). These patterns were: 1) pine replacing spruce-fir at the close of Algonquin time; 2) the increase, dominance, and decrease of pine; and 3) a marked rise of spruce and fir in the upper layers, attributed to climatic cooling.

The results of this study are quite general compared with more recent work, particularly since Potzger lacked dated sediments. Also, the presentation of results as pollen percentages may not precisely represent vegetation composition. (On an unrelated note, Potzger commented "nowhere has the writer seen more windfall damage to forests.")

Charcoal analyses from cores of four lakes on Isle Royale did not yield conclusive results (Raymond 1975). Distinct intervals of high charcoal influxes were apparent over the last 1000 years, although precise frequencies could not be established. The author suggested that decreasing the sample size interval and obtaining more radiocarbon ages would aid in determining fire frequencies.

Live and Dead Matter

Cooper's (1913) study of the climax forest of Isle Royale yielded information not only on the composition of the forests at the turn of the century but also on the occurrence and effects of natural disturbances. He concluded that the dominant forest was composed of balsam fir, paper birch, and white spruce (Picea canadensis). Balsam fir was by far the most abundant, with more small than large individuals. (Balsam fir made up 78.7% of the sample within six climax quadrats, though only 33.3% were 2.5 dm or more in diameter.)

Cooper mentioned white pine as an occasional towering tree scattered throughout the forest and stated "there is no indication that in recent times it has ever been abundant." Black spruce (Picea mariana), tamarack, and quaking aspen were found "here and there" in the climax forest. American yew (Taxus canadensis, referred to as ground hemlock by Cooper) was considered the most important lower plant, even more important than many trees. The effect on the forest

composition which Cooper attributed to Taxus was great: "its influence lies in the completeness with which it occupies and shades the ground, preventing tree reproduction over large areas." In one quadrat, it was described as being "plainly responsible for the lack of young tree growth and the resulting openness of the forest."

Regarding disturbance effects, Cooper thought that fires were far less frequent and destructive on the island as compared with the mainland. He reasoned that "because of its insular position the forest has been less liable to destruction by fire, and the many bays and channels separating various portions of the main island and the outlying islets have served as effective barriers against its spread." However, he also stated that "it is nearly certain that fire has played a part in the vegetational history of almost all if not the entire forested area of the island." He did not differentiate between human or naturally caused fires, acknowledging both. Regarding human-caused fires, his assertions were based on known patterns of use by miners and the assumed patterns of use by Indians on the island.

Smithwick Island was chosen as a sampling site because effects of recent fires were not evident. However, "a layer of carbonaceous material with fragments of charcoal" was found in one place at a depth of one-third of a meter. Although the number of burned areas or extent of fires was

not cited, the "exceedingly rapid" development of the forest after a fire was described.

Cooper concluded that the most prevalent cause of disturbance within the climax forest was wind. The effects of windfall were alluded to in five of the six climax quadrats described. He stated that balsam fir was especially liable to wind damage (because of "fungus attacks and diseases of many kinds") which accounted for the rapid decrease in numbers of this species when great size or age were attained. Paper birch was not considered to be particularly susceptible to damage by wind due to its "elastic branches and extensive though shallow root system." White spruce was also noted as being able to withstand severe winds without breaking. On the main-island sites, Cooper thought that shelter from wind allowed trees to attain greater heights. Openings created by windfalls were recognized as being opportunities for the successful reproduction of balsam fir, paper birch, white spruce, and tamarack.

Cooper's studies led him to believe that "the climax forest is a complex of windfall areas of differing ages. . . . This mosaic or patchwork changes continually in a manner that may almost be called kaleidoscopic when long periods of time are considered. The forest as a whole, however, remains the same, the changes in various parts balancing each other."

Historical Accounts

In his discussion on windfall in a northern hardwood forest, Stearns (1949) cites references to wind disturbance in land surveys and geologic surveys. The report of geologist R. D. Irving (1880) provides a good example of the usefulness of some early accounts to corroborate information from other sources:

The traveling is rendered yet more difficult by the frequent areas of timber, known as 'windfalls.' These are well enough known in all of the Wisconsin forests, but never so well known as to be welcome to the 'packer' through the woods. They are like great swaths having been prostrated by hurricanes, and are often sharply defined from the standing timber around. The trees at times lie all in one direction, but in other cases are wholly without such arrangement, having been prostrated by a tornado. The great windfall of September, 1872, so far as my knowledge goes, is as much as forty miles in length, though it is reported to have a greater length than this. It crosses the Chippewa river in Sec. 23, T. 40 N., R. 5 W., with a width of about one and one half miles. . . . When last traversed in 1877, this windfall had been partly burned over, but was, for the most part, made more impenetrable than ever on account of the new and

dense growth of bushes and small trees. In crossing it in the Penokee Range it was found necessary to cut the way with an axe for nearly a mile and a half.

Russell (1983) conducted a study based entirely on historical accounts to assess the occurrence of Indian-set fires in the northeastern United States. She examined 35 documents (determined to be historically accurate) from the 16th and 17th centuries which described Indians, vegetation, or both from the Carolinas to Maine. Russell concluded that there was no strong evidence that Indians purposely burned large, forested areas and that frequent use of fire was most likely a local occurrence. Their use of fire did, however, increase fire frequency and have some local effect on vegetation.

Although these results do not necessarily pertain to the Great Lakes region, this study provides another good example of the potential usefulness of historical information.

Integrated Approaches

Heinselman (1973) reported the extensive results of several years of research on the fire history of the BWCA. He concluded that "fire was the key rejuvenating factor in the Canoe Area, maintaining a dynamic mosaic of forest age classes and community types, keeping species diversity and production high, and maintaining long-term stability of the

system." Stand origin and fire-year maps indicated that nearly all of the 1,300,000 acres of forest had burned one or more times from 1595 to 1972. However, 83% of the area that burned before suppression programs were instituted burned during just nine major fire years. Examination of climatic data and records of the incidence of major fires from 1840-1910 indicated that the season of year, along with weather patterns before and during a fire, were important in determining its behavior, size, and ecological effect. Historic fire patterns were also linked to landscape features which acted as either natural firebreaks or firepaths.

Denton and Barnes (1987b) examined relationships between contemporary tree species distributions and climatic variables for the state of Michigan. Their integrated approach involved the use of Continuous Forest Inventory and National Weather Service data. Associations with climatic variables were determined for extreme southern species, species found throughout Lower Michigan but not in Upper Michigan, and for extreme northern species. Distributions were generally correlated with more than one climatic variable. For example, both white spruce and balsam fir were found to be associated with low growing season heat sum, short growing season, low annual extreme minimum temperatures, cold winters, cool summers with variable temperatures, cool nights, and high precipitation relative to water demand. The authors point out that the correlation

of species distribution with certain climatic factors cannot indicate causality and can only suggest hypotheses that require verification.

Another example of an integrated approach is Collman, Rakstrom, & Farris. The fire and logging history of Voyageurs NP, NPS contracted study out of Michigan Tech

DISCUSSION

Present vegetation distribution in southern portions of this ecotone is complicated by the fact that much of the land has been long converted to farming and intensive development. Only isolated presettlement remnants remain, and conterminous land use coupled with pronounced local ecotonal influences most likely have significantly altered plant community composition and plant distribution patterns over time. However, from northern portions of Michigan's Lower Peninsula to the western extent of this study area, the region remains mostly forested. But even here, the history of past and present logging, changed fire frequency, manipulated deer populations, and fundamental change in seed sources have had and are having an effect on vegetation distributions.

The pronounced shift in relative dominance of forest species and composition still evident in central Lower Michigan are confirmed by earlier studies adjacent to the southern shore of Lake Michigan and in the northern Indiana studies of the early 20th century. The importance of lacustrine influence and ground water table levels on forest species distribution was noted then as now. Frequent fire on predominantly dry, often sandy sites vegetated by prairie, wet prairie, or savanna appears consistent with recent studies. As earlier stated, climate is the primary factor responsible for demarcating a species' range, while edaphic factors largely determine local occurrences.

In central portions of this ecotone, where vegetation records remain much more intact, the influence of the prevailing winter Canadian polar air mass is quite evident. Lake Superior, ecologically almost an arctic lake, is the only Great Lake to remain open all winter. While this considerably reduces low winter temperature extremes in Michigan's Upper Peninsula, the lake is a thermal sink during summer which allows the high occurrences of white spruce and balsam fir even into Michigan's Northern Lower Peninsula. Lake Michigan's mass is much smaller and it usually freezes over during winter. But along its southeastern coast there is a significant lacustrine effect which lengthens the growing season and permits southern forest species to extend their range northward much beyond their presence in eastern Michigan. Balsam fir has a "mirror image" distribution in Northern Lower Michigan quickly dropping in occurrence especially along the Lake Michigan shore. This is likely due to its need for a high precipitation/evapotranspiration ratio. Swamps, large beaver ponds, and small and large lakes northward from Michigan's Northern Lower Peninsula are usually ringed with balsam fir for the same reason. Around small water bodies it is the high water table that favors this species. Near Lake Superior it is probably the low evapotranspiration potential.

The historical literature and recent studies appear to support the theme of the importance of edaphic conditions in

determining the local occurrence of many species. As to the specific mechanisms operating locally, there is considerable "noise" in the research results, likely because so many species are near or at the limits of their northern, southern, and even western distribution. This ecological "noise" is quite evident when examining the research results for pines. White, red, and jack pine are generally accepted as being "fire-dependent", but the causal mechanism for their local occurrence varies widely. This is especially true for white pine, which has a significantly wider tolerance range for meteorological and some site factors such as shading. Its present high frequency in Michigan's Upper Peninsula and documented historical frequency, at least during the last few centuries, lends well to the fire hypothesis. Its occurrence in southern Michigan, generally along ponds or lakes, reflects its relative high precipitation/evapotranspiration needs while fire's past role is in question.

One factor often overlooked in this region is the probability that ecological change following the relatively recent deglaciation and change in large lake levels may still be occurring at a moderate rate. One of the most pronounced reminders is soil development. There is evidence to suggest that species distribution westward and especially northward is restricted by the interaction of climate and edaphic factors. But change in both of these factors may be responsible for the apparent expansion of species' range

seen today. Historical and current research results strongly suggest that this is the case for beech. Its patchiness along its northern range appears to directly depend upon local soil conditions and Lake Superior mitigating extremely low winter temperatures. Beech and a number of other species are present evidence of the widely varying regional role of climate and the local role of edaphic factors for species near their range limits.

RECOMMENDED FUTURE STUDY

Based upon this assessment of the literature, we feel that a number of selected studies should be seriously considered in the near future. These would be of immediate benefit in filling gaps in the existing literature, and would make a significant contribution in developing management strategy¹⁴ especially for selected parks. This list is not exhaustive, but represents our best current estimate of near-term information needs.

1) Analyze the General Land Office (GLO) survey records for each park unit to reconstruct forest composition and quantitatively assess the occurrence of natural disturbance. Bearing tree data for each area can be transcribed onto data sheets or onto maps of the same scale to provide for visual, qualitative assessments of taxa distributions and associations. Geologic maps (prepared by the U.S. Geologic Survey) and soil maps (prepared by the U.S. Soil Conservation Service) could also be consulted. The degree of association of species and site-factors could be determined using appropriate statistics. The frequency of fire and windthrow could also be determined from surveyors' notes by calculating recurrence intervals of these disturbances. Using the same methodology for analysis of the GLO records will result in presettlement maps and disturbance data of comparable quality and detail for each of the park units.

2) Collect and analyze sediment cores from representative drainages to determine pollen and charcoal influxes, particularly for the past two hundred years. Changes in forest composition can be noted which may reflect the influence of fire, settlement (logging), or a changing climate. Analyzing the charcoal records of several different areas can aid in determining the regional role of fire and also if fires regimes were altered by initial settlement. Fire frequencies for specific park units can be calculated. Cores should be taken from appropriate locations within park units in which reliable stratigraphic analyses have not already been conducted.

3) Determine the spatial relationships between climate and tree distribution throughout the region. The first component of such a study would be the computation and mapping of appropriate climatic variables relevant to plant growth. This data could be obtained from various National Weather Service recording stations. Secondly, tree distributions could be determined from U.S. Forest Service Continuous Forest Inventory data. Mapping at a relatively small scale would be appropriate considering the regional extent. Since CFI data are available from 1928 to the most recent surveys, and certain climatic variables are available since 1872, temporal comparisons of species distributions and climate conditions are also possible, at least for areas of minimal human disturbance. Appropriate statistics could

identify significant associations. This approach would provide a broad regional perspective of tree species distribution as related to climatic conditions of the Great Lakes.

4) Conduct park-specific studies of mechanisms responsible for present and historical vegetation distribution and community structure. All the national park units in the Great Lakes basin are relatively small. Therefore, local conditions affecting the occurrence of a plant species may be very significant. Relating climate to present or recent-past species distributions provides little resolution of the specific factors or mechanisms responsible for local occurrence. Paleoecological cores have the same interpretative limitations, being generally confined to detecting climatic change or local fire. The local importance of soil, microclimate, competition, presence of symbionts, geographic position (as adjacent a large lake) and windthrows can rarely be detected let alone quantified, by these procedures. Selected studies, focused on one or a few parks, could be undertaken to identify those factors acting on such systems at least over the last 200 to 300 hundred years. One factor which could be investigated is windthrow, which our literature survey suggests could be very significant for parks located downwind of and conterminous to the large lakes. This effort would require acquiring significant amounts of basic data on forest dynamics of major species. Once acquired, however, they

could be coupled with existing vegetation data on regeneration, growth, and mortality simulated into the future (past?) through modification and application of models such as JABOWA and FORET.

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