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Relationships Between Soils and Presettlement Forests in Baraga County, Michigan

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ABSTRACT.—Soils data and data on the presettlement forests of Baraga County, taken from the General Land Office (GLO) Survey, were stored and analyzed in a geographic information system (GIS). The purpose of the research was to determine county-wide witness tree distributions and autecological relationships among 14 major tree species and soil wetness and texture, in this geologically and edaphically diverse region of northern Michigan. In all, 12,760 trees were coded by species, location and diameter from the GLO data, which were recorded between 1846 and 1853. Tree data were overlain on soil mapping units which were coded by natural drainage class and particle-size family. All trees located in mapping unit complexes (two or more soil types) or within 25 m of certain soil boundaries were eliminated from further consideration through a selection/buffering procedure leaving 6210 trees of 14 species for use in the analysis. Contingency tables were calculated to assess the strength and direction of the relationships between each tree species and soil texture, soil wetness and texture/wetness combinations.

County-wide distributions of species were strongly related to soil patterns, with a prominent forest ecotone occurring near the boundary between two distinct till provinces. Most upland forests were dominated by sugar maple and yellow birch; prevalent lowland species included balsam fir, black spruce and white cedar. Hemlock was common only near Lake Superior on sandy tills that lacked a silt cap. Especially notable was the association between a nearly pure stand of jack pine and the dry sandy soils of the Baraga (glacial outwash) Plains. Evidence for widespread disturbance by wildfires on the level plains contrasts with the relatively long period of only small gap-scale disturbances that existed on more rolling, mesic and wet sites.

INTRODUCTION

General Land Office (GLO) survey data on individual tree characteristics (location, species, diameter) and forest composition have frequently been used in historical-ecological-geographical studies. Applications have included: (1) estimation of the impact of Native Americans on primeval ecosystems or vice versa (Neuenschwander, 1957; Jones and Kapp, 1972; Dorney, 1981); (2) qualitative and quantitative reconstruction of vegetation patterns and community characteristics at the time of European settlement, which are then often compared to modern analog communities or relict stands (Blewett and Potzger, 1950; Siccama, 1971; Anderson and Anderson, 1975; Delcourt, 1976); (3) estimation of natural disturbance type and frequency in presettlement forests (Canham and Loucks, 1984; Whitney, 1986); and (4) relating presettlement vegetation to edaphic controls (Crankshaw *et al.*, 1965; Catana, 1967; Whitney, 1986; Leitner *et al.*, 1991). Our study focuses on the last three and has a distinct geographic scope.

Most analyses of forest communities based on GLO surveys have incorporated information on the physical environment (*e.g.*, soils, elevation, topography, fire, climate, etc.) in partial explanation of the presettlement vegetation patterns (*e.g.*, Kline and Cottam, 1979). Strahler (1977) refers to the "geographic approach" to plant-site factor relationships as

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one in which species preferences are elucidated by superposition of spatial patterns (of plants) onto maps of environmental parameters. Studies focusing on soils data in their analyses of presettlement vegetation patterns range from the synecological analysis of Howell and Kucera (1956), in which a small scale map of "prairie soils" was superimposed upon a map of presettlement prairie communities [*see also* Kilburn (1959)], to the rigorous quantitative analyses of relationships between soil characteristics and species autecology presented by Strahler (1977) and Whitney (1986). Crankshaw *et al.* (1965) examined interactions between original forest composition and soil types by using multiple regression techniques. Many of the above-mentioned papers focused on patterns of vegetation present at the time of the GLO surveys, but few studies have emphasized the spatial distributions of individual species and their relationships with edaphic factors (including Whitney, 1982, 1986; Leitner *et al.*, 1991).

The purpose of this research was to compare the spatial distribution of soil drainage and texture with information on pre-European settlement tree locations for Baraga County, in Michigan's Upper Peninsula. We were most interested in soil drainage and texture, as compared to other soil attributes, because they are most important to plant growth (cf. Curtis, 1959) and are readily available in soils databases (Berndt, 1988). Data on soil nutritive status, perhaps equally important to plant growth and competition, were deemed too spatially variable to adequately map on a county-wide basis, and are in part dependent on soil texture.

In order to facilitate the study of vegetation-soils relationships, maps (also called layers) of each of the themes (*e.g.*, soils and vegetation) were digitized and stored within a geographic information system (GIS). Basic analytical operations of modern GIS software, including map reclassification, distance-buffer generation and map overlay (Burrough, 1986), were used to process the data and prepare them for statistical analysis to test relationships. GLO survey data on the locations and species of trees were coded and stored within the GIS as point features. Digitized soil survey data were reclassified to produce polygon representations of drainage and texture across the county. Disturbances in Baraga County's forests, noted by the surveyors, were also noted and stored as linear features.

A benefit of GIS methods for this type of study, once the data have been entered into the system, is the ease with which maps can be generated and integrated with other thematic layers, enabling researchers to more fully visualize and analyze the distributions described in the GLO data. The combination of analytical methods used in this study, including map generation, map overlay and statistical analysis, provided multiple lines of evidence on which descriptions of species distributions in the presettlement forests, and their relationships with soils, are based.

STUDY AREA

Climate.—Baraga County, bordering Lake Superior in northern Michigan, has a cool, humid continental climate. Alberta, located in the W-central portion of the county at 393 m above sea level, is warmer and receives less precipitation than Herman, 10 km to the E, at 546 m (Fig. 1). Much of this variation may be attributed to orographic effects and air mass modification by Lake Superior. Snowfall generally occurs from September through April, and becomes more prevalent farther from the lake (higher elevations). Mean daily temperatures are 15–20 C in July and −15–−10 C in January. Freezing temperatures are possible at all times of the year.

Landforms and soils.—Many of the soils and landforms in Baraga County have glacial origins. The county was essentially deglaciated by 10,500 BP, but the northern townships were covered by deposits associated with the Marquette readvance at 9900 BP, which left

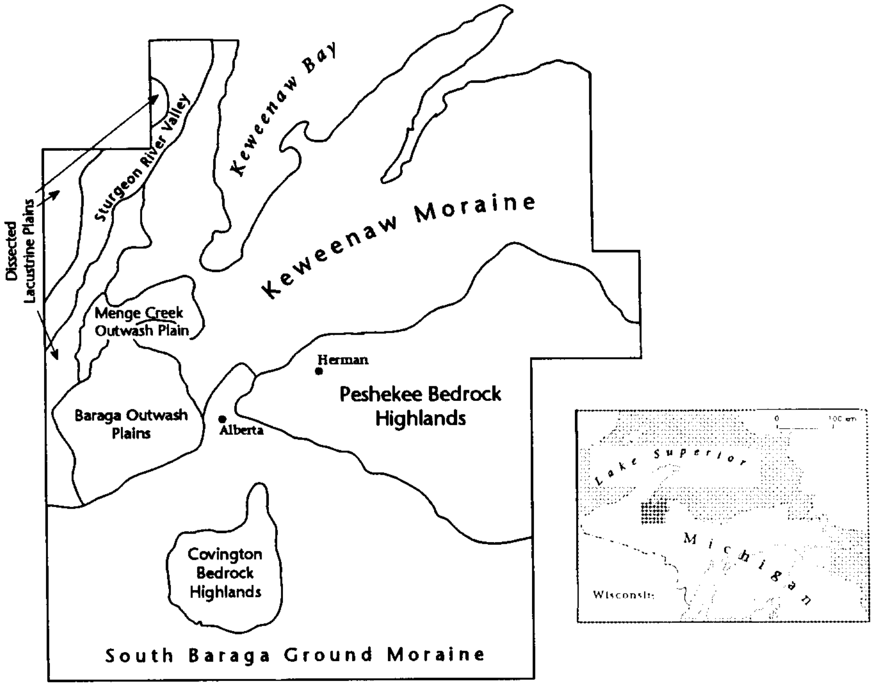


FIG. 1.—Physiographic regions of Baraga County, after Berndt (1988) and others

behind the Keewenaw moraine (Saarnisto, 1974; Drexler, 1977). The most prominent physiographic region is the Peshekee Bedrock Highlands in E-central Baraga County (Fig. 1). This hilly, remote area has thin glacial drift covering Precambrian rocks, primarily granite and gneiss. The loamy sand and sandy loam tills of the Keweenaw moraine roughly follow the outline of Keweenaw Bay in the northern portion of the county. In eastern Baraga County the southern edge of this moraine adjoins the Peshekee Highlands. In the W-central portion of the county the sandy, xeric soils of the flat, largely undissected Baraga Outwash Plains contrast with the more rolling loamy sand and sandy loam drift of the dissected Menge Creek Outwash Plains (Figs. 1, 2). At the southern edge of the Baraga Plains the soils become wetter and swamps are widespread, as the plains merge into the Sturgeon River floodplain. This river runs E-W across the center of the county, turns N, and eventually exits the county in the extreme NW corner (Fig. 1). The South Baraga Ground Moraine covers most of southern Baraga County, except for a small outlier of the Peshekee Highlands, called the Covington Bedrock Highlands. The Peshekee or Covington Highlands, as well as the South Baraga Ground Moraine, are intermittently covered with a layer of silty, probably eolian, sediments ranging up to 60 cm in thickness (Fig. 2). These sediments are absent on and N of the Keewenaw moraine. Many parts of the county contain numerous small pockets of organic sediments, mapped as Histosols (Berndt, 1988). Large areas of Histosols are also found in the Sturgeon River Valley.

Upland locations in the Peshekee Highlands are dominated by Typic Fragiorthods (Champion series) and Typic Haplorthods (Michigamme series) (Table 1; Berndt, 1988). These moderately well and well-drained soils are developed in a thin (40-60 cm) layer of silty sediments overlying either sandy loam till or fresh bedrock (Fig. 2). The northern

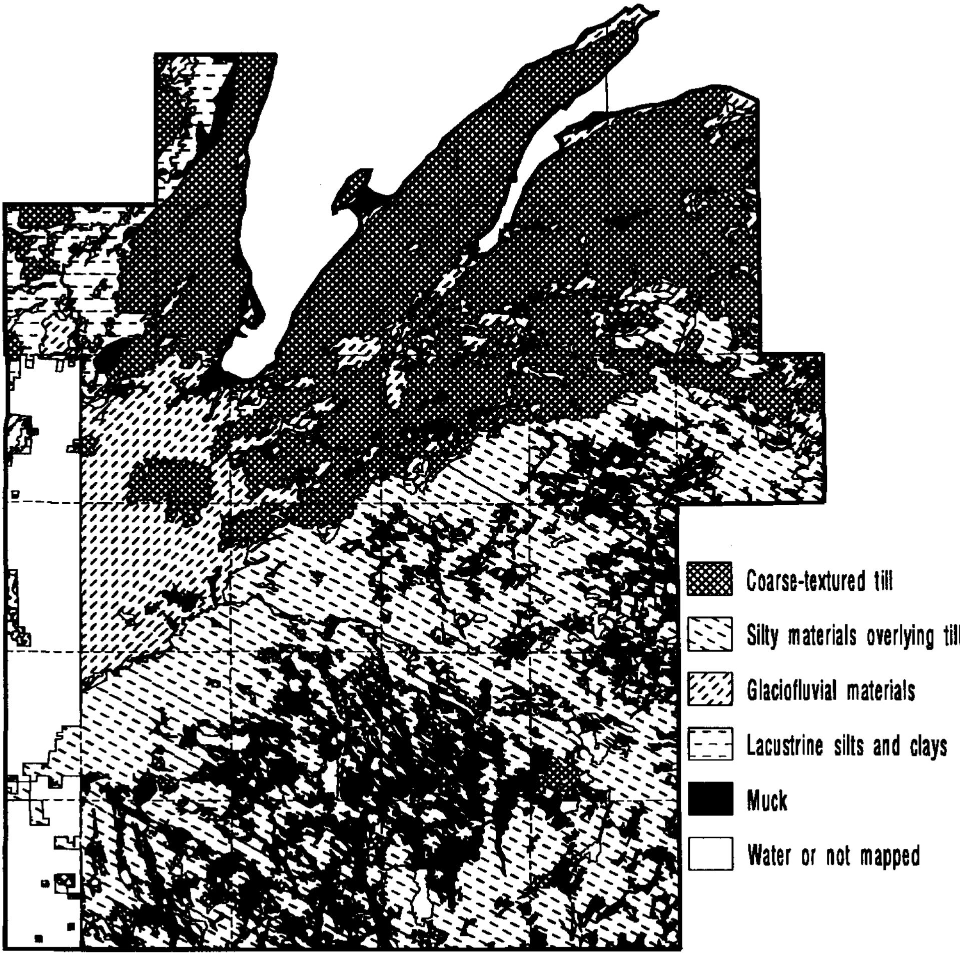


FIG. 2.—Soil parent materials of Baraga County. Data from Berndt (1988) have been subsequently coded into classes. Mapping unit polygons smaller than 2,000,000 ft² (18.6 ha) have been joined to adjacent, larger polygons to eliminate unecessary detail. Missing data in the SW corner of the county represent Ottawa National Forest Service land, for which soils data do not currently exist at the level of detail needed for this study

boundary of the silts coincides with the distal face of the Keewenaw moraine (Fig. 1). Tills get markedly redder and sandier from S–N. On the South Baraga Ground Moraine, Typic Fragiaquods (Net series) commonly occur downslope from Champion soils. Much of the Baraga Outwash Plains is occupied by excessively drained Typic Udipsamments (Grayling series) and is surrounded by Endoaquods (Au Gres and Kinross series) in low landscape positions in the E and Haplorthods (Kalkaska and Keewenaw series) on the Keewenaw moraine to the W and N (Berndt, 1988). On the Keweenaw Moraine various Alfic families of Spodosols (Munising, Skanee and Yalmer) also have formed (Table 1). Many of the till soils have a fragipan (Bx horizon).

Contemporary forest vegetation.—Forest communities in the county are similar to those of

TABLE 1.—Major soil series of Baraga County, Michigan

Soil series	Percentage of county[1]	Drainage class	Textural family	Comments
Champion	14.4	Well or moderately-well	Coarse-loamy	Widespread, silt overlying glacial till, SE and E part of the county; fragipan at 40–60 cm
Michigamme	8.9[2]	Well or moderately-well	Coarse-loamy	Dominates Peshekee Highlands physiographic province where drift is thin; thin silty sediments overlying either (a) bedrock or (b) thin till over bedrock
Amasa	4.2	Well	Coarse-loamy	Widespread soil, silt overlying sandy (often cobbly) drift
Carbondale and Tacoosh[3]	10.1	Very poorly	Organic	Dominant organic soils in shallow depressions
Kalkaska	3.7	Somewhat excessively	Sandy	Best developed sandy soil in the county, on outwash plains and sandy moraines
Rubicon	1.7	Excessively	Sandy	Intermediate in development between Kalkaska and Grayling, on outwash plains
Grayling	1.7	Excessively	Sandy	Dominates Baraga Plains physiographic province, very low water-holding capacity

[1] For complexes, the area of each contributing soil is assumed to be equal
[2] Includes some acres of rock outcrop
[3] These two series were mapped as a complex; acreage for each individual series is not available

surrounding areas (Graham, 1941; Fassett, 1944; Frederick *et al.,* 1976; Mladenoff and Howell, 1980; Albert and Barnes, 1987). Mesic sites with mature forests are dominated by sugar maple (*Acer saccharum* Marsh.), hemlock [*Tsuga canadensis* (L.) Carr.], yellow birch (*Betula alleghaniensis* Britton.), and ironwood [*Ostrya virginiana* (Mill.) K. Koch]. White pine (*Pinus strobus* L.) and red pine (*Pinus resinosa* Ait.) are nowhere dominant but are conspicuous on sandy dry sites. Jack pine (*Pinus banksiana* Lamb.) dominates the most xeric sandy soils, although most of these stands were planted rather than naturally regenerated following fire. Wet sites and organic soils have stands of white cedar (*Thuja occidentalis* L.), black ash (*Fraxinus nigra* Marsh.) and tamarack [*Larix laricina* (Du Roi) K. Koch] in either pure or mixed assemblages. About 91% of the county is currently forested (Berndt, 1988). No attempt was made to sample or map contemporary forest assemblages of the county, or to compare modern forest vegetation to presettlement patterns.

MATERIALS AND METHODS

Soils data.—Mapping and overlay functions were performed using the ARC/INFO GIS package (ESRI, 1992). A preliminary digital copy of the soil map of Baraga County (Berndt, 1988) was obtained from the Michigan Department of Natural Resources. Land in the Ottawa National Forest, some of which is in the SW corner of the county, was not included in the Soil Survey (Fig. 2), allowing only 93% of the county's soils to be analyzed.

Polygon position and attribute accuracy were verified by comparing paper plots of the digital map with the published survey at its original scale (1:20,000). Because we were interested primarily in soil drainage class and soil textures, we simplified this map, which used more than 50 different soil series in more than 140 mapping units, by reclassifying the soil series according to drainage class and textural family. Textural family classifications and natural soil drainage classes were determined for each soil mapping unit (Berndt, 1988). Where a series spanned two drainage classes, it was assigned to the drier class. Mapping unit complexes (containing more than one soil series) were treated as missing information when their component soil series differed in either drainage class or textural family. Polygon boundaries that separated mapping units of one series, but with different slope classes, were eliminated, because we chose not to study the influence of slope on vegetation. Similarly, boundaries that separated units of different series but with the same drainage classes *and* textural families were eliminated. The simplified soil map was used in all subsequent operations.

Surveyors' field data.—Baraga County was surveyed from 1846 to 1853. Copies of the transcribed GLO survey field notes were obtained at the archives of the State of Michigan Library, Lansing. Data were gathered for trees (witness trees) which marked section corner and quarter-section corner locations. Trees falling on section lines (bearing trees) were also recorded. Trees located at the edges of lakes or rivers (meander post trees) were not included in the data set because soils at such locations are highly variable across short distances; soil maps do not normally include such small-scale variation. Hereafter, both witness and bearing trees are referred to as "witness trees."

Data gathered from the surveyors' notes were entered into a spreadsheet, including a species code, diameter at breast height (DBH, in inches), and direction and distance (in links) from a corner. Species codes were based on the common names used by the surveyors (Table 2). Geographic coordinates were calculated on the basis of the direction and distance information of each tree relative to the appropriate section corner. Section corner coordinates in the state plane coordinate system were obtained from the Michigan Department of Natural Resources. Following conversion of the tree locations into a point coverage (digital map) in ARC/INFO, paper maps of the position, species and diameter at breast height (DBH) for all trees were plotted and compared with the original survey notes to verify the proper entry of the locational and attribute data. After data entry errors in both the soil and the witness tree data had been corrected, a point-in-polygon overlay (*i.e.*, overlay of tree data, represented as points, on soils data, represented as polygons) was performed to determine the soils series present.

Uncertainty and bias in the data.—Surveyor bias exists in the GLO notes. The potential misuse of GLO survey data for vegetation reconstruction has been addressed by Cottam (1949) and Bourdo (1956). Although we did not collect data against which to analyze bias in the data, some mention of possible survey bias and error is appropriate here.

Surveyors tended to ignore small-diameter trees when choosing witness trees because of the difficulty in inscribing the appropriate locational data on the tree (Leitner and Jackson, 1981). This bias may explain the relatively few small trees recorded in the county (*cf.*, red maple, Table 2). Red maple is a small tree that is tolerant of a wide variety of soil types (Walters and Yawney, 1990) and should have been a common forest associate in Baraga County (Jacobs, 1965). Although many sites in Baraga County are edaphically amenable to red maple, small, understory red maple trees may have been overlooked by surveyors in favor of larger individuals of other species.

Other problems with the Baraga GLO notes are associated with nomenclature. Because the surveyors used common names for the trees, it was difficult to assign every tree its proper genus and species (Table 2). For example, the various surveyors in Baraga County

TABLE 2.—Arboreal species used as witness trees in the GLO survey of Baraga County, Michigan: 1846–1854[1]

Common name	Scientific name	Surveyors' notation	N before buffering	N after buffering	Mean DBH[3] cm
Sugar maple	*Acer saccharum* Marsh.	Sugar	2623	1546	29.8
Eastern hemlock	*Tsuga canadensis* (L.) Carr.	Hemlock, Hem	1864	726	37.0
Yellow birch	*Betula alleghaniensis* Britton.	Y Birch, Yellow Birch	1742	885	32.4
Balsam fir	*Abies balsamea* (L.) Mill	Fir, Balsam	1426	651	20.4
Spruce spp.	*Picea mariana* (Mill.) B.S.P.	Spruce	1228	654	23.4
Northern white cedar	*Thuja occidentalis* L.	Cedar	1134	550	27.9
Red maple	*Acer rubrum* L.	Maple	489	217	24.2
Tamarack	*Larix laricina* (Du Roi) K. Koch	Tamarack, Tamk, Tam	484	273	23.8
Eastern white pine	*Pinus strobus* L.	W Pine, White Pine, Pine	421	177	55.4
Jack pine	*P. banksiana* Lamb.	Spruce Pine, Spr Pine, S Pine	336	229	19.1
White birch	*Betula papyrifera* Marsh.	W Birch, Birch	272	108	27.3
Aspen	*Populus* spp.	Popple, Aspen	139	66	24.5
Basswood	*Tilia americana* L.	Lynn, Basswood	126	68	33.6
Black ash	*Fraxinus nigra* Marsh.	B Ash, Black Ash	124	60	25.7
Red pine	*Pinus resinosa* Ait.	Yellow Pine, Norway Pine	121	—[2]	39.2
Ironwood	*Ostrya virginiana* (Mill.) K. Koch	Ironwood	96	—	17.7
Elm	*Ulmus americana* L.	Elm	82	—	30.4
Black cherry	*Prunus serotina* Ehrh.	Cherry, Black Cherry	19	—	19.7
Alder	*Alnus* spp.	Alder	6	—	12.7
White ash	*Fraxinus americana* L.	W Ash, White Ash	4	—	31.1
Red oak	*Quercus rubra* L.	R Oak	3	—	21.2

[1] In order of occurrence as witness trees, from most frequently used to least. Nomenclature follows Burns and Honkala (1990)

[2] Fewer than 50 trees remained after buffering

[3] Mean DBH was calculated before buffering

used three common names to describe two species of *Betula*: "Birch," "Y[ellow] Birch," and "W[hite] Birch." Early in the study we (erroneously) assumed that "Birch" was synonymous with white birch, and thus all entries for "Birch" or "W Birch" were coded similarly. The deputy surveyor who worked two townships in the NW corner of the county, however, did not use these terms in the same manner as the other surveyors. In this area, "Birch" trees were abundant; apparently the surveyor either did not differentiate between the two birch species, recording all as "Birch," or labeled *Betula alleghaniensis* as "Birch" and *Betula papyrifera* as "W Birch." Similarly, the person who surveyed the exterior lines of the northern two tiers of townships also could have labeled many yellow birch trees as "Birch," since a high number of "Birch" witness trees were observed in this part of the county along exterior lines, but are noticeably lacking from interior lines. Similar nomenclatural difficulties have been noted for Alger County, also in northern Michigan (Frederick *et al.*, 1976).

An additional nomenclatural issue arises with respect to *Fraxinus* (ash). White ash and black ash were given separate codes in our database while green ash (*Fraxinus pennsylvanica* Marsh.), which is also native to the area (Kennedy, 1990), was not mentioned in the surveyors' notes (Table 2). Trees recorded as "Ash" without reference to the specific type were coded as black ash because white ash and green ash are only rarely observed in the region (Schlesinger, 1990).

Error also may have been introduced into this analysis by the soils data. The inherent complexity and spatial variability of the soils in this recently deglaciated landscape has undoubtedly led to inclusions of unlike soils in a mapping unit (*e.g.*, McCormack and Wilding, 1969; Mokma, 1987). This type of error has not been quantified for Baraga County, but is probably no less than 10% inclusions of unlike soils, based on discussions with field mappers and direct field observations. Whitney (1986) performed a similar analysis for two counties in southern Michigan, using older, smaller scale soil maps in which inclusions would have been still more prevalent. His residual scores and G^2 statistic values were generally comparable but often smaller than ours (Tables 3, 4), which was expected given an analysis that used highly site-restrictive tree locations on small-scale, low quality soil maps with numerous inclusions.

In order to account for the imprecise nature of both the soil unit boundary locations and the tree locations, all trees within a given distance of a soil boundary were eliminated from the statistical data set, although they were retained in the database for creating maps of species distributions and for calculating mean DBH values. The trees were eliminated by identifying their location near soil unit boundaries using a GIS procedure called buffering (Burrough, 1986). The choice of an appropriate buffer width was a trade-off between sample size (larger buffers reduce the number of trees used in subsequent statistical calculations) and data quality (by eliminating trees closest to the boundaries, the certainty that the remaining trees were located on the correct soil series increased). A 25-m buffer was chosen (Barrett *et al.*, 1993). The additive uncertainty in the soil boundaries was first estimated by assuming that the smallest line width made on the soil survey maps was 0.5 mm (Tobler, 1988). The scale of the maps was 1:20,000, implying that lines on the map were no more precise than ± 10 m (*i.e.*, the ground equivalent of 0.5 mm). Uncertainty in the location of the trees was difficult to determine because it depended on the accurate location of the section corner and the straightness of the line between section corners, among other factors (Bourdo, 1956). The surveys of Baraga County were of high enough quality that resurveys were not required, as elsewhere, and the errors in tree locations were estimated to be ± 15 m.

Trees located within mapping unit complexes or on unmapped areas within the Ottawa National Forest were retained for species distribution maps, but were not used in the statistical analyses. From our original data set of 12,760 trees, all those within 25 m of a soil boundary (2857) were eliminated. Next, 3536 trees located on soil mapping unit complexes and in the unmapped Ottawa National Forest were removed from the database. Finally, species for which there were fewer than 50 observations (157 additional trees) were removed, leaving 6210 trees in the final database (48.7% of the original 12,760 trees).

Disturbance data.—Locations and linear sizes (distance along section lines) of natural canopy gap disturbances (Runkle, 1982; Foster and Reiners, 1986; Schaetzl *et al.*, 1989) by windfall and fire were calculated from the GLO notes. We recognized windfall disturbances that were either (1) recently formed, or (2) past disturbances. Recently formed windfalls were noted as such by the surveyors, as were burns, either with a measurement and notation

TABLE 3.—Standardized residuals and frequencies expressing the degree of association between species and soil drainage class[1]

Species	Excessively Residual (N)	Somewhat excessively Residual (N)	Well Residual (N)	Moderately well Residual (N)	Somewhat poorly Residual (N)	Poorly Residual (N)	Very poorly Residual (N)	G^2 statistic
Sugar maple	−53.3	0.58	194.9	0.6	−54.0	−38.3	−232.0	986.6
	(16)	(57)	(1361)	(47)	(46)	(10)	(9)	
Red maple	−0.0	0.1	6.3	−1.4	7.6	−3.1	−31.2	74.6
	(11)	(8)	(160)	(3)	(30)	(3)	(2)	
White pine	32.9	−0.1	0.2	−0.1	−1.0	−3.1	−5.5	35.5
	(27)	(5)	(112)	(4)	(11)	(2)	(16)	
Jack pine	2899.2	−7.6	−136.4	5.3	−6.5	−0.0	−37.0	1261.4
	(200)	(0)	(1)	(12)	(8)	(8)	(0)	
Yellow birch	−35.8	0.1	44.4	−2.1	−0.0	−10.4	−55.3	210.5
	(6)	(31)	(689)	(17)	(74)	(14)	(54)	
White birch	11.9	−1.9	−0.0	3.2	−0.1	0.3	−3.2	18.1*
	(14)	(1)	(64)	(6)	(8)	(5)	(10)	
Basswood	−0.1	−0.0	2.4	2.5	−0.1	−0.1	−9.1	19.7*
	(3)	(2)	(51)	(4)	(5)	(2)	(1)	
Hemlock	−4.1	36.7	−0.0	2.0	76.1	0.5	−72.6	224.6
	(26)	(54)	(436)	(26)	(129)	(30)	(25)	
Aspen	−1.8	43.7	−0.4	0.8	3.6	−0.1	−7.0	38.9
	(1)	(12)	(36)	(3)	(10)	(2)	(2)	
Black ash	−1.5	−2.0	−12.5	0.1	7.1	100.0	1.9	70.4
	(1)	(0)	(15)	(2)	(11)	(17)	(14)	
Spruce	−27.2	−7.5	−96.4	−9.2	−3.0	−0.4	676.8	700.5
	(4)	(9)	(200)	(5)	(42)	(21)	(373)	
Balsam fir	−12.2	−0.1	−0.1	1.0	0.0	0.2	3.7	22.8
	(14)	(20)	(388)	(22)	(56)	(26)	(125)	
White cedar	−16.9	−5.8	−45.1	0.6	24.8	38.7	91.5	225.1
	(7)	(8)	(21)	(18)	(80)	(48)	(179)	
Tamarack	−14.5	−9.1	−110.4	−7.4	−6.2	84.4	502.9	593.0
	(0)	(0)	(30)	(0)	(11)	(39)	(193)	
Total N	330	207	3753	169	521	227	1003	

[1] Includes only species with 50 or more observations after buffering soil boundaries
* $0.001 < P < 0.05$. All other values in the table are significant at $P < 0.001$

as they encountered it (as in "16.00 [the position along the line] Enter Burnt Pine Plains") or in the line summaries (such as "Land first 60 chains level and mostly burnt land"). For past windfalls, indirect evidence was used, such as notations like "thick undergrowth of hazel, maple, vines, etc." and "enter poplar and cedar thicket." We totaled the distance of section lines noted as disturbed for each category, and determined the relative percentage of section lines in the county that had been so disturbed (Lorimer, 1977; Whitney, 1986; Seischab and Orwig, 1991).

Statistical analysis and map generation.—Individual species relationships with drainage and texture classes were examined using contingency table analysis. Following Whitney (1986, 1990), a 2 × n contingency table was constructed for each species-soil variable combination, where n was the number of classes for the soil variable. We ultimately produced 30 contingency tables (15 species × 2 soil variables).

TABLE 4.—Standardized residuals and frequencies expressing the degree of association between species and soil textural family

Species	Sandy Residual (N)	Coarse-loamy Residual (N)	Fine-loamy Residual (N)	Fine Residual (N)	Organic Residual (N)	G^2 statistic
Sugar maple	−8.7	128.8	−9.8	−18.2	−232.0	709.0
	(256)	(1241)	(30)	(10)	(9)	
Red maple	0.2	6.9	0.0	0.0	−31.2	62.7
	(46)	(156)	(8)	(5)	(2)	
White pine	2.2	0.1	−0.2	0.2	−5.5	9.4**
	(44)	(107)	(5)	(5)	(16)	
Jack pine	730.1	−131.4	−7.8	−5.2	−37.0	760.7
	(228)	(1)	(0)	(0)	(0)	
Yellow birch	−11.2	45.7	−0.3	−13.0	−55.3	167.7
	(131)	(669)	(27)	(4)	(54)	
White birch	2.0	−1.3	0.5	29.5	−3.2	23.8
	(28)	(54)	(5)	(11)	(10)	
Basswood	3.1	−0.0	9.4	−0.2	−9.1	24.4
	(20)	(39)	(7)	(1)	(1)	
Hemlock	43.7	−2.3	14.9	35.9	−82.6	207.0
	(224)	(392)	(44)	(41)	(25)	
Aspen	7.4	−3.4	34.0	1.5	−7.0	39.6
	(23)	(27)	(11)	(3)	(2)	
Black ash	−3.0	0.0	1.9	−1.4	1.9	9.6*
	(6)	(36)	(4)	(0)	(14)	
Spruce	−68.3	−63.8	−11.9	−0.6	676.8	695.0
	(38)	(225)	(6)	(12)	(373)	
Balsam fir	−5.0	−0.2	7.3	0.1	3.7	17.4*
	(104)	(371)	(35)	(16)	(125)	
White cedar	−9.6	−23.8	4.5	33.2	91.5	150.1
	(77)	(223)	(28)	(33)	(179)	
Tamarack	−334.6	−54.4	−5.7	−4.4	502.9	437.8
	(11)	(66)	(2)	(1)	(193)	
Total N	1236	3617	212	142	1003	

* $0.001 < P < 0.05$

** $0.05 < P$. All other values in the table are significant at $P < 0.001$

Strahler's (1977) method of calculating the "signed" standardized residual of each contingency table cell was used to represent the degree of association between a given soil variable class and a species. The standardized residual for each cell, measuring the relationship between the soil type and the species, was calculated as:

$$(\text{observed frequency} - \text{expected})^2/(\text{expected})$$

which represents the strength of association. In the contingency tables we report this value with the appropriate sign to represent the direction of association, positive or negative. The closer a standardized residual is to 0.0, the less likely the species was to occur more or less frequently than expected by chance on the type of soil. For example, a high positive standardized residual value suggests that the species was more frequently observed on that particular soil than would have been expected by chance. The G^2 statistic, also called the likelihood ratio chi-square (SAS Institute, 1985), was used to test the significance of the association between a species and a soil variable (*e.g.*, soil texture or wetness) across all classes, and is identical to the G statistic reported in Whitney (1986). A higher G^2 indicates a stronger relationship; lower values indicate a less significant relationship.

Finally, using a subjective classification procedure based on dot map distributions of witness trees, a presettlement forest association map was compiled for the county. The map assumes that witness tree selection and frequency are in direct proportion to the actual frequencies in the presettlement forests. Ideally, this map would have been compiled using additional information from summaries of the vegetation compiled by the surveyors. Our map, based on witness tree data, requires subjective judgment on our part but is not susceptible to the surveyor bias involved in the summaries of major tree species encountered along a mile transect.

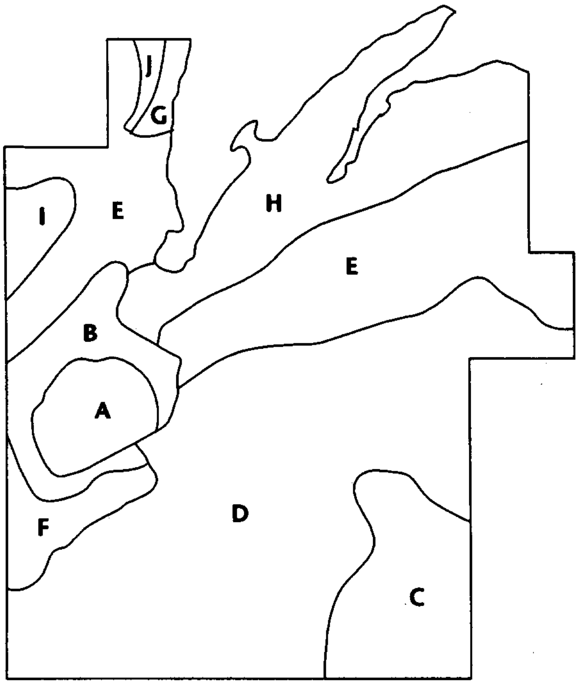
RESULTS AND DISCUSSION

Species-site relationships.—Surveyors' notes describe most of Baraga County as mature forest of varying composition. The only sizable tracts described as "open" were burned areas of jack pine on the Baraga Plains (*see* below). Several small "open meadows" and marshes were also noted, although their total acreage was negligible. Sugar maple, yellow birch, red maple and white pine were common on most upland sites, except those dominated by the excessively drained soils (Tables 1, 3 and 4). Somewhat poorly drained sites had a higher proportion of hemlock. Well-developed, sandy Spodosols (Kalkaska series) were dominated by hemlock and sugar maple. Aspen and white birch were frequent invaders of disturbed sites, along with white pine, which may have been more restricted to canopy gaps. Bog sites were not dominated by a single species, but had instead a diverse assemblage of four conifer and one broadleaved species at each site.

Mesic species.—The upland mesophytic forests of Baraga County were similar to those elsewhere in the Great Lakes region (Mladenoff and Howell, 1980; Whitney, 1987). Most of these forests were mature, as evidenced by the frequent surveyors' comments (*e.g.*, "timber heavy and very handsome," and "W Pine first rate"). Beech (*Fagus grandifolia* Ehrh.) is absent from these forests, however, as it reaches its westernmost range limit at the eastern boundary of the county (Woods and Davis, 1989; Tubbs and Houston, 1990).

A prominent feature in the county is a conspicuous NE-SW trending "ecotone" (units D and E, Fig. 3). Several species, such as hemlock (Figs. 3, 4A), occurred more frequently as witness trees on one side or the other of this zone. The densities of recorded sugar maple (Fig. 4B), as well as of ironwood, basswood, elm and black ash, were greatest within this zone. This ecotone may be climatic, but it may also be related to soils. In S and SE Baraga County, silty sediments cover sandy loam tills or bedrock. North and W of the ecotone, the tills are sandier, and the silt cap is absent (Fig. 2).

The distribution of sugar maple witness trees in the eastern half of the county parallels the SW-NE trending Keewenaw moraine (Figs. 1, 4B). Although much of the landscape S of the Keewenaw moraine is well-drained, the prevalence of numerous small areas of poorly drained mineral soils and very poorly drained organic soils to the S (Fig. 4D) explains, in part, the low density of sugar maple in that region. The low density of sugar maple in northwestern and W-central Baraga County may be explained by the increased frequency of moderately well-drained and wetter soils in the NW (units F through I), as well as the prevalence of dry, sandy soils in the W-central (units A, B; Figs. 2, 3). The eastern portion of unit E (Fig. 3) lies on sandy Keewenaw till, on which sugar maple does not dominate (Fig. 1). The more eastern of the two areas of unit E contained higher numbers of sugar maple probably because it is a sedimentological transition zone; the till to the N primarily



Dominant Tree Species*

	Upland Forest Species	Lowland Forest Species
A.	Jack pine	Not commonly observed
B.	Red pine, White pine, Aspen, White birch	Balsam fir
C.	Sugar maple, Yellow birch, White pine	White cedar
D.	Sugar maple, Yellow birch	Balsam fir, Black Spruce, White cedar, Tamarack
E.	Sugar maple, Hemlock, Yellow birch Ironwood, Red maple	Balsam fir, Elm, Ash
F.	Hemlock, Sugar maple, Yellow birch	White cedar
G.	Yellow birch, Hemlock	Balsam fir
H.	Hemlock, Sugar maple, Yellow birch Ironwood, Basswood	White cedar
I.	Hemlock	White cedar, Balsam fir
J.	none	Tamarack

* in approximate order of abundance

FIG. 3.—Forest association map, ca. 1850. Boundaries are based on subjective interpretation of printed maps of witness, quarter section, and bearing trees recorded in the GLO notes

consists of loamy sands, while the till along the southern extent is finer textured and contains more coarse fragments (L.R. Berndt, pers. comm.; Fig. 2). Finally, of all sugar maple-dominated stands in the county (units C-E; Fig. 3), the greatest intermixture of other tree species occurred in unit E. This pattern may be due to a combination of diverse soil and parent material patterns superimposed upon a highly dissected and irregular topography (Fig. 1), allowing for multiple microsite situations that are within the tolerance limits of numerous species.

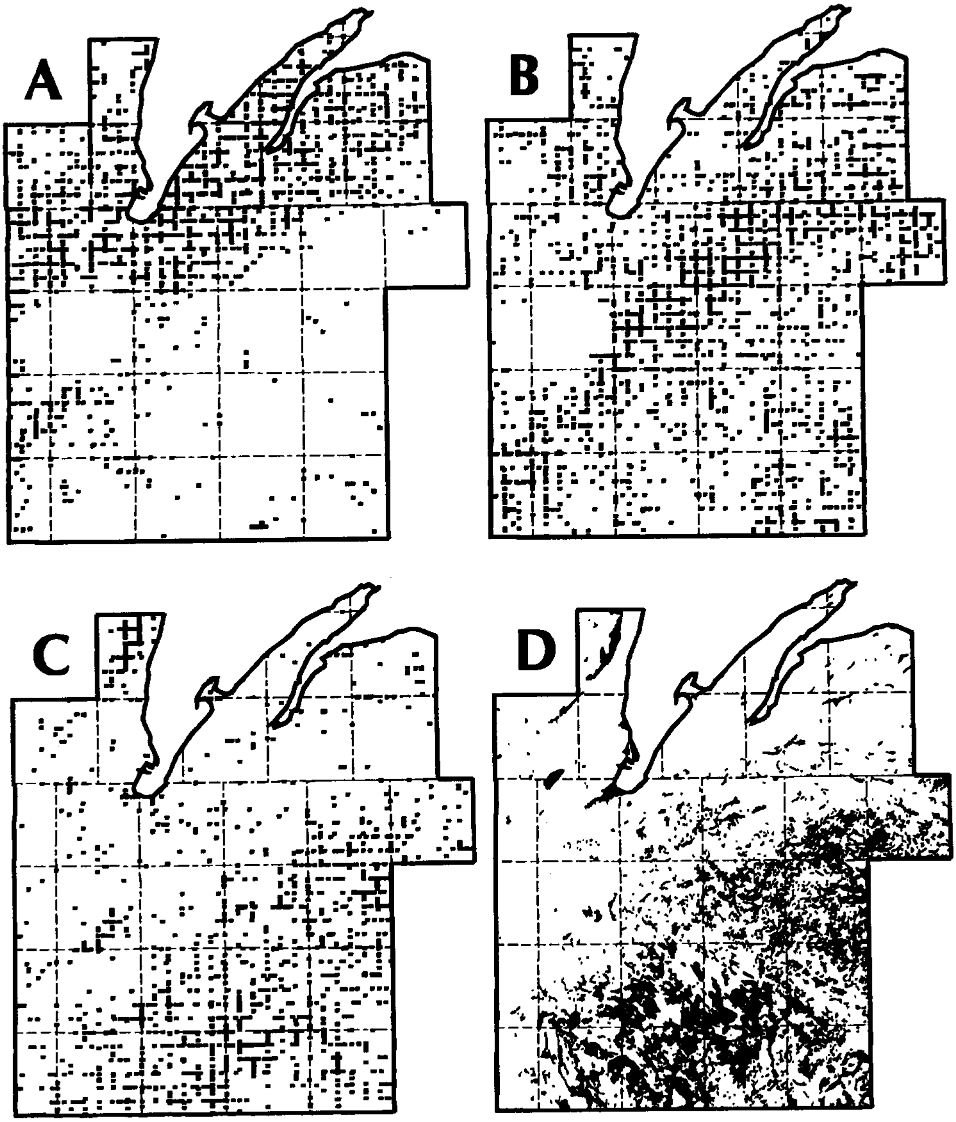


FIG. 4.—(A) Distribution of hemlock witness trees, from GLO data. (B) Distribution of sugar maple witness trees, from GLO data. (C) Distribution of tamarack and black spruce witness trees, from GLO data. (D) Distribution of very poorly drained organic soils. Parts of the three partial townships in the SW corner of the county are in the Ottawa National Forest and are not included in the soils data set

Sugar maple occurred 1546 times and was by far the most frequent witness tree in Baraga County (Table 2), and its mean size was intermediate (29.85 cm DBH). The highly significant G^2 statistic values for sugar maple (Tables 3, 4) point to its restriction to coarse-loamy, well-drained soils, with presumably high nutrient contents (Crankshaw *et al.*, 1965; Host *et al.*, 1987). In this sense, it is rivalled only by jack pine and spruce (presumably black spruce, based on site preferences) in its degree of site- and soil-specificity. Sixty percent of the trees were located on mapping units that were well-drained and 58% of the trees were on coarse-loamy mapping units (Tables 3, 4). Forty-eight percent of the trees were located on mapping units that were both well-drained *and* coarse-loamy. Thus, sugar maple's dominance of the upland forests of the county, evidenced by its high frequency of use as a witness tree, is explained not so much by a tolerance for a variety of diverse site conditions, as by the widespread occurrence of soils on which it is successful, and by the relative lack of recent disturbance (*see* below).

Yellow birch, second in total witness tree abundance, had similar site preferences to those of sugar maple, but was not quite as site-restricted. This species was probably more abundant than the data in Table 2 would indicate, because of the nomenclatural issue discussed above.

Red maple was an infrequent witness tree. It occurred on sites in Baraga County that were edaphically similar to those of sugar maple, despite a well-noted tolerance for dry-mesic and xeric conditions elsewhere (Lorimer, 1984; Host *et al.*, 1987; Nowacki *et al.*, 1990). Red maple's tolerance for a wide variety of sites is evident from Tables 3 and 4. It had a moderately strong negative association only for organic soils.

Hemlock occurred frequently on mesic and wet-mesic sites only in the northern part of the county (Fig. 4A), an area of acid, sandy till without an appreciable silt cap (Fig. 1). A −0.0 standardized residual for hemlock on well-drained soils attests to the fact that hemlock was not more or less common on these sites than expected by chance. Somewhat excessively drained, sandy soils, however, supported many more hemlock witness trees than would have been expected by chance (standardized residual: 36.7). In Baraga County, Kalkaska and Rubicon are the most common somewhat excessively drained soil series (Table 1). Both are Spodosols with prominent spodic horizons, which enable the soils to retain more water and supply more nutrients than Udipsamments such as Grayling, an excessively drained series. In northern Baraga County hemlock is presently found in dense groves on these soils in sheltered microclimatic areas such as coves and steep slopes with northern aspects (L.R. Berndt, pers. comm.). In this part of the county the mile summaries from the survey notes often describe the following: "Land broken many ravines and high sharp ridges. Timber with hemlock, Y birch, pine . . ." In most summaries of this deeply incised morainic landscape, hemlock was the first species mentioned. Because surveyors were instructed to list species in order of abundance, this indicates that hemlock was very common. On the Allegheny Plateau, Whitney (1990) also found hemlock to be associated with shady ravines.

The southern limit of dense hemlock populations is the county-wide ecotone that runs linearly from the SW corner of the county to a point some 10–15 km S of the Lake Superior shore in NE Baraga County (Fig. 4A, and discussed above). South of this zone, a thin layer of silty sediments covers much of the landscape, winter snows are deeper and persist longer, and summers are shorter. Here, hemlock is rare but is occasionally found on upland sites which have well-drained, coarse-loamy, fertile soils (*i.e.*, Champion and Watton soils, Table 1). Although found in only a small section of SW Baraga County, Watton soils supported a much higher proportion of the hemlock witness trees than did Champion soils, possibly because Watton soils (1) are finer-textured, and/or (2) lack the root-restricting fragipan (Bx horizon) of Champion soils.

Hydric species.—Five species dominated soils that were somewhat poorly drained or wetter: black spruce, white cedar, balsam fir, tamarack and black ash. In lowland forests of northern Wisconsin, these same five species had high importance values (Curtis, 1959). The wetland forests of presettlement Baraga County were similar to those elsewhere in Michigan, although balsam fir and, to a lesser extent, black spruce were more common in the swamp forests of Baraga County than in the swamps of southern Michigan (Whitney, 1987).

Spruce, although common, was the most site-restricted hydric species. It was found almost exclusively on very poorly drained organic soils (Tables 3, 4, Fig. 4C, D), mostly S of the county-wide tension zone. These sites are found in pockets of organic soils developed in glacial kettles and bedrock depressions. The spatially restricted character of black spruce and balsam fir to low, wet sites points out that Baraga County had few if any pockets of upland boreal forest at the time of European settlement.

Tamarack, like black spruce, had strong affinities for very poorly drained organic sediments (Tables 3, 4, Fig. 4C, D), although tamarack was also present on poorly drained and somewhat poorly drained lacustrine, till, and outwash-derived soils. A concentration of tamaracks was located in the northernmost part of the Sturgeon River valley, where currents are sluggish and surficial deposits are dominated by organic soils (Fig. 1). This area was described by surveyors as "land mostly open - tamarack swamp wet some rushes" and "cranberry & rushes also grass on some places." In his summary of township 52 N range 33 W, the surveyor reported that "A large open tamarack swamp extends nearly the whole length of the township on the east side of the Sturgeon River . . . the trees are small and scrubby."

White cedar, apparently less exacting in site requirements than the other wetland species, nevertheless had a negative association with dry soils, possibly because the bedrock in Baraga County is acidic and this species, when found on thin rocky soils, is almost always over carbonaceous rocks. Black ash occurred relatively infrequently as a witness tree ($n = 60$). It was most common on poorly drained mineral soils (Table 3). Balsam fir was perhaps the most ubiquitous of the wetland species, being negatively associated only with well-drained or drier soils, and, like other less restricted species, having a low G^2 statistic. Like hemlock, balsam fir was most often noted in areas of broken land and steep slopes on drier soils and in shade.

Xeric species.—Drier, sandier sites in Baraga County supported jack pine, red pine and white pine and, to a lesser extent, hemlock and aspen (Tables 3, 4). Unlike other parts of the Great Lakes region in which magnificent pine forests were widespread (Hushen *et al.*, 1966; Kapp, 1978; Jacobson, 1979; Mladenoff and Howell, 1980; Whitney, 1986, 1987), one rather extensive, open stand of jack pine represented the most significant upland conifer-dominated forest of any areal extent in Baraga County. Jack pine was almost wholly restricted to the dry, flat Baraga Plains, where droughty Grayling soils dominated the landscape (Table 3, Figs. 1, 5A). The high G^2 values for jack pine on sandy soils (704.1) and on excessively drained soils (2636.6) point to its extreme site preference.

Red pine and white pine were concentrated on the sandy soils immediately NW of the Baraga Plains. In fact, red pine was seldom encountered elsewhere; white pine, on the other hand, was found in association with more mesic species throughout the county. The low, positive G^2 values for white pine point to its wide tolerance for soil texture and drainage, although its strongest preference was for excessively drained, sandy soils. This preference enhances its competitiveness in gaps and fire-disturbed areas, frequent sites of establishment (Maissurow, 1935). Hemlock and aspen were not restricted to the more xeric soils, both also having affinities for finer-textured and wetter soils (Tables 3, 4).

Indications of disturbance.—Surveyors noted two types of canopy disturbance in Baraga County: fire and windfall. Fire-related disturbances were more widespread than windfalls (Table 5) but, with minor exceptions, were restricted to the Baraga Plains (Fig. 6). From the map in Figure 6 it appears that not all burned areas on the Baraga Plains were reported, since section lines shown as having been burned surround, at times, other areas not so noted. Wind-related canopy gaps, a few of which had also burned subsequent to windfall, were generally infrequent ($<1\%$ of all surveyed lines) and scattered throughout the county (Fig. 6).

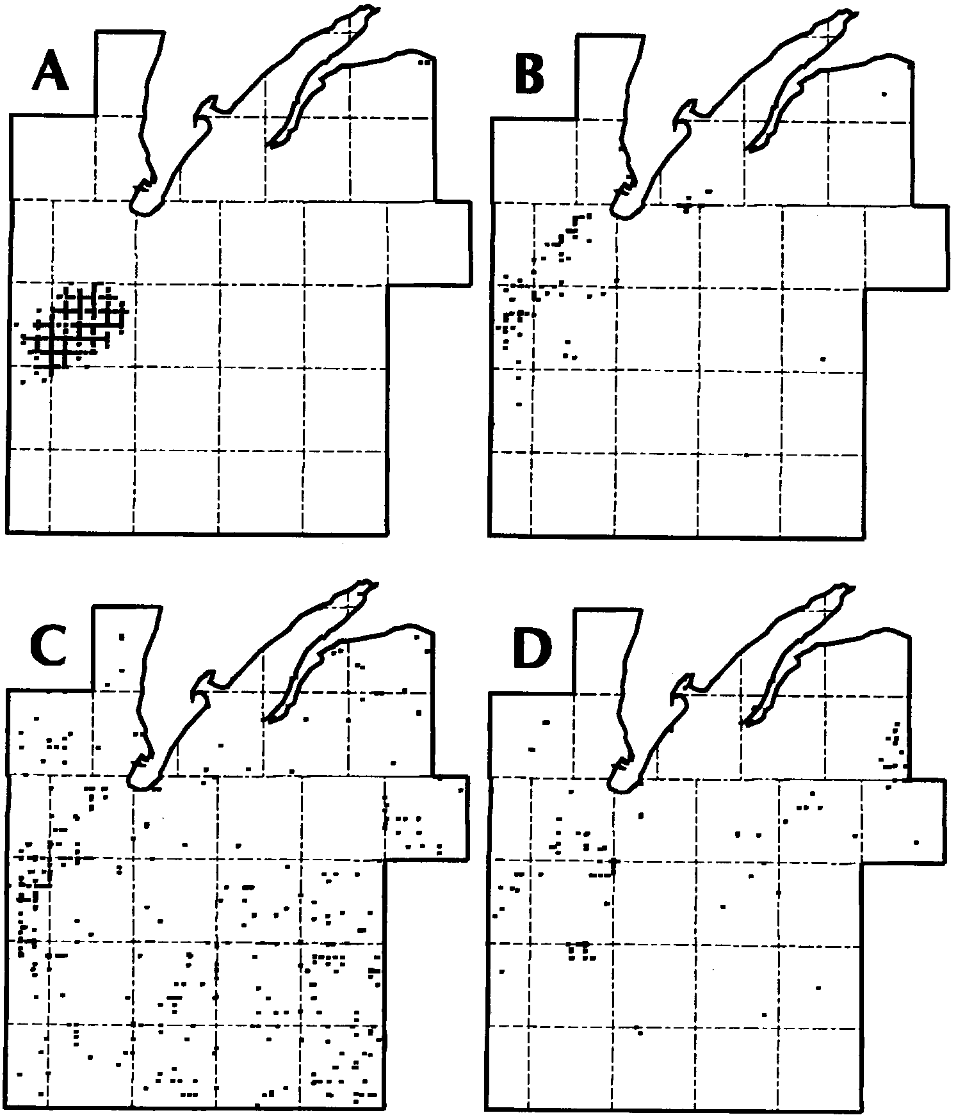


FIG. 5.—(A) Distribution of jack pine witness trees, from GLO data. (B) Distribution of red pine witness trees. (C) Distribution of white pine witness trees. (D) Distribution of aspen witness trees

The strict association of fires with the Baraga Plains points out the unique nature of this soil/landform/vegetation assemblage. As noted above, jack pines were generally restricted to the Baraga Plains. Surveyors described the Baraga Plains as "thinly timbered," "level burnt pine plains," and "dwarf pine plains." Many witness trees, most of which were jack pine, were "dead" or "dry." Other comments included: "timber mostly dead being burnt," "burnt and dead spruce pine, sweet fern [*Comptonia peregrina*] and sand cherry [probably *Prunus pensylvanica* L. f.]", and "sight tree omitted for want of timber." Presettlement

TABLE 5.—Linear extent of disturbances recorded in GLO notes, Baraga County

	Windthrow (direct evidence only)	Windthrow (direct and indirect evidence)	Fire	All disturbances
Total line length affected	10,010 m	17,716 m	46,157 m	63,873 m
Percent of total surveyed lines	0.32	0.58	1.52	2.10

wildfires were common on the plains (Schaetzl, 1986). A later map of the western upper peninsula singled out the Baraga Plains as an area of "burnt pine" (U.S. Dep. Interior, 1873). The Plains are perched above the Sturgeon River valley and the Keewenaw moraine to the N and W (Fig. 1), as noted in surveyor comments such as "ascend 20 ft to burnt land." The perched Plains would have allowed relatively unrestricted entry of strong W and NW winds into the region. Fires on the Plains would have provided an ideal environment for frequent jack pine establishment, as it invades areas recently disturbed by fire and outcompetes almost all other species on dry sandy sites (Simard and Blank, 1982; Abrams, 1984).

Jack pine was noticeably absent from the SE corner and the northern tip of the Baraga Plains. Surveyors described the former area as an "open swamp." . . . "timbered with tamarack, spruce, fir and cedar." Thus, wet soils in the former and rolling topography in the latter probably acted to decrease fire frequency and intensity in these areas as indicated by one surveyor's comment, "leave swamp and enter burnt plains." Support for this contention

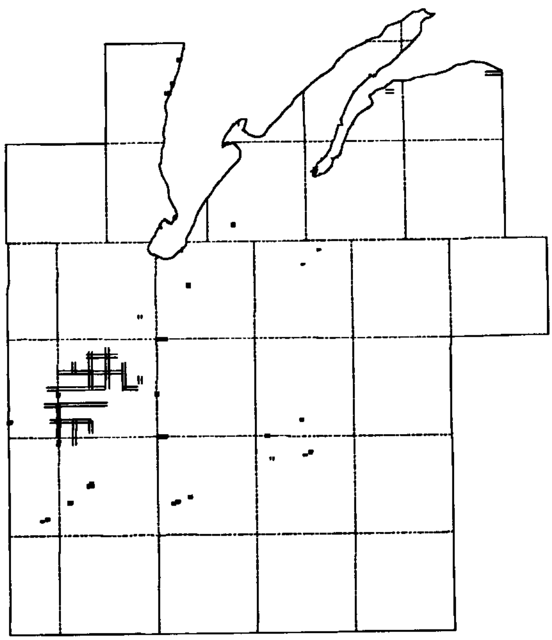


FIG. 6.—Distribution of disturbances, from GLO data. Solid bold lines denote windfalls explicitly indicated in the GLO notes; thin double lines denote burns

is also provided by species distribution maps, which show unusually high densities of (1) white birch and aspen at all edges (Fig. 5D); (2) hemlock at the southern edge (Fig. 4A), and (3) red and white pine at the western and northern limit of the Baraga Plains (Fig. 5B, C).

Sites in other Michigan counties dominated by jack pine were also dry and sandy (Whitney, 1986). Although in other parts of Michigan red pine was a common associate of jack pine (Whitney, 1986), red pine was virtually absent from the jack pine barrens of the Baraga Plains probably because of intense burns just before the survey. On the most xeric sites in southern Michigan, however, jack pine did and still does form dense, nearly pure stands (Whitney, 1986).

White pine, like jack pine, benefits from fire disturbance. Although infrequently present throughout the county, it was recorded most frequently in areas immediately surrounding the Baraga Plains (Fig. 5C). The western part of the Baraga Plains, where white pine was most common, is an area of relatively dry, sandy Haplorthods (Berndt, 1988). As argued above, periodic fires probably swept across the Baraga Plains and may have reached its edges. The soils along the western edge (Rubicon and Rousseau series) are slightly higher in nutrients and water-holding capacity than are the Grayling soils in the center of the plains, and fire probably burned these somewhat moister soils less frequently, permitting white pine to gain dominance over the more xeric jack pine.

The Baraga Plains, with its monospecific jack pine stands surrounded by early successional species, had a forest community like that described on the Yellow Dog Plains of Marquette County, about 60 km to the NE. The Yellow Dog Plains have been dominated by jack pine for ca. 9000 yr, with very stable forest boundaries (Brubaker, 1975). The long-term link of a stable jack pine community and high fire frequencies supports the contention that forest composition and disturbance frequency have been important in the development of sandy Michigan soils (Mokma and Vance, 1989). Those parts of the landscape most prone to fire and associated with xeric jack pine forests are also associated with weakly developed soils, especially the Grayling series. Mesophytic hardwood forests dominated by sugar maple often have the most developed sandy (Kalkaska) soils. Rubicon soils, intermediate in development, were commonly forested with red and white pine. Increased fire frequency, from Kalkaska to Rubicon to Grayling sites, is postulated to not only retard forest succession to more mesophytic species but also to destroy more completely the O horizon (the litter layer), which is the source of organic acids for the podzolization process (Mokma and Vance, 1989; Schaetzl, 1994).

The paucity of burns outside the Baraga Plains suggests that northern hardwood forests in the rest of the county experienced very long fire return times, and were rarely affected by severe fires. In northern Lower Michigan, Whitney (1986) estimated that northern hardwoods forests experienced fire return times of 1389 yrs. Fire return times in northern Wisconsin and other parts of Michigan's Upper Peninsula suggest that severe fire in northern hardwood forests was rare, and played a limited role in forest development (Canham and Loucks, 1984; Frelich and Lorimer, 1991).

Windfall disturbances were also scarce in Baraga County (Table 5, Fig. 5D). Windfalls were uncommon in the presettlement forests of northern Lower Michigan (Whitney, 1986), but apparently somewhat more common in northern Wisconsin (Canham and Loucks, 1984). Data on wind-related disturbances in Baraga County are consistent with more detailed evidence in other parts of northern Michigan that severe windfall disturbance was relatively infrequent (return time over 1500 yr) in northern hardwood forests (Frelich and Lorimer, 1991).

Aspen and white birch, both shade-intolerant species typical of recently disturbed sites, had low G^2 values, indicating their lack of specific site preferences. These species were widespread, with white birch being slightly more common on finer-textured soils as well as on more mesic sites (Table 4; Nowacki *et al.,* 1990). Site factors such as light conditions and the presence/absence of bare mineral soil are potentially more important than soil wetness or texture for these species (Curtis, 1959). The low numbers of aspen and white birch (together comprising less than 3% of all witness trees; Table 2), coupled with the distribution of the windfall-related disturbances present at the time of survey, suggest that large-scale and gap- and patch-type disturbances were not widespread in the mid-19th century in Baraga County. Only near the edges of the wildfire-prone Baraga Plains were aspen and white birch mentioned frequently in section line descriptions and present in moderate densities (Fig. 5D), and here their presence would have been due to repeated fires, not windfalls.

The general absence of northern red oak in Baraga County also supports our contention that disturbance on mesic sites in Baraga County, especially by fire, was spatially restricted (Crow, 1988). Mladenoff and Howell (1980) and Nowacki *et al.* (1990) noted the general unimportance of red oak in presettlement stands in northern Wisconsin, attributing its increased dominance in current stands to postsettlement disturbance. Crow (1988) noted that red oak has similar edaphic requirements to sugar maple, and fire results in the establishment and retention of the oak component of mesic sites (Dorney, 1981). Conflicting findings on the ability of red oak to invade canopy gaps (Kline and Cottam, 1979; Ehrenfeld, 1980), such as those formed by treefalls (Schaetzl *et al.,* 1989), coupled with abundant evidence of its ability to colonize recently burned areas suggest that fire had not been a frequent disturbance factor on mesic sites in Baraga County prior to European settlement. It should be noted, however, that the general absence of red oak in Baraga County may not have been so much due to lack of recent disturbance as lack of a seed source (Oliver, 1978), and the lack of seeds may have been a result of long disturbance-free periods some time before the early 1800's. These findings emphasize the contrast in disturbance regimes (and likely stand age structure) between the northern hardwoods forest of the northern Lake States and the much more disturbance-prone conifer forest types of the same region (Heinselman, 1973, 1981; Frissell, 1973; Swain, 1973; Simard and Blank, 1982; Clark, 1990).

Geographical distributions and edaphic relationships in the presettlement data illustrate the adaptations of species to particular environmental conditions. Our results for soil-species associations agree with other literature on the subject. Soil moisture and texture were important factors in determining the presettlement forest compositions in this county. Windfall disturbance was rare throughout the county. Fires were common in the Baraga Plains, but not elsewhere. There the interaction between disturbance (*i.e.,* fire), soil characteristics (*i.e.,* weakly developed, excessively drained, and sandy soils), and species autecology (*i.e.,* jack pine dominance) were evident.

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