FOREST COMPOSITION AND SOIL TEXTURE RELATIONSHIPS ACROSS THE TENSION ZONE, CENTRAL LOWER MICHIGAN

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ABSTRACT

FOREST COMPOSITION AND SOIL TEXTURE RELATIONSHIPS
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By

Kimberly Ellen Medley

Relationships between forest composition and soils across the Michigan vegetation tension zone were examined. It was hypothesized that patterns of tree species and soil texture are significantly associated and that coarse-textured soils increase abruptly northward across the tension zone. It was also hypothesized that needleleaf trees increase significantly northward, they are more strongly associated to coarse-textured soils than are deciduous species to fine-textured soils, and the relationships between forest physiognomy and soil texture are stronger north of a sharp transition toward coarse-textured soils.

Data on presettlement forest composition and soils were recorded from the land office survey notes and the modern soil surveys along three south-north belt transects. The results from several statistical analyses demonstrate that distribution of tree species, forest physiognomy, and soil texture are significantly related. Needleleaf trees are most frequent on coarse-textured soils, and sugar maple on fine-textured soils, but the nearly equal distribution of most deciduous species, and the predominance of beech, on all soil textures lessened the strength of the association and dependent variable (tree species) predictability. Coarse-textured soils and needleleaf tree percentages increase signicantly north across the tension zone with similar northward trends. Contrasts identified between the transects reflect east-west variation in overall forest composition and the distribution northward of coarse-textured soils. It is concluded that the occurrence of needleleaf trees is closely related to coarse-textured soils within this region such that the underlying soils pattern helps define the tension zone.

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A THESIS

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To James A. Rinier

Yes, I dig the soil, plants, landscape... And I thank you, Professor Rinier, for the many years of enthusiastic instruction you have given on these topics within the Department of Geography at Kent State University, Ohio.

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INTRODUCTION

The "tension zone" in the central lower peninsula of Michigan is a south-north change in vegetation from a predominantly deciduous forest to one characterized by a mixture of deciduous and coniferous trees. Like "tension zones" elsewhere, this one separates two vegetation associations with species from either association attaining dominance in response to local site factors. This sharp transition may be described floristically through an analysis of the presence or absence of particular species, or ecologically by the change in the relative dominance of all plant species. More simply, it may be described physiognomically; for example, the frequency of needleleaf trees in the present (and presettlement) forest appears to increase abruptly northward across the tension zone. The nature and possible locational control of this physiognomic transition will be the focus of this thesis.

In Michigan, the northward gradient from a deciduous forest to a mixed coniferous forest appears to be controlled ultimately by climate, but the sharpness of the change may be attributable to other factors. These factors may be biotic (e. g. species competition), topographic (e. g. specific to landform type) or edaphic (e. g. soil texture) in nature. This study is concerned specifically with the possible relationship between forest composition and the texture of the upper soil profile across the tension zone. The underlying hypothesis is that evergreen species, increasing in abundance northward, show a high association with coarse-textured soils, and that these soils are more prevalent north of a sharp transition across central Lower Michigan. If this view is correct, the distribution of needleleaf trees is edaphically controlled and the underlying soils pattern across the central lower peninsula helps define the tension zone.

CHAPTER I

REVIEW OF LITERATURE AND STATEMENT OF THE PROBLEM

Literature Review

References to the Michigan tension zone occur in three broad contexts in phytogeographical literature; studies of the major forest associations of the lower peninsula, the tension zone itself, and the relationship between soil and forest distribution near, or within, the study area. This review will focus on a summary of the literature within each context.

In an early description of Michigan plant geography, Beal and Wheeler (1892) maintained that the flora of the lower peninsula was generally common to all regions due to the "uniform surface of the peninsula," and that the "pinelands" of the northern lower peninsula were intermixed with hardwoods south to a latitude of 43 degrees north, with the pinelands becomming less frequent to nonexistent south of that latitude. Darlington (1945), reemphasized the importance of that latitude of change in his review of the taxonomic literature on the flora of Michigan, stating that the principal deciduous area was south of that line. Dice (1931) described the boundary between two biotic provinces, Ohioan and Alleghenian, at that approximate latitude, and noted a belt of intergradation along this boundary where components of the Ohioan province, characterized by its deciduous trees, intermingle with components of the Alleghenian, an extensive development of pines.

The importance of this vegetation boundary near 43 degrees north latitude has also been summarized by other investigators in the description of major forest associations. For example, Nichols (1935) stated that the boundary between the "Hemlock-White Pine-Northern Hardwood Region" and a deciduous forest to the south crosses the central lower peninsula of Michigan near this latitude. He emphasized the transitional nature of this mixed forest association with its southern boundary ("a great tension zone") consisting of large areas of either coniferous species, deciduous species, or a mixed composition of northern and southern climax types. Nichols speculated that deciduous species would succeed at localities where they were edaphically favored. Braun (1950) established a similar line between a "Hemlock Hardwood" and a "Beech Maple forest." Braun and Nichols emphasized the mixture of climax forest types across the boundary, supporting an earlier conclusion of Cowles (1901) and, in Michigan, Whitford (1901) that edaphic or physiographic climaxes may persist in a region dominated by another major plant association. Curtis (1950) extended the forest association boundary into Wisconsin, separating a southwest southern-hardwood and a northeast conifer-hardwood forest association. The boundaries established by Braun, Nichols, Dice and Curtis are all coincident across central Lower Michigan.

The existence of a transition between major plant associations described by these authors was not always supported by other research. Quick (1923) concluded that there was no persistent separation of forest types in Lower Michigan and that the beech-maple association was capable, if left undisturbed, of occupying all of the soils of the region. Gleason (1924) supported Quick's conclusion, emphasizing the successional nature of the evergreen species. Benninghoff (1960) agreed with Quick's "concept of unity" (one climax forest association) after examining the beech-maple stand phytosociology both north and south of the vegetation boundary defined by Braun and Nichols. Therefore, one possible objective of an examination of the Michigan tension zone would be to establish the location of significant change in forest composition, hence, define the occurrence of more than one plant association, (successional or climax) across central Lower Michigan.

Several people have presented information concerning possible controls of plant distributions across the tension zone of Michigan. Livingston (1903) referred to a "zone of tension" when he described the upland plant communities of Kent County, Michigan. Although he was recording vegetation distribution on a somewhat disturbed landscape, he noted a significant change in the predominant vegetation cover (from deciduous to coniferous tree species) along "a wavy east and west line passing through Rockford" (page 51). He suggested that the change in plant species could be attributed to a south to north trend toward cooler climate. Livingston emphasized, however, the importance of the distribution of contrasting surficial material and the consequent variation in the ability of the surficial material to hold water (dependent on particle size). He suggested that the lighter surficial material of Northern Kent County is less suited to hardwood species. This conclusion was supported in a later study by Livingston (1905) in Roscommon and Crawford Counties.

D. Harvey (1919) referred to a "great tension zone" in Lake County and adjacent areas where the northward extension of the deciduous forest formation intermingled with the southern relicts of the northeastern evergreen forest formation. He stressed, however, that the evergreen forest was an edaphic climax which had maintained itself, and may do so perpetually, against a successional conversion toward the regional climax association (mixed hardwood). Although this may be so, he suggested: "It is evident that ecological conditions permit in certain widely distributed areas over the entire region the development of the deciduous climax forest . . . either as maple-beech or mixed hardwood" (page 213).

Potzger (1948) examined temporal forest change in the tension zone as shown by pollen data. He defined the zone as an area approximately thirty miles north and south of a line extending from Muskegon to Saginaw. Although Potzger found evidence that temporal fluctuations in vegetation along the tension zone far exceeded those in locations north and south of the zone, he, as well as Curtis (1959) in Wisconsin, identified a persistence in the tension zone throughout glacial times. Potzger concluded that "it is not a time factor influencing the northward movement of plants," and that the latitudinal gradient in an unspecified climatic control appeared sufficient to prevent such a successional trend through Michigan vegetation history.

In examining the transition from prairie and southern hardwoods in southwestern Wisconsin to a conifer-hardwood forest in the northeast, Curtis and McIntosh (1951) found only a continuum of forest change rather than a sharp transition. The lessened gradient, they suggested, may be attributed to the simpler floristic composition of the southwest vegetation and the lack of a sharp corresponding gradient in certain environmental factors. They hypothesized that a greater floristic complexity, or a sharper environmental gradient, may result in a more distinct change in vegetation across a tension zone.

J. C. Elliot (1952, 1953) worked within Missaukee County, assuming it to be representative of the tension zone. He concluded that: (1) the vegetation now (a disclimax) is very different from that interpreted from the original survey; and, (2) the data support the contentions of Quick (1923) that the whole lower peninsula would support a maple-beech association given time for the vegetation to come into equilibrium with the climate. He maintained that disturbance factors (lumbering and fires) have eliminated coniferous species as dominants within the region, and that the normal course of succession is toward a maple-beech association.

T. Hushen, et. al. (1966) found that the presettlement forest in Montcalm County consisted of a complex and variable mosaic of forest associations characterized by abundant white pine and beech. They observed that white pine, beech, and red maple maintain a "broad ecological tolerance" for different soils which may explain their prominence in the transition zone. Later, Kapp (1978), in a study of presettlement forests in the Pine River watershed of Montcalm and adjacent counties, identified the botanical ranges of several forest species that compete within this area of the tension zone.

Recently two research projects were completed which focused on the distribution of flora across the tension zone. McCann (1979) located a "floristic tension zone" which she defined as a concentration of the northern range limits of southern plants. Initially she established that the range limits of northern species are not significantly concentrated and therefore are not indicative of a floristic tension zone. In an attempt to determine an "ecological" or "physiological" explanation for this concentration of southern species ranges, she identified a number of possible causes and examined the gradient expressed by each factor across the zone. She noted that the latitudinal change in growing degee days corresponded closely with the designated floristic tension zone and concluded that this factor (described as insufficient heat) limited enough species to produce the transition.

Brewer (1982) studied the ecological basis of the tension zone by examining the range limits of tree species. He noted a correlation between the northern limits of southern trees and the southern limits of hemlock and white pine. From this observation, Brewer concluded that the "northern conifers played a major role in causing the presettlement tension zone for southern trees."

Soils, as an environmental control within the Michigan tension zone, have not been adequately studied. Livingston (1903, 1905) observed the presence of pines on a lighter surficial material but made these observations at only two locations in the lower peninsula. As mentioned, Hushen, et. al. (1966) examined soils within only one county. McCann (1979) argued that soils were not a causal factor in the tension zone on the basis that the glacial drift boundaries failed to correspond with the floristic boundary, and also that the present soil differences (e. g. podzolization) were probably the result of vegetation and climate rather than causing the vegetation difference.

That soils may be important to plant distribution is clearly revealed in other works. Wilde (1933) emphasized the correlation between pines and sandy soils, hardwoods and loamy soils, and conifers and hardwoods and clayey soils in the Lake States. Transeau (1935) suggested that "mature" and "immature" soils may be an influence along tension zones. Eggler (1938), in Wisconsin, observed that maple-basswood forests grow only on till soils whereas pines occur on extensive areas of outwash. Nutter (1973) identified contrasting trends in vegetation composition on soils of different textures in Antrim and Montmorency County.

Veatch (1959) published a map of the Michigan presettlement forest which clearly depicts a northward transition from hardwood to mixed coniferous forest across the tension zone. He compiled the map using the established correlation between soils and vegetation distribution enhanced at a few localities with information from survey notes and/or botanical literature. The location of the vegetation transition corresponded closely with a sharp gradient northward toward a predominance of coarse-textured soils depicted on Veatch's earlier soils map (1953).

More recently, data concerning water holding capacities of various levels in the soil profile were plotted on several maps (Schneider and Erickson, 1967). A decrease in soil water holding capacity, at all levels of the soil profile, was depicted northward across the tension zone.

The northward trends observed in forest composition (toward mixed coniferous), soils (toward coarse-textured soils) and soil water holding capacities (toward lowered capacities) coincide across central

Lower Michigan. Eyre (1968), in the book Vegetation and Soils, emphasized that a coarse and siliceous soil will weather to a material that permits rapid leaching. It is well documented (e. g. Eyre, 1968; Daubenmire, 1962) that coarse soil texture is associated with a low water holding capacity, low nutrient availability, and low pH, and in sum may be an important controlling factor in plant distribution. The association between this factor and forest composition across the tension zone should be more closely examined.

Statement of the Problem

There appear to be three areas of insufficient understanding that concern the tension zone: (1) whether a distinct south-north transition in the major forest associations occurs in central Lower Michigan; (2) the identification of a physical factor or set of factors most closely associated with forest composition across this transition; and, (3) the latitudinal distribution of that physical factor(s).

Statement of Hypotheses. The main hypotheses of this study are concerned specifically with the latitudinal distribution of coarse-textured soils northward across the tension zone, and the relationship between forest composition and underlying soil texture in this region. The first hypothesis is that presettlement forest composition, as defined by the number of individuals of representative tree species, is significantly associated with soil texture. Secondly, it is hypothesized that the extent of upland areas characterized by coarse-textured soils increases significantly northward across the tension zone. I anticipate that a test of these hypotheses will reveal a close association between needleleaf evergreen trees and coarse-textured soils, and that the occurrence of these soils increases sharply from south to north.

To further clarify these patterns, I will test three subhypotheses which evaluate the trend in forest physiognomy, as an indicator of the forest transition, and the corresponding association to soil texture. These hypotheses are: (1) the percentage of trees that are needleleaf increases significantly northward across the tension zone; (2) the needleleaf trees are more site specific to sands than are the broadleaf deciduous species to finer-textured soils; and, (3) a stronger association occurs between tree physiognomic type and soil texture north of a sharp transition toward coarse-textured soils within the tension zone.

The Study Rationale. An identification of all aspects of forest composition that change across the Michigan tension zone is beyond the expectations of this thesis. The presence of a transition, however, may be better determined through an examination of forest physiognomy. I will focus on this criterion in the examination of vegetation across the tension zone.

If the location of representative broadleaved or needleleaf trees is significantly associated with a physical factor such as soil texture, this factor may be an environmental determinant of local forest distribution. Moreover, if soils of specific textures are distributed along a nonuniform gradient northward across the tension zone, the forest transition may be related to this gradient. The significance and strength of the association between representative tree species and various soil textures should indicate the degree of correspondence and therefore define the relationships that exist between forest composition and underlying soil texture across the Michigan tension zone.

CHAPTER II

METHODS

Definition of the Study Area

I incorporated background literature and a knowledge of the physical environment in the demarcation of the study area. J. E. Potzger (1948), in his pollen research across the tension zone, defined the area as extending approximately thirty miles either side of a line from Saginaw to Muskegon. This zone coincides with a transition in soil types depicted on Veatch's soils map (1953) and a decrease in the soil profile water holding capacity (Schneider and Erickson, 1963). The tension zone examined in this study was defined by these works (Figure 1).

Data Retrieval (the Sampling Design)

The Belt Transects. The sampling of vegetation and soils was completed along three belt transects which extend south to north across the tension zone in an upland physiographic region (Figure 2). No transects were located in the Saginaw Bay Lowlands where the low relative relief and the predominance of poorly drained mineral soils within the lowlands might obscure soil texture-forest relationships. Furthermore, lowland sites are known to have a successional development and climax forest which differs from that characteristic of a region. The sampling area, secondly, was located east of the approximate

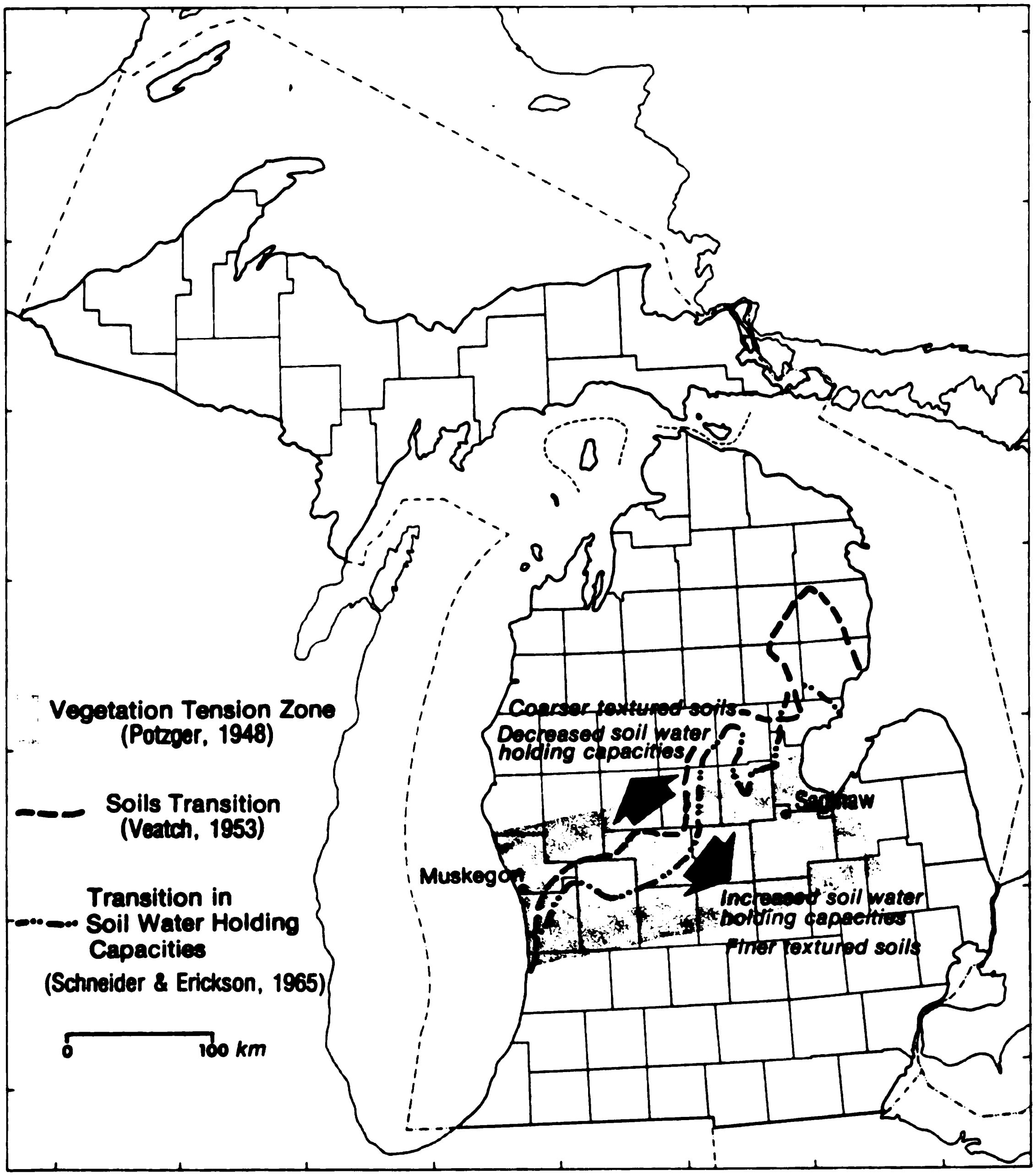


Figure 1. The study area.

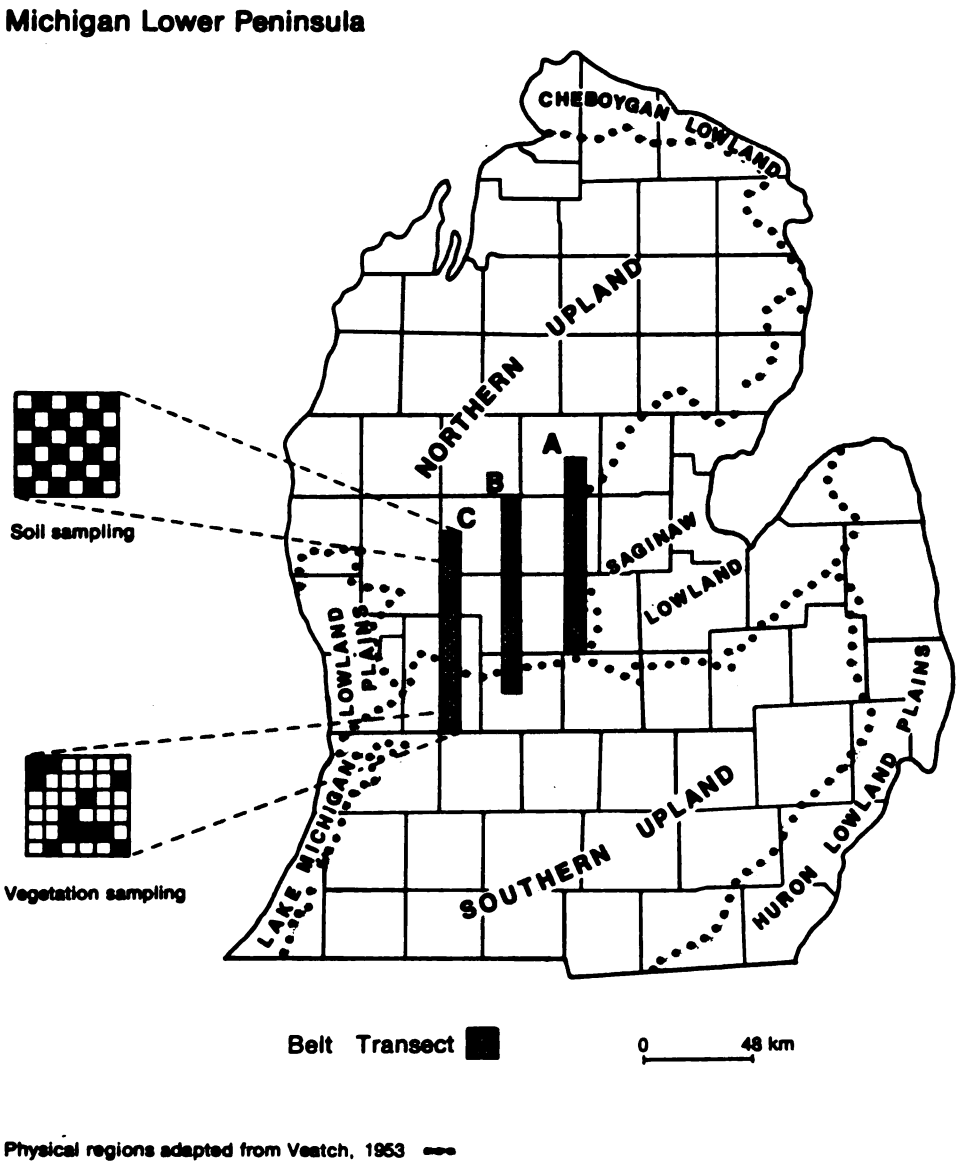


Figure 2. Location of the belt transects and and the sampling design.

longitude of Grand Rapids, Michigan, where at least some of the climatic influences of Lake Michigan diminish (N.D. Strommen, 1974). The acquisition of data from three separate transects (identified as **A**, **B**, and **C**) was designed to optimize the reliability of the study results, and their location in a physiographic region with only limited wetlands should facilitate the study of the vegetation and soil transition on upland sites.

Each belt transect is a linear plot one township wide (9.6 km. or 6 mi.) and ten townships long (96 km. or 60 mi.). The width of these transects provided sufficient data points at close intervals to examine soil texture-forest relationships from south to north. The total area, 576.6 square kilometers (360 sq. mi.), and the number of samples taken allowed separate analyses to be maintained along each transect. The total area from which data were obtained was 1728 square kilometers (1080 sq. mi.).

<u>The Presettlement Forest</u>. Agricultural and urban land uses are currently dominant in the tension zone, and the woodlands that remain have suffered considerable alteration. Consequently, they are limited in extent and the spatial variation in their composition may be more related to succession and peculiarities of site history. The composition of the presettlement forest was probably more closely related to the physical environment and, hence, was examined in this study.

Presettlement forest data were obtained from the General Land Office Survey notes (see Appendix 1a). This source has been used extensively in vegetation studies elsewhere, e. g. Ohio (Sears, 1925), Indiana (Potzger, Potzger and McCormick, 1956), Michigan (Kenoyer, 1930, 1934, 1940, 1943; Hushen, et. al., 1966; Brewer, et. al., 1984). Crankshaw, et. al. (1965) used survey notes as a source of quantitative data in a multiple regression analysis which tested the relationship between vegetation type and various soil parameters, and Nutter (1973) used presettlement vegetation data in a quantitative analysis of "soil texture and forest change" in Antrim and Montmorency counties. Bourdo (1956) outlined the use of the General Land Office Survey notes, detailing the techniques used to identify bias and its application to quantitative research.

The survey notes are arranged by township in large volumes located in the Lands Division of the Department of Natural Resources, State of Michigan. As the surveyors mapped the section lines within a township they recorded witness or bearing trees (at section corners and at the middle of a section line) and line trees (along a section line) by common tree name, location, and diameter at breast height. I recorded only tree name and location.

Data available from all sections within a township exceeded that needed for effective statistical analyses. Therefore, I collected a stratified random sample along each transect by using a computer-generated random numbers table which listed numbers one through six (J. M. Lipsey, 1983). Using these numbers, I chose one or more sections from each six-mile wide row, a technique that ensured at least one sampling unit (15-18 samples) at 1.6 kilometer (1 mile) intervals from south to north (see Figure 2). A stratified random sampling design was advantageous because it allowed for an examination of the entire transect as well as specific portions along it from south to north.

The sample of presettlement trees obtained by this method was not tested for bias, but the presence of bias was estimated by checking for consistency between the sampled trees and the forest descriptions in the survey notes. The likelihood that the witness trees represent a seriously biased sample of the presettlement forest is small unless the surveyors repeatedly chose trees not representative of the forest. I saw no evidence of such bias as I collected the data. Further, I assumed that the presettlement forest was relatively undisturbed, and hence, would be representative of natural forest distribution. Hushen, et. al. (1966) tested the sample obtained from the survey notes on Montcalm County and found that bias in the trees identified was not present.

Soil Texture. All recorded trees, identified by location in the survey notes, were mapped on detailed soils maps available within the modern county soil survey reports (post 1960; see Appendix 1b). Each mapped tree was assigned to a soil mapping unit and a respective soil series.

All soil series located in Michigan, irrespective of county, have been classified into a soil management group (D. L. Mokma, 1982) on the basis of the dominant profile texture (upper 5 feet), and further classified by drainage characteristics. Crankshaw, et. al. (1965) suggested that probably enough time had elapsed between the land survey and the soil survey (approximately 100 years) to alter surface soil characteristics such that a correlation between presettlement forest composition and soils might be invalid unless characteristics of the B horizon also were included with the other soil information. The soil management unit, because it represents an average of the A and B horizon textures, incorporates this information.

The soil textures and appropriate class designations used in this study are identified in Table 1. I considered only the textural class of zonal mineral soils, omitting from the data set those trees located on organic, recent alluvial, and bedrock soils which are localized and maintain a vegetation composition not characteristic of the regional pattern. In the original scheme of soil management units (D. L. Mokma, 1982), those mineral soils developed from uniform parent materials are represented by one number, and soils developed from two parent materials or with contrasting textures in their profiles are represented by a fraction. I later designated an average value to the soils classed between two units and aggregated soils of similar textures ("Final Class" in Table 1) in order to maintain an adequate sample within each textural type.

A separate data set was acquired from the county surveys for the analysis of the soil textural gradient. I used a stratified systematic sampling technique to ensure an adequate sample, at close intervals, from south to north. Data were obtained from every second section by starting in the most southwestern section of the transect and sampling east then west respectively (see Figure 2). Within each section, the soil mapping unit was determined from the county soil survey map at .4 kilometer (.25 mile) intervals from east to west and south to north. Each soil mapping unit was assigned a soils series name and corresponding soil management unit, which then were combined as labeled in Table 1. Only the distribution of coarse-textured soils (textures 4 and 5) was observed in this analysis.

Table 1. Characteristics and final classes of soil management units used in the analysis.

Soil Management Units	Textural Characteristics	Final Class
Texture 1	fine clay, over 60% clay clay, 40-60% clay clay loam & silty clay loam	2
Texture 2.5	loam and silt loam	
Texture 3	sandy loam	3
Texture 3/2	sandy loam, 20-40 inches over loam to clay loam	
Texture 3/5	sandy loam 20-40"	
Texture 3.5	between texture 3 & 4	
Texture 4	loamy sand	4
Texture 4.5	between texture 4 & 5	
Texture 5	sand with strong subsoil development	5
Texture 5.3	sand with medium subsoil development	
Texture 5.7	sand with weak or no subsoil development	
Texture 4/2	sand to loamy sand 20-40" over loam to clay loam	c/f
Texture 4/1	loamy sand, 14-40 inches, over clay	
Texture 5/2	sand to loamy sand, 40-60" over loam to clay loam	

Modified from the Extension Bulletin (E-1262) entitled; "Soil Management Units and Land Use Planning" by D.L. Mokma; reprinted April 1982, Cooperative Extension Service, Michigan State University.

Data Analysis

Analysis of Forest Composition and Soil Texture Relationships. The tree species frequencies on each soil texture class, recorded along each transect, were arranged in three contingency tables. Overall patterns were observed by averaging, from the three transects, tree species frequencies on each soil texture and the frequencies of all tree species on representative fine (texture 2) and coarse-textured (textures 4 and 5) soils, and further clarified, by identifying contrasts and similarities between the transects in tree species distributions. The first hypothesis addressing the significance of the association between tree species and soil textural classes was tested using the Pearson's chi square statistic. The null hypothesis, that no association exists between tree species and soil texture, depicted frequencies that could be expected, and the Pearson's chi square test determined the significance of the divergence between these expected frequencies and the observed values (Blalock, 1979).

The assumptions of the test are that the population can be divided into discrete classes, the outcomes are independent of one another, and the sample size is relatively large. Taylor (1977) suggests, with respect to sample size, that no more than twenty percent of the contingency table cells have an expected frequency of less than five. Although the sample size was large for each transect, the frequencies of several of the trees were very low. It was necessary to combine the frequencies of trees with assumed similar habitats to maintain at least eighty percent of the expected cell frequencies at five or greater.

The chi square statistic is approximated by the following equation:

$$X^2 = \sum \frac{(observed - expected)^2}{expected}$$

The calculation procedure is detailed elsewhere (e. g. Winkler and Hays, 1975; Blalock, 1979). Notice, however, that a greater difference between the observed and expected frequencies results in a larger chi square value, and, furthermore, in a contingency table, the computed result equals the sum of all individual cell chi square calculations. In this study the contingency table compiled for each transect was complex (6 rows by 6 columns) and the respective recorded sample size was large. With everything else equal, the greater the number of cells, the greater the chi square value, with this increase offset only partially by the calculation of the degrees of freedom:

$$df = (r - 1)(c - 1)$$

where r and c are the number of rows and columns, respectively. Moreover, the chi square value is very sensitive to the size of a sample. If the sample is large, as recommended for this test, "virtually any 'degree' " of a statistical relationship will show up as a significant result (Winkler and Hays, 1975).

The significance level in the chi square analysis, consequently, was not only an indication of the relationships between tree species and soil textures, but also the complexity of the contingency table and the large data set. Therefore, to enhance the interpretibility of the results, I calculated two indices which measure both the overall strength of the association and the predictive power of the independent variable (soil texture). The phi coefficient (Φ) measures association strength by adjusting the chi square values for a large sample (Nie, et. al., 1975; Winkler and Hays, 1975). The Cramer's V (**V**) statistic is a "modified version of the phi which is suitable for larger contingency tables" (Nie, et. al., 1975, page 224). The calculation and relationship between these two indices is as follows:

$$\Phi = \sqrt{X^2/n} \qquad V = \sqrt{\Phi^2/L-1}$$

phi coefficient **Cramer's V**

By dividing the phi coefficient by the smaller dimension (rows or columns) of the contingency table (**L**), which has been subtracted by one, the index is adjusted to vary between zero (no association) and one (absolute association). One undesirable feature of the Cramer's V statistic is that the computed value is dependent on the rows or columns for its interpretation; a larger number of rows or columns will result in a greater index value (W. J. Conover, 1971).

As an index of predictive association, the asymmetric lambda statistic was calculated by the following equation:

$$\lambda_b = \frac{\left(\text{sum of the maximum values in each column}\right) - \left(\text{maximum value of the row marginals (totals)}\right)}{\text{n - maximum value of the row marginals (totals)}}$$

(Winkler and Hays, 1975, Nie, et. al. 1975). The index assessed the predictive power of the independent variable (soil texture) in identifying the dependent variable (the occurrence of a particular tree species) and varied from 0 (no improvement in prediction or reduction in the probability for error) to 1 (prediction can be made without error).

The chi square statistic, the Cramer's V, and the asymmetric lambda indices, calculated for each transect, should indicate: (1) the significance of the association between tree species and soil texture; (2) the strength of the association; and, (3) the predictive power of the independent variable (soil texture). The analysis of Transect **A** was completed manually, whereas the stastistics for Transect **B** and **C** were calculated using the **Statistical Package for the Social Sciences**, (Nie, et. al., 1975) on the mainframe computer (Control Data Cyber 750) at Michigan State University.

Analysis of the Soil Texture Gradient. The stratified systematic sample of soil texture allowed the frequency of each textural unit to be examined at .4 kilometer (.25 mile) intervals from south to north, and the analysis focused on the frequency of coarse-textured (texture 4 or texture 5) soils at each interval. Scattergrams (Nie, et. al., 1975) were produced to observe the northward trend (frequency of texture 4 or 5 with distance) and to identify the location of the most distinct increase in the occurrence of each respective soil texture. I separated the recorded data at that location, thereby forming two samples which represented south and north, respectively.

The Student's t statistic was computed to determine whether the mean frequency of soil texture 4 or 5 increased significantly north of the established break. The precise calculation of the Student's-t difference of means test is well documented (e. g. Nie, et. al. 1975, Blalock, 1979, Winkler and Hays, 1975). The test assumes that the samples are drawn from populations of equal variances. An F test, which measured the similarity in the sample variances north and south, was used additionally to determine whether the results of the actual t-test computation (a pooled variance estimate), or, if the variances were not equal, the approximated t-value (a separate variance estimate) were interpreted (W. K. Klecka, et. al., 1975). The null hypothesis, that there is no significant increase in the mean frequencies of texture 4 or 5 north of the line, was rejected if the alpha value of a one-tailed test exceeded .01.

Although the t-test revealed the significance of the different mean frequencies in coarse-textured soils north and south of a designated line, it can not depict the trend that occurs northward along each transect. A regression analysis, employing dummy variables, was used to clarify the northward trend in the occurrence of coarse-textured soils across the tension zone. This analysis was designed to examine the frequency of texture 5 (the most coarse soil texture) as it was related both to distance (**X**), and to its position north or south of the line established in the t-test. A designation of north or south was incorporated into the equation through the use of an additive and multiplicative dummy variable (D_i) where **D**=1 if **Y** is north of the break and **D**=0 if **Y** is south of the break. The final regression equation was as follows:

$$Y = a + b_1X + b_2(D_1) + b_3D_2X$$

where **Y** is the frequency of soil texture 5, **a** is the y-intercept, **X** is the distance northward along the transect, D_1 is the additive dummy, and D_2 is the multiplicative dummy. If **Y** is north of the break the equation would be as calculated above, but if **Y** is south of the line the effects of the dummy variable are eliminated from the equation:

$$Y = a + b_1X + b_2(0) + b_3(0)$$

$$Y = a + b_1X$$

The examination of the results focused on the significance of the **a** (y-intercept) and **b** (slope coefficient) values in the equation. If **Y** is north of the break, the **a** value would have the additive effect of b_2, and the slope of **X** (b_1) would increase by b_3. Significant **a** and b_1 values indicate that the linear trend south (and north) has a slope and y-intercept different from zero, and significant b_2, and b_3 coefficients indicate that the linear trend north of the break is different from the trend south of the break. The R^2 value, for the overall equation, depicts the percentage of variance in the northward distribution of soil texture five explained by the equation. Further detail on the application and interpretation of linear regression using dummy variables may be obtained elsewhere (Johnson, 1972; Nie, et. al. 1975).

Analysis of Forest Physiognomy and Soil Texture Relationships (Transects B and C). The first subhypothesis addressed the percentage increase in needleleaf trees northward across the tension zone. From the original data recorded on the presettlement forest I was able to calculate, by township, the percentage of all trees that were needleleaf. As I was interested in a possible northward trend in the relationship between the percentage of needleleaf trees and the extent of coarse-textured soils, I separated the recorded data at the same location used previously in the t-test examination of the soil texture gradient. The data sets, south (n_1) and north (n_2) remained large so it was possible to assume an approximate normal population, and the significance of the different frequencies of needleleaf trees south (k_1) and north (k_2) was determined through a computation of the z-statistic, where p_1 and p_2 were the sample proportions south and north respectively (Yamane, 1973). The true proportions of needleleaf trees to all trees south (π_1) and north (π_2) were examined as follows:

$$H_0: \pi_1 = \pi_2 \qquad \hat{\pi} = \frac{k_1 + k_2}{n_1 + n_2} \qquad Z = \frac{p_1 - p_2}{\sqrt{\hat{\pi}(1-\hat{\pi})(1/n_1 + 1/n_2)}}$$
$$H_1: \pi_1 < \pi_2$$

I was specifically interested in determining whether there was a notable increase in the percentage of needleleaf trees north of the preestablished division across each transect and in the computed significance of this increase. I rejected the null hypothesis, that the north percentage is not greater, if the alpha value exceeded .01 (one-tailed test).

The data concerning presettlement tree species frequencies on different soil textures were reorganized into a subtable to facilitate determination of which portions of the overall contingency table contributed most to the significance of the tree species-soil texture association (chi square), strength (Cramer's V), and dependent variable (tree species) predictability (asymmetric lambda). I examined the frequencies of the broadleaved deciduous species and the needleleaf evergreen species on each soil texture class. The reduction in the number of rows and columns (cell frequencies) enhanced the interpretability of the chi square and Cramer's V statistic because their computed values were not increased as much by the complexity of the contingency table as in the examination of individual tree species.

Changes observed in the computed statistics, as they compared to the examination of individual tree species-soil texture relationships (hypothesis one), clarify the site specificity of these two physiognomic groups.

The frequencies of the two physiognomic groups on each soil texture were separated south and north of the predetermined break in coarse soil texture. A recalculation of the statistics for each table was completed to assess the relative increase in association significance and strength, as well as the predictability of the dependent variable (tree species), north of this break.

CHAPTER III

RESULTS

Analysis of Forest Composition and Soil Texture Relationships

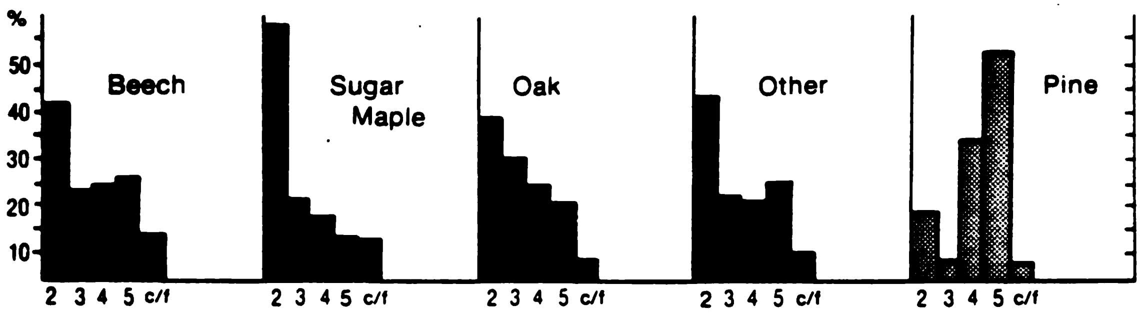
Presettlement Forest and Soil Texture. The number of trees recorded along each transect, including only those on mineral soils, was 1089, 1161, and 1246 for transect **A**, **B**, and **C** respectively (see Appendix 2a). Beech (*Fagus grandifolia*) was the most common tree recorded, exceeded only by oak (*Quercus spp.*) along transect **C**. Sugar maple (*Acer saccharum* or *Acer nigrum*) was a well-represented species along transect **A** (highest frequency) and **B**, but was lower in frequency along transect **C**. In contrast to the distribution of sugar maple, oak was most common on transect **C** and had a very low occurrence along transect **A**. Elm (*Ulmus spp.*), maple (*Acer spp.*, probably *Acer rubrum*), black ash (*Fraxinus nigra*), lynn (*Tilia americana*) and other species (e. g. *Ostrya virginiana*, *Prunus spp.*) were infrequently recorded. I assumed these species to be similar in their preferred habitats, hence, they were combined into one group which I labeled "other mesic deciduous species" (Harlow, Harrar, and White. 1979).

The needleleaf trees recorded were pine (*Pinus strobus*, and unspecified pines), hemlock (*Tsuga canadensis*), cedar (*Thuja occidentalis*) and tamarack (*Larix laricina*). Tamarack and cedar were combined into one category, which I regarded as representative of a poorly drained habitat. The combined frequency of tamarack and cedar was the lowest of all tree categories and, in some cases, I combined the frequencies of these two species with hemlock, forming a category which I labeled "other needleleaf species".

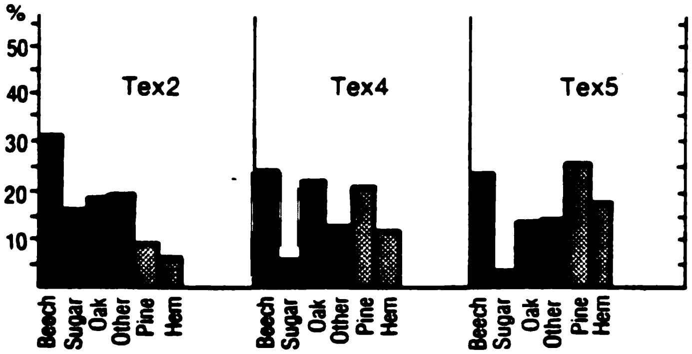
The recorded occurrences of fine and coarse-textured soils varied between the transects (see Appendix 2b). A higher frequency of fine-textured soils was recorded along transect **A** than transect **B** or **C**. Transect **C** had the highest frequency of coarse-textured soils (textures 4 and 5), soil texture class 3 was most frequent along transect **B**, and texture class 15 (coarse over fine soil textures) was infrequent along the three transects.

<u>Tree-Species Categories-Soil Texture Class Frequencies</u>. Several overall patterns were observed in the distribution of a tree species category on all soil textures (Figure 3a) and in the distribution of all tree species categories on representative fine and coarse-textured soils (Figure 3b). Beech, oak, and other mesic deciduous species, although most frequent on soil texture 2, were generally abundant on all soil texture classes. Sugar maple appeared to be primarily site specific to fine-textured soils (soil texture 2), whereas pines and hemlock were identified primarily on coarse-textured soils, being most frequent on soil texture 5 (Figure 3a). Beech was the most frequent tree on representative fine (texture 2) and coarse-textured (texture 4 or 5) soils, exceeded only slightly by pine on soil texture five, and the occurrence of needleleaf species, relative to the other deciduous species, increased noticeably on the coarser-textured soils (Figure 3b).

An examination of the relationships present along the individual



a. Distribution of tree species or species category on all soil texture classes.



b. Distribution of all tree species or species categories on representative fine and coarse-textured soils.

Figure 3. Frequency percentages averaged from the three transects.

transects, however, revealed several major contrasts to the general patterns (see Appendix 3a). First, the frequencies of beech and oak were actually greatest on texture 2 on only transect **A**, but were highest on texture 3 along transect **B** and on texture 5 along transect **C**. These patterns correspond directly to the extent of each soil texture, with texture 2 being most frequent along transect **A**, texture 3 along transect **B**, and texture 5 along transect **C**. Second, the localized distribution of sugar maple on soil texture 2 was most apparent on transect **C** (70.6%) and least apparent on transect **B** (21%), and further, along transect **B**, pine appeared less site specific to soil texture 5 (31%, as compared to 62% on transect **C**). Third, pine was actually most frequent on soil texture 4 along transect **A**, in contrast to transects **B** and **C** where it was most frequent on texture 5. Finally, beech was the most common tree on the representative fine and coarse-textured soils along each transect, with the exception that it was exceeded by pine on soil texture 5 along transect **B**, and exceeded by oak on texture 4 and 5 and pine on texture 5 along transect **C**. These contrasts indicate that there is some east-west variation in the observed site-specificity or relative frequency of a tree species category.

Statistical Results. The chi square value, computed for each transect, exceeded a critical value of approximately 53 at an alpha value less than .001 (Table 2), indicating that the summed divergence between observed and expected frequencies was significant. The Cramer's V index, varying from 0 to 1, was highest along transect **C** (.21) and lowest along transect **B** (.16) (Table 2). The chi square values computed for each transect indicated, in addition to the

Table 2. Tree species categories-soil texture class relationships, the statistical results.

Transects	Chi square	df(r-1)(c-1)	Cramer's V	Asymmetric lambda
Transect **A**	185.73	24	.21	0
Transect **B**	122.30	24	.16	.007
Transect **C**	231.79	20	.22	.03

Critical chi square is approximately 53

at alpha < .001

significance of the tree species-soil texture association, that the values computed for the Cramer's V are statistically accurate estimations of the strength of the association (Norcliffe, 1977). The asymmetric lambda index calculated for each transect, varying from 0 to 1, equaled approximately zero (Table 2). There was no decrease in the probability for error, in choosing a tree species, if a soil texture is known.

Analysis of the Soil Texture Gradient

Location of a Sharp Gradient. Scattergrams, which showed the frequency of textures 4 and 5 at .4 kilometers from south to north along each transect, depicted a sharp increase in soil texture 5 (the most coarse soil) at 67.2 kilometers along transects **B** and **C**, and much less distinctly along transect **A**. The data set was separated, forming a south and north sample, at that location.

Among texture 4 soils, no sharp increase was recognizable along either transects **B** or **C**. On transect **A**, however, I observed a significant break in the distribution at 76.8 kilometers, and because it was on these soils in transect **A** that needleleaf trees were most frequently recorded, I examined additionally the significance of this break.

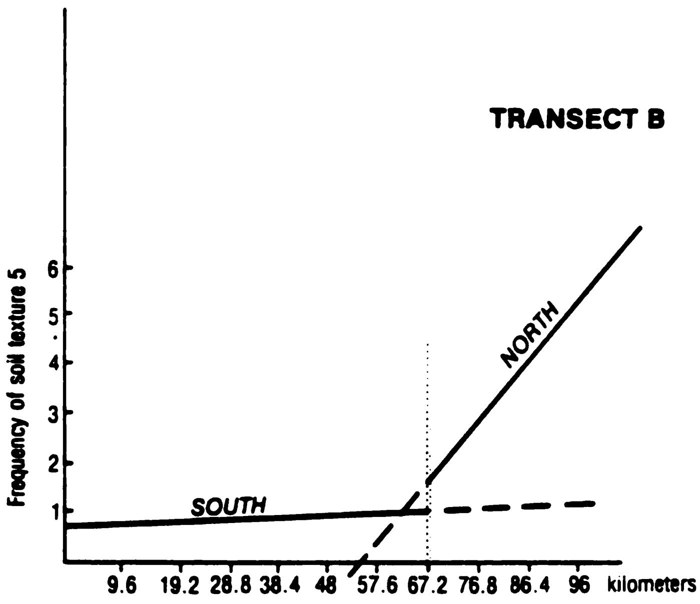
Student's T Test Results. The mean frequency of soil texture 5 at .4 kilometer intervals along transect **A** was 1.04 for the sample south of 67.2 kilometers and 1.46 for the north sample (Table 3). This slight increase north of the recognized break was not significant (alpha = .05), and, furthermore, the overall occurrence of this soil along transects **B** and **C** and in each transect the north mean exceeded

Table 3. Student's t-test results.

TRANSECT DIVISION	MEAN	F—TEST Value	F—TEST Sig.	T—TEST Value	T—TEST Sig.
TRANSECT A (texture 5)					
South T9N-T15N	1.05	1.07	.722	-1.89 (pooled)	.060
North T16N-T18N	1.46				
TRANSECT B (texture 5)					
South T7N-T13N	.98	2.59	.000	-9.80 (separate)	< .001
North T14N-T16N	3.74				
TRANSECT C (texture 5)					
South T5N-T11N	2.84	2.17	.000	-9.96 (separate)	< .001
North T12N-T14N	7.08				
TRANSECT A (texture 4)					
South T9N-T16N	1.307	2.54	.000	-8.84 (separate)	< .001
North T17N-T18N	4.604				

that in the south (Table 3). The negative t-values (a separate variance estimation) were significant at an alpha value less than .001, thereby indicating that the mean south frequency of texture 5 (u_1) was significantly less than the mean north frequency (u_2) along these two transects. The mean frequency of soil texture 4, south of 76.8 kilometers along transect **A** (1.307), was significantly less than north (4.604) at an alpha value less than .001.

Regression analyses. The linear equation determined for transect **A** had a low R^2 value (.12), indicating that very little of the variance in the occurrence of soil texture 5 was explained by the equation. This result, as well as the insignificant t-test result, prevented any detailed observations on the linear trend of texture 5 north and south of the designated break along this transect. The linear equation for transect **B**, however, had a R^2 value equal to .44 and the y-intercept (**a**), as well as each of the slope coefficients, was significantly different from zero. These results indicate that, along transect **B**, the south (and north) gradient was significantly different from zero and the linear trend to the south ($Y = .55 + .01X$) was significantly different from the trend to the north ($Y = -6.05 + .12X$) (Figure 4a). The linear equation calculated for transect **C** yielded a high R^2 value (.57) and the y-intercept (**a**), as well as each of the slope coefficients, was significantly different from zero. As in transect **B**, the south (and north) gradient was significantly different from zero and the linear trend to the south ($Y = 1.95 + .26X$) was significantly different from that north of the break ($Y = 32.75 + -.314X$) (Figure 4b). The south and north linear equations for transects **B** and **C** reveal a.



b.

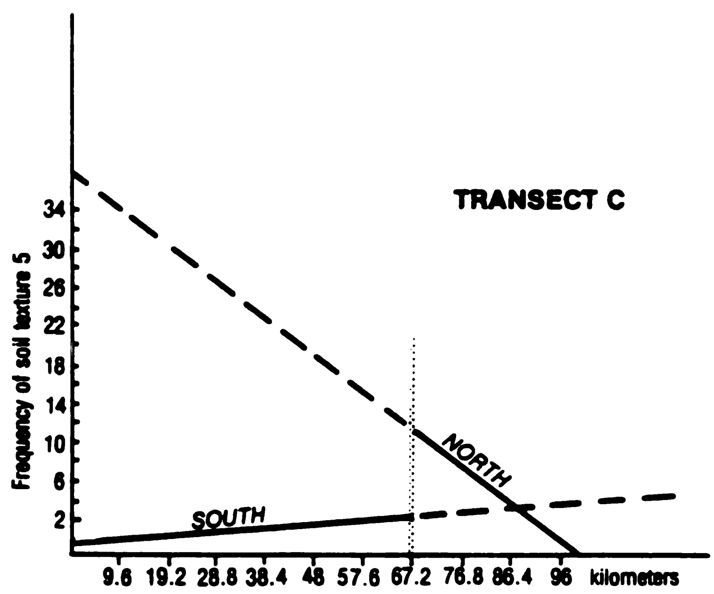


Figure 4. Graphic representations of the linear equations.

a similarity in the trends along both transects south of the break, but distinct differences are observed north of the break.

Analysis of Forest Physiognomy and Soil Texture Relationships (Transects B and C)

Needleleaf Tree Percentages. A northward increase in the percentage of all trees that were needleleaf occurred along both transects; this percentage reached a maximum of 47 per cent at 96 kilometers along transect **B** and 45 per cent at 86.4 kilometers along transect **C** (see Appendix 3b). Along transect **B**, the mean percentage of needleleaf trees south of the line (29%) was less than north of the line (43%). Along transect **C**, the differences were less, with averages of 25 per cent south of the line and 37 per cent north of the line. The computed z-statistic was high for transects **B** (161.79) and **C** (147.62), and, at an alpha value less than .001, the north percentages were significantly greater.

A graph of the northward trends in the percentage of needleleaf trees and mean soil texture (an average of the frequencies of all textural classes) shows a correspondence between these two measures (Figure 5). In addition to the overall similarity in the two distributions, the decline in needleleaf trees along transect **C** at 28.8 kilometers and the sharp increase again at 38.4 kilometers corresponds to a finer and coarser mean soil texture, respectively, just as the decline in needleleaf trees along this transect at 86.4 kilometers corresponds to a trend toward finer-textured soils.

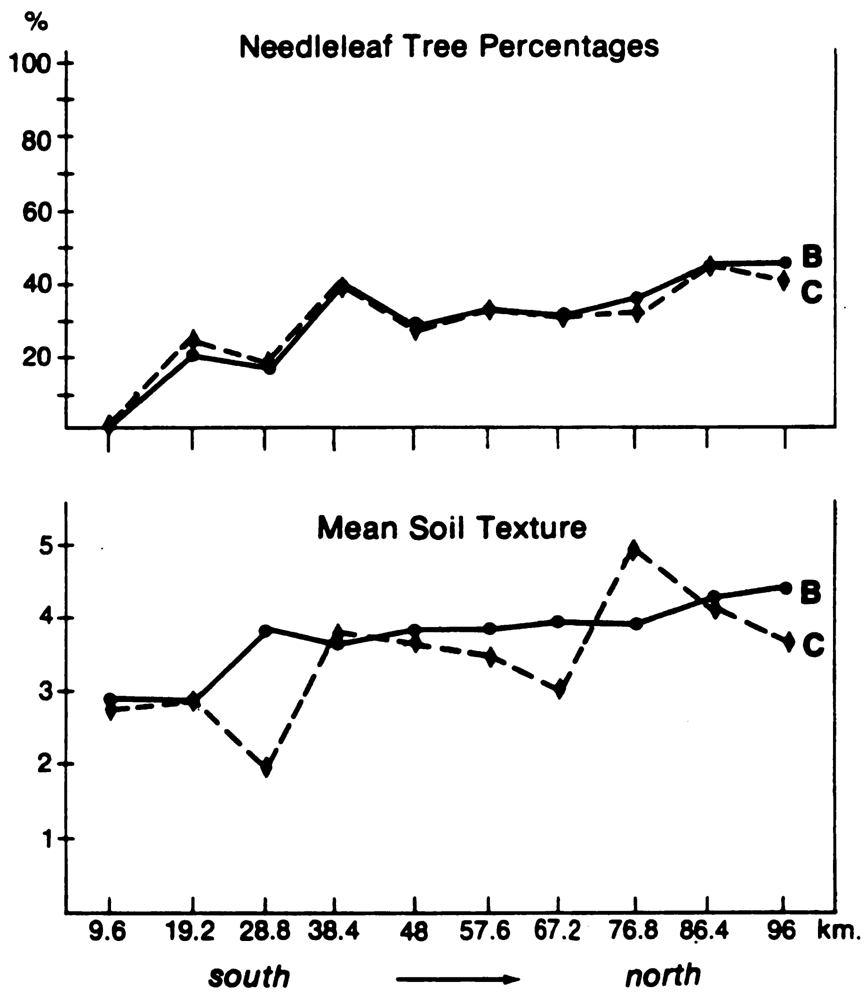


Figure 5. Northward trends in needleleaf tree percentages and mean soil texture.

Forest Physiognomy-Soil Texture Relationships. The deciduous tree species were the most frequent physiognomic group on all soil textures, although they were exceeded by needleleaf species on soil texture 5 along transect **C** (see Appendix 3c). Deciduous tree species exhibited little site specificity to a soil texture, having similar frequencies on all soils (transect **B**), or having highest frequencies on fine (texture 2) and coarse (texture 5) soil texture (transect **C**; see Appendix 3c). The needleleaf species were most frequent on the coarse-textured soils, with 58 per cent of the trees occurring on texture 5 along transect **B** and approximately 75 per cent of the trees occurring on textures 4 and 5 along transect **C**.

In each transect the chi square value exceeded the critical value (20) at an alpha value less than .001 (Table 4). In this analysis of physiognomic groups, the Cramer's V and the asymmetric lambda indices increased slightly from those computed in the examination of tree species categories (Table 4 and Table 2). The strongest association (highest Cramer's V value; .25) was obtained for the physiognomic groups along transect **C** (Table 4).

Forest Physiognomy-Soil Texture Relationships South and North. No difference was apparent in the computed statistics for the south and north portions of transect **B**, but a noticeable difference was observed in the chi square statistic and the Cramer's V index computed for the south and north portions of transect **C** (Table 5). In the analysis of transect **C**, the chi square value south of the break (12.63) was below the critical chi square value (approximately 13), or, in other words, insignificant (alpha = .01), but north of the break, although the sample size was less, the chi square value (25.03) was significant

Table 4. Forest physiognomy and soil texture relationships, the statistical results.

Transects	Chi square	df(r-1)(c-1)	Cramer's V	Asymmetric lambda
Transect B	64.96	4	.24	.02
Transect C	76.33	4	.25	0

Critical chi square is approximately 20

at 4 df and alpha < .001

Table 5. Forest physiognomy and soil texture relationships south and north, the statistical results.

Transects	Chi square	df(r-1)(c-1)	Cramer's V	Asymmetric lambda
Transect B				
south (n=688)	30.27	4	.210	.002
north (n=473)	18.04	4	.200	.063
Transect C				
south (n=898)	12.62	4	.119	0
north (n=348)	25.03	4	.268	0

Critical chi square is approximately 13

at 4 df and alpha = .01

(alpha < .001). Furthermore, the Cramer's V index computed for the two samples indicated that the strength of the association north of the break (.268) exceeded the computed association strength to the south (.119). The extent of soil texture 5 (~70% of the sampled sites) was much greater north of the break, with a resulting high occurrence of deciduous (62.8% of all deciduous trees) and needleleaf (77.6% of all needleleaf trees) species on that soil texture (see Appendix 3d). As in all prior analyses of the predictability of the dependent variable (tree species or physiognomic group), the calculated asymmetric lambda value was approximately zero.

Results Summary

Tree species categories and physiognomic groups showed a significant association to soil texture classes along the examined belt transects, with the exception of a statistically insignificant association computed for the south sample along transect **C**. Needleleaf tree species were distinctly more frequent on coarse-textured soils, and sugar maple was identified primarily on fine-textured soils, but beech, oak, and other mesic deciduous species showed little specificity to a particular soil texture class. The mean frequency of soil texture class 5 increased significantly north of 62.4 kilometers along transects **B** and **C**, though differences occur in their trends north of the identified break. The occurrence of soil texture class 4 increased significantly northward along transect **A**. A significant increase in needleleaf trees (as a percentage of all trees) was measured northward along the transects and their relative percentages from south to north corresponded directly to the distribution of coarse-textured soils.

CHAPTER IV

DISCUSSION

The Hypotheses and Related Observations

Forest Composition and Soil Texture Relationships. The first hypothesis states that presettlement forest composition, as defined by the number of individuals of representative species, is significantly associated with soil texture. Based on the results of the chi square analysis completed for each of the three transects, I reject the null hypothesis that there is no association and conclude that the association is statistically significant.

The high chi square values (and corresponding low alpha values), however, were partially the result of the large data set recorded for each transect and the large number of rows and columns in the contingency tables. The Cramer's V index, adjusting for the large recorded samples, indicated that the strength of the overall association was not great. The localized distribution of pines on coarse-textured soils and sugar maple on fine-textured soils increased the Cramer's V index, while the high occurrence of beech, oak, and other mesic deciduous species on all soil texture classes decreased it. The frequency of those species not site specific exceeded the combined occurrence of pines and sugar maple and is possibly the explanation for the low computed values. Transect C had the highest Cramer's V value, the most pines, and the greatest extent of coarse-textured soils, whereas transect B had the greatest extent of soil texture 3, a texture to which no tree species appeared to be site specific, and the lowest Cramer's V value. The predominance of beech on nearly all soil textures and its high overall frequency was the primary reason for the low asymmetric lambda index values. In nearly every case for the three transects, beech would be the predicted tree when the soil texture class is known.

The contrasts in the relative frequencies of tree species categories between the three transects appear to depict an east to west transition in forest composition. Beech and sugar maple declined in frequency westward, while pine, and especially oak, increased westward. Because pines appear to be noticeably specific to coarse-textured soils, their increase may be an expression of the increase westward in coarse-textured soils. "Oak upland forest" occupies more land area than any other natural community in southern Michigan (Gysel and Arend, 1953; as cited in Parmelee, 1953) and this community type has been described by Braun (1950) as extending northeastward over the Wisconsinan-aged drift, from the Prairie Peninsula into southern Michigan, as large isolated tracts. The westward increase of oak, as well as the decrease of beech and sugar maple, that I detected may be an expression of the overall transition from beech-maple to oak dominated forests.

The Northward Gradient in Coarse-textured Soils. I hypothesized, secondly, that the extent of upland areas characterized by coarse-textured soils increases significantly northward across the tension zone. Based on the t-test results, I accept this hypothesis, at least regarding soil texture class 5 (the most coarse soil) along transects B and **C** and texture 4 along transect **A**. At an alpha value equal to .05, the null hypothesis, stating that there is no significant increase, could not be rejected in the analysis of soil texture 5 along transect **A**.

The distribution of soil texture 5, and its association to forest compostion, differed along transect **A** from transect **B** and **C**. The occurrence of this soil texture was low, it failed to show a sharp increase northward or a definable northward trend, and pines were not particularily frequent on this texture class, occurring most frequently on soil texture 4. It appears that the distribution of this soil texture along transect **A** was localized and exhibited contrasting characteristics, such as poor soil drainage or a high water table, which were not examined in this study and complicated general relationships between soil texture and tree species distributions.

Although the mean frequency of soil texture 5 increased significantly north of 67.2 kilometers along transect **B** and **C**, the northward trend from that location was distinctly different between the two transects. There was a sharp increase at 67.2 kilometers along transect **B** and a gradual positive trend north of that location in contrast to transect **C**, where a much sharper increase was observed at the south-north division, but the trend north of that location was negative. The break determined along transect **C** is located in the region of the Muskegon River watershed which is predominantly overlain by glacial outwash that is characterized as a layering of sand and gravel (Farrand, and Bell, 1982). North of this location the transect is on coarse-textured till (sandy loam-loamy sand) and to the south the transect is on medium to fine-textured till, so that there appears to be a distinct change in the texture of the drift (to very coarse) at the break examined along this transect in contrast to transect B which trends north across predominantly fine to coarse-textured ice-deposited features. Although this distribution of glacial deposits may explain the difference between the two transects, it was beyond the scope of this thesis to examine thoroughly the reasons for the observed northward trends in soil texture.

Forest Physiognomy and Soil Texture Relationships. The tension zone is defined in this study by an abrupt increase in the occurrence of needleleaf tree species. The z-test results, addressing the first subhypothesis, show that the percentage of needleleaf trees is significantly greater north of a significant increase in the occurrence of soil texture 5. Furthermore, the northward trend in the frequency of these species and this coarse soil texture, along both transects, is positive, with any decrease in the frequencies of needleleaf tree species corresponding to a decrease in the extent of coarse-textured soils. The similarity between the northward trends in coarse soil texture and needleleaf tree species and their statistically significant increase northward across the tension zone suggest that these soils may partially dictate the distribution of the needleleaf evergreen physiognomic group.

The second subhypothesis states that the needleleaf trees are more site specific to sands than are the broadleaf deciduous species to finer-textured soils. The statistical examination focused on both physiognomic groups (broadleaved deciduous and needleleaf evergreen) together, where it is shown that they are significantly associated to soil texture classes. The greater frequency of deciduous species, exhibiting little site specificity, resulted in a moderately low observed association strength and low predictability of either physiognomic group when given a soil texture class. The overall results from this examination of physiognomic groups-soil texture relationship differ little from the analysis of individual tree species categories, but the site specificity of needleleaf species, over that of the deciduous species, is further clarified.

Only along transect C was a stronger association (greater Cramer's V value) observed between soil texture and forest physiognomy north of a significant increase in coarse-textured soils (subhypothesis 3). Moreover, in the analysis of this transect, the chi square value computed for the north sample, with a smaller sample size (n), exceeded that computed for the south sample. These higher values, however, appear to be an expression of the higher frequency of soil texture 5 relative to the other soil textures north of the break and the resulting high frequency of deciduous and needleleaf species on this soil texture, rather than a northward trend toward greater site specificity. The specificity of needleleaf trees to coarse-textured soils was similar from south-north within the sampled region.

In sum, the subhypotheses served to clarify the existing relationships between forest composition and soil textures by focusing on the northward transition in forest physiognomy, forest physiognomy-soil texture relationships, and the south-north contrasts between observed relationships across the transition. It was beyond the limits of this study to measure relative increases in each tree species category, at intervals northward, in order to determine the abruptness of the transition in forest composition and its relationship to a soil texture gradient. However, the significantly higher north percentage of needleleaf trees suggests that the change in forest composition at the tension zone is abrupt and supports a conclusion that more than one plant association occurs across central Lower Michigan.

The correspondence that I found between the northward trend in needleaf trees and coarse-textured soils suggests that the overall physiognomic transition may vary in response to the soil texture gradient. For example, a sharp gradient toward coarse-textured soils is characterized by abrupt physiognomic change, a lessened soil texture gradient by an obscured physiognomic transition, and a nonlinear gradient in coarse soil texture by a nonlinear trend in the occurrence of needleleaf trees. These patterns are consistent with a suggestion by Curtis and McIntosh (1951) that the nature of a gradient in an influencing environmental control may dictate the abruptness of a vegetation tension zone. Although contrasts in the forest transition and soil texture gradient were identified between transects B and C, more evidence would be needed to confirm the existence of significant east-west differences in the abruptness of the forest transition as a possible response to dissimilar northward gradients in the distribution of coarse-textured soils.

The examination of forest physiognomic groups clarified the site specificity of needleleaf trees to coarse-textured soils, but it failed to support the relationship observed earlier between sugar maple and fine soil texture. The tension zone, if defined indirectly by a significant increase northward in coarse-textured soils, may be best described by a sudden increase in the relative frequency of needleleaf tree species, but one might expect this increase to coincide with a decline in sugar maple, which has a low frequency on these soils. Finally, the dissimilar results which concern the strength of the association between forest physiognomic groups and soil texture classes (transect B, transect C, and north and south) may be, as mentioned, attributable to different trends in the distribution of coarse-textured soils, or they may be a response to different relative frequencies of all soil texture classes, but they do not appear to be a reflection of a difference in the site specificity of a physiognomic group.

Combining the results from the examination of the subhypotheses and the primary hypotheses, as they relate to the underlying research problem of this thesis, I draw several conclusions. The significant increase in needleleaf species northward indicates a noticeable change in forest composition across the tension zone. These species, as a physiognomic group, appear to be primarily site specific to coarse-textured soils, occurring with deciduous species on these soils, and increasing in frequency in direct correspondence to an increase in coarse-textured soils. The extent of upland area overlain by coarse-textured soils increases abruptly across the tension zone, even though there is variation in the northward trend from east to west. The abrupt increase in coarse-textured soils and needleleaf species northward and the significant overall association identified between the two suggest that the distribution of needleleaf tree species across this region may be, to a degree, edaphically controlled.

The question arises in the interpretation of the overall results, however, whether the statistical relationship observed between needleleaf trees and coarse-textured soils is coincidence and the real northward control is climate. Needleleaf trees were relatively more frequent on these soils both north and south of the tension zone and no consistent northward change in their site specificity, which would indicate an influence by an additional factor, was observed. I infer from this observation that the distribution of needleleaf trees within the tension zone is not climatically determined. Of course, the ultimate control of the transition toward a mixed-coniferous forest, as characterized by the northern limits of southern broadleaf species and also by the southern limits of northern needleleaf species, is climatic. However, these results focus on the distribution of tree species within this northward climatic transition, and it appears that across this region the sharpness as well as the characteristics of the northward trend toward needleleaf forest are at least partially explained by the distribution of coarse-textured soils. By this view, the tension zone, as defined by an abrupt increase in needleleaf trees, may be best explained by the underlying soils pattern across central Lower Michigan.

Recommendations for Further Research

This study was limited to an examination of hypotheses which address the relationships between one physical factor, soil texture, and presettlement forest composition along three belt transects. In an attempt to extend the focus of this research, I offer three recommendations for further research, and one suggestion for a sampling technique which may be used in subsequent tension zone or other phytogeographical research.

The data recorded along three belt transects were examined separately in order to improve the reliability of the results. Realizing now the spatial variation observed in forest composition and soils (east-west, and south-north), I recommend first that subsequent study could focus on a comparative examination of the soil texture and forest physiognomic transition along several south-north transects, identifying contrasts in the northward trends in soils and their relationships to forest physiognomy. Furthermore, additional transects positioned east to west across central Lower Michigan may clarify the possible longitudinal transition between oak and beech-maple forests in this region.

It would be incorrect to conclude from the statistically significant results compiled concerning needleleaf species and coarse soil texture that their distribution is necessarily determined in every case by the distribution of these soils. For example, Potzger (1948) emphasized the importance of climatic control when he identified former north and south shifts in the location of the tension zone. McCann (1982) observed an interesting correlation between the range lines of flora and heating degree days, and Brewer (1982) presented evidence on the possible influence of plant competition in determining the northern limits of southern broadleaved species. I suggested earlier that soil drainage may be the reason for the variation in the needleleaf trees-soil texture relationships observed along transect A and, furthermore, site history, a variable only partially controlled by the use of presettlement vegetation records, may be a signicant factor determining forest composition. Further investigation of the northward transition in forest composition could address several possible controlling factors, (e. g. soil texture, depth to water table, climatic variables, topography) and attempt to assess the relative importance of each.

The similarities in the northward transition in presettlement forest compostion and soil texture classes and the statistical significance of their association suggest that similar relationships may be observed between measures of present forest composition or productivity, land use practices, and the northward trend toward coarse-textured soils across the tension zone. This study was limited to an examination of the presettlement forest composition, but a subsequent project could examine the existing patterns of land use and land productivity along the transects as they are related to soil texture and presettlement forest composition. The study results may depict the usefulness of soil texture or natural (presettlement) vegetation as indirect measures of land productivity.

Each of the three suggested research areas demands an effective sampling technique to obtain information on presettlement forest composition, one or more physical factors, and current land cover/land use. For instance, this study constitutes one of several studies in Michigan based on data collected from presettlement forest records for research analyses or vegetation mapping; the recorded data are maintained in tables identifying location, tree species, and, in some cases, tree diameter. I know of no program to compile this information into a computer data base or a geographic information system.

A computer data base consisting of point data compiled by location could identify tree species as recorded from the survey notes and a number of other factors that would be of interest to phytographical research. If these data were available in such a systematic form, several smaller projects could be combined into a more thorough examination of the northward transition in vegetation across central Lower Michigan.

A computer data base would be appropriate for detailed or site specific analyses but would be more tedious to compile, whereas the incorporation of data into a geographic information system would be easier to compile and useful to broader research topics or applied to current land use decisions. The Center for Remote Sensing at Michigan State University (Lusch and Enslin, 1984) is currently developing a "statewide data base of land-surface information" consisting of data for areal units (grid cells) that are one square kilometer. Incorporated into this geographic information system is an identification of land cover, average available soil water capacity, general topography and multiple vector windward distance to the Great Lakes. Presettlement forest composition could be recorded at 1.6 square kilometer intervals (one section), using a classification system satisfactory to most phytogeographical research and entered into this statewide land-base system. These data could then be analyzed using the other information available on the statewide data base and, most importantly, data collected for one location could be easily used in subsequent research.

CHAPTER V

SUMMARY AND CONCLUSIONS

The objective of this study was to identify possible relationships between forest composition and the texture of the upper soil profile across the vegetation tension zone of central Lower Michigan. It was suspected that needleleaf species are site specific to coarse-textured soils, which increase abruptly across this region. I hypothesized that the measured association between tree species and soil textures is statistically significant and, secondly, that the occurrence of coarse-textured soils increases significantly across the tension zone. I further examined these relationships through an analysis of forest physiognomy, hypothesizing that, first, the percentage of all tree species that are needleleaf increases significantly northward, second, a statistically significant association exists between forest physiognomy (broadleaved-deciduous and needleleaf-coniferous) and soil texture classes, and third, the measured association strength between forest physiognomy and soil textures is greater north of a sharp transition toward coarse-textured soils.

Data were recorded on the presettlement forest composition, its relationship to specific soil texture classes, and the distribution of soil texture classes along three belt transects which extend south to north across central Lower Michigan. The association between tree species categories or forest physiognomic groups and soil texture classes was analyzed using the chi square statistic (statistical significance), Cramer's V index (strength of the association) and the asymmetric lambda index (predictability of the dependent variable; tree species). Scattergrams were examined to identify a sharp increase in the occurrence of coarse-textured soils (texture 4 or 5) at .4 kilometer intervals and the Student's t-test measured the statistical significance of that increase. Multiple regression analyses depicted the linear trend in the occurrence of texture 5 northward along each transect, and the differences in the trend north and south of the identified sharp increase in that soil texture. The percentage of all recorded trees that were needleleaf was calculated at 9.6 kilometer intervals and compared to the northward trend in mean soil texture. The significance of the increase in needleleaf tree percentages was measured (z-statistic) at the break identified in the analysis of the soil texture gradient.

Tree species categories are shown to be significantly associated to soil texture classes, but the measured strength of that association and the predictability of the dependent variable (tree species) is lessened by the more frequent occurrence of trees that exhibit little site specificity (e. g. beech, oak, and other mesic deciduous species), and the predominance of beech on nearly all soil textures. Pines and sugar maple appear to be predominantly site specific to coarse and fine-textured soils, respectively. Pine and oak are more common in the central and western transects, where sugar maple and beech are less important.

A significant increase in soil texture 5 (the most coarse soil) was identified toward the north along transects B and C and in soil texture 4 along transect **A**. Soil texture 5 was infrequent and needleleaf species showed little preference to these soils along transect **A**, suggesting that the distribution of this soil texture was localized and exhibited characteristics, such as poor drainage, that differed from transects **B** and **C** and were not examined in this study. Significant linear equations depicting the northward trend in soil texture 5 along transects **B** and **C** indicated that the trend north and south of the break along both transects was different from zero, and that the linear trend north of the break was significantly different from that south of the break. Additionally, the north trends were noticeably different between the two transects.

The percentage of all trees that are needleleaf increases significantly northward along transects **B** and **C**, and this trend coincides with the relative distribution of coarse-textured soils. Needleleaf tree species are noticeably site specific to sands, whereas the deciduous species are equally frequent on all soil textures or are most frequent on fine and coarse-textured soils. These relationships identified between forest physiognomy (needleleaf and broadleaf trees) and soil texture classes was similar south and north of a distinct increase in the occurrence of soil texture 5. Overall, the results demonstrate that needleleaf tree species and coarse-textured soils increase abruptly across central Lower Michigan and that needleleaf trees occur primarily on coarse-textured soils, such that the distribution of these soils within this region may help define the vegetation tension zone.

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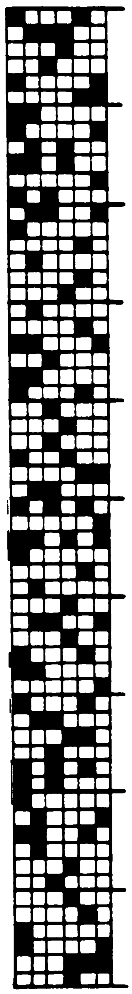
APPENDICES

APPENDIX 1

THE SOURCES OF RECORDED DATA

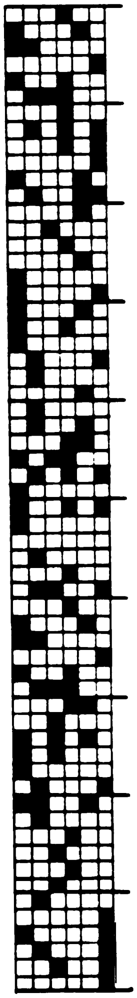
a. The Presettlement Forest*

Transect A (R4W)



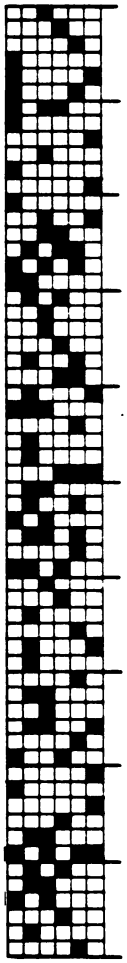
T18N	Volume 49	1856
T17N	Volume 49	1850
T16N	Volume 49	1837
T15N	Volume 49	1838
T14N	Volume 49	1838
T13N	Volume 49	1838
T12N	Volume 49	1832
T11N	Volume 49	1832
T10N	Volume 33	1831
T9N	Volume 33	1831

Transect B (R7W)



T16N	Volume 52	1839
T15N	Volume 52	1839
T14N	Volume 52	1839
T13N	Volume 52	1839
T12N	Volume 52	1839
T11N	Volume 52	1839
T10N	Volume 37	1838
T9N	Volume 37	1838
T8N	Volume 37	1836
T7N	Volume 37	1831

Transect C (R10W)



T14N	Volume 55	1838
T13N	Volume 55	1837
T12N	Volume 54	1837
T11N	Volume 40	1837
T10N	Volume 40	1837
T9N	Volume 40	1837
T8N	Volume 40	1837
T7N	Volume 40	1837
T6N	Volume 40	1831
T5N	Volume 40	1831

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*All data were obtained from the General Land Office Survey Notes, identified here by the volume number of the compiled notes and the date the survey was completed. Sampled sections are black.

b. The Soil Survey Reports

Clare County	Modern soil survey was published in 1979. Soil survey maps are on an aerial photograph background at a scale of 1:15.840.
Gratiot County	Modern soil survey was published in 1979. Soil survey maps are on an aerial photograph background at a scale of 1:15,840.
Ionia County	Modern soil survey was published in 1967. Soil survey maps are on an aerial photograph background at a scale of 1:15,840.
Isabella County	The field work for the modern soil survey is completed but not yet published. Maps were available at the Department of Crop and Soil Science, Michigan State University.
Kent County	The field work for the modern soil survey was completed by May 1984. Maps were available from the Department of Crop and Soil Science, Michigan State University, and the Soil Conservation Service Office in Grand Rapids, Michigan.
Mecosta County	Modern soil survey was completed in 1981. I acquired maps from the Department of Crop and Soil Science, Michigan State University. The soil survey was published in May 1984.
Montcalm County	Modern soil survey was published in 1960. Lithographed (colored) maps are at an approximate scale of 1:20,000.

APPENDIX 2

THE DATA RECORDED

Table A2a. Presettlement forest tree species.

Tree Type	Transect A Freq.	%	Transect B Freq.	%	Transect C Freq.	%
Beech	367	33.7	351	30.2	269	21.6
Sugar Maple	149	13.7	124	10.7	75	6.0
Elm	86	7.9	31	2.7	22	1.8
Lynn	54	4.9	14	1.2	24	1.9
Maple	54	5.0	*	*	62	5.0
Black Ash	70	6.4	22	1.9	9	1.7
Oak	45	4.1	214	18.4	434	34.8
Pine	125	11.5	206	17.7	250	20.1
Hemlock	111	10.2	122	10.5	11	.9
Cedar	*	*	10	.9	1	.1
Tamarack	28	2.6	21	1.8	7	.6
Other	*	*	46	4.0	82	6.6
TOTAL	1089	100%	1161	100%	1246	100%

*no data recorded

Table A2b. Tree species categories.

Tree Type	Transect A Freq.	%	Transect B Freq.	%	Transect C Freq.	%
Beech	367	33.7	351	30.2	269	21.6
Sugar Maple	149	13.7	124	10.7	75	6.0
Oak	45	4.1	214	18.4	434	34.8
Pine	125	11.5	206	17.7	250	20.1
Hemlock	111	10.2	122	10.5	19	1.5
Tamarack	28	2.6	31	2.7	*	*
Other	264	24.2	113	9.7	199	16.0
TOTAL	1089	100%	1161	100%	1246	100%

*no data recorded

Table A2c. Soil management units.

Texture Class	Transect A Freq.	Transect A %	Transect B Freq.	Transect B %	Transect C Freq.	Transect C %
TEX1	244	22.4	25	2.2	167	13.4
TEX2	324	29.7	107	9.2	141	11.3
TEX3	61	5.6	140	12.1	94	7.5
TEX4	199	18.3	264	22.7	232	18.6
TEX5	147	13.5	237	20.4	480	38.5
TEX3/5	*	*	30	2.6	16	1.3
TEX4/2	66	6.1	64	5.5	51	4.1
TEX3/2	48	4.4	29	2.5	21	1.7
TEX5/2	*	*	12	1.0	15	1.2
TEX3.5	*	*	142	12.2	3	.2
TEX2.5	*	*	93	8.0	2	.2
TEX4.5	*	*	18	1.6	2	.2
TOTAL	1089	100%	1161	100%	1246	100%

*no data recorded

Table A2d. Soil texture classes.

Texture Class	Transect A Freq.	%	Transect B Freq.	%	Transect C Freq.	%
TEX2	568	52.1	225	19.4	310	24.9
TEX3	109	10.0	341	29.4	134	10.8
TEX4	199	18.3	282	24.3	234	18.8
TEX5	147	13.5	237	20.4	480	38.5
TEXc/f	66	6.1	76	6.5	88	7.1
TOTAL	1089	100%	1161	100%	1246	100%

APPENDIX 3

TABLES COMPILED IN THE DATA ANALYSIS

Table A3a. Tree species categories-soil texture classes-- the contingency tables.

Transect A

frequency row % column %	TEX2	TEX3	TEX4	TEX5	TEX15	row total
BEECH	210 57 37	36 10 33	61 17 31	44 12 30	16 04 24	367
SUGAR MAPLE	101 68 18	16 11 15	8 05 04	9 06 06	15 10 23	149
OAK	26 58 04	9 02 08	5 11 02	2 04 01	3 07 05	45
PINE	25 02 04	13 10 12	59 47 30	24 19 17	04 03 06	125
HEMLOCK	38 34 07	6 05 05	34 31 17	23 21 16	10 09 15	111
TAMARACK[1]	11 39 02	3 11 03	1 04 0	11 39 07	2 07 03	28
OTHER[2]	157 59 28	26 01 24	31 12 16	34 13 23	16 06 24	264
column total	568	109	199	147	66	1089

Table A3a continued.

Transect B

frequency row % column %	TEX2	TEX3	TEX4	TEX5	TEX15	row total
BEECH	64 18.2 28.4	116 33.0 34.0	89 25.4 31.6	58 16.5 24.5	24 6.8 31.6	351
SUGAR MAPLE	26 21.0 11.6	37 29.8 10.9	33 26.6 11.7	17 13.7 7.2	11 8.9 14.5	124
OAK	58 27.1 25.8	81 37.9 23.8	49 22.9 17.4	21 9.8 8.9	5 2.3 6.6	214
PINE	28 13.6 12.4	52 25.2 15.2	54 26.2 19.1	64 31.1 27.0	8 3.9 10.5	206
HEMLOCK	9 7.4 4.0	22 18.0 6.5	28 23.0 9.9	50 41.0 21.1	13 10.7 17.1	122
TAMARACK[1]	12 38.7 5.3	6 19.4 1.8	5 16.1 1.8	8 25.8 3.4	* * *	31
OTHER[2]	28 24.8 12.4	27 23.9 7.9	24 21.2 8.5	19 16.8 8.0	15 13.3 19.7	113
Column total	225	341	282	237	76	1161

*no data recorded

Table A3a continued.

Transect C

frequency row % column %	TEX2	TEX3	TEX4	TEX5	TEX15	row total
BEECH	88 32.7 28.4	24 8.9 17.9	40 14.9 17.1	91 33.8 19.0	26 9.7 29.5	269
SUGAR MAPLE	53 70.7 17.1	5 6.7 3.7	4 5.3 1.7	7 9.3 1.5	6 8.0 6.8	75
OAK	77 17.7 24.8	75 17.3 56.0	108 24.9 46.2	161 37.1 33.5	13 3.0 14.8	434
PINE	27 10.8 8.7	11 4.4 8.2	37 14.8 15.8	156 62.4 32.5	19 7.6 21.6	250
HEMLOCK[3]	5 26.3 1.6	1 5.3 .7	7 36.8 3.0	4 21.1 .8	2 10.5 2.3	19
OTHER[2]	60 30.2 19.4	18 9.0 13.4	38 19.1 16.2	61 30.7 12.7	22 11.1 25.0	199
column total	310	134	234	480	88	1246

[1]Tamarack and cedar are combined in this category

[2]Other mesic deciduous species

[3]Other needleleaf species, combining hemlock, tamarack and cedar

Table A3b. Relative proportions of needleleaf trees to all trees (calculated at 9.6 kilometers).

DISTANCE	TRANSECT B	TRANSECT C
9.6 km	.009	.01
19.2	.21	.24
28.8	.17	.19
38.4	.39	.39
48	.29	.28
57.6	.33	.33
67.2*	.32	.31
76.8	.35	.32
86.4	.45	.45
96 km	.47	.41

* A break was established in the recorded proportions at this location forming south and north samples, respectively. The proportion measured at 67.2 kilometers was included in the south sample.

Table A3c. Forest physiognomy-soil texture classes-- the contingency tables.

Transect B

frequency row % column %	TEX2	TEX3	TEX4	TEX5	TEX15	row total
BROADLEAVED	176 21.9 78.2	261 32.5 76.5	195 24.3 69.1	115 14.3 48.5	55 6.9 72.4	802
NEEDLELEAF	49 13.6 21.8	80 22.3 23.5	87 24.2 30.9	122 34.0 51.5	21 5.8 27.6	359
column total	225	341	282	237	76	1161

Transect C

frequency row % column %	TEX2	TEX3	TEX4	TEX5	TEX15	row total
BROADLEAVED	279 28.5 89.7	122 12.5 91.0	190 19.4 81.2	320 32.8 66.7	67 6.9 76.1	977
NEEDLELEAF	32 11.9 2.6	12 4.5 1.0	44 16.4 3.5	160 59.5 12.8	21 7.8 1.7	269
column total	310	134	234	480	88	1246

Table A3d. South and north forest physiognomy-soil texture classes--the contingency tables.

Transect B (south)

frequency row % column %	TEX2	TEX3	TEX4	TEX5	TEX15	row total
BROADLEAVED	142 27.3 81.6	191 36.7 80.3	127 24.4 72.6	43 8.3 53.1	17 3.3 85.0	520
NEEDLELEAF	32 19.0 18.4	47 28.0 19.7	48 28.6 27.4	38 22.6 46.9	3 1.8 15.0	168
column total	174	238	175	81	20	688

Transect B (north)

frequency row % column %	TEX2	TEX3	TEX4	TEX5	TEX15	row total
BROADLEAVED	34 12.1 66.7	70 24.8 68.0	68 24.1 63.6	72 25.5 46.2	38 13.5 67.9	282
NEEDLELEAF	17 8.9 33.3	33 17.3 32.0	39 20.4 36.4	84 44.0 53.8	18 9.4 32.1	191
column total	51	103	107	156	56	473

Table A3d continued.

Transect C (south)

frequency row % column %	TEX2	TEX3	TEX4	TEX5	TEX15	row total
BROADLEAVED	252 32.3 89.4	116 14.9 90.6	165 21.1 89.7	197 25.2 82.4	51 6.5 78.5	781
NEEDLELEAF	30 25.6 10.6	12 10.3 9.4	19 16.2 10.3	42 35.9 17.6	14 12.0 21.5	117
column total	282	128	184	239	65	898

Transect C (north)

frequency row % column %	TEX2	TEX3	TEX4	TEX5	TEX15	row total
BROADLEAVED	26 13.3 92.9	6 3.1 100	25 12.8 50.0	123 62.8 51.0	16 8.2 69.6	196
NEEDLELEAF	2 1.3 7.1	0 0 0	25 16.4 50.0	118 77.6 49.0	7 4.6 30.4	152
column total	28	6	50	241	23	348