SOIL TEXTURE AND FOREST CHANGE IN NORTHERN LOWER MICHIGAN

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ABSTRACT

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By

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Forest variation through time and space was examined in the study. Two hypotheses were tested to account for variation as expressed by spatial uniformity of composition and amount of temporal forest change over space. One hypothesis was that these two phenomena are related to the local climate. More specifically, the hypothesis was that where the local climate is ameliorated by lake influences in northern Lower Michigan, spatial uniformity of composition will be greater and amount of temporal forest change since postsettlement disturbance will be less. The second hypothesis was that temporal forest change varies with soil texture. More specifically, this hypothesis was that where soil texture is coarser, amount of compositional change since postsettlement disturbance will be greater.

A sampling of the present-day forests of northern Lower Michigan was done in the field under different conditions of local climate and on different soil textures. Similar samples of the presettlement forest were made using data from the General Land Office Survey.

Importance values were calculated for the tree species in the samples, and several indices were derived to determine extent of forest change through time and over space.

It was found that where the local climate has been ameliorated by lake influences, spatial uniformity of the forest communities is greater and amount of compositional change since postsettlement disturbance has been less. Forest change was also found to be related to soil texture, however the relationship was not found to be linear.

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A THESIS

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To my brother, Kevin,

whose handicap has not

prevented him from having

a gentle and loving personality

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CHAPTER I

INTRODUCTION

Many aspects of the forests of northern Lower Michigan have been examined. Generally, these studies have dealt with either variation in composition over space or succession within the forests through time. Few have sought to relate these spatial and temporal variations to specific environmental factors. Climate and soil have been designated as the two general factors that interact with forests to produce changes in forest structure and composition (1), and within northern Lower Michigan, texture has been suggested as the soil property having the greatest influence on forest inter-site compositional variation (2). These two factors, climate and soil texture, were examined herein in hopes of producing a more explicit understanding of their relationship to the spatial and temporal variations of forests.

Two research hypotheses were tested. The first hypothesis was that amount of forest change following disturbance varies with soil texture in a positive and linear way, i.e. as texture becomes coarser, change becomes greater. Assuming uniform histories, coarser textured soils should show greater site degradation and more compositional change than finer soils after disturbance because they are more permeable and, consequently, suffer a greater reduction in base saturation through leaching, especially after vegetation is removed and the soil is exposed to the full impact of the elements. Hence, finer textured soils are generally more fertile and less likely to exhibit a loss in fertility after site disturbance and, therefore, logically should permit a faster return to the original composition.

A second hypothesis was that within northern Lower Michigan, spatial variations in forest composition and amount of temporal forest change are related to differences in the local climate. More specifically, it was hypthesized that where the local climate is ameliorated by lake influences, forest composition will be more spatially uniform, i.e. there will be less inter-site differentiation, and departures of the present composition from that of the presettlement forest will be less. The justification for this hypothesis is that it was thought the amelioration would give a higher percentage of the affected area a mesic character, allowing mesic species to become more widespread, and regeneration to the original composition would thus proceed at a faster rate because the amelioration would mute site changes after disturbance. Hence, the present forests will show less change and more closely resemble the presettlement composition. Because the ameliorating influence generally diminishes with distance from Lake Michigan, spatial variation in forest composition was hypothesized to decrease and amount of compositional change through time to increase with increasing distance from Lake Michigan.

Samples of forest composition were made within northern Lower Michigan in the fall of 1972 on varying soil textures and at various distances from Lake Michigan. A quantitative reconstruction of the presettlement forest composition on similar sites was made from field notes of the General Land Office Survey. Comparison of vegetation change was then made between the presettlement and modern composition on each soil type. Spatial variation was determined by comparing several indices of vegetational uniformity as well as amount of change in composition through time between varying distances from Lake Michigan.

CHAPTER I--LITERATURE CITED

1. Spurr, S. H. 1964. Forest Ecology. The Ronald Press Co., New York. pp. 3-4.

2. Nichols, G. E. 1935. "The hemlock-white pine-northern hardwood forest region of eastern North America." Ecology 16:403-422.

CHAPTER II

DESCRIPTION OF THE STUDY AREA
(THE PHYSICAL SETTING)

Northern Lower Michigan was the area selected for testing the hypotheses of the study. This area was chosen primarily for the following reasons: first, forest covers a greater percentage of the landscape compared to other regions easily within the author's access; second, there is a "lake influence" that varies in significance over the area's range, which figured prominently in one of the study's hypotheses; third, original land survey records were easily accessible for the area; and fourth, the author's slight familiarity with the area, which facilitated automobile reconnaissance. Within this general area samples were obtained from Antrim County in northwestern Lower Michigan and Montmorency County in northeastern Lower Michigan (Figure 1). These two counties were chosen for sampling because each still remained heavily wooded (60.79% of the total area of Antrim County and 80.80% of Montmorency County), (1), each was surveyed and mapped by soil type, a necessity for hypothesis testing, and each is affected to different degrees by climatic modification from Lake Michigan.

Physiographically, northern Lower Michigan has been classified as part of the Great Lake Section of the Central Lowlands Province (2). This entire province is characterized by topography that is dominantly a result of Pleistocene glaciation processes. Numerous lakes, poor

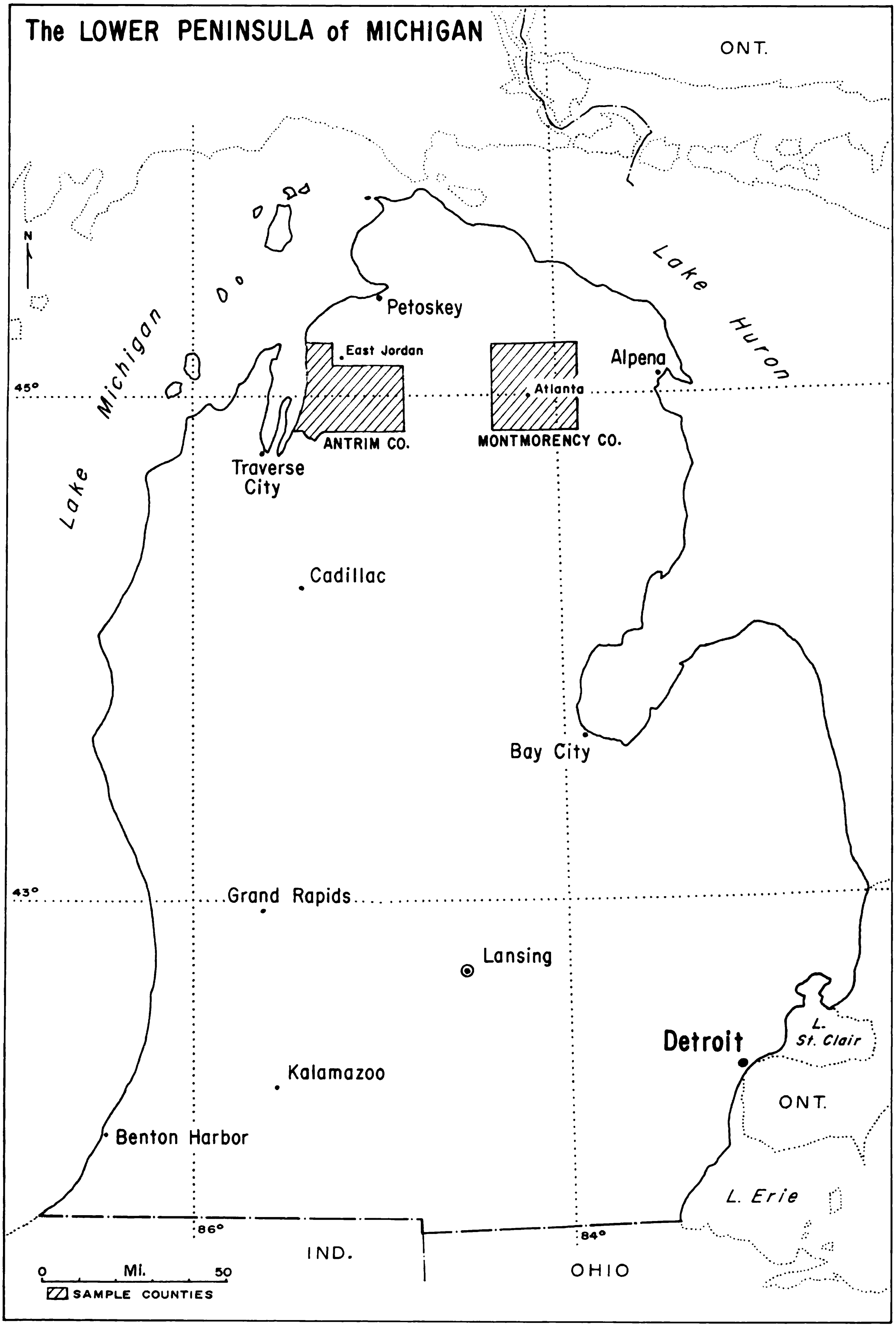
The LOWER PENINSULA of MICHIGAN
ONT.
N
Lake Huron
Lake Michigan
Petoskey
East Jordan
Alpena
45°
Atlanta
ANTRIM CO.
MONTMORENCY CO.
Traverse City
Cadillac
Bay City
43°
Grand Rapids
Lansing
Detroit
L. St. Clair
ONT.
Kalamazoo
Benton Harbor
L. Erie
86°
84°
IND.
OHIO
0 MI. 50
SAMPLE COUNTIES

Figure 1.

drainage, and young, primarily depositional, topography are relatively more common in the Great Lake Section than others of the province (3). The two sample counties were both covered by the last two Wisconsinan ice advances to affect the Central Lowlands, the Port Huron and Valders substages (4, 5), and their present surface relief is primarily a result of deposition from these substages over the pre-existing topography. The Valders ice sheet began retreating from the study area around 11,000 years ago (5, 6), and since that time both counties have been free of glacial ice.

The maximum extent of the Port Huron and Valders ice sheets is marked by the Port Huron Moraine (5). This prominent morainic system passes through both Antrim and Montmorency counties (7). Other topographic features common to both counties are large expanses of outwash plain, ground moraine, and former lake beds. Drumlins, a rather unique glacial feature, are common in the western portions of Antrim County as well as adjacent Charlevoix County. Because glacial deposition was so recent, evidence of stream erosion is slight throughout northern Lower Michigan. Thus, in the two sample counties swamps and numerous lakes are common and streams are few and small. This is mainly due to the youth of the topography, but also because of the large areal extent of pervious sand and gravel in both counties (8, 9).

In most of Montmorency County elevations range from 900 to 1,100 feet above sea level. The highest parts of the country are at the south and southwest, reaching between 1,200 and 1,300 feet, and the lowest are at the eastern county line along the Thunder Bay River, reaching only 700 or 800 feet (8). In Antrim County the local relief is more heterogeneous. It is greatest in the west and central portions and generally more plain-like in the southeast. Elevation ranges from about 580 feet at the shore of Grand Traverse Bay on the west to about 1,300 feet in the eastern part of the county (9).

The mineral soils of northern Lower Michigan fall into the great soil group known as podzol* (10, 11).† Podzolic soils are characteristic of cool, humid forested regions. Their profiles typically show strong horizon differentiation and have, to some degree, an organic layer, a very thin organic-mineral layer, a gray leached layer, and a dark colored illuvial layer in sequence from the top (12).

In each of the sample counties the soil types range in texture from loam to sand, but the extent of coarse textured soils in each is considerable compared to most other areas of Michigan. About 60% of the total land area in Montmorency County and about 50% in Antrim County is composed of sand and loamy sand textured soils, and another 16% in the former and 40% in the latter is of a sandy loam texture (Table 1).

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* Soils known as podzols in the older classification are included in the order "spodosol" in the new U.S.D.A. classification (12).

† Non mineral or organic soils are generally limited to poorly drained areas and are of small extent in Montmorency and Antrim Counties.

Table 1. Percentage of total land area in each soil textural class in each sample county.

	Sand	Loamy sand	Sandy loam	Loam, silt loam and clay loam	Organic soils	Total
Montmorency Co.	43.3	17.7	16.1	9.0	13.9	100
Antrim Co.	47.3	0	39.8	5.3	7.6	100

(Adapted from Veatch *et al.*, 1928 and 1930), (8, 9).

Within Antrim County most soils fall into four soil series: Onaway (Alfic Haplorthods)*, Kalkaska (Typic Haplorthods), Emmet (Alfic Haplorthods), and Rubicon (Entic Haplorthods). In Montmorency County four series also predominate: Emmet, Rubicon, Grayling (Spodic Udipsamments), and Montcalm (Alfic Haplorthods), (Table 2). Soil series differ from one another in fundamental ways. Most of these differences, though, can be traced to the nature of the parent material from which the series was derived; all soils of a particular series have developed from the same parent material and have been modified into textural types by other soil forming factors (12).

* The tentative subgroup into which each series is placed in the new U.S.D.A. classification system is given in parentheses (13).

Table 2. Percent area of important soils in each sample county*

	Onaway sandy loam	Kalkaska sand	Emmet sandy loam	Rubicon sand	Grayling sand	Montcalm loamy sand
Montmorency Co.	0	0	11.9	22.0	14.0	11.2
Antrim Co.	14.1	23.2	11.1	20.2	0	0

(Adapted from Veatch *et al.*, 1928 and 1930), (8, 9).

Two of the four extensively occurring soil series in Antrim County have developed from sandy parent materials which are medium acid in reaction and low or very low in lime, and two have developed from sandy or silty parent materials which are calcareous in reaction and high to moderate in lime (Table 3). The former two series (Kalkaska and Rubicon) are found mostly in the eastern half of Antrim County and the latter two (Onaway and Emmet) mostly in the western half. This distribution is probably related to both the underlying bedrock lithology and the local depositional environment (9).

In Montmorency County three of the four extensively occurring soil series (Rubicon, Grayling, and Montcalm) are derived from sandy parent materials. The Emmet series alone is derived from sandy loam parent material which is of calcareous reaction and high to moderate

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* Kalkaska sand and Montcalm loamy sand were formerly named Emmet sand and Roselawn sandy loam, respectively, in these counties and Rubicon sand presently incorporates <u>two</u> soils that were formerly differentiated into types on the basis of topography, namely "Rubicon sand" on the level sites and "Roselawn sand" on the rolling sites (14).

Table 3. General physical and chemical properties of extensively occurring soil series in the sample counties (15).

Soil series	County where most extensive A=Antrim M=Montmorency	Amount of lime present in parent material	Texture of parent material	Color of parent material	Reaction of parent material	Permeability
Onaway	A	High to Moderate	Silt Loam	Light Brown & Brown	Calcareous	Moderate to Moderately Slow
Kalkaska	A	Low or Very Low	Sand	Light Yellowish Brown	Medium Acid	Rapid
Emmet *	A, M	High to Moderate	Sandy Loam	Brown	Calcareous	Moderate
Rubicon	A, M	Low or Very Low	Sand	Light Yellowish Brown	Medium Acid	Rapid to Very Rapid
Grayling	M	Low or Very Low	Sand	Pale Brown	Medium to Slightly Acid	Very Rapid
Montcalm	M	Low	Loamy Sand to Sand	Pale Brown to Yellowish Brown	Slightly Acid to Neutral to Calcareous	Moderate to Rapid

* Although the Emmet series is developed from a calcareous parent material, it does not retain its calcareous nature in the upper layers of its horizons as does the Onaway series (15).

in lime. It is confined mostly to the west central portion of the county, but also occurs in small to medium size patches throughout. Except in the northern part of Montmorency County where some soils show "an appreciable influence . . . from the (nearby) Devonian and Silurian formation," little influence is exerted on the soils by the preglacial bedrock, because of the thickness of glacial deposits (8). Thus, in Montmorency County the parent material of the mineral soils is mostly sandy and acid in reaction except in the few areas where the Emmet series is extensive or in the north where some less extensive series have parent materials derived from nearby calcareous lithologic formations.

The climate of northern Lower Michigan has been classified as a humid continental cool summer type (16). It is characterized by rigorous winters, short mild summers, and a large number of cloudy days (8, 9). It also varies somewhat from coastal to interior locations because of the influence of the Great Lakes but particularly Lake Michigan because of its upwind location (17). The sum effect of this "lake influence" in terms of environmental stress is to ameliorate the climate to some degree on the lee side of the lakes, particularly in coastal areas (Table 4).

Although the weather stations of Table 4 are at nearly identical latitudes, East Jordon, located in the immediate lee of Lake Michigan, has somewhat warmer mean monthly temperatures and more even distribution of precipitation than Atlanta. The amelioration is perhaps best illustrated, though, by the difference in the mean length of the freeze-free period at the two locations; it averages 24 days longer at East Jordan.

Table 4. Representative climatic data for northern Lower Michigan (16).

East Jordan, Charlevoix Co. (western coastal)

Months	J	F	M	A	M	J	J	A	S	O	N	D	Year
Mean monthly temps. (°F.)	21.0	20.6	28.7	43.0	53.6	63.6	67.8	66.7	59.2	50.0	37.2	26.1	44.8
Mean monthly precip. (in.)	1.86	1.16	1.52	2.58	3.04	3.21	2.18	3.03	3.99	2.89	3.37	1.99	31.45
Mean length growing season	120 days												

Atlanta, Montmorency Co. (eastern interior)

Months	J	F	M	A	M	J	J	A	S	O	N	D	Year
Mean monthly temps (°F.)	18.7	19.8	28.0	42.3	53.2	63.3	67.1	65.4	57.9	48.6	35.4	23.7	43.6
Mean monthly precip. (in.)	1.30	1.06	1.37	2.37	2.85	3.21	3.01	2.98	3.25	2.15	2.29	1.38	27.22
Mean length growing season	96 days												

The lake influence is minimal in Montmorency County because of both its interior position and sheltered location to the east of an upland (17). In western locations including Antrim County, however, "the influence of Lake Michigan is significant throughout most of the year" (17). The climate of northern Lower Michigan thus varies from a predominantly continental type in the interior to one of quasi-marine characteristics in the west.

The presettlement vegetation of northern Lower Michigan has been classified as part of the Hemlock-white pine-northern hardwoods region (18). This region was characterized as a mosaic of predominantly deciduous, predominantly coniferous, and mixed forest communities. The deciduous and mixed forest communities occurred on the mesic sites, while two different coniferous communities were found on the xeric and hydric sites (19). The mesic forests consisted mostly of sugar maple *(Acer saccharum)*, beech *(Fagus grandifolia)*, and hemlock *(Tsuga canadensis)*, with some intermixture of yellow birch *(Betula allegheniensis)*, basswood *(Tilia americana)* and white pine *(Pinus strobus)*. The xeric forests consisted mostly of jack pine *(Pinus banksiana)*, red pine *(Pinus resinosa)*, and white pine, inhabiting progressively more mesic sites, respectively, and the hydric forests consisted mostly of black spruce *(Picea mariana)*, arborvitae *(Thuja occidentalis)*, and larch *(Larix laricina)*. Due to postsettlement disturbance, however, the modern vegetation of northern Lower Michigan varies somewhat from the presettlement pattern. The greatest changes have been in the reduction of certain coniferous species, such as white pine, red pine, and hemlock, and the proliferation of certain successional species, such as jack pine on the most xeric sites (20) and aspen *(Populus* sp.*)* on most other sites (21).

The two sample counties conform to these typical vegetational patterns to a high degree. Nearly all of the forest communities characteristic of the Hemlock-white pine-northern hardwoods region were present in the presettlement forests of each (8, 9). In Antrim County the hardwood communities were of greatest extent, but conifers were abundant in some areas (9). In Montmorency County the original forest cover appears to have been more heterogeneous with a greater intermixture of coniferous and deciduous communities (8).

Thus, to summarize, the two sample counties have similar topography of glacial origin, though in Antrim County the surface relief is greater in some locations. Both have extensive areas of coarse textured soils in which the lime content of the parent material varies. Local differences in climate occur due primarily to the influence of Lake Michigan, with Antrim County being the more "marine" in character and Montmorency the more "continental". And both are included in the same natural vegetation region, though in Antrim County the original forest appears to have consisted of a greater percentage of deciduous communities.

CHAPTER II--LITERATURE CITED

1. Pfeifer, R. E. and Spencer, J. S. 1966. The Growing Timber Resource of Michigan: Northern Lower Peninsula. Michigan Dept. of Natural Resources, Lansing, Mich. p. 38.

2. Fenneman, N. M. 1938. Physiography of Eastern United States. McGraw-Hill Book Co., New York.

3. Thornbury, W. D. 1965. Regional Geomorphology of the United States. John Wiley and Sons, Inc., New York. p. 228.

4. Horberg, L. 1956. "Bedrock topography and Pleistocene glacial lobes in central United States." Jour. Geol. 64:101-116.

5. Hough, J. L. 1958. Geology of the Great Lakes. Univ. of Ill. Press, Urbana.

6. Flint, R. F. 1957. Glacial and Pleistocene Geology. John Wiley and Sons, Inc., New York.

7. Martin, H. M. 1955. "Map of the surface formations of the southern peninsula of Michigan." Publ. 49., Dept. of Natural Resources, Lansing, Mich.

8. Veatch, J. O., *et al.* 1930. Soil Survey of Montmorency County, Michigan. U.S. Govt. Printing Office, Washington, D.C.

9. _______, *et al.* 1928. Soil Survey of Antrim County, Michigan. U.S. Govt. Printing Office, Washington, D.C.

10. _______. 1932. "Soil maps as a basis for mapping original forest cover." Pap. Mich. Acad. Sci., Arts, and Letters. 15:267-273.

11. Whiteside, E. P., *et al.* 1968. Soils of Michigan. Co-op. Ext. Ser., Agr. Exp. Sta., Mich. State Univ., E. Lansing. p. 8.

12. Miller, C. E., *et al.* 1965. Fundamentals of Soil Science. John Wiley and Sons, Inc., New York. pp. 267-269, 471.

13. Schneider, I. F., *et al.* 1967. "Tentative placements of Michigan soil series in the new soil classification system." Mimeographed paper, Dept. Soil Sci., Mich. State Univ., E. Lansing.

14. Personal communication from Dr. E. Whiteside of the Soil Science Dept. at Michigan State Univ., E. Lansing, April 5, 1973.

15. Taken from soil series description sheets secured from the Soil Science Dept. at Michigan State Univ., E. Lansing.

16. Trewartha, G. T. 1954. An Introduction to Climate. McGraw-Hill Book Co., New York.

17. Climate of Michigan By Stations. 1971. Mich. Dept. of Agriculture (Mich. Weather Service), E. Lansing.

18. Braun, E. L. 1950. Deciduous Forests of Eastern North America. The Blakiston Co., Philadelphia. (Republished in 1972 by Hafner Pub. Co., New York.)

19. Nichols, G. E. 1935. "The hemlock-white pine-northern hardwood forest region of eastern North America." Ecology 16:403-422.

20. Roth, F. 1902. "The jack pine plains of Michigan." Forestry and Irrig. 8:413-416.

21. Gates, F. C. 1930. "Aspen association in northern Lower Michigan." Bot. Gaz. 90:233-259.

CHAPTER III

REVIEW OF THE LITERATURE

The present-day variation in composition of the Hemlock-white pine-northern hardwoods region as defined by Braun (1) and Nichols (2) has been studied extensively. Most of these studies have dealt with composition of undisturbed forest stands, but secondary vegetation is by far most characteristic of the region today, especially in the Great Lakes area (1). The region extends from northern Minnesota and southeastern Manitoba across southern Canada and the northern Great Lakes to New England, most of New York, and northern Pennsylvania with outliers occurring as far south in the Allegheny Mountains as West Virginia (1). Two main divisions have been recognized, the Great Lakes-St. Lawrence Division in the west and the Northern Appalachian Highland Division in the east; red spruce *(Picea rubens)* and hemlock *(Tsuga canadensis)* occur much more abundantly in the eastern division, whereas white pine *(Pinus strobus)* is more likely to have climax or terminal status in the western division (1). Distinctive physiographic sub-climaxes also occur in the region (1, 2). These are the pine communities, consisting of white, red *(Pinus resinosa)*, or jack *(Pinus banksiana)* pine, on the xeric sites and the swamp forests or bog communities, consisting of elm *(Ulmus* sp.*)*-ash *(Fraxinum nigra)*-red maple *(Acer rubrum)* or larch *(Larix laricina)*, black spruce *(Picea mariana)*, and/or arborvitae *(Thuja occidentalis)*, respectively, on the hydric sites.

Nichols noted that the region is made up of four groups of tree species whose ranges overlap. These are: (1) species primarily of the boreal forest, whose centers of distribution are north of the region (balsam fir, *Abies balsamea*), white *(Picea glauca)* and black spruce, larch, and jack pine), (2) species whose ranges lie within the region and extend little beyond it (hemlock, white and red pine, and yellow birch *(Betula allegheniensis)*, (3) species whose ranges are within the region but which also range well south of it (sugar maple, *Acer saccharum)*, and basswood *(Tilia americana)*, and (4) species primarily of the eastern deciduous forest, whose centers of distribution are south of the region (beech, *Fagus grandifolia*), and white ash *(Fraxinus americana)*, (2). Thus, the region is a transition between the deciduous and boreal forest formations, but also contains some uniquely characteristic elements, as listed in group two (2, 3).

An opposing view to the distinctiveness of the Hemlock-white pine-northern hardwoods region has been voiced by Maycock and Curtis (4). They contend that the forests of the Great Lakes area represent a vegetational gradient from north to south with a more or less continuously varying nature, i.e. that the broadleaved forests of the south continuously become more coniferous in composition moving northward. Thus, they state, "to imply that any one of the many possible phases of community structure is either distinctively of one type or the other, or possesses a nature entirely its own is to refute this continuous nature."

Flaccus and Ohmann support this continuous view from their work on northern hardwood stands in northeastern Minnesota (5). They show that conifers are more important in the north than south of their study area, with basswood completely lacking in the north but becoming a third major dominant southward.

One of the primary factors responsible for change in forest composition is the nature of the site, or habitat, that the forest occupies. Climate and soil conditions have been noted as the two broad controlling influences that determine the quality of a forest site (6). The influence of soil properties on forest composition has been elucidated for some time. As early as 300 B.C. the Greek, Theophrastus, concluded after studying the vegetation in his locality that it was differences in the soil that accounted for differences in the vegetation types (7). The profound influence that climate has on the distribution of vegetation, as well as soil groups, was probably first realized by Russian soil scientists (8). More recently, Wilde has summed up these influences by stating that, "climatic factors are responsible in a large scale for the boundaries of distribution of forest species, while the soil determines more precisely the composition of the main forest stand, the occurrence of shrubby and herbaceous vegetation, the intensity of growth, the possibility of natural reproduction, etc." (9).

In northern Michigan, environmental factors exert a significant influence on forest composition. Two forest types dominate the Porcupine Mountains of western Upper Michigan (10). The more extensive type has been found to consist largely of sugar maple, but a more mesic hemlock forest was found on the north slope of the range closest to Lake Superior whose presence was attributed to the generally cooler, moister environment found on that site.

Westveld arrived at the same conclusion concerning hemlock in his study of forest composition on different soil types across Upper Michigan (11). Also, sugar maple and beech were found to be most abundant on loams, sandy loams, and loamy sands, whereas American elm *(Ulmus americana)* was most abundant on moist soils and basswood was confined largely to heavier loams or calcareous soils. Yellow birch, balsam fir, and ironwood *(Ostrya virginiana)* were found to be equally abundant on practically all soil types studied.

Working in Roscommon and Crawford Counties in northern Lower Michigan in 1902, Livingston attempted to relate the original forest cover to different soil types (12). He found that hardwoods (consisting mainly of sugar maple, beech, and some hemlock), white pine, red pine, and jack pine were found on progressively droughtier and coarser textured soils, respectively. He concluded that "the main factor in determining the distribution of forests on the uplands of this region is that of the size of soil particles." In a later, more geographically extensive study in northern Lower Michigan, Harper arrived at the same conclusion (13).

Gleason concluded from his study of "maple-beech" communities in northern Lower Michigan that composition of the hardwood forests is primarily a function of available soil moisture (14). Benninghoff and Gebben, also working with beech-maple stands, stated that "within the

Lower Peninsula beech-maple communities are of the nature of edaphically selected segregates within the oak-hickory region in the south and within the hemlock-white pine-northern hardwoods in the north" (15).

Forest succession in northern Michigan as well as post-Pleistocene phytogeographic changes, also received considerable attention. Potzger and his associates in a number of studies, working with fossil pollens from bogs, found that the general succession has gone from forests dominated by spruce after the close of the Pleistocene to an association of pine dominance and finally to a hemlock-deciduous association which dominates the undisturbed forest stands of northern Michigan today (16, 17, 18, 19). They have also attempted to correlate these successional changes with changes in climate and migration of species northward since the Pleistocene. In an early study Wilson and Potzger showed that the hemlock-deciduous species of the latest successional stage have not been as important in Montmorency County around Middle Fish Lake as northward in Cheboygan County around Douglas Lake (16). In Montmorency County pine pollen has remained very important up to the present.

Succession was probably first studied in northern Michigan by Beal in 1888 (20). He was concerned with explaining why secondary growth was different from the original. Roth later noted that jack pine was the most abundant secondary growth on logged over sandy areas of northern Michigan (21). Gates, however, concluded that on more mesic sites the aspen association made up the most extensive secondary vegetation and would remain so when fires occurred at infrequent intervals (22, 23).

In 1900 and 1901 Cowles set forth his ideas on "physiographic ecology" which attempted to relate forest succession to the physiographic or geomorphic cycle (24, 25). He noted that in recently glaciated areas, where the topography has not been subjected to much erosion, such as in Michigan, many hydrophytic and xerophytic sites exist as well as the mesophytic ones, and each of these sites is inhabited by a different vegetational assemblage. With time, he contended, erosion would ultimately make the area completely mesophytic, and the mesophytic assemblage would then inhabit the entire region. He also pointed out that evolution to a mesophytic condition is more rapid on clay than sand "because of the ease with which water is held and humus formed" in the former, while sand "possesses opposite physical characteristics" (24).

Whitford followed Cowle's ideas in the study of forest development in northern Michigan (26). He concluded that in evolution to a mesophytic condition, southern deciduous species were displacing the northern conifers, and that the whole lower peninsula "would support a beech-maple association given time for vegetation to come into equilibrium with the climate." He also noted that the advance toward the climatic climax is more rapid on clayey soils than on coarser ones.

The idea that the forest of Lower Michigan would eventually succeed to a beech-maple climax association was again echoed in later studies by Quick (27), Gates (28), and Elliot (29). Elliot even suggested that "the northern portion of Michigan's lower peninsula should not be considered as a part of the mixed conifer-northern hardwood forest of eastern North America, but that the coniferous species play a relic role in a deciduous forest community as climax."

One of the more recent innovations in the study of forest succession from presettlement to modern times has been the use of original land survey data (30). Lutz (31), Stearns (32), Potzger, *et al.* (33), and Lindsey, *et al.* (34) have provided noteworthy examples of its use outside of Michigan, while in Michigan Kenoyer (35), Elliot (29), and Hushen, *et al.* (36) have made use of it in their studies.

The studies by Elliot and Hushen, *et al.*, are particularly noteworthy because the former was made in northern Lower Michigan and the later at the "tension zone" between the Hemlock-white pine-northern hardwoods region and the Beech-maple region as defined by Braun (1). Elliot examined the composition of secondary forests on various soil types and compared the overall composition in his study area to the presettlement composition. He noted that there was a great reduction in coniferous species in the later forests. Hushen, *et al.*, determined the relative dominance and relative density of the presettlement forest trees on various soil types, but did not quantitatively compare the early forest composition to the present-day forests.

In a final study concerning the rate of secondary forest succession in northern Michigan, Voss staked out quadrats in "representative stands of hardwoods, bog forest, aspens, and jack pines" on soils that had been recently denuded from the laying of a pipeline (37). He concluded after studying the quadrats periodically for more than a decade that "the area which promised to return most rapidly to a forest cover was the one in the hardwoods," and that the jack pine stand showed the poorest rate of succession.

Thus, change in composition from presettlement to modern forests has been studied (29, 31, 32, 33, 34, 35, 36), and soil texture has been related to secondary forest composition (29) and presettlement forest composition (12, 36). Rate of succession has also been noted in various forest types (37), but evidently no study from northern Michigan has sought to relate rate of succession or amount of change in forest composition to soil texture or climate, except in a vague theoretical sense (16, 17, 18, 19, 24, 25, 26, 27).

CHAPTER III--LITERATURE CITED

1. Braun, E. L. 1950. Deciduous Forests of Eastern North America. The Blakiston Co., Philadelphia. (Republished in 1972 by Hafner Pub. Co., New York.) pp. 337-440. 306.

2. Nichols, G. E. 1935. "The hemlock-white pine-northern hardwood forest region of eastern North America." Ecology 16:403-422.

3. Frothingham, E. H. 1915. "The northern hardwood forest: its composition, growth and management." U.S.D.A. Bull. 285.

4. Maycock, P. and Curtis, J. T. 1960. "The phytosociology of boreal and conifer-hardwood forests of the Great Lakes Region." Ecol. Monogr. 30:1-35.

5. Flaccus, E. and Ohmann, L. F. 1964. "Old-growth northern hardwood forests in northeastern Minnesota." Ecology 45:448-458.

6. Spurr, S. H. 1964. Forest Ecology. The Ronald Press Co., New York. pp. 3-4.

7. Theophrastus. 1965. "Enquiry into plants." in Readings in Ecology. Kormondy, E. J. (ed.), Prentice-Hall, Inc., Englewood Cliffs, New Jersey. pp. 2-4.

8. Glinka, K. 1914. Die Typen der Bodenbildung. Berlin, Germany. (Translated into English as: Marbut, C. F. 1927. The Great Soil Groups of the World and Their Development. Edwards Bros., Ann Arbor.)

9. Wilde, S. A. 1933. "The relation of soils and forest vegetation of the Lake States region." Ecology 14:94-105.

10. Darlington, H. T. 1930. "Vegetation of the Porcupine Mountains, northern Michigan." Pap. Mich. Acad. Sci., Arts, and Letters. 13:9-65.

11. Westveld, R. H. 1933. "The relation of certain soil characteristics to forest growth and composition in the northern hardwood forest of northern Michigan." Mich. Agr. Expt. Sta. Tech. Bull. 135:51 pp.

12. Livingston, B. E. 1905. "The relation of soils to natural vegetation in Roscommon and Crawford Counties, Michigan." Bot. Gaz. 39:22-41.

13. Harper, R. M. 1918. "The plant population of northern Lower Michigan and its environment." Bull. Torr. Bot. Club. 45: 23-42.

14. Gleason, H. A. 1924. "The structure of the maple-beech association in northern Michigan." Pap. Mich. Acad. Sci., Arts, and Letters. 4:285-296.

15. Benninghoff, W. S. and Gebben, A. I. 1960. "Phytosociological studies of some beech-maple stands in Michigan's Lower peninsula." Pap. Mich. Acad. Sci., Arts, and Letters. 45:83-91.

16. Wilson, L. R. and Potzger, J. E. 1943. "Pollen study of sediments from Douglas Lake, Cheboygan County and Middle Fish Lake, Montmorency County, Michigan." Ind. Acad. Sci. Proc. 52:87-92.

17. Potzger, J. E. 1946. "Phytosociology of the primeval forest in Central Northern Wisconsin and Upper Michigan, and a brief post-glacial history of the lake forest formation." Ecol. Monogr. 16:211-250.

18. ________. 1948. "A pollen study in the tension zone of Lower Michigan." Butler Univ. Bot. Stud. 8:161-177.

19. Zumberge, J. H. and Potzger, J. E. 1956. "Late Wisconsin chronology of the Lake Michigan basin correlated with pollen studies." Bull. Geol. Soc. Amer. 67:271-288.

20. Beal, W. J. 1888. "Observation on the succession of forests in northern Michigan." Bot. Gaz. 13:239-240.

21. Roth, F. 1902. "The jack pine plains of Michigan." Forestry and Irrig. 8:413-416.

22. Gates, F. C. 1912. "The vegetation of the region in the vicinity of Douglas Lake, Cheboygan County, Michigan." Ann. Rep. Mich. Acad. Sci. 14:46-106.

23. ________. 1930. "Aspen association in northern Lower Michigan." Bot. Gaz. 90:233-259.

24. Cowles, H. C. 1900. "The physiographic ecology of northern Michigan." Science 12:708-709.

25. ________. 1901. "The physiographic ecology of Chicago and vicinity: a study of the origin, development, and classification of plant societies." Bot. Gaz. 31:73-108, 145-182.

26. Whitford, H. N. 1901. "The genetic development of the forest soils of northern Michigan; a study in physiographic ecology." Bot. Gaz. 31:289-325.

27. Quick, B. E. 1923. "A comparative study of the distribution of the climax association in Southern Michigan." Pap. Mich. Acad. Sci., Arts, and Letters. 3:211-245.

28. Gates, F. C. 1926. "Plant succession about Douglas Lake, Cheboygan County, Michigan." Bot. Gaz. 82:170-182.

29. Elliot, J. C. 1953. "Composition of upland second growth hardwood stands in the tension zone of Michigan as affected by soils and man." Ecol. Monogr. 23:271-288.

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

31. Lutz, H. J. 1930. "Original forest composition in northwestern Pennsylvania as indicated by early land survey notes." Jour. Forestry. 28:1098-1103.

32. Stearns. F. W. 1949. "Ninety years change in a northern hardwood forest in Wisconsin." Ecology 30:350-358.

33. Ptozger, J. E., *et al.* 1956. "The forest primeval of Indiana as recorded in the original U.S. land surveys and an evaluation of previous interpretations of Indiana vegetation." Butler Univ. Bot. Stud. 13:95-111.

34. Lindsey, A. A., *et al.* 1965. "Soil relations and distribution map of the vegetation of presettlement Indiana." Bot. Gaz. 126:155-163.

35. Kenoyer, L. A. 1934. "Forest distribution in southwestern Michigan as interpreted from the original land survey (1826-32)." Pap. Mich. Acad. Sci., Arts, and Letters. 19:107-111.

36. Hushen, T. W., *et al.* 1966. "Presettlement forest patterns in Montcalm County, Michigan." Mich. Bot. 5:192-210.

37. Voss, E. G. 1965. "Comparative revegetation of denuded areas in northern Michigan." Pap. Mich. Acad. Sci., Arts, and Letters. 50:139-160.

GENERAL REFERENCES

Ching, K. K. 1954. Forest Succession on the Well-Drained Soils in the Higgins Lake Area of Michigan. Ph.D. Thesis, Mich. State Univ., E. Lansing.

Clayberg, H. D. 1920. "Upland societies of Petoskey-Walloon Lake region." Bot. Gaz. 69:28-53.

Cooper, W. S. 1913. "The climax forest of Isle Royale and its development." Bot. Gaz. 55:1-44, 115-140, 189-235.

Graham, S. A. 1941. "Climax forests of the Upper Peninsula of Michigan." Ecology 22:355-362.

Ku, T. 1954. Forest Succession on the Poorly-Drained Soils in the Higgins Lake Area of Michigan. Ph.D. Thesis, Mich. State Univ., E. Lansing.

CHAPTER IV

METHODS

Field Methods

Twenty-six forest stands were sampled in the field representing seven different soil types. The stands were selected on the following basis: first, they had to be located on one of the soil types under consideration. This was determined by using a soil map during automobile reconnaissance and locating only stands within areas that were mapped under one of the soil types used in the study. The soil types used were selected because of their wide extent within the county and their variation in textural properties from other soils being used. Second, on each soil type a wide geographic, or spatial, distribution of stands was sought, in an attempt to reduce the effect of variation in forest composition that might have been induced by local factors, such as recent disturbance due to logging or fire. Third, in accordance with the second criterion, only stands that had not been recently disturbed were selected. Since all stands were second growth and had been disturbed to some degree, though, this criterion was somewhat more subjective than the others. Fourth, only stands that were located on well drained upland sites were selected in order to eliminate the effect that excessive moisture would have on forest composition. Fifth, whenever possible, only stands that were of a fairly large size were selected so that sampling could be carried on within the stand at a distance greater than 75 feet from the forest's edge to reduce any "edge effect" on the composition.

The point-quarter method was used for sampling the stands (1). Several transects were made through the stand, each consisting of sample points 20 or more paces apart, depending on the density of the forest, i.e. greater distance between sampling points was required in more open forests to avoid sampling the same trees twice. The species name and d.b.h. (diameter at breast height) of the tree nearest to the sample point in each quarter around the point as well as its distance from the point was recorded on a sample sheet for each stand (Appendix I). Only trees with a d.b.h. greater than 2 inches were sampled.

It has been suggested that out of the variety of forest sampling procedures currently accepted, the point-quarter method yields the greatest amount of information per sampling time involved (2). Others have indicated that in very low density vegetation other methods may be more appropriate (3), but this method is essentially the same as that used in the General Land Office Survey of presettlement forests (1, 4). Since data from that survey were used to construct the presettlement forest composition of the sample counties, the point-quarter method appeared the most logical choice to use in the field survey to facilitate comparison between the presettlement and modern samples.

The number of trees samples per stand was based on a qualitative evaluation of the forest composition. Generally, sampling was terminated when the data collected from each woodlot appeared to reflect accurately the composition of the stand. Consequently, stands that were composed primarily of only one or two tree species, such as jack pine *(Pinus banksiana)* forests, required a smaller sample than more heterogeneous stands, such as the beech-maple *(Fagus-Acer)* hardwood forests. A more quantitative method of determining sample size based on a "species-area curve" has been elucidated (5). Because it was doubtful this method would give much more accurate results than the one used, however, and because of its time-consuming nature, it was not utilized in the present study.

Archival Methods

General Land Office Survey field notes for the state of Michigan were the primary source of data for constructing a quantitative sample of the presettlement forests of the sample counties. These field notes are located at the Land's Division of the Michigan Department of Natural Resources in Lansing, Michigan. The procedure for constructing presettlement forest composition from these notes has been outlined elsewhere (6). That outline was followed in this study with the exception that distance between trees was not calculated because it is a time-consuming procedure, and its contribution to the solution of the problem did not appear to justify its calculation.

Briefly, the procedure consisted of first identifying a township to be sampled from a soils map of the respective sample county and then locating the correct volume of field notes for the township. Reading through the volume and correlating the surveyor's transects and survey posts with locations on the soils map was the next step.

After the site of a survey post was located on the soils map, witness trees were included in the sample if the survey post was located well within the boundaries of one of the soil types predetermined for sampling and two or more trees were recorded. The survey post location was then noted with a pencil mark directly on the soils map, a precaution to avoid using a point more than once. The point location was then recorded on a sample sheet for that county and soil type (Appendix I), and the species name and diameter of the witness trees selected around the point were recorded next to it.

As with the modern field survey, the sample size selected for each soil type in the archival sample depended on the diversity of tree species present. Generally, when each soil type-sample contained a large number of trees and no new species were being encountered with further sampling, the sample was terminated. Also, a wide distribution of sample points throughout each county was generally sought to reduce the effect of any local disturbances that might have been present at that time. In one instance, when the areal extent of a soil type was comparatively small within the sample county and thus would have yielded only a very small number of sample points, the sample was extended onto a contiguous area covered by the soil type in an adjoining county.

Analysis of Data

The data gathered in the field and from archival samples were used to derive values pertaining to forest composition. These values were relative density, relative dominance, relative frequency, and importance value. The procedure for their calculations is given by the following equations (7):

$$\text{Relative density} = \frac{\text{Number of individuals of the species}}{\text{Number of individuals of all species}} \times 100$$

$$\text{Relative dominance} = \frac{\text{Total basal area of the species}}{\text{Total basal area of all species}} \times 100$$

$$\text{Relative frequency} = \frac{\text{Number of points of occurence of the species}}{\text{Number of points of occurence of all species}} \times 100$$

$$\text{Importance value} = \text{Relative density} + \text{Relative dominance} + \text{Relative frequency}$$

These values were calculated for each of the tree species on each of the soil types in each of the sample counties for both the field and archival samples.

The importance value has been noted as "an excellent indication of the vegetational importance of a species within a stand" and has been recommended in preference to other importance indices (8). Also, it is useful in those studies where comparison is desired but where distance between sampled trees is not measured (1). Thus, it was calculated for this study, in which an accurate apparaisal of vegetational importance independent of distance could be used to assess differences of forest composition over space and through time.

Spatial variation in forest composition was determined through two measures, the index of biotal dispersity (9) and the mean weighted coefficient of community. The index of biotal dispersity is a value devised to measure the similarity of any number of species lists, and is defined by the following equation:

$$\frac{100\ (T-S)}{(n-1)\ S},$$

where "n" is the total number of species lists of an area, "S" is the total number of species in the area, and "T" is the arithemetical sum of $s_1+s_2+\ldots s_n$, where s_i is the number of species on each list. The values of the index range from 0 to 100, indicating no phytogeographic uniformity of the area and complete uniformity, respectively. The index was calculated in both the field and archival samples using each sample county as an area and the forest species on each soil type as a separate species list. The phytogeographic uniformity between the counties was then compared by their ratings on the index. The major disadvantage of the index, when used to determine forest uniformity, is that it is based solely on presence or absence of species and thus does not take into consideration other features of forest composition which are often of more importance to the biogeographer, such as density, dominance, or frequency. As noted above the importance value does encompass all of these features.

Because a measure was desired that would incorporate all of the advantageous features of the importance value and would also measure the uniformity of a number of species lists, the mean weighted coefficient of community was also derived. A coefficient of community can be weighted by any measure of species abundance to derive an index of similarity (10). Therefore, important measures of forest composition are retained when the importance value is used to weight the contribution of a species in a coefficient of community, and comparison of communities is then based on each species importance rather than just its presence or absence, as with the unweighted coefficient.

Furthermore, a coefficient of community compares only two species lists, and thus a measure was needed that would compare any number of species lists because there were more than two per county. A suitable index measuring the similarity of more than two lists was derived by calculating a weighted coefficient of community for each possible combination of species lists per county and then taking the mean of those calculated coefficients. The formula for calculating the weighted coefficients was

$$\frac{2w}{a + b} \times 100,$$

where "a" was the sum of the quantitative measures used (importance values) of the trees on one species list, "b" was the similar sum of a second list, and "w" was the sum of the smaller value for only those species which were in common between the two lists (11). Thus, if two lists have exactly the same species with exactly the same importance values the weighted coefficient will be 100, since a and b will be equal and both will equal w. If no species are common between the two lists, the coefficient will be zero. The range from no resemblance to complete identity, therefore, is 0 to 100.

If the species' quantitative measures are expressed as percentages, this coefficient reduces to simply w, or the sum of the smaller percentages of those species which have a value above zero on both species lists (12). Thus, by changing each species importance value to a percentage of the summed total of all species importance values on their respective list (theoretically, 300), the weighted coefficient between any two lists becomes simply the sum of the smaller percentages of those species common to both lists.

In this study, the forest species present on each soil type were used as a separate species list, and the mean value was taken for each sample county in each time period from the weighted coefficients calculated between each combination of soil types. The degree of uniformity of species' relative importance between the counties was then compared by their ratings on the mean coefficient.

An additional advantage of using a mean coefficient is that its values are directly comparable to those of other coefficients of community because it also ranges from 0 to 100, indicating no uniformity and complete uniformity, respectively. The obvious disadvantage is that it is time-consuming to calculate and becomes unwieldy as the number of species lists, and possible combinations, increases. This idea of deriving a mean coefficient of community for a number of species lists per area is not without precedent (9), but evidently a mean coefficient of community has never been used with species lists weighted by importance values, a surprising fact in view of the utility this measure holds for studies dealing with the spatial variation of forest composition.

Spatial variation of forest composition in each time period and changes of forest composition through time in each sample county were used to evaluate the hypothesis that local climate affects those forest variations. Spatial variation in each of the time periods was determined by comparing the indices of biotal dispersity and the means of the weighted coefficients of community between the sample counties. Changes through time were assessed by noting the differences in the indices of biotal dispersity and means of the weighted coefficients of community between the archival and field samples in each county.

To evaluate the hypothesis that different degrees of compositional change had occurred on different soil textures, values were derived for each soil type rather than for each county, and two indices were involved. One was a weighted coefficient of community, calculated between time periods on each soil type, and the other was the sum of the absolute changes in importance values, also calculated between time periods on each soil type. The former value is similar to that used to determine spatial variation, except that time separates the two communities rather than space. In contrast, the change in importance value is a more precise measure and is based on the assumption that the sum of the changes in the importance values for all species is a measure of the total change in a forest community through time. By taking the means of these two coefficients as they are represented on the soil types in each sample county, one can derive two measures of the county's overall degree of change in forest composition across the spectrum of the soil textures. Thus, these means were also used to evaluate the climatic hypothesis concerning changes in forest composition through time in each sample county.

Finally, correlation-regression analysis was also used to test the local climate hypothesis. For this analysis each sampled stand represented an observation. Change in forest composition through time, using the sum of absolute changes in importance values measure, was used as the dependent variable. No truly "climatic" variable could be readily obtained to represent the local climate, since all weather stations in the study area were relatively widely dispersed compared to the observations; therefore, using data from the closest weather stations would have produced only a very few differing values because there were only a few close stations to each county. However, as noted previously, climate is dominantly a function of distance from Lake Michigan in the study area. So, distance from Lake Michigan to each observation was used as a surrogate independent variable to represent the local climate.

A computer program was used for the correlation-regression analysis (13). The Michigan State University CDC 6500 computer was used for the computations. An F test was used to determine the significance of the simple correlation between the dependent and the independent variable (14).

CHAPTER IV--LITERATURE CITED

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

2. Lindsey, A. A., *et al.* 1958. "Field efficiencies of forest sampling methods." Ecology 39:428-444.

3. Penfound, W. T. and Rice, E. L. 1957. "An evaluation of the arms-length rectangle method in forest sampling." Ecology 38:660-661.

4. Stearns, F. W. 1949. "Ninety years change in a northern hardwood forest in Wisconsin." Ecology 30:350-358.

5. Cain, S. A. 1938. "The species-area curve." Am. Midl. Nat. 19:573-581.

6. Cottam, G. 1949. "The phytosociology of an oak woods in southwestern Wisconsin." Ecology 30:271-287.

7. Phillips, E. A. 1959. Methods of Vegetation Study. Holt, Rinehart and Winston, Inc., New York. pp. 43-44.

8. Curtis, J. T. and McIntosh, R. P. 1951. "An upland forest continuum in the prairie-forest border region of Wisconsin." Ecology 32:476-496.

9. Koch, L. F. 1957. "Index of biotal dispersity." Ecology 38: 145-148.

10. Greig-Smith, P. 1964. Quantitative Plant Ecology. 2nd. Ed., Butterworths and Co., Washington. pp. 136-137, 143.

11. Oosting, H. J. 1956. The Study of Plant Communities. 2nd. Ed., W. H. Freeman and Co., San Francisco. pp. 77-78.

12. Bray, J. R. and Curtis, J. T. 1957. "An ordination of the upland forest communities of southern Wisconsin." Ecol. Monogr. 27:325-349.

13. Wittick, R. I. 1971. Technical Report 71-1. Computer Inst. for Soc. Sci. Res., Mich. State Univ., E. Lansing. pp. 6-8.

14. Blalock, H. M. 1960. Social Statistics. McGraw-Hill Book Co., New York. pp. 302-305.

CHAPTER V

RESULTS

The Samples

Sixteen of the twenty-six forest stands that were sampled in the field were located in Montmorency County, and ten were located in Antrim County (Figure 2). A total of 1,332 trees were sampled; 796, representing five soil types, made up the samples from Montmorency County, and 536, representing three soil types, made up the samples from Antrim County. A total of 1,422 trees made up the archival sample; 1,008 were located in Montmorency County and 414 were located in Antrim County, representing the same soil types in each county as the field samples (Table 5).

Results of Data Analyses

The calculated importance values for the species on each soil type in Antrim and Montmorency counties for both the archival and field samples reveal that differences of composition exist through both time and space (Tables 6 and 7). The most obvious spatial differences are that fewer species were important in Antrim than Montmorency County in both presettlement and modern times, and that less soil type differentiation of species was apparent in Antrim County in both time

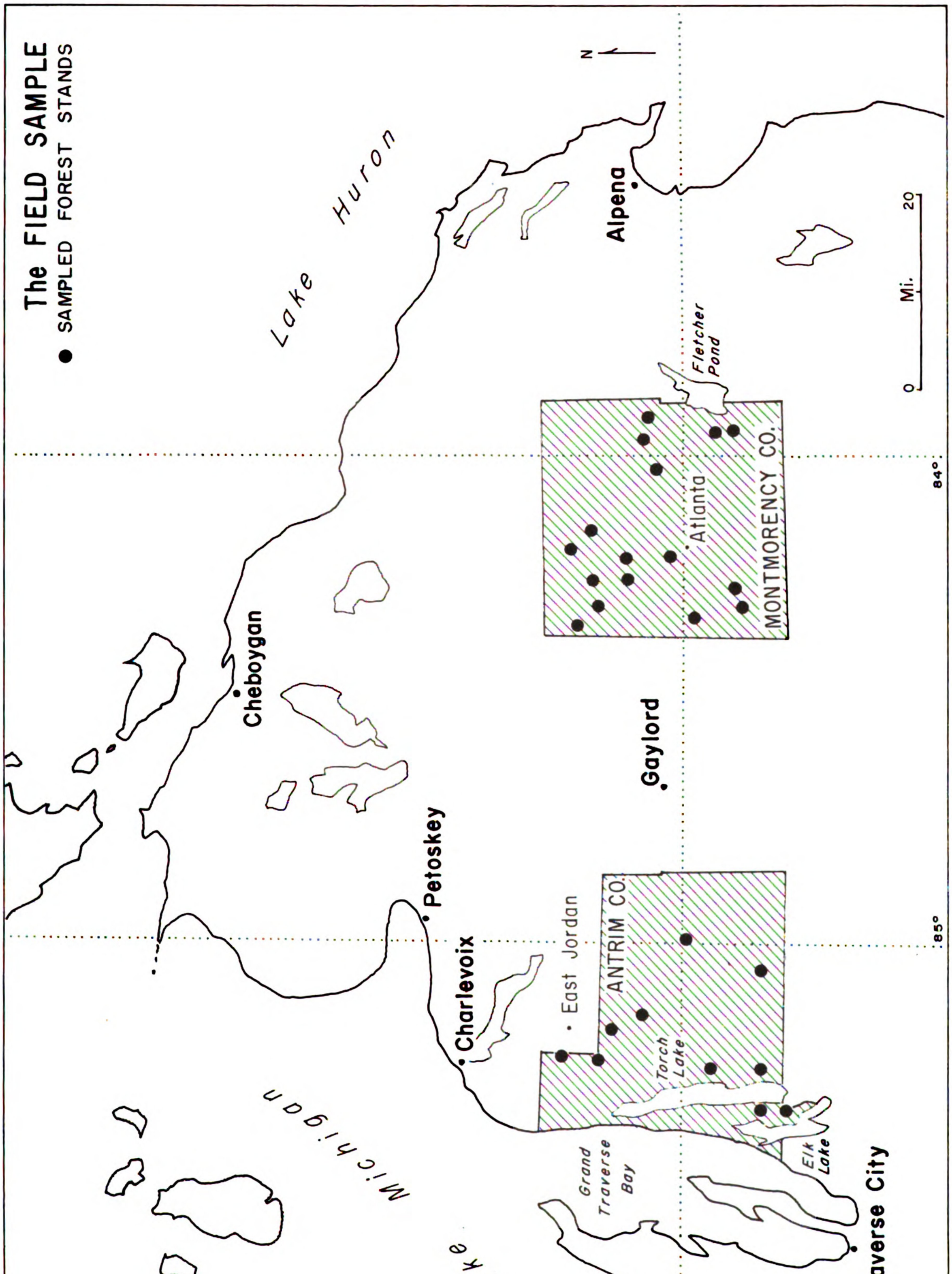

The FIELD SAMPLE
● SAMPLED FOREST STANDS
Lake Huron
Lake Michigan
Alpena
Cheboygan
Petoskey
Charlevoix
Gaylord
Atlanta
East Jordan
Traverse City
Grand Traverse Bay
Torch Lake
Elk Lake
Fletcher Pond
MONTMORENCY CO.
ANTRIM CO.
N
0
Mi.
20
84°
85°
45°

Figure 2.

periods as well. The most obvious temporal difference is the great reduction of the large conifers between the presettlement and modern samples.

Table 5. Total numbers of trees sampled.

Soil Type	Field Sample	Archival Sample
	Montmorency Co.	
Grayling Sand (5.7)*	228	280
Rubicon Sand (5.3)	96	128
Montcalm Loamy Sand (4.0)	160	202
Emmet Sandy Loam (3.0)	184	262
Onaway Loam (2.5)	128	136
Total	796	1,008
	Antrim Co.	
Kalkaska Sand (5.0)	216	170
Onaway Sandy Loam (2.5)	264	204
Onaway Loam (2.5)	56	40
Total	536	414
Grand Total	1,332	1,422

* The soil management group number of each soil is given in parenthesis to more precisely reflect its textural properties. Each soil series has a characteristic number. The numbers "indicate the relative coarseness of the mineral materials in the upper three feet of the soil profile" (1). They range in value from 0 for the finest textured clays to 5.7 for the coarsest textured sands, and each value is expressed to the nearest tenth.

Table 6. Importance values of species sampled from General Land Office Survey field notes.

	Soil type with soil management group number							
	Grayling sand (5.7)	Rubicon sand (5.3)	Montcalm loamy sand (4.0)	Emmet sandy loam (3.0)	Onaway loam (2.5)	Kalkaska sand (5.0)	Onaway sandy loam (2.5)	Onaway loam (2.5)
Tree species	Montmorency County					Antrim County		
Pinus banksiana	186	32	27					
Pinus resinosa	83	171	146	11	4			
Pinus strobus	24	45	52	4	19			
Acer saccharum		5	6	92	39	133	112	91
Acer rubrum			2					
Fagus grandifolia		7	16	134	164	98	120	141
Tilia americana				9		4	13	
Quercus rubra	3	8	6	1				
Quercus ellipsoidalis								
Quercus velutina								
Quercus alba			5					
Betula allegheniensis		9	8	6		3	1	
Betula papyrifera					5	9	1	
Tsuga canadensis		10	8	35	57	35	23	53
Populus grandidentata	0*	13	20	3	4			
Populus tremuloides								
Amelanchier sp.								
Prunus serotina								
Ulmus sp.			1	3		19	29	10
Fraxinus americana								
Ostrya virginiana			1					
Abies balsamea			1	1	2			
Thuja occidentalis					8			8

* Occasionally a genus such as *Populus* was not differentiated into species in the General Land Office Survey, but was grouped under one name such as "Aspen". This grouping is reflected in the matrix where a cell represents more than one species on a soil type.

Table 7. Importance values of species sampled in the field, fall, 1972.

Tree species	Grayling sand (5.7)	Rubicon sand (5.3)	Montcalm loamy sand (4.0)	Emmet sandy loam (3.0)	Onaway loam (2.5)	Kalkaska sand (5.0)	Onaway sandy loam (2.5)	Onaway loam (2.5)
	Montmorency County					Antrim County		
Pinus banksiana	245	65						
Pinus resinosa	13							
Pinus strobus								
Acer saccharum			41	137	196	195	199	239
Acer rubrum	11	25	54					
Fagus grandifolia			7	9	33	32	22	9
Tilia americana			5	47	19	22	23	
Quercus rubra	2	61	85		6			
Quercus ellipsoidalis / velutina	17	24	3					
Quercus alba		10	2					
Betula alleghenienis				10				
Betula papyrifera		4	15	2	4			
Tsuga canadensis								10
Populus grandidentata		100	70	6			0	
Populus tremuloides	3		2			6		
Amelanchier sp.	1	8						
Prunus serotina	1		1			1	0	
Ulmus sp.					5	28	42	39
Fraxinus americana			1	44	12	11	2	
Ostrya virginiana			3	34	18		4	
Abies balsamea								
Thuja occidentalis								

Within the archival sample in Montmorency County, pine *(Pinus)* species were very important on every soil type but were completely lacking in Antrim County, where the most important species on every soil type were sugar maple *(Acer saccharum)* and beech *(Fagus grandifolia)* with some hemlock *(Tsuga canadensis)* and elm *(Ulmus* sp.*)*, (Table 6). Within the modern field sample, the spatial differences between the counties still persist, but postsettlement disturbance has shifted the balance of importance on every soil type (Table 8). In Montmorency County pine species are currently important on only two of the coarsest textured soil types; bigtooth aspen *(Populus grandidentata)* on other coarse textured sites, and sugar maple on the finer textured sites, are the most important species on the remaining soils. In Antrim County sugar maple, beech, and elm are still important, but hemlock has lost importance status everywhere.

Temporal differences are best shown by the changes in species importance values from presettlement to modern times (Table 8). These values indicate, generally, that greater changes in species importance have taken place in Montmorency County. The species showing the greatest decrease in importance are white pine *(Pinus strobus)*, and red pine *(Pinus resinosa)*, beech, and hemlock, while the greatest increases have occurred in jack pine *(Pinus banksiana)* on the droughty Grayling sand, oaks *(Quercus* sp.*)* and aspens *(Populus* sp.*)* on the intermediate textured soils, and sugar maple on the finer textured soils. In Antrim County sugar maple has increased greatly on every soil type with a corresponding decrease in beech and hemlock.

Table 8. Direction and amount of change in importance value of species from presettlement to modern times.

	Soil type with soil management group number							
	Grayling sand (5.7)	Rubicon sand (5.3)	Montcalm loamy sand (4.0)	Emmet sandy loam (3.0)	Onaway loam (2.5)	Kalkaska sand (5.0)	Onaway sandy loam (2.5)	Onaway loam (2.5)
Tree species	Montmorency County					Antrim County		
Pinus banksiana	+59	+ 33	- 27					
Pinus resinosa	-70	-171	-146	- 11	- 4			
Pinus strobus	-24	- 45	- 52	- 4	- 19			
Acer saccharum		+ 20	+ 35	+ 45	+157	+62	+87	+148
Acer rubrum	+11		+ 52					
Fagus grandifolia		- 7	- 9	-125	-131	-66	-98	-132
Tilia americana			+ 5	+ 38	+ 19	+18	+10	
Quercus rubra	+16	+ 26	+ 82	- 1	+ 6			
Quercus ellipsoidalis / *velutina*								
Quercus alba		+ 10	- 3					
Betula alleghenien sis		- 5	+ 7	+ 4		- 3	- 1	
Betula papyrifera				+ 2	- 1	- 9	- 1	
Tsuga canadensis		- 10	- 8	- 35	- 57	-35	-23	- 43
Populus grandidentata	+ 3*	+ 87	+ 52	+ 3	- 4			
Populus tremuloides						+ 6		
Amelanchier sp.	+ 1	+ 8						
Prunus serotina	+ 1		+ 1					
Ulmus sp.			- 1	- 3	+ 5	+ 9	+13	+ 29
Fraxinus americana			+ 1	+ 44	+ 12	+11	+ 2	
Ostrya virginiana			+ 2	+ 34	+ 18		+ 4	
Abies balsamea			- 1	- 1	- 2			
Thuja occidentalis					- 8			- 8

* Occasionally a genus such as *Populus* was not differentiated into species in the General Land Office Survey, but was grouped under one name such as "Aspen". This grouping is reflected in the matrix where a cell represents more than one species on a soil type.

The gross differences apparent between species as demonstrated from their importance values can be more finely analyzed by examining their differences in relatives density, dominance, and frequency (Appendix II). Furthermore, by comparing each of these values to the importance value, it is possible to determine the degree to which each of the three compositional features has contributed to a species' total importance. Thus, for example, in the archival sample on Rubicon sand (Table 6) jack pine had an importance value of 32, but its relative density of 15 contributed most to that value. Red pine on the same soil had an importance value of 171; its relative dominance of 71, however, contributed most to its importance. Hence, in that situation, the density of jack pine was its most important compositional feature, whereas red pine's dominance was its most important feature.

The index of biotal dispersity shows the degree of phytogeographic uniformity of the soil types surveyed in each sample county. The calculated values of the index are higher in Antrim County and hence suggest that it has had greater overall phytogeographic uniformity than Montmorency County in both presettlement and modern times (Table 9). Both counties have shown a decrease in the index value since presettlement time, indicating a greater phytogeographic heterogeneity in the present forest, but the change has been less in Montmorency County. Thus, both counties today show nearly the same degree of heterogeneity.

Table 9. Indices of biotal dispersity.

County	Archival Samples	Field Samples	Change
Antrim	69	45	-24
Montmorency	46	38	- 8

As mentioned in the methods section, the index of biotal dispersity is based on the presence or absence of species on each soil type. The weighted coefficient of community calculated for each soil type, however, is based on the measures of density, dominance, and frequency. Thus, while the index of biotal dispersity measures the phytogeographic uniformity of each county, the mean of the weighted coefficients of community indicates the degree of uniformity of species' relative importance for each county, i.e. the higher the coefficient, the more similar is the relative contribution of all the species to the forest.

The mean weighted coefficients reveal that the present uniformity of species importance differs greatly between Antrim and Montmorency Counties (Table 10), even though, as noted above, the range of species in both counties is similar. The ratio of indices of biotal dispersity between Antrim and Montmorency County is 45:38, while that of the means of the weighted coefficients of community is much wider at 84:19. Thus, uniformity of species importance is at least four times greater in Antrim County. The mean coefficients also indicate that the uniformity of species importance between the two counties

Table 10. Weighted coefficients of community.

Antrim County

	Kalkaska sand	Onaway sandy loam
Onaway sandy loam	91	
Onaway loam	78	84
Archival Sample		
Onaway sandy loam	85	
Onaway loam	78	81

Means

84	19
81	34

Montmorency County

	Grayling sand	Rubicon sand	Montcalm loamy sand	Emmet sandy loam
Field Sample				
Rubicon sand	33			
Montcalm loamy sand	7	56		
Emmet sandy loam	0	3	22	
Onaway loam	1	3	22	67
Archival Sample				
Rubicon sand	48			
Montcalm loamy sand	46	89		
Emmet sandy loam	5	15	18	
Onaway loam	7	17	20	73

has widened since presettlement time, i.e. the relative contribution of the species to the forest has grown more dissimilar between the two counties.

The weighted coefficients of community calculated between the soil types indicate which soils are most alike in terms of overall forest composition (Table 10). Thus, the present composition on Kalkaska sand in Antrim County is more similar to that of Onaway sandy loam than Onaway loam because the weighted coefficient is higher for the former combination than the latter.

The degree of compositional similarity between communities of the presettlement and present forest on each soil type is shown in Table 11. These coefficients indicate that the degree of past to present similarity does not necessarily vary positively nor linearly with soil texture but does vary greatly between the different soil types, and apparently more so in Montmorency than Antrim County. For example, in Montmorency County the coefficient on Grayling sand is the highest for the county at 68, indicating that it exhibits the greatest overall degree of compositional similarity to its presettlement analog, while the coefficient on Montcalm loamy sand, the lowest for the county, is only 18, indicating the least degree of similarity to its presettlement analog. Thus, the range of values in the county is 50; in Antrim County the range is only 23. Therefore, it can be assumed that in Montmorency County degree of compositional change through time is more related to soil type differences, whereas in Antrim County degree of change is more homogeneous between the differing soil types. The mean of these coefficients for each county

Table 11. Weighted coefficients of community between presettlement and modern times per soil type.

Soil Type	Weighted Coefficient	Mean Coefficient Per County
	Montmorency Co.	
Grayling Sand	68	
Rubicon Sand	21	
Montcalm Loamy Sand	18	$\overline{x}$ = 34
Emmet Sandy Loam	40	
Onaway Loam	25	
	Antrim Co.	
Kalkaska Sand	62	
Onaway Sandy Loam	59	$\overline{x}$ = 53
Onaway Loam	39	

indicates the degree to which the composition of the present forest over the soil types sampled is similar to presettlement composition. Thus, the present overall composition of Antrim County shows a greater degree of similarity to its presettlement composition than that of Montmorency County.

The degree of change in forest composition implied above by the weighted coefficients between time periods has been measured more directly by the sum of absolute changes in importance values measure, calculated for each soil type. While the weighted coefficient specifically indicates a comparison of compositional similarity between presettlement and modern times, the latter value specifically measures <u>amount</u> of change and thus may be of greater use when a more quantitative measure of change is needed. Also, the two values vary inversely, i.e. as amount of change increases, degree of compositional similarity decreases.

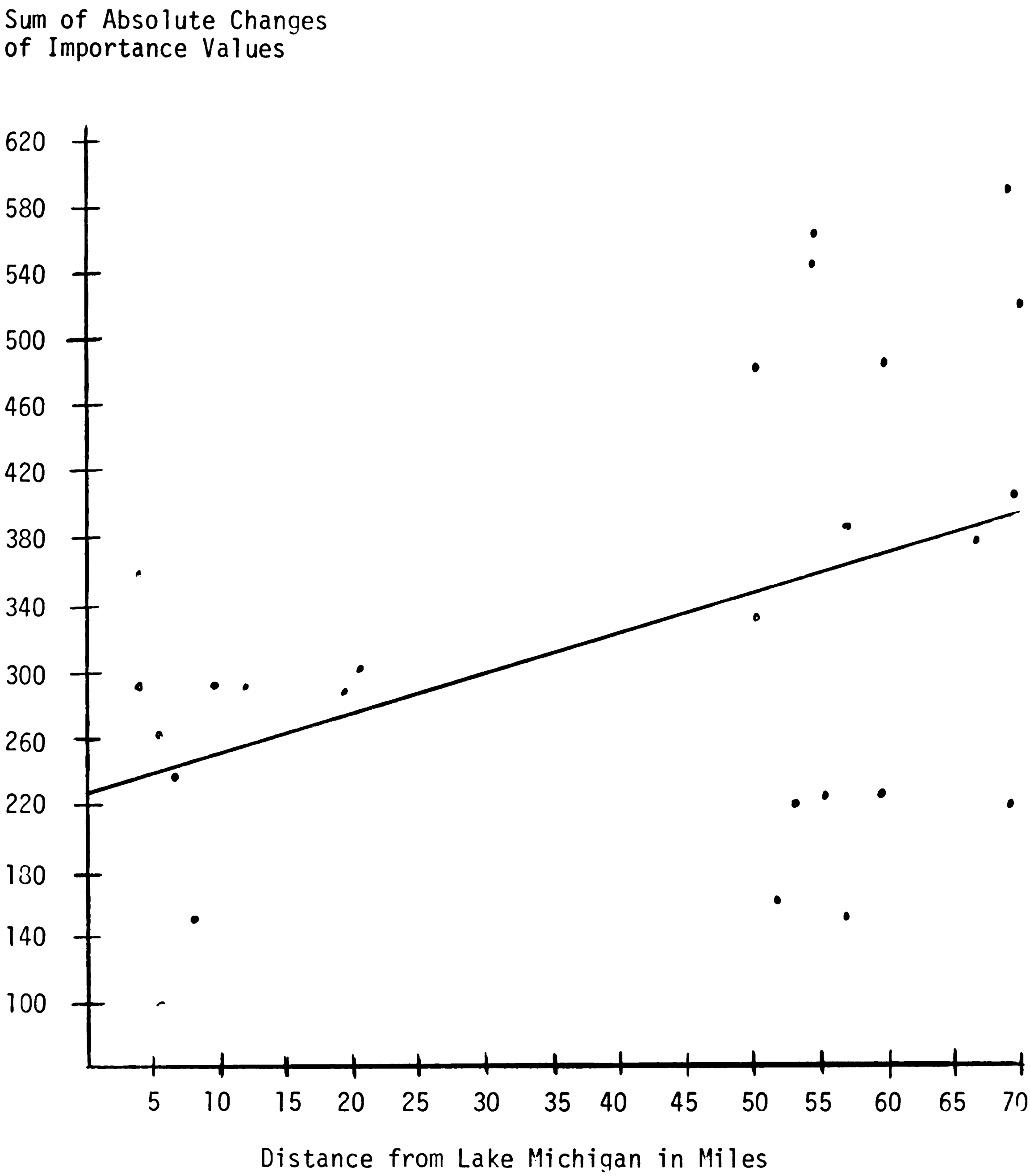
The summation values indicate that in Montmorency County, Montcalm loamy sand has exhibited the greatest change in composition from past to present with a value of 484; the low value of 185 of Grayling sand indicates that it has shown the least amount of change in composition through time (Table 12). The changes in Antrim County have generally been less as demonstrated by comparison of the county's mean change values. Also, inspection reveals that the range of change values between the soil types is narrower in Antrim than in Montmorency County, indicating that amount of change is less influenced by soil type differences in the former.

The correlation-regression analysis using the sum of absolute change in importance values measure as the dependent variable produced an r value of 0.44 against distance from Lake Michigan as an independent variable. A subsequent F test showed the coefficient to be significant at the .05 level but not at the .01 level. The greater range of forest change through time in Montmorency County is again illustrated by the larger variation in change of the individual sampled forest stands, which were used as observations in the correlation-regression analysis (Figure 3). This distribution indicates, perhaps best of all, that amount of change in forest composition is more dependent on specific, local site characteristics in Montmorency than in Antrim County.

Table 12. Sum of absolute changes of importance values between presettlement and modern times per soil type.

Soil Type	Sum	Mean Absolute Change Per County
	Montmorency Co.	
Grayling Sand	185	
Rubicon Sand	473	
Montcalm Loamy Sand	484	$\bar{x}$ = 387
Emmet Sandy Loam	350	
Onaway Loam	443	
	Antrim Co.	
Kalkaska Sand	220	
Onaway Sandy Loam	239	$\bar{x}$ = 273
Onaway Loam	360	

Thus, to summarize, the latter measures showed that Antrim County had a higher degree of phytogeographic uniformity and uniformity of species' importance than Montmorency County in both presettlement and modern times. It was also demonstrated that the present forests of Antrim County show greater similarity to their presettlement composition, and less change through time, than those of Montmorency County. Change in forest composition was found to be related in some degree to soil type, particularly in Montmorency County, but the relationship did not prove to be positive nor linear with soil texture.



r = 0.44
Sig. of F: > .05 < .01

Figure 3. Regression of temporal forest change against distance from Lake Michigan.

Finally, it was shown by correlation-regression analysis that distance from Lake Michigan was a statistically significant factor in determining forest change through time.

CHAPTER V--LITERATURE CITED

1. Christenson, D. R., *et al.* 1972. Fertilizer Recommendations for Michigan Vegetables and Field Crops. Ext. Bull. E-550, Co-op. Ext. Ser., Michigan State Univ., E. Lansing. pp. 27-30.

CHAPTER VI

DISCUSSION

The Hypotheses

It was originally hypothesized that within northern Lower Michigan where the local climate is ameliorated by lake influences, forest composition will be more spatially uniform, i.e. there will be less inter-site differentiation of communities, and amount of compositional change since postsettlement disturbance will be less; hence, the present composition will more closely resemble the original forest than in areas more distant from the lake. A more specific hypothesis was that amount of forest change through time also varies lineraly with soil texture, i.e. as texture becomes coarser, change becomes greater.

The index of biotal dispersity and the mean weighted coefficient of community were both significantly higher in Antrim than Montmorency County in both the presettlement and modern forests. Thus, phytogeographic uniformity and uniformity of species importance have been more characteristic of Antrim than Montmorency County since at least the time just prior to settlement. The difference between the indices of biotal dispersity between the two counties has narrowed through time while the difference between their mean weighted coefficients of community has widened (Tables 9 and 10), an apparent contradiction that can be easily explained. As stated previously, the index of biotal dispersity is based solely on presence or absence of species, whereas the latter is based on the density, dominance, and frequency of the individual species. The smaller number of species in Antrim County in both time periods has meant that a slight change in the richness of the canopy composition could have a much greater effect on phytogeographic uniformity there. Thus, even though the species lists of Antrim County usually showed fewer differences in number of species per time period than Montmorency County, they exhibited less uniformity through time because of the smaller number of species.

In contrast to the index of biotal dispersity, the difference between the mean weighted coefficients of community widened through time because the forests of Antrim County became more uniform with respect to the densities, dominances, and frequencies of the component species. The reduction in uniformity in Montmorency County was evidently due to the great change in importance of the large conifers. While in presettlement times either white pine *(Pinus strobus)*, red pine *(Pinus resinosa)*, or hemlock *(Tsuga canadensis)* dominated or shared dominance to a large degree on every sampled soil type, today they show very little importance anywhere in the county (Tables 6 and 7). In Antrim County no such compositional changes have occurred. Sugar maple *(Acer saccharum)* and beech *(Fagus grandifolia)* were the dominant trees on all the surveyed soil types in presettlement times, and they remain so today, though hemlock has suffered drastic reduction there, too (Table 8). With the great reduction of hemlock as well as beech, sugar maple has shown an increase on every soil type in the modern forests. The fact that there is a higher degree of uniformity of species' relative importance today than in presettlement time is probably largely due to the prolific regeneration of sugar maple throughout the county.

The results indicate that the degree of compositional change from the presettlement to present forest has been greater in Montmorency than Antrim County. Also, the correlation coefficient between sums of absolute changes in importance values and distance from Lake Michigan has indicated that temporal change increases with increasing distance from Lake Michigan. Therefore, amount of forest compositional change since postsettlement disturbance has generally been less in localities nearer to Lake Michigan.

It is also evident from the data that different amounts of change in forest composition through time are generally related to different soil textures (Tables 11 and 12). Temporal forest change, however, does not appear to be linearly related to relative soil texture as indicated by the change values per soil type, i.e. the coarser the texture, not necessarily the greater the change. The soils which have shown the greatest amount of change from their presettlement state, Rubicon sand and Montcalm loamy sand, had soil management group numbers of 5.3 and 4.0, respectively, indicating intermediate textures of the soils sampled. These same soils were also those that showed the greatest red pine-white pine importance in the presettlement forest (Table 6). Their great change was evidently due to the logging of these large trees and slow regeneration of the original species afterwards.

Thus, the hypothesis that in northern Lower Michigan spatial forest uniformity is greater and amount of change through time is less in areas where the lake influence is prominent is accepted. The hypothesis that amount of forest change through time varies linearly with soil texture is not accepted, as indicated from the results of the study.

These conclusions should not be accepted uncritically, though, because there is the possibility that factors other than soil texture or local climate, either wholly or in part, accounted for the differences in forest variation. Past history and physiographic position of a site are two other important factors in determining the spatial variation of forests in this region (1). Physiographic position was probably not an important factor in determining variation in this study because only well-drained soil types were used, but past history of the sites could very well have led to the differences in forest spatial variation, as well as temporal variation, and upset the assumption of uniformity of disturbance.

Differences in past history might have included different kinds and degrees of disturbance between the sites or different species composing the presettlement composition between the sites, both of which could affect rate of regeneration after disturbance. Different degrees of disturbance would have resulted between sites if some were only logged while others were logged and burned. In the latter case, if the fire was sufficiently hot or extensive, most local seed sources could have been destroyed, altering the rate of succession to follow (2).

When different species composed the presettlement forest on different sites, regeneration following disturbance probably proceeded at different rates. For example, under most conditions rate of regeneration would be much faster in a disturbed beech-maple forest than in an equally disturbed white pine-red pine forest because the latter species may not reestablish themselves nor grow as rapidly as the hardwood species. In addition, vegetative reproduction enables sugar maple to regenerate very quickly following logging if fire damage has not been severe. This contrast of regeneration rates probably contributed to the differing amounts of compositional change between Antrim and Montmorency Counties because they were largely composed of different assemblages of species.

Although texture has been acknowledged as the soil property having the greatest effect on forest variation in this region (1), soil properties other than texture may have accounted for some of the spatial and temporal variation shown in the study. The most important non-textural feature was probably soil reaction, which is largely controlled by amount of lime present in the soil parent material (Table 3). Thus, even though two soil types are alike in all respects except for amount of lime contained in each, they could differ in forest composition.

Limitations of the Study

It became apparent at various times during the study that certain limitations were inherent in some of the data or that certain modifications of the research plan at an earlier phase would have possibly increased the usefulness of the data for hypotheses evaluations. The limitations included various sources of error in the General Land Office Survey data. The research modifications that may have been desirable included improving data precision or comparability between the two time periods.

Bias in selection of witness trees, bias in determination of tree diameter, and error in location of survey posts are unfortunate features of the General Land Office Survey (3). Several tests have been devised to determine whether or not the bias in the selection of witness trees of a particular survey is statistically high enough to invalidate its use for presettlement forest sampling (3). Most of the tests require calculation of distance from the survey posts to their witness trees, but, as noted previously, these distances were not calculated for the present study. One of the tests is independent of distance, however, and requires simply the tabulation of the quarter in which the closest witness tree was located around each survey post. This frequency distribution of closest witness tree quarters is then analyzed by chi-square to determine its statistical probability. Thus, samples can be eliminated if the frequency is unlikely to occur by chance, indicating that the trees were not randomly selected. Unfortunately, the existence of this test was not known until after the archival sample was completed; therefore, neither the tabulation nor the test was done. Bias in selection of tree species is not likely to be an important handicap in most studies since "the choice of species adjacent to a corner was limited" (3). Thus, even though the degree of bias was not determined quantitatively, it probably does not greatly affect the relatives frequency nor density calculated in the present study.

Bias in determination of tree diameter existed because of the surveyor's inability to estimate accurately, but for the purposes of this study, it was felt that a large degree of estimation inaccuracy could be tolerated without significantly affecting the final results, so great were the overall importance value differences between the species. A large amount of inaccuracy was not suspected, however, since errors of estimate tended to be compensating in the early survey work (3). Thus, the relative dominance values calculated for the archival sample probably did not differ too greatly from those of the actual presettlement forest.

Error in location of survey posts may have weakened the value of the data because of the possibility that witness tree location would then not correspond with the mapped soil type being used to identify a particular sample. This problem is not considered to be crucial, however, because of the high apparent correspondence between vegetation in the field notes and soil type on the soil maps, i.e. when the soil type changed between locations the recorded vegetation usually did, too. As a precaution, however, only witness trees were recorded for a soil type if their survey post was located well within the boundaries of the soil type being sampled.

Certain modifications of the research plan might have been beneficial, such as an increase in the minimum size of trees in the field sample from 2" d.b.h. to 3", 4" or even 5" d.b.h. Witness trees were seldom selected with a d.b.h. less than 4". Thus, in the field sample many of the smaller trees such as serviceberry *(Amelanchier* sp.) were not a part of the archival sample, a fact that reduced the comparability of the two data sets.

The only measures used in the study to differentiate the mapped soil types by texture were the textural epithet of the soil type name, e.g. "sand" in Grayling sand, and the soil management group number of each soil type series. Since each of these "measures" supplies only a very general characterization of a soil type and since significant variation in texture, as well as other soil properties, may exist even within a soil type (4), actual soil samples from each sampled forest stand would have enhanced the reliability of the soil input. The samples could then have been analyzed for percentage of sand, silt, or clay to provide a more precise interval scale measure of soil texture for the study.

A greater diffusion of sampling locations throughout northern Lower Michigan would have also been a beneficial modification, particularly if the locations had been near weather stations. This would have allowed more precise representation of the local climate because climatic data from the station closest to each sampled area could have been used as more explicit surrogates of local climate than distance from Lake Michigan.

Therefore, because of these limitations, acceptance of the results and hypotheses of the study is qualified. More extensive studies that will be able to control these limitations, in part by incorporating the modifications described above, are undoubtedly needed before the relationships between local climate, soil texture, and forest variation are resolved.

CHAPTER VI--LITERATURE CITED

1. Nichols, G. E. 1935. "The hemlock-white pine-northern hardwood forest region of eastern North America." Ecology 16:403-422.

2. Spurr, S. H. 1964. Forest Ecology, The Ronald Press Co., New York. p. 185.

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

4. Millar, C. E., *et al*. 1965. Fundamentals of Soil Science. John Wiley and Sons, Inc., New York. p. 255.

CHAPTER VII

SUMMARY AND CONCLUSIONS

This study was undertaken in hopes of increasing the understanding of spatial and temporal variations in forest composition within northern Lower Michigan. Two hypotheses were advanced for testing. The first hypothesis was that amount of temporal forest change following disturbance varies with soil texture in a positive and linear way, i.e. as texture becomes coarser, change becomes greater. A second hypothesis was that within northern Lower Michigan, spatial variations in forest composition and amount of temporal forest change are related to differences in the local climate. More specifically, it was hypothesized that where the local climate is ameliorated by lake influences, forest composition will be more spatially uniform, i.e. there will be less inter-site differentiation, and departures of the present composition from that of the presettlement forest will be less.

Field samples of forest composition were collected on various soil textures both in Antrim County, near Lake Michigan, and in Montmorency County, in the interior of northeastern Lower Michigan. The presettlement forest composition of the same soil types was determined from the field notes of the General Land Office Surveys of the two counties.

Importance values were calculated for the tree species on each soil type and in each county for both the modern and presettlement forest samples. Various indices were then calculated from the species present in each sample or from the species' inportance values which allowed comparison of the forests through both time and space.

The forests closer to Lake Michigan were found to be more uniform in terms of the phytogeographic distribution of the component species and their importance value distribution than those in northeastern Lower Michigan. The samples nearer to Lake Michigan also showed a closer resemblance to their presettlement composition. Thus, the hypothesis was accepted that the forests under the lake influence of Lake Michigan in northern Lower Michigan are more spatially uniform and today support a forest whose composition approaches that of the original. Temporal forest change was also found to vary with soil texture, but the findings did not indicate that this was a linear relationship. Thus, the hypothesis that amount of forest change through time varies linearly with soil texture was not accepted from the results of the study.

The results must also be interpreted in light of the limitations of the study. These included possible biases and errors in the General Land Office Survey data. The General Land Office Survey may contain biases in selection of witness trees, which could have rendered the sample significantly non-random to make it useless; bias in determination of tree diameter, a less serious limitation, but which could have upset certain calculations concerning the species' basal area; and error in location of survey posts, which could have upset soil type identification of sample points in soil transition areas. Because of the great differences of composition between soil types, none of these deficiences were judged to have limited the data for use in this type of study.

Other factors, besides local climate and soil texture, which could have accounted for differences in forest variation were differing past histories of the sites, including differing degrees of site disturbance and/or differences in presettlement composition and regeneration rates, and also differences other than texture between the soil types, notably differences in soil reaction.

Changes or modifications in the research plan which are recommended for future studies similar to the present one are:

1. Increasing the minimum d.b.h. to 4" of trees in modern samples to make the samples more comparable to presettlement forest samples derived from the General Land Office Survey.

2. Determining soil texture of sampled stands from one of more soil samples taken in each stand and analyzing for percent clay, silt, and sand.

3. More greatly diffusing the sampling locations, ideally locating sample stands near weather stations so that weather data can be used from the closest station to represent the local climate of each stand.

LIST OF REFERENCES

LIST OF REFERENCES

Beal, W. J. 1888. "Observation on the succession of forests in northern Michigan." Bot. Gaz. 13:239-240.

✓Benninghoff, W. S. and Gebben, A. I. 1960. "Phytosociological studies of some beech-maple stands in Michigan's Lower peninsula." Pap. Mich. Acad. Sci., Arts, and Letters. 45:83-91.

Blalock, H. M. 1960. Social Statistics. McGraw-Hill Book Co., New York. pp. 302-305.

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

✓ Braun, E. L. 1950. Deciduous Forests of Eastern North America. The Blakiston Co., Philadelphia. (Republished in 1972 by Hafner Pub. Co., New York.) pp. 337-440, 306.

Bray, J. R. and Curtis, J. T. 1957. "An ordination of the upland forest communities of southern Wisconsin." Ecol. Monogr. 27:325-349.

Cain, S. A. 1938. "The species-area curve." Am. Midl. Nat. 19: 573-581.

Christenson, D. R., *et al.*, 1972. Fertilizer Recommendations For Michigan Vegetables and Field Crops. Ext. Bull. E-550., Co-op Ext. Ser., Mich. State Univ., E. Lansing. pp. 27-30.

Climate of Michigan by Stations. 1971. Mich. Dept. of Agriculture (Mich. Weather Service), E. Lansing.

Cottam, G. 1949. "The phytosociology of an oak woods in southwestern Wisconsin." Ecology 30:271-287.

________, and Curtis, J. T. 1956. "The use of distance measures in phytosociological sampling." Ecology 37:451-460.

Cowles, H. C. 1900. "The physiographic ecology of northern Michigan." Science 12:708-709.

________. 1901. "The physiographic ecology of Chicago and vicinity: A study of the origin, development, and classification of plant societies." Bot. Gaz. 31:73-108, 145-182.

Curtis, J. T. and McIntosh, R. P. 1951. "An upland forest continuum in the prairie-forest border region of Wisconsin." Ecology 32:476-496.

Darlington, H. T. 1930. "Vegetation of the Porcupine Mountains, northern Michigan." Pap. Mich. Acad. Sci., Arts, and Letters. 13:9-65.

Elliot, J. C. 1953. "Composition of upland second growth hardwood stands in the tension zone of Michigan as affected by soils and man." Ecol. Monogr. 23:271-288.

Fenneman, N. M. 1938. Physiography of Eastern United States. McGraw-Hill Book Co., New York.

Flaccus, E. and Ohmann, L. F. 1964. "Old-growth northern hardwood forests in northeastern Minnesota." Ecology 45:448-458.

Flint, R. F. 1957. Glacial and Pleistocene Geology. John Wiley and Sons, Inc., New York.

Frothingham, E. H. 1915. "The northern hardwood forest: its composition, growth and management." U.S.D.A. Bull. 285.

Gates, F. C. 1912. "The vegetation of the region in the vicinity of Douglas Lake, Cheboygan County, Michigan." Ann. Rep. Mich. Acad. Sci. 14:46-106.

________. 1926. "Plant succession about Douglas Lake, Cheboygan County, Michigan." Bot. Gaz. 82:170-182.

________. 1930. "Aspen association in northern Lower Michigan." Bot. Gaz. 90:233-259.

✓Gleason, H. A. 1924. "The structure of the maple-beech association in northern Michigan." Pap. Mich. Acad. Sci., Arts, and Letters. 4:285-296.

Glinka, K. 1914. Die Typen der Bodenbildung. Berlin, Germany. (Translated into English as: Marbut, C. F. 1927. The Great Soil Groups of the World and Their Development. Edwards Bros., Ann Arbor.)

Greig-Smith, P. 1964. Quantitative Plant Ecology. 2nd Ed., Butterworths and Co., Washington. pp. 136-137, 143.

Harper, R. M. 1918. "The plant population of northern Lower Michigan and its environment." Bull. Torr. Bot. Club. 45:23-42.

Horberg, L. 1956. "Bedrock topography and Pleistocene glacial lobes in central United States." Jour. Geol. 64:101-116.

Hough, J. L. 1958. Geology of the Great Lakes. Univ. of Ill. Press, Urbana.

Hushen, T. W., *et al.* 1966. "Presettlement forest patterns in Montcalm County, Michigan." Mich. Bot. 5:192-210.

Kenoyer, L. A. 1934. "Forest distribution in southwestern Michigan as interpreted from the original land survey (1826-32)." Pap. Mich. Acad. Sci., Arts, and Letters. 19:107-111.

Koch, L. F. 1957. "Index of biotal dispersity." Ecology 38:145-148.

Lindsey, A. A., *et al.* 1958. "Field efficiencies of forest sampling methods." Ecology 39:428-444.

✓ ________., *et al.* 1965. "Soil relations and distribution map of the vegetation of presettlement Indiana." Bot. Gaz. 126:155-163.

✓ Livingston, B. E. 1905. "The relation of soils to natural vegetation in Roscommon and Crawford Counties, Michigan." Bot. Gaz. 39:22-41.

Lutz, H. J. 1930. "Original forest composition in northwestern Pennsylvania as indicated by early land survey notes." Jour. Forestry. 28:1098-1103.

Martin, H. M. 1955. "Map of the surface formations of the southern peninsula of Michigan." Publ. 49., Dept. of Natural Resources, Lansing, Mich.

Maycock, P. and Curtis, J. T. 1960. "The phytosociology of boreal conifer-hardwood forests of the Great Lakes Region." Ecol. Monogr. 30:1-35.

✓ Millar, C. E., *et al.* 1965. Fundamentals of Soil Science. John Wiley and Sons, Inc., New York. pp. 255, 267-269, 471.

Nichols, G. E. 1935. "The hemlock-white pine-northern hardwood forest region of eastern North America." Ecology 16:403-422.

Oosting, H. J. 1956. The Study of Plant Communities. 2nd Ed., W. H. Freeman and Co., San Francisco. pp. 77-78.

Penfound, W. T. and Rice, E. L. 1957. "An evaluation of the arms-length rectangle method in forest sampling." Ecology 38:660-661.

Pfeifer, R. E. and Spencer, J. S. 1966. The Growing Timber Resource of Michigan: Northern Lower Peninsula. Michigan Dept. of Natural Resources, Lansing, Mich. p. 38.

Phillips, E. A. 1959. Methods of Vegetation Study. Holt, Rinehart and Winston, Inc., New York. pp. 43-44.

Potzger, J. E. 1946. "Phytosociology of the primeval forest in Central Northern Wisconsin and Upper Michigan, and a brief post-glacial history of the Lake Forest Formation." Ecol. Monogr. 16:211-250.

________. 1948. "A pollen study in the tension zone of Lower Michigan." Butler Univ. Bot. Stud. 8:161-177.

________., *et al.* 1956. "The forest primeval of Indiana as recorded in the original U.S. land surveys and an evaluation of previous interpretations of Indiana vegetation." Butler Univ. Bot. Stud. 13:95-111.

Quick, B. E. 1923. "A comparative study of the distribution of the climax association in Southern Michigan." Pap. Mich. Acad. Sci., Arts, and Letters. 3:211-245.

Roth, F. 1902. "The jack pine plains of Michigan." Forestry and Irrig. 8:413-416.

Schneider, I. F., *et al.* 1967. "Tentative placements of Michigan soil series in the new soil classification system." Mimeographed paper, Dept. Soil Sci., Mich. State Univ., E. Lansing.

✓ Spurr, S. H. 1964. Forest Ecology. The Ronald Press Co., New York. pp. 3-4, 185.

Stearns, F. W. 1949. "Ninety years change in a northern hardwood forest in Wisconsin." Ecology 30:350-358.

Theophastus. 1965. "Enquiry into plants." in Readings in Ecology. Kormondy, E. J. (ed.), Prentice-Hall, Inc., Englewood Cliffs, New Jersey. pp. 2-4.

Thornbury, W. D. 1965. Regional Geomorphology of the United States. John Wiley and Sons, Inc., New York. p. 228.

Trewartha, G. T. 1954. An Introduction to Climate. McGraw-Hill Book Co., New York.

✓ Veatch, J. O. 1932. "Soil maps as a basis for mapping original forest cover." Pap. Mich. Acad. Sci., Arts, and Letters. 15:267-273.

________., *et al.* 1928. Soil Survey of Antrim County, Michigan. U.S. Govt. Printing Office, Washington D.C.

________., *et al.* 1930. Soil Survey of Montmorency County, Michigan. U.S. Govt. Printing Office, Washington D.C.

Voss, E. G. 1965. "Comparative revegetation of denuded areas in northern Michigan." Pap. Mich. Acad. Sci., Arts, and Letters. 50:139-160.

✓ Westveld, R. H. 1933. "The relation of certain soil characteristics to forest growth and composition in the northern hardwood forest of northern Michigan." Mich. Agr. Expt. Sta. Tech. Bull. 135: 51 pp.

Whiteside, E. P., *et al.* 1968. Soils of Michigan. Co-op. Ext. Ser., Agr. Exp. Sta., Mich. State Univ., E. Lansing. p. 8.

Whitford, H. N. 1901. "The genetic development of the forest soils of northern Michigan; a study in physiographic ecology." Bot. Gaz. 31:289-325.

Wilde, S. A. 1933. "The relation of soils and forest vegetation of the Lake States region." Ecology 14:94-105.

Wilson, L. R. and Potzger, J. E. 1943. "Pollen study of sediments from Douglas Lake, Cheboygan County and Middle Fish Lake, Montmorency County, Michigan." Ind. Acad. Sci. Proc. 52: 87-92.

Wittick, R. I. 1971. Technical Report 71-1. Computer Inst. for Soc. Sci. Res., Mich. State Univ., E. Lansing. pp. 6-8.

Zumberge, J. H. and Potzger, J. E. 1956. "Late Wisconsin chronology of the Lake Michigan basin correlated with pollen studies." Bull. Geol. Soc. Amer. 67:271-288.

GENERAL REFERENCES

Ching, K. K. 1954. Forest Succession on the Well-Drained Soils in the Higgins Lake Area of Michigan. Ph.D. Thesis, Mich. State Univ., E. Lansing.

Clayberg, H. D. 1920. "Upland societies of Petoskey-Walloon Lake region." Bot. Gaz. 69:28-53.

Cooper, W. S. 1913. "The climax forest of Isle Royale and its development." Bot. Gaz. 55:1-44, 115-140, 189-235.

Graham, S. A. 1941. "Climax forests of the Upper Peninsula of Michigan." Ecology 22:355-362.

Ku, T. 1954. Forest Succession on the Poorly-Drained Soils in the Higgins Lake Area of Michigan. Ph.D. Thesis, Mich. State Univ., E. Lansing.

APPENDICES

APPENDIX I

SAMPLING FORMS

Sampling Forms

Field Sampling Form

Stand no. ____

County ____

Location of stand ______________________________________

____

Soil type ____

Slope orientation ______________________________________

Appendix I--continued

Stand No. Field Sampling Form

II	I
(1) Nearest tree species ________	(1) Nearest tree species ________
(2) Dist. from pt.________	(2) Dist. from pt.________
(3) Tree d.b.h.________	(3) Tree d.b.h.________
III	**IV**
(1) Nearest tree species ________	(1) Nearest tree species ________
(2) Dist. from pt.________	(2) Dist. from pt.________
(3) Tree d.b.h.________	(3) Tree d.b.h.________

II	I
(1) Nearest tree species ________	(1) Nearest tree species ________
(2) Dist. from pt.________	(2) Dist. from pt.________
(3) Tree d.b.h.________	(3) Tree d.b.h.________
III	**IV**
(1) Nearest tree species ________	(1) Nearest tree species ________
(2) Dist. from pt.________	(2) Dist. from pt.________
(3) Tree d.b.h.________	(3) Tree d.b.h.________

Appendix I--continued

Archival Sampling Form

County: Soil type:

Tier	Range	Bordering sections	Tree species	Diameter	Basal area

APPENDIX II

RELATIVES DENSITY, DOMINANCE, AND FREQUENCY VALUES OF THE SAMPLES

Relatives Density, Dominance, and Frequency Values of the Samples

Relative Densities of Species Sampled from General Land Office Survey Field Notes.

Tree species	Grayling sand (5.7)	Rubicon sand (5.3)	Montcalm loamy sand (4.0)	Emmet sandy loam (3.0)	Onaway loam (2.5)	Kalkaska sand (5.0)	Onaway sandy loam (2.5)	Onaway loam (2.5)
	Montmorency County					Antrim County		
Pinus banksiana	72	15	13					
Pinus resinosa	19	52	41	3	1			
Pinus strobus	6	14	16	1	3			
Acer saccharum		2	2	29	12	44	36	28
Acer rubrum			1					
Fagus grandifolia		3	7	49	60	38	49	55
Tilia americana				3		1	3	
Quercus rubra	1	3	2	0				
Quercus ellipsoidalis								
Quercus velutina								
Quercus alba			2					
Betula alleghaniensis		4	3	2		1	0	
Betula papyrifera					2	3	0	
Tsuga canadensis		3	3	10	18	10	5	13
Populus grandidentata	0*	5	9	2	1			
Populus tremuloides								
Amelanchier sp.								
Prunus serotina								
Ulmus sp.			0	1		4	5	3
Fraxinus americana								
Ostrya virginiana			0					
Abies balsamea			0	0	1			
Thuja occidentalis					3			3

* Occasionally a genus such as *Populus* was not differentiated into species in the General Land Office Survey, but was grouped under one name such as "Aspen". This grouping is reflected in the matrix where a cell represents more than one species on a soil type.

Appendix II--continued

Relative Dominances of Species Sampled from General Land Office Survey Field Notes.

Tree species	Grayling sand (5.7)	Rubicon sand (5.3)	Montcalm loamy sand (4.0)	Emmet sandy loam (3.0)	Onaway loam (2.5)	Kalkaska sand (5.0)	Onaway sandy loam (2.5)	Onaway loam (2.5)
	Montmorency County					Antrim County		
Pinus banksiana	72	6	4					
Pinus resinosa	19	71	66	7	2			
Pinus strobus	6	13	18	2	13			
Acer saccharum		1	2	31	14	47	38	34
Acer rubrum			0					
Fagus grandifolia		1	3	38	51	24	28	32
Tilia americana				3		1	5	
Quercus rubra								
Quercus ellipsoidalis / *velutina*	1	1	1	0				
Quercus alba			1					
Betula allegheniensis		1	1	2		1	0	
Betula papyrifera					1	2	0	
Tsuga canadensis		4	2	15	19	15	12	29
Populus grandidentata / *Populus tremuloides*	0*	2	2	0	1			
Amelanchier sp.								
Prunus serotina								
Ulmus sp.			0	1		9	17	3
Fraxinus americana								
Ostrya virginiana			0					
Abies balsamea			0	0	0			
Thuja occidentalis					1			1

* Occasionally a genus such as *Populus* was not differentiated into species in the General Land Office Survey, but was grouped under one name such as "Aspen". This grouping is reflected in the matrix where a cell represents more than one species on a soil type.

Appendix II--continued

Relative Frequencies of Species Sampled from General Land Office Survey Field Notes.

Tree species	Grayling sand (5.7)	Rubicon sand (5.3)	Montcalm loamy sand (4.0)	Emmet sandy loam (3.0)	Onaway loam (2.5)	Kalkaska sand (5.0)	Onaway sandy loam (2.5)	Onaway loam (2.5)
	Montmorency County					Antrim County		
Pinus banksiana	67	11	10					
Pinus resinosa	23	48	39	1	1			
Pinus strobus	7	18	18	1	3			
Acer saccharum		2	2	32	13	42	38	29
Acer rubrum			1					
Fagus grandifolia		3	6	47	53	36	43	54
Tilia americana				3		2	5	
Quercus rubra								
Quercus ellipsoidalis / *velutina*	1	4	3	1				
Quercus alba			2					
Betula alleghenensis		4	4	2		1	1	
Betula papyrifera					2	4	1	
Tsuga canadensis		3	3	10	20	10	6	11
Populus grandidentata / *Populus tremuloides*	0*	6	9	1	2			
Amelanchier sp.								
Prunus serotina								
Ulmus sp.			1	1		6	7	4
Fraxinus americana								
Ostrya virginiana			1					
Abies balsamea			1	1	1			
Thuja occidentalis					4			4

* Occasionally a genus such as *Populus* was not differentiated into species in the General Land Office Survey, but was grouped under one name such as "Aspen". This grouping is reflected in the matrix where a cell represents more than one species on a soil type.

Appendix II--continued

Relative Densities of Species Sampled in the Field, Fall, 1972

	Soil type with soil management group number							
	Grayling sand (5.7)	Rubicon sand (5.3)	Montcalm loamy sand (4.0)	Emmet sandy loam (3.0)	Onaway loam (2.5)	Kalkaska sand (5.0)	Onaway sandy loam (2.5)	Onaway loam (2.5)
Tree species	Montmorency County					Antrim County		
Pinus banksiana	88	25						
Pinus resinosa	3							
Pinus strobus								
Acer saccharum			16	57	77	80	70	80
Acer rubrum	2	9	21					
Fagus grandifolia			3	2	10	3	4	1
Tilia americana			1	10	3	5	7	
Quercus rubra	0	17	27		0			
Quercus ellipsoidalis / velutina	3	5	0					
Quercus alba		3	0					
Betula alleghaniensis				2				
Betula papyrifera		1	4	0	0			
Tsuga canadensis								1
Populus grandidentata		36	19	1			0	
Populus tremuloides	0		0			1		
Amelanchier sp.	0	3						
Prunus serotina	0		0			0	0	
Ulmus sp.					0	6	13	16
Fraxinus americana			0	13	2	3	0	
Ostrya virginiana			1	11	4		1	
Abies balsamea								
Thuja occidentalis								

Appendix II--continued

Relative Dominances of Species Sampled in the Field, Fall, 1972.

	Soil type with soil management group number							
	Grayling sand (5.7)	Rubicon sand (5.3)	Montcalm loamy sand (4.0)	Emmet sandy loam (3.0)	Onaway loam (2.5)	Kalkaska sand (5.0)	Onaway sandy loam (2.5)	Onaway loam (2.5)
Tree species	Montmorency County					Antrim County		
Pinus banksiana	88	20						
Pinus resinosa	2							
Pinus strobus								
Acer saccharum			10	39	62	53	76	91
Acer rubrum	2	2	12					
Fagus grandifolia			1	3	7	24	8	3
Tilia americana			1	23	9	8	5	
Quercus rubra	1	26	34		5			
Quercus ellipsoidalis / velutina	6	11	2					
Quercus alba		3	1					
Betula alleghaniensis				4				
Betula papyrifera		1	6	2	3			
Tsuga canadensis								4
Populus grandidentata		35	32	4			0	
Populus tremuloides	1		1			2		
Amelanchier sp.	0	1						
Prunus serotina	0		0			0	0	
Ulmus sp.					4	10	10	2
Fraxinus americana			0	15	5	3	1	
Ostrya virginiana			0	8	6		1	
Abies balsamea								
Thuja occidentalis								

Appendix II--continued

Relative Frequencies of Species Sampled in the Field, Fall, 1972.

Tree species	Grayling sand (5.7)	Rubicon sand (5.3)	Montcalm loamy sand (4.0)	Emmet sandy loam (3.0)	Onaway loam (2.5)	Kalkaska sand (5.0)	Onaway sandy loam (2.5)	Onaway loam (2.5)
	Montmorency County					Antrim County		
Pinus banksiana	69	20						
Pinus resinosa	8							
Pinus strobus								
Acer saccharum			15	41	57	62	53	68
Acer rubrum	7	14	21					
Fagus grandifolia			3	4	16	5	10	5
Tilia americana			3	14	7	9	11	
Quercus rubra	1	18	24		1			
Quercus ellipsoidalis / velutina	8	8	1					
Quercus alba		4	1					
Betula alleghenienis				4				
Betula papyrifera		2	5	0	1			
Tsuga canadensis								5
Populus grandidentata		29	19	1			0	
Populus tremuloides	2		1			3		
Amelanchier sp.	1	4						
Prunus serotina	1		1			1	0	
Ulmus sp.					1	12	19	21
Fraxinus americana			1	16	5	5	1	
Ostrya virginiana			2	15	8		2	
Abies balsamea								
Thuja occidentalis								