A DENDROCHRONOLOGICAL APPRAISAL OF CLIMATIC, EDAPHIC, AND FLORISTIC PATTERNS IN NORTHWESTERN INDIANA

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This is to certify that the

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ABSTRACT

A DENDROCHRONOLOGICAL APPRAISAL OF CLIMATIC, EDAPHIC, AND FLORISTIC PATTERNS IN NORTHWESTERN INDIANA

By

Frank Lane Charton

Northwestern Indiana is a tension zone between different phytogeographical regions. The actual penetration of mesophytic species such as _Fagus grandifolia_ (beech) and _Acer saccharum_ (sugar maple) to the southwest, or of more xerophytic types such as _Quercus_ (oak) and _Carya_ (hickory) species to the northeast, is largely determined by local interactions of variables such as soil, topography, site history, and possibly local climate. The purposes of this study were to assess the relative influences of soils and climate in determining the distributions of mesophytic and xerophytic forest types in northwestern Indiana and to search for tree-ring evidence of any locally important climatic patterns, particularly in the vicinity of La Porte where an anomalously high precipitation pattern was recorded from 1930-63. An additional aim was to compare the relative sensitivities of _Quercus velutina_ (black oak) and _Quercus alba_ (white oak) to environmental stress. It was hypothesized

that patterns of tree-ring variation in northwestern Indiana would indicate a general westward gradient of increasing moisture stress, and that local departures from the regional tree-ring chronology would be present in wood samples from the La Porte area.

Tree cores and soil samples were collected from thirty-four stands of white oak and six stands of black oak near selected weather stations in Lake, Porter, and La Porte Counties, Indiana. Analysis of variance and inter-correlation techniques applied to 81-year tree-ring chronologies provided statistical parameters which permitted an evaluation of tree-response to environmental variation. The regression of these parameters against soil texture suggested a positive relationship between moisture stress and the amount of very fine clay in the subsoil. Frequently, tree sensitivities were about 15-20% higher on finer-textured soils than on coarse soils.

Regression analyses of tree-ring indices and selected climatic data indicated significant relationships between spring and early summer weather to total annual ring-width. While dendrochronological investigations did not suggest a direct climatic control of the forest ecotone, the restriction of mesic species such as Fagus grandifolia (beech) to sites of moderated moisture stress indicates that climate may be marginal to the survival of mesic species in the area. It was concluded that the immediate control of the forest transition in northwestern Indiana is very likely soil texture. Thus, the hypothesis of increasing moisture stress westward through northwestern Indiana appears to have been supported, but the stress is evidently related to a westward transition to finer-textured soils rather than to a general climatic gradient.

Comparisons of white oak and black oak tree-ring parameters yielded higher sensitivities to environmental stress in black oak. In future dendrochronological research, black oak will probably be a more useful species than white oak when available.

Evidence for an anomalous precipitation regime in tree-cores obtained from the La Porte vicinity was inconclusive. Correlations between tree-ring indices and selected climatic data did not reveal the post-1930 decreases which would be expected with unusually large increases of moisture, and decreases of tree sensitivity after 1930 were no greater than would be attributed to aging. It is suggested that any deviations in the tree-ring record at La Porte resulting from local climatic variations probably would have been obscured by either declining sensitivity accompanying forest maturation and/or by the already low sensitivity characteristic of the oaks growing on the coarse soils near La Porte.

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By

Frank Lane Charton

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To Sylvia

Who asks so very little but gives so very much.

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CHAPTER I

INTRODUCTION

Indiana has been characterized as a dynamic botanical region in which many plant species reach their geographical limits (Lindsey, 1932; Parker, 1936; Friesner, 1937; Deam, 1953; Petty and Jackson, 1966). Of particular interest within the state are the three northwestern counties (Lake, Porter, La Porte) bordering Lake Michigan where an interfingering of mesic and relatively xeric plant communities is found (Figure I-1). In this tension zone between different phytogeographical regions, various ecotones are present (Pepoon, 1927, p. 79; Harman, 1970; Elton 1970a, 1970b). The actual penetration of mesophytic communities to the southwest, or of xerophytic elements to the northeast, is largely determined by local interactions of physical variables such as soil, topography, site history, and possibly local climate (Braun, 1967, p. 322). The purposes of this study are: (1) to assess the role of soils in producing growth stresses in certain plants; (2) to seek evidence from an analysis of stress information provided by tree-ring data as to whether the present distributions of certain mesic communities in northwestern Indiana

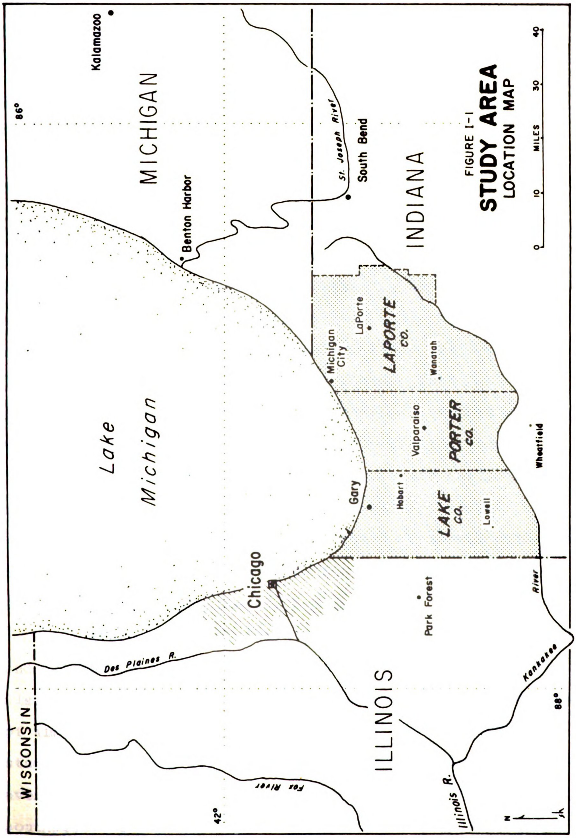

FIGURE I-1
STUDY AREA
LOCATION MAP

are at a probable potential limit, or whether these ranges could be extended westward; (3) to search for tree-ring evidence of any locally important climatic patterns, particularly in the vicinity of La Porte, Indiana.

Nature of the Problem

Although most researchers have emphasized the importance of soil and/or climatic factors in controlling the region's ecotonal character, considerable disagreement has arisen over the relative importance of these physical factors. A review of the available literature suggests several general considerations. 1. Local edaphic patterns may be strong determinants of vegetation patterns. Westward along the Valparaiso Moraine, a transition to finer-textured soils and a change in forest types from beech-maple to oak-hickory occur in the vicinity of Valparaiso, Indiana (Krumbein, 1933; Fuller, 1925, pp. 1-4). Evidence presented by Elton (1970b) indicates that the change in forest types may be dependent upon the edaphic gradient.

2. There may be climatic gradients of varying scales and origins in northwestern Indiana which influence plant distributions. Visher's (1935) climatic maps show a decrease of almost five inches in rainfall southwestward across the study area; annual average temperatures and July and August average temperatures indicate slight increases toward the southwest. In the western part of the study area, precipitation-evaporation ratios decrease, precipitation becomes

more variable from year to year, and summer drought occurs with increasing frequency (Transeau, 1905; Borchert, 1950). Locations near the eastern shore of Lake Michigan receiving wind flow from the lake in summer generally have lower average summer temperatures than stations located farther inland or westward and, in winter, experience a delay in the arrival of first killing frosts and minimum temperatures (Leighly, 1941; Visher, 1944, p. 63). Snowfall to the east of the southern end of Lake Michigan is substantially higher than at stations located in the western part of the study area (Changnon, 1968a) and could influence soil moisture conditions during the early part of the growing season. Lake modification of other climatic elements such as humidity, cloudiness, and frequency of fog probably exert some influence upon plant development.

An especially interesting climatic phenomenon has been presented by Changnon (1968b) who described a localized anomalous warm season precipitation pattern in northwestern Indiana centering on the city of La Porte. Changnon attributed the substantial increases in precipitation, moderate rain days, thunderstorm days, and hail days during the period 1925-63 ". . . to inadvertent man-made modification . . ." resulting from the addition of heat, moisture, and particulate matter to the atmosphere by the Chicago-Gary industrial complex, thirty miles to the west. Holzman and Thom (1968), however, have presented evidence challenging the reality of the anomaly, claiming that changes in observers and recording procedures produced inaccuracies in the weather data. The debate remains apparently unresolved.

3. Vegetation patterns in the study area may not be fully adjusted to the present climatic regime. Several researchers have suggested the likelihood that various floristic types in northwestern Indiana may not have reached their potential western climatic limit (Cowles, 1901a; Fuller, 1925; Friesner, 1937). Furthermore, climatic changes are believed to have occurred in this region during post-glacial times (Benninghoff, 1963). Thus, the possibility exists that floral distributions are not in complete harmony with existing climatic conditions.

Hypotheses and Research Aims

The general hypotheses of this research are that (1), patterns of tree-ring variation in northwestern Indiana will indicate a general westward gradient of increasing moisture stress, and (2), that local departures from the regional tree-ring chronology are present in wood samples taken from the vicinity of La Porte. Data gathered with regard to the second hypothesis should thus reflect on the existence and areal extent of the precipitation anomaly. The assumption underlying this project is that the tree-ring record of northwestern Indiana represents an accessible but largely unused source of data for the analysis of local phytogeographical and climatological problems.

One specific research aim is to assess the role of soils in producing growth stresses in plants, as evidenced by tree-ring analysis. The pattern of soils in northwestern Indiana is quite complex; and, if the relative roles of selected climatic variables in promoting or limiting tree growth are to be properly evaluated, some indication of soil influences is needed. Estes (1970) showed a relationship between tree-ring variation and gross soils differences in the Central Mississippi Valley.

A second specific aim is to identify possible evidence for an incomplete phytogeographical adjustment to recent climatic conditions in northwestern Indiana; relative degrees of climatic stress may be inferred from dendrochronological patterns. If tree-ring analysis indicates acute climatic stress near the mesophytic-xerophytic transition line, then it would appear that the beech-maple community is at a probable western limit in this area. But should evidence indicate that climatic stress is not extreme, the suggestion by several writers (Cowles, 1901b; Fuller, 1925; Friesner, 1939) of incomplete beech-maple migration westward would be a worthwhile consideration.

A third research aim is to seek tree-ring evidence of any locally important climatic patterns. Of special concern is the anomalous climatic pattern in the vicinity of La Porte, Indiana, described by Stout (1962) and Changnon (1968b, 1970).

The majority of tree-ring research in North America has been performed in semi-arid environments of the western

United States, where climatic-hydrologic problems have been a practical concern; consequently, certain operational considerations are less a factor there than in the more humid eastern United States where far less systematic tree-ring research has been done. A notable problem in the humid east is a lack of research on the suitability of different deciduous species for tree-ring analysis. Beech, maple, elm, and ash have proved unsatisfactory in one way or another, but a need exists for more accurate information regarding which species would be useful. Various kinds of oak have been examined with moderate success in several studies. For example, Senter (1938) and Miller (1950) studied white oak, Estes (1970) looked at white and black oak, and Robbins (1921), Fuller (1938), and Harman and Elton (1971) used red oak. Yet most of these studies provide little grounds for quantitatively comparing the responsiveness of the different oak species for tree-ring research, particularly as responsiveness relates to soil textural variability. With the extensive distribution, the variety of habitats, and the readily discernible growth rings of many oak species, oaks appear to be a promising source of data for tree-ring research. Therefore, as an aid to future tree-ring studies an additional research aim will be to evaluate the usefulness of two oak species for dendrochronological purposes. White oak (Quercus alba), because of its presence throughout the study area and its adaptability to a wide variety of sites and soils (Gaisner, 1951; Fowells, 1965, p. 632), will be the primary data source of this project; and, black oak (*Quercus velutina*) will be examined from several selected sites for comparative purposes. This procedure should provide a basis for estimating the adaptability of these species to tree-ring analysis.

CHAPTER II

THE PHYSICAL SETTING

Study Area

The study area consisted of Lake, Porter, and La Porte Counties, the three northwestern counties bordering Lake Michigan (Figure I-1). The region is located between 41 degrees and 42 degrees north latitude and between $86^{\circ}30'$ and $87^{\circ}30'$ west longitude.

Most of the topographic features of northwestern Indiana resulted from Pleistocene glaciation and associated fluvial and lacustrine processes. The landscape presents a variety of depositional features including end moraines, outwash plains, kames, lake plains, valley trains, and kettle holes, as well as many closely related postglacial features such as lakes, sand dunes, and peat bogs (Schneider, 1966). Drainage lines in the area often are too poorly developed to have provided outlets for numerous upland depressions or to have lowered the local and regional water tables sufficiently to eliminate subsoil saturation (Richason, 1960). Consequently, extensive wetlands persist. Most of the wetland environments in northern Indiana are till plains with a perched water table, undrained depressions within moraines, and porous sand plains of glacio-fluvial origin characterized by a perenially high regional water table. The drier sites generally correspond to gravelly moraines, porous terraces, outwash deposits, and sand dunes (Richason, 1960).

Displaying a topography formed largely during the Wisconsin glacial stage, the study area is comprised of three major physiographic divisions (Figure II-1) (Mallott, 1922; Wayne and Zumberge, 1965). The Valparaiso Morainic Area is an arcuate end-moraine complex located approximately five to ten miles inland from (and roughly parallel to) the shore of Lake Michigan. Northward, between the morainic upland and Lake Michigan Iies the Calumet Lacustrine Plain, and to the south the Kankakee Outwash and Lacustrine Plain. Regional drainage north of the upland is to Lake Michigan via the Calumet River System, and, to the south, the Kankakee Basin drains to the Mississippi River.

The Valparaiso Moraine averages about 150 feet higher than the Calumet Lacustrine Plain. Most of the moraine ranges between 700 and 800 feet above sea level (or about 120-220 feet above the level of Lake Michigan) with some elevations to 950 feet. From Valparaiso, Indiana, to the Michigan state line the moraine is generally higher and more rugged than the wider part further west, which in places resembles a gently undulating till plain; the more rugged eastern part is also the most complex in terms of materials and landforms (Schneider, 1966). In La Porte County, the

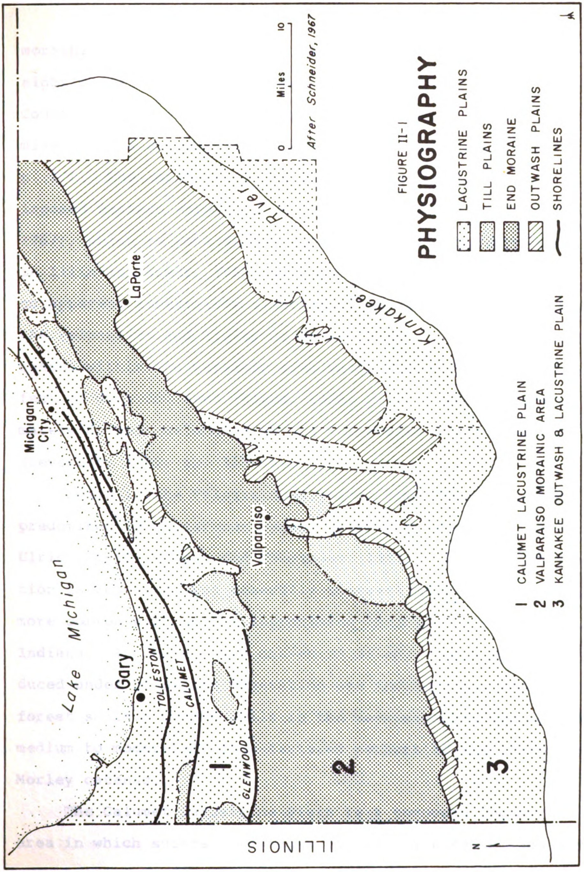
FIGURE II-I
PHYSIOGRAPHY
LACUSTRINE PLAINS
TILL PLAINS
END MORAINE
OUTWASH PLAINS
SHORELINES
1 CALUMET LACUSTRINE PLAIN
2 VALPARAISO MORAINIC AREA
3 KANKAKEE OUTWASH & LACUSTRINE PLAIN
0 Miles 10
After Schneider, 1967
Lake Michigan
Gary
Michigan City
LaPorte
Valparaiso
Kankakee River
TOLLESTON
CALUMET
GLENWOOD
1
2
3
ILLINOIS
N

morainic area consists of a single belt approximately eight miles wide; farther west in Lake and western Porter Counties, the system widens to a maximum of about thirteen miles and is composed of three low ridges (Wayne, 1956, p. 17). The northernmost of these ridges may be a superimposed eastern extension of the Tinley Moraine (Schneider, 1967), which is considered to be a discrete morainic unit in Illinois (Bretz, 1955, p. 28). Krumbein (1933) found no apparent textural or lithological dissimilarities between the Valparaiso and Tinley tills in Indiana. Drift thicknesses within the morainic area range from less than 150 feet to over 250 feet (Wayne, 1956, p. 17), with approximately 65 feet belonging to the Valparaiso Moraine proper (Leverett, 1899, pp. 353-55).

Soils in the Valparaiso Morainic Area developed from predominantly calcareous parent materials (Bushnell, 1918; Ulrich, 1944; Wenner and Persinger, 1967). Textural variation is enormous, but generally coarser-textured soils are more common east of the approximate location of Valparaiso, Indiana. In the western one-third of the area soils produced under grassland vegetation are interspersed among forest soils. Common soils in the morainic area include the medium to moderately fine-textured members of the Galena and Morley catenas.

The Calumet Lacustrine Plain is a compound lacustrine area in which successive stages of glacial Lake Chicago are represented at step-like intervals by nearly continuous beach ridges (Wayne and Zumberge, 1965). According to Schneider (1967) the highest former shoreline (Glenwood) at 640 feet is about 60 feet above the current level of Lake Michigan and in most places follows the boundary between the lake plain and the Valparaiso Morainic Area; lower strandlines are evidenced by beaches at intermediate positions, notably at 620 feet (Calumet) and 605 feet (Tolleston). Many of the beach ridges are covered with stabilized sand dunes which rise as much as 40 feet above the adjoining lake bottom; former offshore bars and spits are common; and large dunes are conspicuous along the shore of Lake Michigan (Schneider, 1966).

Soils in the Calumet Lacustrine Plain typically are imperfectly to poorly drained calcareous sands, silts, and clays; the better drained soils usually are found in dunal areas where drainage is often excessive. Prominent soils include the Plainfield, Otis, and Bono series.

The Kankakee Outwash and Lacustrine Plain extends through northwestern Indiana from Illinois to Michigan. Most of the area is low and poorly drained, consisting of sands and gravels which were deposited as outwash plains and valley trains by glacial meltwaters during several different phases of Wisconsin glaciation (Wayne, 1966). The landscape is comprised of extensive sand plains interrupted occasionally by stabilized sand dunes. Soils in the area vary widely in mineralogical composition, and they tend to increase in coarseness with proximity to the Kankakee River (Ulrich, 1966). For example, common soils from north to south include the Tracy, Door, and Fox loams, the Maumee and Gilford sandy loams, and the Plainfield and Oshtemo sands.

Climatically the region is classified Temperate Continental-Warm Summer (Dfa) according to the Koeppen system (Trewartha, 1968, p. 398). Local climates result from a variety of interacting influences, but two regional climatic controls are especially noteworthy (Trewartha, 1961, pp. 251-52). Largely because of the dynamic effect of the Rocky Mountain cordillera, westerly wind flow at middle and upper tropospheric levels over North America frequently assumes a relatively stationary wave pattern for extended time intervals (Harman, 1971, p. 19). The characteristic positioning of the wave pattern maintains a mean upper level trough over the eastern United States (O'Connor, 1961), which promotes surface cyclogenesis (Trewartha, 1961, p. 252). The humid, highly variable climate of eastern North America results from an interplay of these factors.

Climate varies longitudinally across the study area. For example, the July-August average temperature ranges from 72°F to 74°F east to west; annual precipitation varies from 34 to 35 inches in the west to 38-40 inches in the east; and snowfall averages from less than 40 inches in western Lake County to over 60 inches in northeastern La Porte County

(Schall, 1966). The January-February average temperature for northwestern Indiana is around 25°F, and the yearly mean is slightly less than 50°F (Visher, 1935). Total warm season (April-September) precipitation averages about 20 inches annually, but varies slightly with east-west location (Visher, 1944, p. 127); a slight dual warm season maxima occurs in June and September (Trewartha, 1961, p. 284). The prevailing wind direction is from the southwest in summer and northwest in winter (Schall, 1966).

Northwestern Indiana displays a diversity of vegetation which reflects both a complicated botanical history involving climatic changes and a variegated physical setting. Within the region approximately 300 species from more northerly ranges reach their southern limits (Deam, 1940, p. 16); plants typical of drier regions to the south and southwest are common (Deam, 1953, p. 121; Petty and Jackson, 1966); and a sizeable contingent of species typical of the Coastal Plain and the Lower Mississippi Valley has been described by Peattie (1922), Parker (1935), and Friesner, 1937). The region is generally regarded as a phytogeographical tension zone between the prairie-oak, oak-hickory, and beech-maple forest types (Shreve, 1917; Braun, 1950, p. 323; Shelford, 1963, p. 19; Kuchler, 1964).

Perhaps the most prominent phytogeographical feature within the area is the extension of mesophytic plants, notably <u>Fagus grandifolia</u> (beech) and <u>Acer saccharum</u> (sugar maple), from Michigan southwestward along the Valparaiso Moraine into relatively xeric forests dominated by Quercus alba (white oak), Q. velutina (black oak) and Q. macrocarpa (burr oak) (Figure II-2). The rather abrupt terminus of this mesophytic forest occurs in mid-Porter County near the city of Valparaiso. For a more complete description of the beech-maple forest in northwestern Indiana see Elton (1970a, ch. III).

Review of the Phytogeographical Literature

The pronounced vegetational changes across northwestern Indiana were recognized by earlier students of the region. Cowles (1901a, 1901b), Fuller (1925, pp. 1-4), and Gordon (1936) documented the presence of beech-maple forests on the morainic hills of La Porte County, with a predominance of oak increasing toward the west; and Blatchley (1897), Gleason (1923), Pepoon (1927), Transeau (1935), and Parker (1936) furnished useful descriptions of the prairie-forest ecotone in northwestern Indiana and northeastern Illinois. However, through the years there has been disagreement over the cause(s) of the region's ecotonal nature, although the majority of studies have emphasized the importance of soil and/or climatic factors.

Visher (1935) prepared a set of maps depicting lower precipitation values in prairie areas than in bordering forested areas. He concluded that the poorer forests and

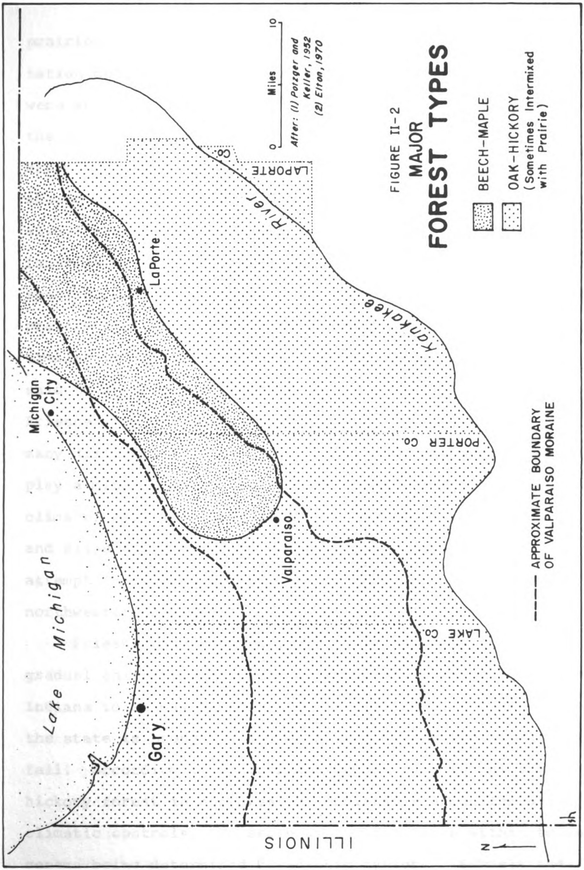

FIGURE II-2
MAJOR
FOREST TYPES

prairies of northwestern Indiana are the result of precipitation deficiencies, whereas higher snowfall totals eastward were suggested as the reason for more extensive forests to the east. Transeau (1935), maintaining that climatic factors are more influential than soil factors as prairie determinants, showed that the forest type invaded by prairie communities is always oak-hickory and never beech-maple. Beech-maple was found on sites sufficiently mesophytic to accommodate other species capable of crowding out prairie species; therefore, prairie species invade those forest areas climatically most similar to the true prairie. Irregularity of rainfall was said to be a critical factor in the maintenance of prairies. Friesner (1937), noting that prairie indicators occur on many different soil textures, concluded that edaphic factors play a minor role in prairie delimitation when compared to climate, especially rainfall. To the contrary, Pepoon (1927) and Bliss and Cox (1964) emphasized edaphic factors in an attempt to explain the presence of prairie communities in northwestern Indiana.

Friesner and Potzger (1937) have asserted that the gradual shift from beech-maple dominated forests in southern Indiana to an oak-hickory type in the northern one-fifth of the state is brought about by a drop in average annual rainfall. According to Potzger and Keller (1952), the oak-hickory forest in northwestern Indiana is a manifestation of climatic controls, the segregation of species within these genera being determined by edaphic factors. Schmelz and

Lindsey (1970) attempted to correlate different forest associations with soil moisture qualities. They demonstrated a preference of beech-maple for intermediate positions between very wet or very dry sites. Oak-hickory associations correlated well with drier sites. Kilburn (1959) emphasized the importance of topography in understanding ecotonal areas in northeastern Illinois.

Beech (Fagus grandifolia) has often been categorized as a sensitive indicator of habitat mesophytism (Potzger and Friesner, 1940; Potzger and Keller, 1952; Friesner, 1942). Rohr and Potzger (1950) and Finley and Potzger (1952) have proposed that the existence of beech and sugar maple in isolated stands west of the general terminus of mesophytic associations is a result of favorable microclimatic conditions, and that the distribution of beech suggests a progressive change in habitat from west to east. Rohr and Potzger (1950) believed that the sharp demarcation between forest associations in northwestern Indiana is striking evidence of either a climatic or an edaphic selection factor in operation. Friesner (1937) attributed the presence of beech-maple in an otherwise oak-hickory forest type area to soil moisture characteristics. Elton (1970a) suggested that the forest contrast has resulted from an environmental gradient, not variable land-use practices or fire.

Several possible explanations of the vegetation patterns in northwestern Indiana may be drawn from the research presented above. First, there are soil variations which may be instrumental in determining plant responses. A notable example may be the abrupt change in forest composition along the Valparaiso Moraine in the vicinity of Valparaiso, Indiana. Elton (1970b) correlated the change in dominance from beech-maple eastward to oak-hickory westward with increases in the amount of clay in the soil substrate. Apparently the greater clay content in soils west of the demarcation serves to reduce the readily available water capacity during periods of moisture stress sufficiently to result in the absence of mesophytic species.

Second, climatic gradients of diverse proportions and origins which may influence plant distributions exist in this area. Harman's (1970) study of a floristic gradient on the dunes along the southeast shore of Lake Michigan illustrates one type of climatic influence existing within the study area. Harman noted a change from the dominance of mesophytic species, primarily Quercus rubra (red oak) and Acer saccharum (sugar maple), in Berrien County, Michigan, to a dominance of the more xerophytic Quercus velutina (black oak) in Porter County, Indiana. He suggested that the lake influence upon nocturnal relative humidity and fire frequency may be causally related to the vegetation pattern. Other studies actually demonstrating relationships between ecotones and climatic variables in the region are rare.

A third possibility concerns the relationship between vegetation patterns and the present climatic regime. A procession of climatic changes is believed to have taken place in the region during postglacial times, but the sequence of change is still subject to question. It is generally conceded, however, that gross changes in vegetation patterns occurred after deglaciation in response to climatic fluctuations (Dillon, 1956).

Most research confirms the presence of a spruce and fir belt in the Central States area which followed the retreat of the glacier northward and persisted until about 8,000 years ago (Potzger, 1946; Deevey, 1949; Davis, 1967; Durkee, 1971). Zumberge and Potzger (1956) established a chronology from pollen strata in southwestern Michigan which shows a pine stage replacing the spruce-fir forest and remaining until about 5000 years ago, when oaks came into prominence. An oak-hickory-broadleaved forest maximum (4,000 years ago) was succeeded by an oak-hickory maximum (3,500), presumably as climate became increasingly warmer and drier. A number of other studies in the region support this overall sequence (Guennel, 1950; Just, 1957; Brush, 1967; Durkee, 1971). But Davis (1965) cautioned against drawing broad vegetational or climatic generalizations from pollen analyses; and Benninghoff (1963) projected the entry of mesophytic species (especially beech) into northwestern Indiana from Michigan about 3,500 years ago, which appears inconsistent with the generally proposed warm, dry climate accompanying the oak-hickory stage. In addition, Benninghoff contended that an earlier southern migration of beech into the area had been blocked by a postglacial prairie peninsula.

Friesner (1937) contended that at least a part of the coastal plain flora in Indiana are still in the process of migrating toward a potential western limit. Elton's (1970b) suggestion of an edaphic, not climatic, control of the sharp demarcation between beech-maple and oak-hickory along the Valparaiso Moraine was discussed earlier, and Finley and Potzger (1952) have documented the presence of isolated stands of beech and sugar maple west of the main beech-maple forest. Several researchers (Cowles, 1901b; Fuller, 1925) have predicted an eventual migration of the beech-maple type from its present position. But Potzger and Friesner (1939) believed that the area occupied by beech has recently been decreasing.

From the evidence presented above, it seems certain that vegetation and climatic patterns in the Great Lakes Region have undergone large-scale changes since glacial retreat. And further, there appears to be justification for considering the possibility that present floral distributions are not in complete agreement with existing climatic conditions.

CHAPTER III

METHODS

Physiological Foundations of Dendrochronology

Early in the 20th century, Dr. A. E. Douglass, an astronomer, presented evidence revealing that the widths of annual rings in trees in semiarid sites correlated with variations in climate. The pattern of wide and narrow rings was so pronounced that he was able to recognize and cross-date the same pattern in tree stumps from nearby areas and to determine the year of tree removal (Douglass, 1919). Following these discoveries, a systematic tree-ring research program was undertaken, the result being the development of a discipline termed dendrochronology, and the establishment of a tree-ring research laboratory in Tucson, Arizona under the auspices of the University of Arizona. Broadly speaking, dendrochronology may be defined as the study of yearly growth patterns in trees and their use in dating past events and in evaluating past climatic fluctuations (Fritts, 1966). Tree-ring relationships are readily measured and tested by quantitative methods, and results are interpretable in terms of modern physiological principles.

A tree stem increases its diameter annually through the formation of a growth ring ("tree-ring") inside the bark by division of cambial cells; upon division, cambial cells produce large, thin-walled xylem cells (earlywood) in the early part of the growing season and small, thick-walled xylem cells (latewood) as the growing season nears an end (Wareing, 1951; Larson, 1962b). The latewood portion of the total annual tree-ring increment appears to be very closely related to conditions during the current growing season (Byram and Doolittle, 1950; Smith and Wilsie, 1961; Kennedy, 1961; Jackson, 1962; Zahner et al., 1964) and commonly exhibits a greater degree of year-to-year variability than earlywood (Bannon, 1962). Earlywood growth typically is only slightly related to current growing season conditions (Lodewick, 1930; Schulman, 1942; Byram and Doolittle, 1950; Woods and Debrunner, 1970), but climatic conditions of the September preceding growth often strongly influence earlywood development (Diller, 1935; Schumacher and Meyer, 1937; Hansen, 1941; Fritts, 1958; Gagnon, 1961).

The dimensions of individual tree-rings are a function of the tree's heredity and environment acting throughout any given growing season (Kramer and Kozlowski, 1960, p. 428). While the relationships between tree growth and external environmental elements are complex and not fully understood, physical variables such as soil moisture, temperature, and photoperiod apparently exert indirect dominance over certain physiological processes, often through the creation of moisture stress within plants. Internal moisture stress readily limits two major processes essential for the diametral increase of tree stems: photosynthesis and production of growth-regulating hormones (Kramer, 1958, ch. 8; Larson, 1962a). The close relationship between environmental controls and arboreal diameter change has been demonstrated in many studies. Mikola (1950), studying conifers in northern Europe, determined annual diameter increment to be dependent upon temperature characteristics of the current growing season; MacDougal (1938) noted a close correspondence between available moisture and diameter increase in several Pacific Coast oak species; and Fraser (1962) found a close correlation between soil moisture and cambial activity in several tree species including northern red oak. In North Carolina, Woods and Debrunner (1970) concluded that total annual radial growth of loblolly pine is influenced by the same factors that influence latewood growth, primarily the availability of soil moisture late in the growing season. An actual decrease in diameter during drought in white pine, black locust, and beech was observed respectively by Freisner and Walden (1946), Daubenmire and Deters (1947), and Fritts (1958). Jackson (1952) recorded daily radial shrinkage in white oak, northern red oak, and southern red oak during periods of moisture stress, and Friesner (1942) recognized linkages between growth of beech in Indiana and climatic factors of the current growing season. Thus, relationships between environmental parameters and diametral

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development of trees are well documented, and one objective of dendrochronology is to assess the strength of these relationships.

In summary, the change in cell-size from earlywood to latewood in trees is a gradual process, and the structural changes and total number of cells within a growth-ring depend upon the environmental and physiological factors that have limited the rate of cell division and enlargement. Therefore, both ring-width and cell structure can be products of environmental influences which are present before and during the growing season. Dendrochronological techniques provide a means of assessing long-term environmental controls of tree response through measurement of yearly ring-width variability.

Procedures in Tree-Ring Analysis

Site Selection

Selection of forested tracts for use in this study was based upon the following criteria: soil drainage and textural uniformity; topography; distance to weather stations; and size, age, and degree of disturbance of forested stands. All field observations and data gathering were completed during the summer of 1971.

The following National Weather Service stations were selected as sources of rainfall and temperature data to be applied in subsequent correlations with appropriate tree-ring indices: South Bend, La Porte, Michigan City, Wanatah, Valparaiso, Wheatfield, Ogden Dunes, Hobart, Lowell, and Park Forest. The relative locations of these ten stations were believed to be sufficient to provide adequate dendroclimatological data coverage for analysis of climatic patterns in northwestern Indiana. Near each weather station four forest stands (Figure III-1) were sampled for collection of tree cores (if stands meeting certain site requirements could not be located within a two-mile radius of a weather station, then fewer than four stands or slightly more distant sites were used).

The selection of multiple woodlots around weather stations served several purposes. One purpose, to be discussed in depth later, was to determine the relative roles of soil textural variation in affecting tree-response (climate was assumed to be constant around each station). A second purpose was to determine whether or not cross-dating, a basic dendrochronological concept, exists among sites around individual stations. Cross-dating assumes that recognizable and synchronously matched variations in ring-width among trees from a local area are evidence of some general environmental control(s) (Schulman, 1950). If cross-dating exists, meaningful analysis of climatic variation may be possible with tree-ring techniques.

For any given weather station the first step in selecting woodlots for sampling was the careful examination of county Soil Survey maps, Soil Conservation Service (SCS) field and interpretive sheets, and topographic maps.

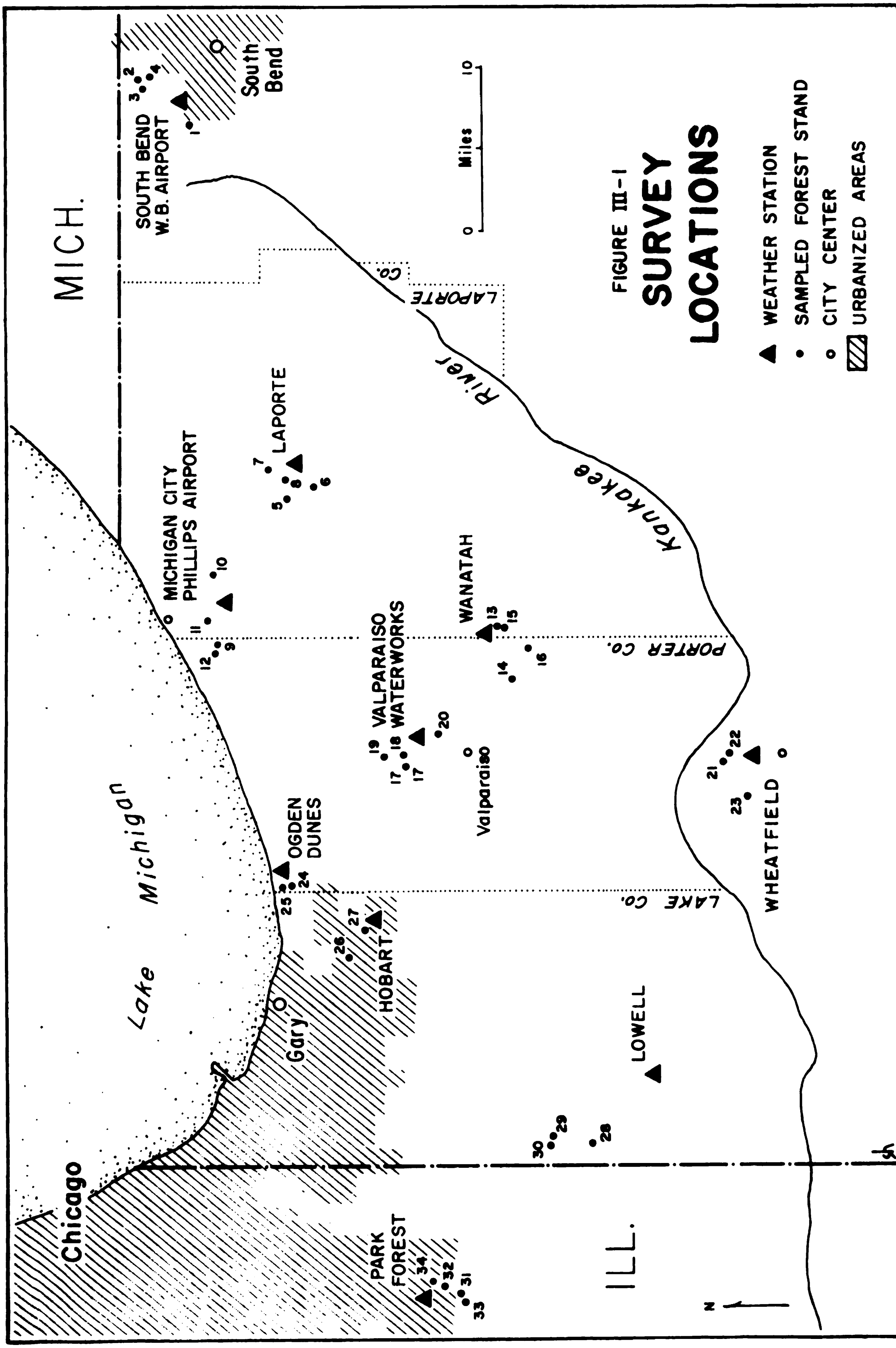

FIGURE III-1
SURVEY LOCATIONS

Where available, the field sheets (aerial photographs with superimposed soil mapping units) were especially helpful because they included photographs of forested tracts as well as soils information.

In the initial phase of site selection, drainage, topography, textural uniformity, and distance to weather stations were important considerations. Most researchers seem to agree that tree response increases with drought stress; thus, an effort was made in this project to select only sites where drought stress was maximized, that is, well-drained sites where a wet soil profile for long periods during the growing season had not been a confusing factor. Under well-drained conditions, trees are more likely to respond directly to immediate climatic conditions, showing a pronounced pattern of common variation particularly in years when moisture approaches the limits of tolerance (Schulman, 1950).

As outlined in the <u>Soil Survey Manual</u> (U.S.D.A., 1951, pp. 205-13), field determination of soil textural classes to a depth of 50 inches was made mainly by rubbing moistened samples between the fingers and estimating relative size distributions from a textural triangle chart. This procedure provided a fast, reasonably accurate means of keeping soil variability to a minimum. Where possible, at least one site per weather station that was texturally akin to sites of surrounding stations was selected in order to establish linkages across the study area. Signs of subsoil reduction processes provided a means of detecting an insufficiently drained site. Even though some mottled colors may occur unassociated with current incomplete drainage (Simonson, 1951; Ruhe, 1956), imperfectly and poorly drained soils are nearly always mottled with various shades of gray, brown, and yellow, particularly within the zone of periodic water table fluctuation (U.S.D.A., 1951; Wilde, 1958; Millar et al., 1965, p. 253).

Study sites were limited to generally level or rolling topography because of the likelihood of eccentric ring development in trees growing on steep slopes. Frequently, leaning trees, or trees on strongly sloping surfaces, produce irregular growth-rings because of an unequal weight distribution within the tree bole (Bauer, 1924; Wardrop, 1965; Stokes and Smiley, 1968, p. 31).

Apparently no definite conclusions have been reached in defining the distance from weather stations at which agreement between recorded climatic data and tree-ring variation may be expected to decline, although inferences may be drawn from two recent articles. Extrapolating from the work of Julian and Fritts (1968) in Colorado, a spatial decay of the ring index to precipitation index relationship was indicated at approximately 15 miles in several conifer species. Estes (1970) correlated precipitation periods and ring indices of white oak in the Central Mississippi Valley and found coefficients averaging .54 at a distance of 40 miles from stand site to rain gauge; but, at 60 miles correlation coefficients had dropped to an average of about .20. In an area as climatically and botanically complex as northwestern Indiana, distances approaching those discussed above probably would have been excessive. Therefore an arbitrary 2-mile radius was set for this study in an effort to reduce unwanted variation resulting from distance decay factors.

Following delimitation of potentially suitable areas, acceptable forest stands were subsequently identified by automobile reconnaissance. Woodlots were appraised for inclusion in this study on the basis of four criteria. First, at least eleven dominant or codominant white oak trees that had not been visibly disturbed by conditions arising beyond the woodlots' margins ("edge effect") had to be present. Second, basal area had to be comparable to surrounding sample sites, for the purpose of maintaining relatively uniform stem size-classes among the different forest stands across the study area. Although no precise limits were set, basal area of most stands was within the 100-115 ft^2 range. Basal area was determined with a Cruz-All aperture angle gauge for point sampling. Third, only trees dating at least to 1885 were considered, as determined from a sample core.

The fourth criterion, degree of disturbance, was more difficult to evaluate. All of the forest stands in the study area probably had been disturbed by human activity to some degree. Stands under consideration were assessed by inspection and in many cases through interview with the owners.

Where severe grazing, cutting, or burning was evident, these stands were omitted from the project.

At this point, forest stands were judged acceptable for inclusion in the project. After acceptance of a stand, a description of site characteristics was entered on a specially prepared form (Appendix I-B).

Specimen Collection

The final step in field data collection was the extraction of tree-cores and subsequent plugging of the small holes made by the extraction instrument (to reduce the possibility of damage to the trees by insects and decay-causing organisms). Sampling procedures used in obtaining tree-cores for this study were derived at the Laboratory of Tree-Ring Research.

From each forest stand, one core from the north and south radii of eleven dominant or codominant white oak trees (*Quercus alba*) were extracted at breast height (4.5 feet above ground) using a 16 inch Jim-Gem increment borer lubricated with beeswax. The number of trees and cores per tree needed to comprise a valid sample has been questioned. Schulman (1942, 1945) used only one core per tree, but Lyons (1939) demonstrated that trees growing on slopes, ridges, or sites with variable depths of shallow soil are likely to grow at uneven rates on different sides of the tree. Lyon recommended using three radii evenly spaced around each tree,

as did Schumacher and Day (1939). Lodewick (1930) undertook a tree-ring analysis with four cores per tree representing the cardinal campass directions, but he found no significant differences among the cores resulting from slope, longer exposure to sun on south and west sides, and crown size or asymmetry. He concluded that one core per tree is sufficient in dendrochronological research.

More recently Fritts et al. (1965) studied a vegetation gradient in northern Arizona taking four cores from five mature trees in selected conifer stands. But in subsequent studies in the same general region, Fritts (1965, 1966) changed to what was considered to be a more representative sampling procedure of regional tree-growth patterns by removing two cores from each of ten trees. This latter method has been applied by Julian and Fritts (1968), Schultz et al. (1970), Woods and Debrunner (1970), Herman and DeMars (1970), and Harman and Elton (1971).

In addition to taking several tree cores from each tree, multiple trees from each site must be sampled. The purpose in obtaining specimens from more than one tree is to check the ring record of any tree against sufficient associated trees for the calculation of a group mean in which random errors have been cancelled as far as possible. The group mean then may be correlated with climatic data and/or may be analyzed with established dendrochronological methods. The replication of samples by collecting two cores from each of ten trees per sampled site is now standard procedure at the Laboratory of Tree-Ring Research (Fritts, 1969).

Specimen Preparation

Following extraction, the tree cores were stored in plastic straws for transportation in the field. Later, to prevent warping the cores were removed from the straws and lashed into specially designed wooden trays for drying. Individual trays were identified as to station, tree, and core. After the cores had dried, they were glued into the trays with each core positioned to exhibit a cross-sectional (transverse) view on the exposed surface for maximum ease in distinguishing annual rings. Once the glue had set, the core surfaces were prepared for measuring.

Several procedures for preparing core surfaces have been devised (Glock, 1937, pp. 5-6; Stokes and Smiley, 1968, pp. 37-46; Estes, 1970). The method used in this study was modified from Estes (1970) and consisted of the following steps: (1) core surfaces were flattened with fine grit (#150) aluminum oxide abrasive on a Black and Decker orbital finishing sander; (2) the flattened surfaces were further smoothed with extra fine grit (#220) aluminum oxide abrasive on the orbital finishing sander; and (3) the smoothed core surface was rubbed lightly by hand with very fine steel wool (#000) to remove the dust from tracheid openings. Annual rings were more distinct in cores prepared with this technique than in experimental cores which had been planed with sharp instruments.

Next, randomly selected cores from a number of woodlots across the study area were examined for age determination; most of the younger woodlots dated from about 1885. Thus, in order to preserve age uniformity among sample data all chronologies were begun at 1890 and continued through 1970. The eighty-one annual rings for this period from each core were measured to the nearest hundredth-millimeter with a DeRouen Dendro-Chronograph (20x magnification) and registered on FORTRAN coding forms; each tree-core was identified by a six-digit number representing the weather station, woodlot, tree, core, and species. To assure that tree-rings were being accurately distinguished with the dendro-chronograph, cross-dating procedures established prominent sequences of wide and narrow rings. When the twenty-two core chronologies (eleven trees) for a woodlot had been measured, ten trees were chosen to represent the stand. This procedure permitted the omission of tree-ring records shorter than eighty-one years, chronologies obscured by internal damage, and chronologies noticeably different from other trees sampled at that site.

Statistical Analyses

Tree-ring measurements for the twenty cores from each site were transferred from the FORTRAN coding forms to punch cards for subsequent computer processing. Several programs adapted to an IBM 6500 computer were obtained from the Laboratory of Tree-Ring Research for analyzing the changes in tree-growth linked with increasing age (Matalas, 1962; Julian and Fritts, 1968). Normally, diameter growth, although affected by many factors, tends to follow a predictable trend in undisturbed trees. At the seedling stage, the first increments are frequently very small until the tree has become established. Subsequent tree-rings increase in width as the tree rapidly enlarges; but as the tree grows older, ring-width gradually decreases (assuming uniform growing conditions) because yearly increments must be spread around increasingly larger stem circumferences (Gessel et al., 1960, p. 13). Typically the growth curve for the outer portion of the tree can be approximated by a negative exponential curve or a straight line. However, disturbances such as lumbering which open the forest canopy normally create a sequence of enlarged tree-rings which are not satisfactorily approximated by the negative exponential curve or straight line and which may bear little relationship to the climatic record. For this reason obviously disturbed woodlots were avoided, and in three cases following examination with the dendrochronograph, forest stands bearing clearly aberrant chronologies were not included in further analyses.

Computer analysis of the tree-ring data proceeded in six general steps:

1. A Ring Width Listing Program (RWLST) was applied to selected woodlots from across the study area primarily for

indications of suspected disturbance. Input for RWLST consisted of the previously assigned six-digit identification number and the annual tree-ring measurements for the period 1890-1970 for each core. Output included a listing of all annual ring-widths of each core by 10-year intervals and the computation of 20-year running mean ring-widths and mean sensitivities (a year-to-year variability measure) at 10-year intervals. RWLST also computed the slope of a regression line fitted to each 20-year period, and summarized the mean ring-width and mean sensitivity for the complete series (all the ring-widths for any core) as well as a plot of the 20-year running mean ring-widths. Ordinarily RWLST is useful in checking for errors in dating, measuring, card punching, and detecting trees with unusual growth characteristics.

2. The Tree-Ring Index Program (INDXA) processed the same raw data as RWLST and provided the basic statistics for ensuing analyses. In raw form, tree-rings from different cores and/or trees cannot be compared. The primary function of INDXA was to convert raw ring-widths into standardized indices, and in so doing, to attempt to remove non-climatic trends (for example, disturbances or unequal growth rates) from the chronology. Through the standardization of individual tree-rings, different core chronologies could be analyzed and compared. INDXA read the raw ring-widths for each core, and then applied a least-squares technique to fit a negative exponential curve approximating the expected decreasing ring-width associated with increasing age to the

tree. If this curve was inapplicable, a straight line of any slope was fitted to the data.

The observed ring-width for each year was divided by the value of the fitted curve for that year to obtain a ring-width index. The resultant indices for each core had a mean of unity and a variance non-dependent upon tree age, position within the stem, and mean growth rate of the tree (Julian and Fritts, 1968). The average index for each year then was calculated from the indices of the twenty cores for each group to form a standardized tree-ring chronology.
In addition to calculating yearly indices, the deviation of the ring-width from the curve, the mean sensitivity, and the square of the index were calculated and printed for each year. At the end of each series the first order serial correlation (which measures the non-randomness of tree-rings from one year to the next), standard deviation of indices, mean sensitivity, mean index, sum of indices, sum of squares of indices, and the type of regression fitted by the computer were printed.

In order to obtain a group chronology for any given site, INDXA required a sequence of series summaries which includes (1) both cores from each of the ten trees; (2) the north core from each of the ten trees; (3) the south core from each of the ten trees; and (4), both north and south cores from all ten trees. The final summary constituted the mean ("group") chronology for that site. For each of these summary steps, the mean indices, statistical error, standard deviation, variance, square of index, number of cores, sum of indices, and sum of squares of indices used in each summary were listed. INDXA also provided punch options for core indices, summary indices, and means of squares of component summaries for application in subsequent computer analyses.

3. The Analysis of Variance Program (ANOVA) was actually a subroutine of INDXA, which applied the mean indices and sums of squares of individual core chronologies produced by INDXA to calculate the estimated mean squares and the variance component for the chronology of individual radii sampled per tree, individual trees, the total sample, and combinations of the preceding (Snedecor, 1956, Ch. II). The printed output from ANOVA contained the raw sum, corrected sum, degrees of freedom, mean squares, and percent of estimated mean squares, and percent of estimated mean squares for the core, tree, and group chronologies.

By definition, the estimated mean squares (EMS) provided an estimate of the variance component for each chronology (Klausmeier and Goodwin, 1961, p. 677), and the percent of estimated mean squares (PC EMS) indicated percentage of the variance arising from differences in chronologies along several radii (YCT), and differences in chronologies among individual trees (YT), as compared to the remaining variability in the group chronology (Y). These figures were helpful in assessing the relative proportion of ring-width variation shared by all trees in the group (Y) as compared to the differences among trees (YT) and the differences between radii within trees (YCT). Thus, the analysis of variance facilitated the evaluation of relative differences and similarities in growth response of trees to their environment (Estes, 1970).

Four chronology parameters produced by INDXA and ANOVA--variance, percentage of total pooled variance contained in the standardized group chronology, serial correlation coefficient for the chronology at a lag of one year, mean sensitivity--were potentially useful in estimating the responsiveness of tree-ring series to growth conditions. The reasoning behind this estimation was as follows: trees (individuals or groups) which are limited frequently by moisture stress show a larger relative variability from year-to-year in tree-ring widths than those which are less often limited. In the latter, the combinations of soil moisture and temperature probably have not been sufficiently extreme to limit growth, and the factors determining growth apparently vary little from one year to the next. Trees restricted by moisture stress usually exhibit similar patterns of wide and narrow rings in all sampled trees from a given site. This similarity was measured by the percentage of total variance appearing in the group chronology (Y) (Julian and Fritts, 1968). Finally, changing rates of growth in parts of individual cores may have been caused by alteration of site factors not related to climate (fire, lumbering); and there may have been physiological feedback mechanisms operating independently of climate which prescribed that wide rings be followed by wide rings and vice versa. The first order serial correlation coefficient (Quenouille, 1952, pp. 166-68) yielded a measure of these linkages in adjacent ring-widths which could have complicated desired statistical relationships (Matalas, 1962). Removal of residuals arising from serial correlation allowed a more precise determination of important environmental parameters (Fritts et al., 1965).

Mean sensitivity is an indication of the relative change in ring index from year to year and was calculated as the absolute difference between adjacent indices divided by the mean of the two indices (Fritts et al., 1965). Individual mean sensitivity indices were averaged to produce a mean value for the entire series. Theoretically, mean sensitivity may be used as a quantitative index of external stress--spatially or temporally. For example, if a general climatic gradient existed across the study area, mean sensitivity should show concomitant changes. Or, if mean sensitivities before and after 1930 at La Porte were markedly different, the implication would be a temporal change in climate.

Therefore, variance, percentage variance maintained by the group, serial correlation, and mean sensitivity were each potentially important statistics in approaching the climatic, edaphic, and phytogeographic questions outlined for this project.

4. The Cross-Correlation Program (XCORR) was another subroutine of INDXA. XCORR calculated inter- and intra-correlations among series for individual woodlots. Inter-correlation represented the mean of all possible linear correlations between tree chronologies within a group of trees, whereas, intra-correlation determined the mean of all possible correlations between radii within individual trees. The Inter-correlation coefficient was especially useful because it indicated the relative degree to which a group of trees was responding together to common environmental stresses. Both coefficients theoretically should have shown positive variation with moisture stress.

5. A Stepwise Multiple Regression Analysis (STEPR) correlated tree-ring indices of selected woodlot chronologies with selected monthly climatic variables representing the year of tree growth and the year preceding growth. After analyzing a statistical relationship between a dependent variable (yearly tree-ring indices) and a set of independent variables (climatic data), STEPR listed the independent variables in order of importance. The criterion of importance was based upon a reduction of sums of squares technique, and the independent variable most important in this reduction at a given step is entered in the regression (Wittick, 1971).

A stepwise multiple regression analysis offered several desirable features for this project. First, the capacity of this manipulation for handling relatively large numbers of variables was essential for studying climate and growth relationships. Even though in some situations one climatic element may be dominant, more often in middle latitudes tree growth is a complex function of interacting factors (Kramer and Kozlowski, 1960, p. 428). Therefore, a statistical analysis capable of combining the statistical influences of multiple factors was more appropriate than a simple regression analysis (Fritts, 1962a). And second, the procedure has been applied with apparent success in a number of studies seeking to correlate tree growth and weather data (Fritts, 1962b; Fritts, 1965a; Fritts, 1969; Woods and Debrunner, 1970; Harman and Elton, 1971).

A possible disadvantage of a stepwise multiple regression technique was an inability to identify common sources of variance among independent variables (Cole and King, 1968, Ch. III). In other words, significant correlations between monthly precipitation and temperature could exist undetected which might yield unrealistic correlation coefficients in the final analysis. However, results from the studies cited above do not suggest this problem. Employing a principal component analysis to examine the inter-correlation of precipitation and temperature data from Colorado, Julian and Fritts (1968) concluded that multicollinearity was of minimal importance. Therefore, the possibility of multicollinearity between temperature and precipitation data from northwest Indiana was recognized, but it was not believed to be a serious concern.

To briefly summarize the procedures of statistical analysis, six computer routines were adapted to an IBM 6500 computer. Following a data listing of selected woodlots, eighty-one yearly raw ring-widths from twenty cores (ten trees) per stand were standardized and averaged to form a mean group chronology. Several measures of tree-ring series sensitivity were derived for each core, tree, and woodlot, and their likely application to questions being considered in this project was discussed. The final step applied a stepwise multiple regression analysis for correlating tree response with selected climatic variables in an attempt to ascertain important plant-climate relationships in northwestern Indiana.

Soils Collection and Analysis

At each site soil samples were collected with a bucket-type soil auger for an indication of subsurface drainage and textural composition. The number of test borings made in any location varied depending upon characteristics of the site, but usually five borings were made. (In some instances where unsuitable site qualities were suspected as many as ten samples were examined.) As discussed previously, only well-drained sites with apparently uniform textures were acceptable for data collection. From two borings soil samples were taken at three depths: the upper solum, or A horizon, the zone of apparent maximum clay accumulation in the B horizon, and the level immediately below a depth of 50". These six samples were stored in individual plastic bags for analysis at Michigan State University. Samples taken below the 50" level were tested in the field with dilute hydrochloric acid.

At the university, all samples were analyzed to determine their particle size distributions according to the Bouyoucos hydrometer method (Forest Soils Committee, 1953; Day, 1965) with several modifications. First, the readings customarily taken at 270 minutes and 720 minutes were replaced by one reading at 480 minutes. For purposes of this study, the 480 minute reading defined the very fine clay fraction of the soil sample. Second, the 480 minute reading was subtracted from the 120 minute reading to determine the clay fraction. (Thus, the very fine clay fraction and the clay fraction together comprised the total clay content of the soil sample.) Finally, the silt fraction was determined by subtracting the combined percentages of sand and clay from 100 per cent. The Bouyoucos system has been demonstrated to be accurate and detailed enough for most analyses of forest soils (Gessel and Cole, 1958).

For approximately one-tenth of the samples duplicate analyses were run to assure congruity of measurement; however, since corresponding results were quite similar in these cases, complete replication was not performed. Initially the two soil samples at corresponding depths from each site were analyzed separately, compared, and then averaged to provide mean values for individual textural components. Later, after sample pairs had proved to be in close agreement (Appendix II-A), the two samples were physically combined prior to running a single Bouyoucos analysis. Final results of the soil textural analyses are given in Appendix II-B. Soil texture was deemed important for this study because evidence suggests that it is an important property in controlling the available moisture within a soil, perhaps the single most important such property (Lund, 1959; Petersen and Cunningham, 1968).

Several procedures were adapted for the study of relationships between tree response and soil textural variation. Results of the soil textural analyses were entered against a parameter representing tree response from each stand in a stepwise multiple regression analysis program in order to determine which, if any, of the textural components might be significantly related to tree growth across the study area. Simple regression analyses of tree response against specific textural fractions (for example, very fine clay) supplemented the findings of the stepwise multiple regression technique. In addition, previously discussed tree-ring parameters provided a basis for making inferential statements. To illustrate, assuming that climate was uniform for the four woodlots

around each weather station, differences in cross-correlation coefficients or percentages of variance shared by groups were considered evidence of relative influences of soil variability. Estes (1970) made a similar assumption.

CHAPTER IV

SOIL TEXTURAL VARIATION AND TREE RESPONSE IN NORTHWESTERN INDIANA

One purpose of this study was to search for tree-ring evidence as to whether the western boundary of the beech-maple forest in northwestern Indiana is fixed by environmental limitations, or whether the boundary is the result of incomplete adjustment to conditions following the Pleistocene Epoch. There is little doubt that an east-west climatic gradient encompasses the study area, but the phytogeographical importance of this gradient is largely undetermined. The problem is complicated by a general difference in soil textures east and west of Valparaiso; this change in soil textures as mapped in Soils of the North Central Region of the United States (1960) corresponds closely with the change in forest composition from mesophytic to the more xeric vegetation types. Thus, the problem became one of evaluating the relative influences of climate and soils upon tree growth through an analysis of the tree-ring record. Since soil patterns across northwestern Indiana are complicated, the first step was to assess the role of soils in producing growth stresses, so that the influences of climate could be better understood.

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As described in detail in Chapter III, the analysis of variance developed by Fritts (1963) for tree-ring studies is an objective method of analyzing large amounts of data and comparing relative growth responses from many different locations. Fritts (1963) and Estes (1970) have demonstrated that the estimated variance components may be especially useful in evaluating the relative similarities and differences in tree-growth response along climatic, edaphic, or biotic gradients. As a general rule, trees limited by environmental stress exhibit similar patterns of wide and narrow rings in all sampled trees from a given site. This similarity is expressed by a high percentage of total variance appearing in the group chronology.

Fritts (1965a; 1965b) and Estes (1970) observed that disturbances by fire or cutting could alter the group chronology and increase the percentage variance among trees and radii. The preceding observation may be an accurate assessment when only a few trees in a stand have been affected; but in the present study large-scale disturbances resulted in inflated group variances. Therefore, since disturbance seemed to distort the analysis of variance values, stands #3, #12, and #13 which were severely disturbed (as determined by examinations of tree cores, variance components, and standard errors) were omitted from further study.

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Results

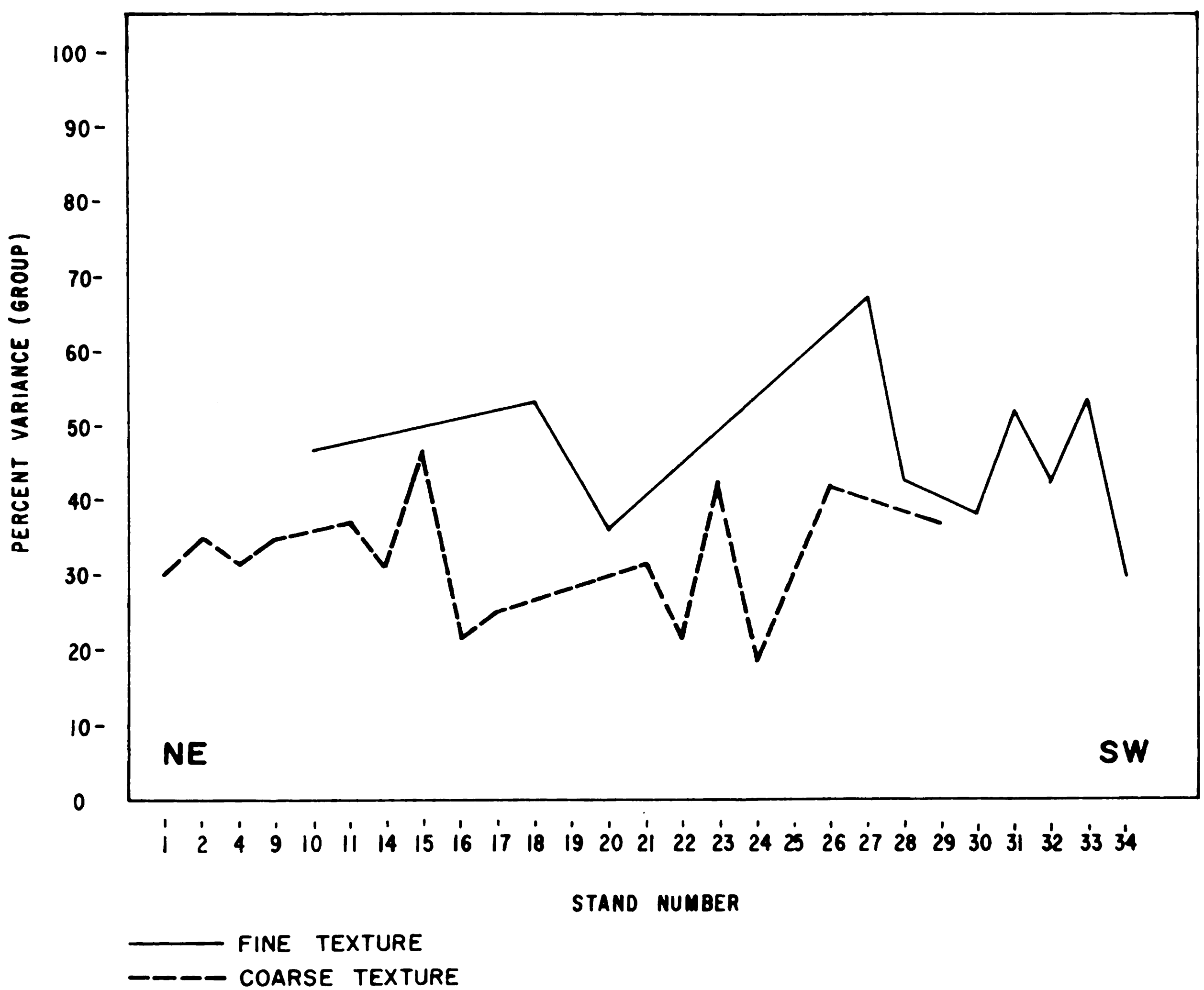
Appendix III-A provides a listing of the variance components for individual forest stands across the study area, as well as a summary of other important statistical parameters provided by the INDXA computer routine. The data in Appendix III-A, and succeeding figures derived from this table, may be used to evaluate the response of forest stands to the environment; but because of the high variability in many of the site records, great care must be used in interpreting these data. The reasons for this high variability are not entirely evident; a comparison of variability among the stands on similar soil textures at nearly any one of the weather stations, where climate is assumed to be constant, suggests that the unexpected differences in chronology sensitivities are the result of site factors such as undetected disturbances and impeded subsurface (below 50 inches) drainage.

Figure IV-1 depicts the trend of the percentage of variance retained by the group in white oak stands across the study area arranged according to gross soil texture. An important feature of the chart is the generally higher group responses on the finer-textured soils compared to the coarser soils. While the significance of the differences in response between stands growing on contrasting soil textures around individual stations could not be determined because of sample size, a simple regression of percentage of variance

Percentage Variance Retained by Groups of

FIGURE IV-1

Percentage Variance Retained by Groups of White Oak Trees on Contrasting Soil Textures



retained by groups across the study area against the percentage of fine material (silt, clay, and very fine clay) in the soil at a depth of 50 inches yielded a highly significant statistical relationship (Figure IV-2). The higher variances and lower standard errors on the majority of finer-textured soils demonstrate the relatively high similarity in growth response for all trees at each of these sites. Most of the finer-textured soils were taken from the western part of the study area, but several of the highest values were obtained from more easterly sites at Valparaiso, site #8, and Michigan City, site #10 (53% and 47% respectively).

Mean sensitivities and cross-correlation coefficients were analyzed by the techniques used in the preceding paragraph. The trend of mean sensitivities was inconclusive, if not unexpected (Figure IV-3), and the statistical relationship between mean sensitivity and soil texture was not significant (Figure IV-4). Aside from wide variability, especially on the coarser soils, and an apparent absence of trend on either texture, mean sensitivity values often did not appear to accurately reflect stress as indicated by the percentage of variance retained by the group. For example, in comparison to other sites at Park Forest, the percentage of variance retained by the group at site #34 appears to be rather insensitive (Appendix III-A); yet, the mean sensitivity value was relatively high. An examination of Fritts' (1965a) and Estes' (1970) mean sensitivities indicates

FIGURE IV-2

Regression of Percentage Variance Retained by Groups Against Total Percentage of Fine Materials (Silt + Clay + Very Fine Clay) in the Soil at a Depth of Fifty Inches

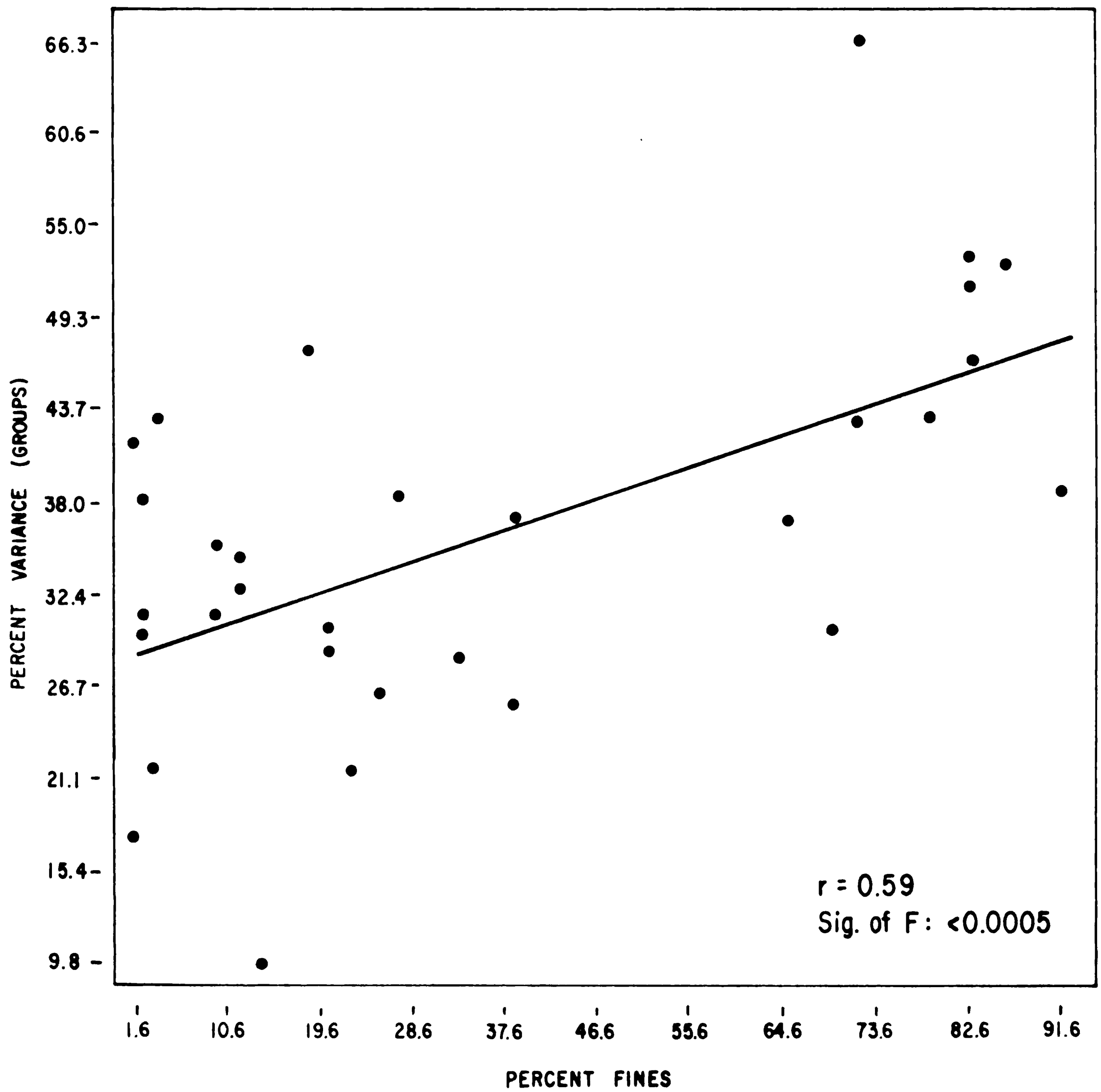
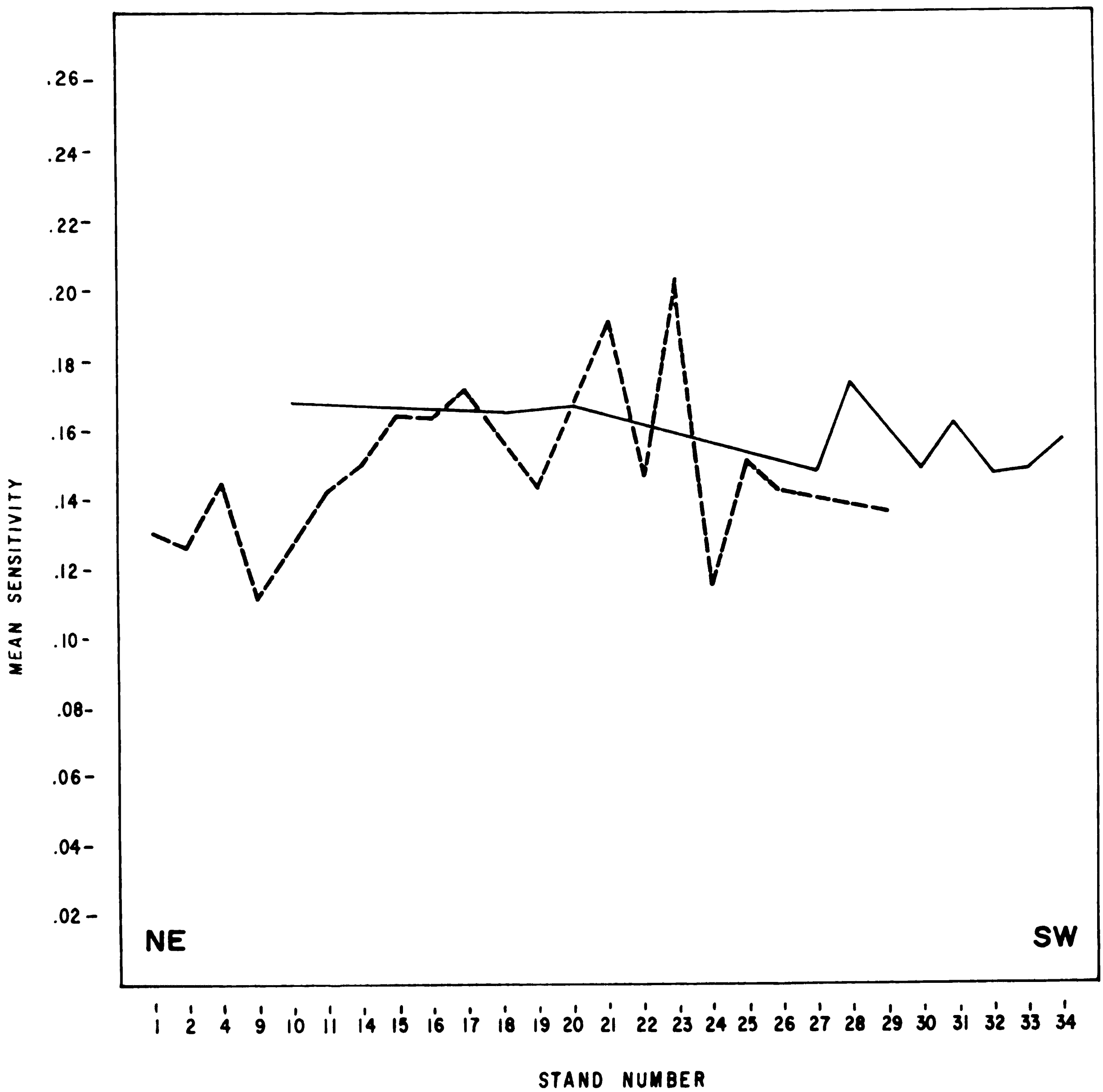


FIGURE IV-3

Mean Sensitivities of White Oak Stands on Contrasting Soil Textures

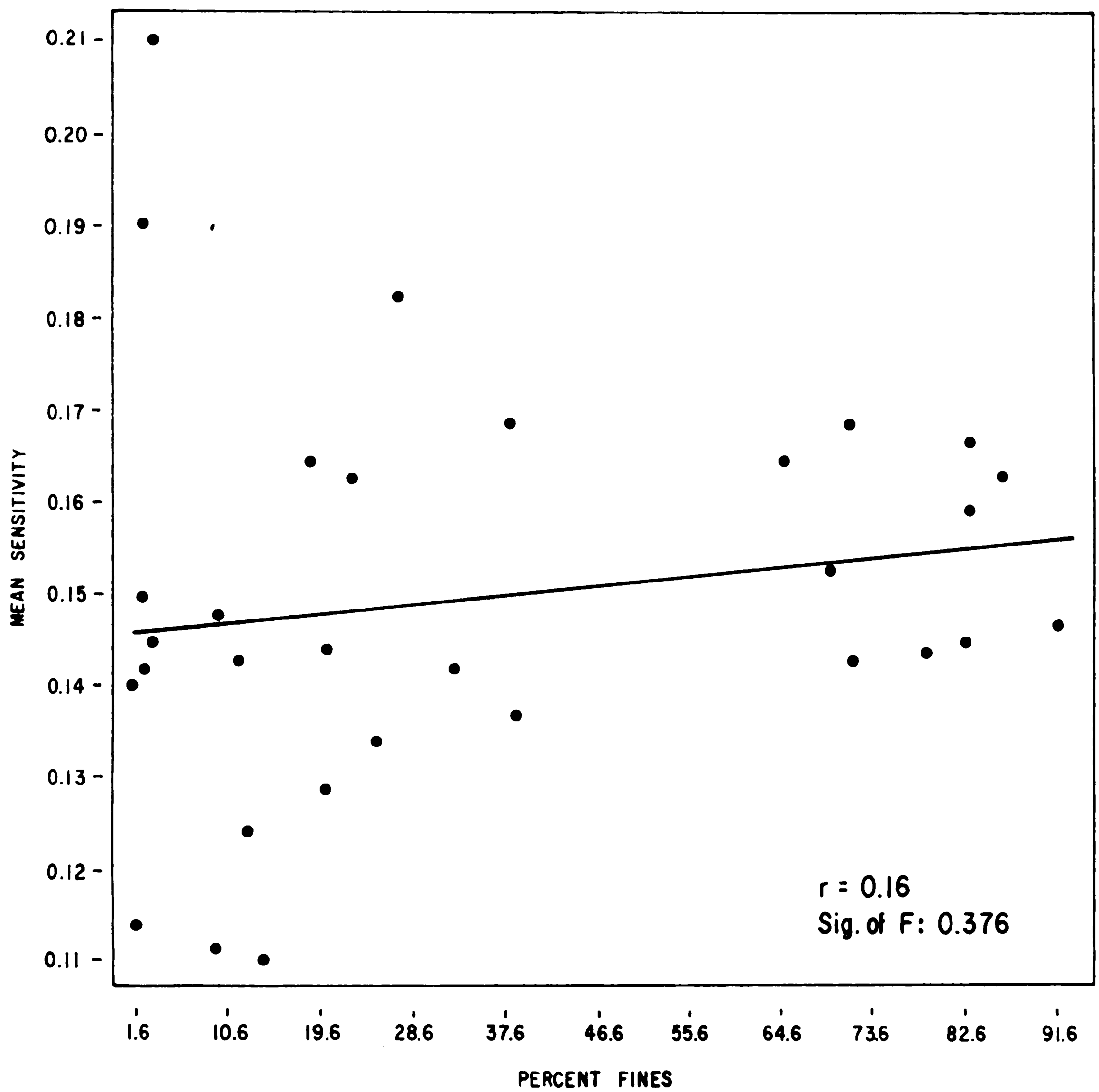


——— FINE TEXTURE

- - - - - COARSE TEXTURE

FIGURE IV-4

Regression of Mean Sensitivity Against Total Percentage of Fine Materials (Silt + Clay + Very Fine Clay) in the Soil at a Depth of Fifty Inches



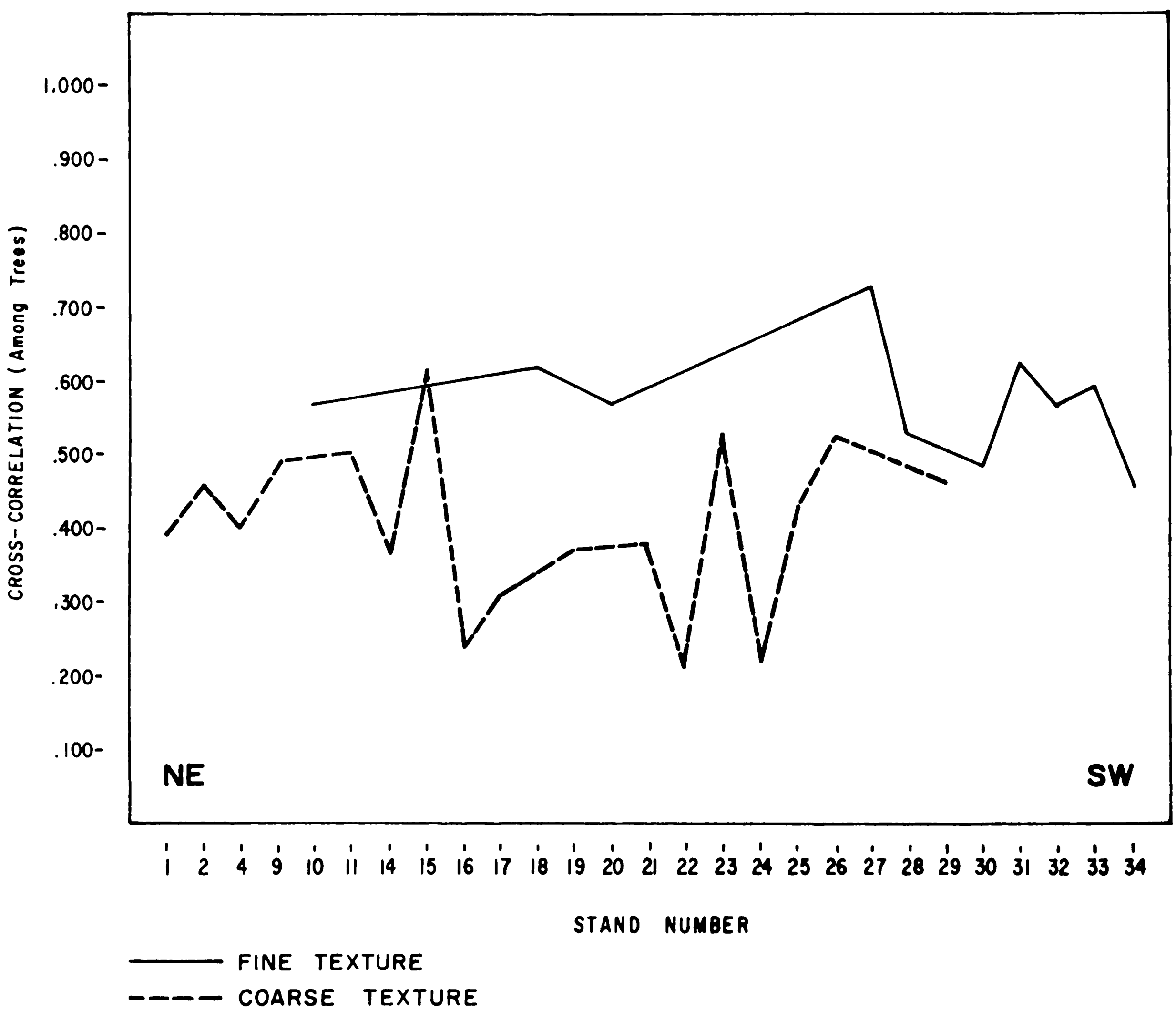
similar inconsistencies. On the other hand, the trends of cross-correlation coefficients among trees (Figure IV-5), a statistic rarely cited in the literature, bear a remarkable resemblence to the trends of percentage variance maintained by the group (Figure IV-1). Individually, or collectively, the cross-correlation coefficients appear to be highly supportive of percentage variance components. This fact probably should not be surprising, since both statistics are a measure of shared variation among trees at individual sites. In future dendrochronological research, cross-correlation coefficients may be a more useful statistic than mean sensitivity when analyzing groups of trees.

Appendix III-B depicts several stations where both fine- and coarse-textured soils were sampled. A comparison of statistics between individual woodlots at each station reveals that in every case the percentage of variance maintained by the group is higher on fine-textured soils than on the coarser soils. Most of the other comparative parameters in the table, except serial correlation coefficients which showed no consistent trend among stands, seem to indicate further that stress is more pronounced on the finer-textured soils.

In a further attempt to define the relationship between soil textural variation and phytogeographical patterns in northwestern Indiana, the stepwise multiple regression analysis program described in Chapter III was applied.

FIGURE IV-5

Cross-Correlation Coefficients Among White Oak Trees on Contrasting Soil Textures



The percentages of sand, silt, clay, and very fine clay for three levels in the soil profile at each site (Appendix II-B) provided the independent variables for the STEPR routine. The percentage of variance maintained by the group at each woodlot represented the dependent variable in each equation; as previously discussed, Fritts (1963, 1965a), Estes (1970) and others have demonstrated this statistics' sensitivity to growing conditions.

Initially the STEPR program included only sites from Valparaiso westward (stations 5 through 10) in order to minimize the effects of the suspected regional climatic gradient. Then the program was re-run to include all woodlots across the study area (excluding the La Porte sites) as a precaution to see whether the results would differ substantially from the first run. In both runs the only statistically significant soil variable entered was the percentage of very fine clay at a depth of 50 inches. In the first run (Appendix II-D) the percentage of very fine clay at a depth of 50 inches reduced the total sum of squares by 33% with a correlation coefficient of .58; the same variable in the second run (Appendix II-E) reduced the total sum of squares by 35% with a .59 correlation coefficient. The statistically significant (.05 level) positive relationship exhibited in both cases indicates that as the amount of very fine clay in the subsoil increases the percentage of the variance shared by the group also increases. The application of these findings in a simple regression analysis (Figure IV-6) further suggests a highly significant positive relationship between very fine clay in the subsoil and tree response.

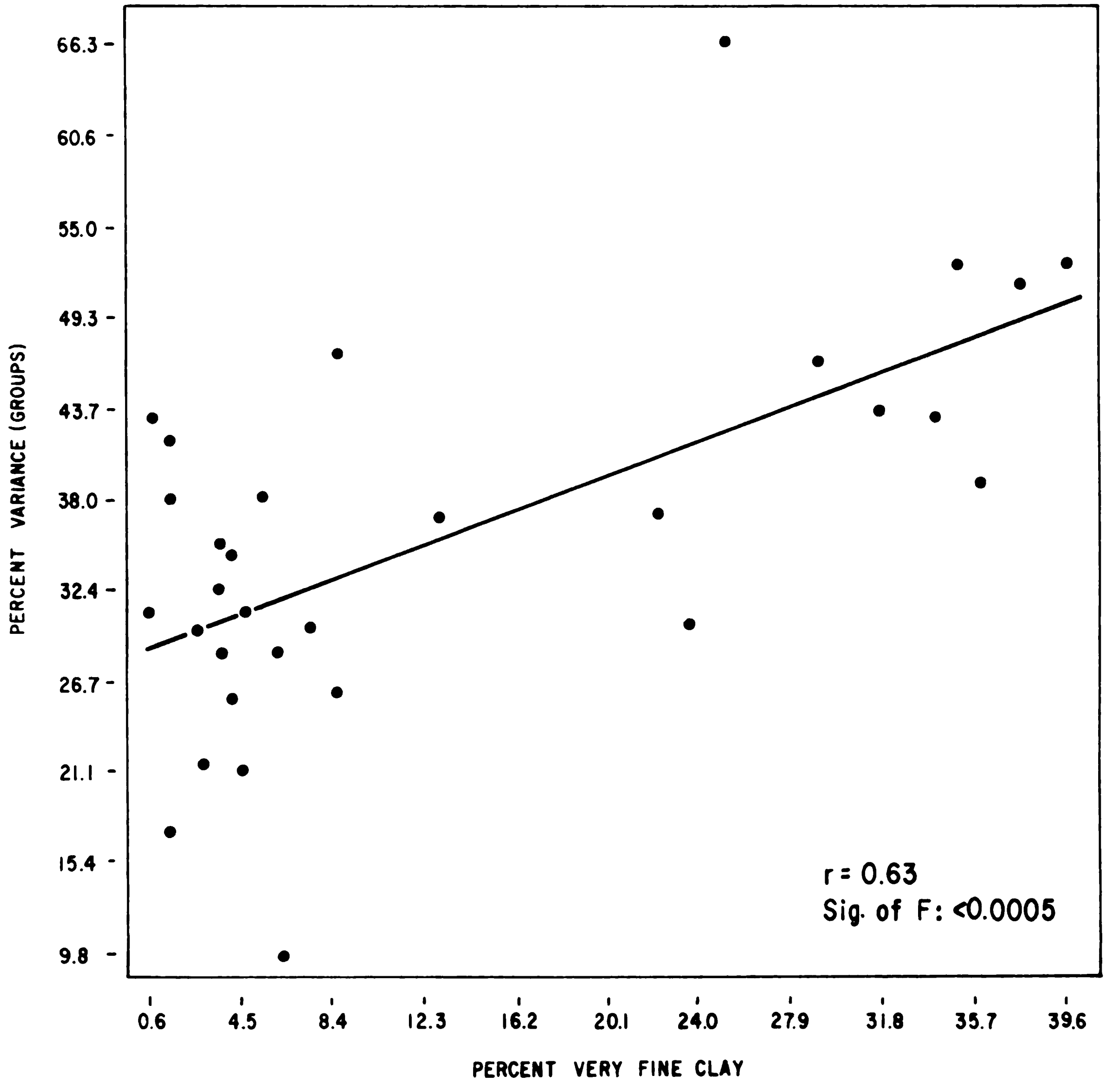
Discussion

Findings in the preceding analyses of soil textural variation and tree response suggest increasingly stressful growing conditions with increases in the amount of very fine clay in the subsoil. Since a large part of the water in the soil is held as a film on the surface of clay particles, the amount of clay in the soil has an influence on the total water holding capacity of the soil (Spurr, 1964, p. 285). However, the total water content of soils is not normally available to plants. Franzmeier et al. (1960) proposed that the tensions at which soil moisture is readily available to plants is between .06 and 6.0 atmospheres. Based upon this finding, they proposed that loamy sands, sandy loams, and loams usually exceed clay loams and clays in readily available water capacity (RAWC). The implication that moisture stress is more extreme on soils with higher clay contents supports the findings of the current research.

In addition, the current results parallel those of Dyksterhuis (1948), Kucera (1957), and Elton (1970a). In the Western Cross Timbers region of Texas, Dyksterhuis found that vegetation patterns were controlled largely by soil-moisture characteristics. Upland stands of post oak

FIGURE IV-6

Regression of Percentage Variance Retained by Groups Against Percentage of Very Fine Clay in the Soil at a Depth of Fifty Inches



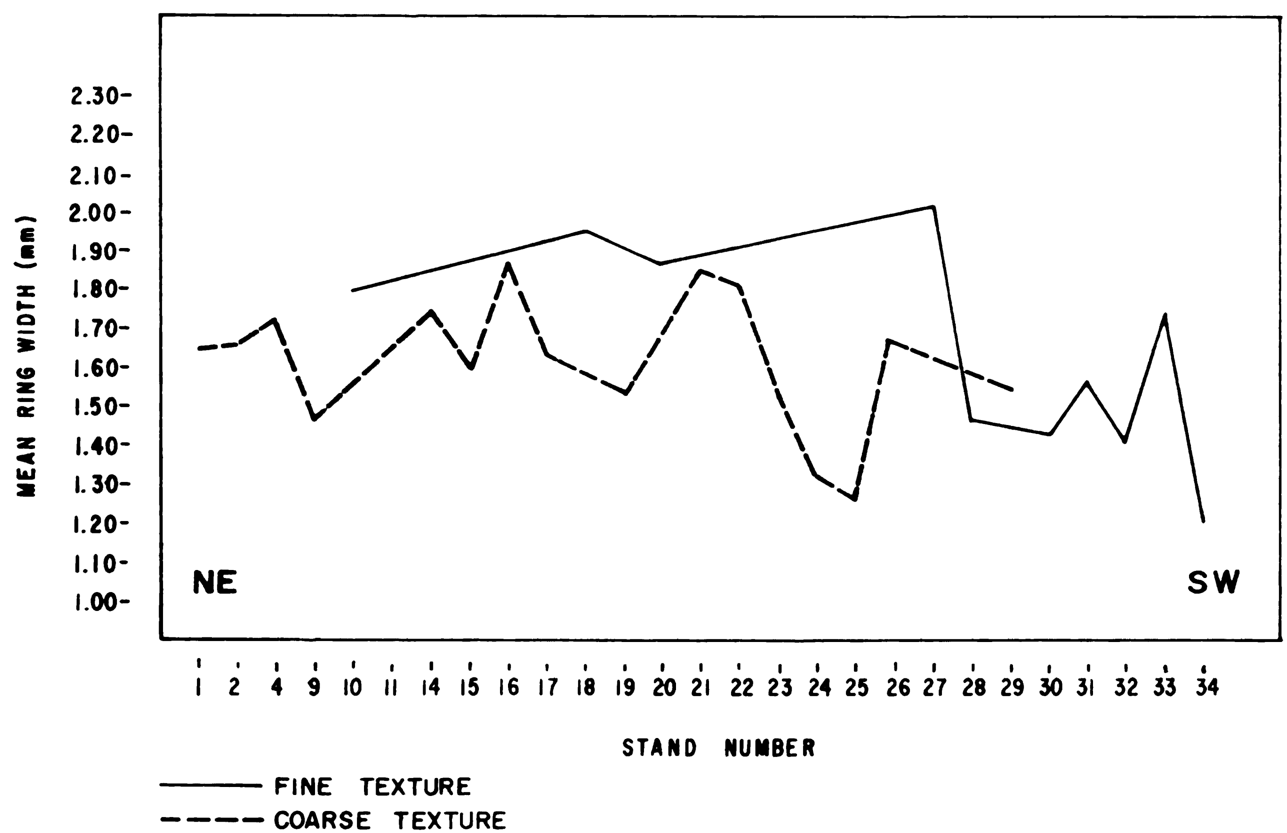
(Quercus stellata) and blackjack oak (Quercus marilandica) were restricted to a belt of coarse-textured soils derived from sandstone where moisture stress is moderated, but on adjacent fine-textured soils to the east and west where moisture was less readily available prairie species persisted. Kucera, working in the southwestern Missouri Ozarks, concluded that edaphic factors were controlling the distribution of prairie and forest vegetation types. Prairie species were restricted to finer-textured soils where drought stress was apparently more acute; and forest species, among them Quercus alba, were prominent on the adjacent coarse-textured chert soils. Elton, after an extensive study of forest and soil patterns along the Valparaiso Moraine in northwestern Indiana, derived negative correlations between the occurrence of mesophytic species and the percentages of silt and clay in the subsoil; conversely, the more xeric oak and hickory species correlated positively with the smaller soil fractions. Elton suggested that the higher [total] clay content of soils west of Valparaiso with their suspected smaller readily available moisture capacities favor more xeric forests of oak and hickory while discouraging the successful competition of more mesic species such as beech and sugar maple. Results of the INDXA and STEPR programs in the present research project appear to confirm Elton's suggestion on the importance of soil clay to plant response in northwestern Indiana, but further indicate that within the total clay fraction, the very fine clay component is probably pre-eminent.

Although it was beyond the scope of this project to make a detailed listing of plant species present in the woodlots under study, some qualitative accounts of the dominant tree species were recorded. Based upon these observations, it appears that there is an apparent shift from mesic to xeric oak species across the research area. Generally, red oak (Quercus rubra) tended to be a canopy dominant (frequently with other species such as beech and sugar maple) on mesic sites in the eastern part of the area, white oak (Quercus alba) was less conspicuous except on the drier sites; black oak (Quercus velutina) was observed typically on sandier, very droughty sites. Near Valpariso and westward, white oak appeared to be the dominant canopy species, but often was accompanied by black oak and burr oak (Quercus macrocarpa); red oak was increasingly found where site qualities, such as soils and topography, provided moister growing conditions. Beyond Joliet, Illinois, approximately thirty miles west of the study area, the author noted that burr oak appeared to be the predominant forest species, followed by white oak and black oak. Burr oak is usually regarded as being a more drought tolerant species than either white oak or red oak (Fowells, 1965, p. 564). Elton's (1970a, p. 38) frequency distributions of tree species across northwestern Indiana indicate a similar distribution of oak species.

It is interesting to note, however, that in the present study and in Elton's (1970a) the area of most frequent occurrence of white oak (approximately the area between Valparaiso, Indiana, and Park Forest, Illinois) may not coincide with the part of the study area where white oak appears to achieve its highest growth rates. Figure IV-7 represents the average ring-widths of all tree cores from each forested stand (excluding the La Porte stands) across the study area. The trend line on coarse-textured soils fluctuates greatly and is generally inconclusive; but the trend line for finer-textured soils is somewhat more consistent, suggesting lower growth rates at the two western-most stations, Lowell and Park Forest (stands 28-34). Conclusions based on these data are highly tentative because of the erratic growth rates on coarser soils and the small sample size representing fine-textured sites, but it appears that white oak may assume forest dominance on the droughtier, finer-textured soils (which predominate toward the west) where competition from more mesic species is less severe. Ring-width is usually inversely related to environmental stress (McGinnies, 1963); thus the apparent westward decline in average ring-widths, at least on finer-textured soils, could indicate more stressful growing conditions presumably brought about by climatic limitation. However, if climate becomes more limiting in the western part of the study area, in the small sample presented here the decrease in ring-widths first appears at the Lowell sites (#28 and #30) well west of the general terminus of the mesophytic forest type.

FIGURE IV-7

Mean Ring-Widths of White Oak Trees on Contrasting Soil Textures



One puzzling feature of Figure IV-7 is the difference in ring-widths between fine- and coarse-textured soils; in most cases the mean ring-widths on fine-textured sites are significantly larger than those from coarse-textured sites. At Lowell, however, the larger value on the coarse-textured site (#29) compared to sites #28 and #30 was not statistically significant. Evidence has pointed toward more stressful growing conditions on finer-textured soils, regardless of location in the study area, when compared to conditions on coarse-textured soils; normally, on more stressful sites growth increments are smaller. However, this figure indicates that in the eastern part of the study area white oak achieves better growth on the finer soils. While the evidence is inconclusive, some speculation can be made concerning reasons for this apparent contradiction. First, these growth differences may be more apparent than real, the result of too few data. To accurately establish growth trends many more data would be required, especially on the coarse-textured soils where variation seems to be larger. Second, if stand densities should prove to be higher on the coarse-textured sites where stress is supposedly less pronounced, competition for available moisture, nutrients, and sunlight possibly would be greater during the infrequent periods of high moisture stress. Thus, by this line of speculation, growth rates might be larger on fine-textured sites where competition is less.

Third, there is some evidence that differential nutrient supplies among soils may be reflected in different growth rates in white oak. Usually a lack of nutrients does not preclude white oak survival, except on the poorest of soils (Fowells, 1965, p. 632). McVickar (1949) observed that white oak in Illinois obtained sufficient nutrients for adequate leaf growth on poorer soils low in replaceable bases, but on the richer soils, significantly higher nutrient contents were contained in the leaves. Arend and Julander (1948) found that oak growth, including white oak, in the Ozarks was higher on soils derived from limestone than shale or sandstone. Einspahr and McComb (1951) in northeastern Iowa recorded generally higher site indices for white oak growing on finer-textured soils such as silty clays and silt loams in comparison to site indices from coarser soils such as sandy loams, loamy sands, and sands. Since the nutrient status of soils is usually related to the amount (and kind) of soil colloids (Donahue et al., 1971, p. 53), and since the coarser soils in the study area are probably more leached of exchangeable bases than the finer soils (Millar et al., 1958, p. 248), the possibility exists that higher nutrient supplies on finer soils could result in higher growth increments of white oak.

Whether or not the transition of oak species across the study area is controlled entirely by edaphic conditions is not clear. The transition from red oak to white oak near

Valpariso seems to be strongly related to soils, but the transition farther west from white oak to burr oak could be the result of a climatic gradient. Data gathered in this project are insufficient to answer this question, but additional soil samples and tree cores west of the present study area might offer a solution: if soil textures were similar to those in the western part of the current study area and tree sensitivities were higher, a climatic influence could probably be inferred.

Summary

Findings of the current research indicate that in northwestern Indiana on well-drained sites growing conditions are more stressful on the finer-textured soils than on the coarser soils. In ecotonal areas, such as northwestern Indiana (Braun, 1950, p. 322), site characteristics are very important in determining what types of plants will occur at any particular location. Thus, it appears quite possible that the higher amounts of very fine clay in the finer-textured soils could reduce the readily available moisture capacity sufficiently to exclude more mesic vegetation types, thereby exerting an important control over phytogeographical patterns in northwestern Indiana.

CHAPTER V

REGIONAL CLIMATE AND THE TREE-RING RECORD

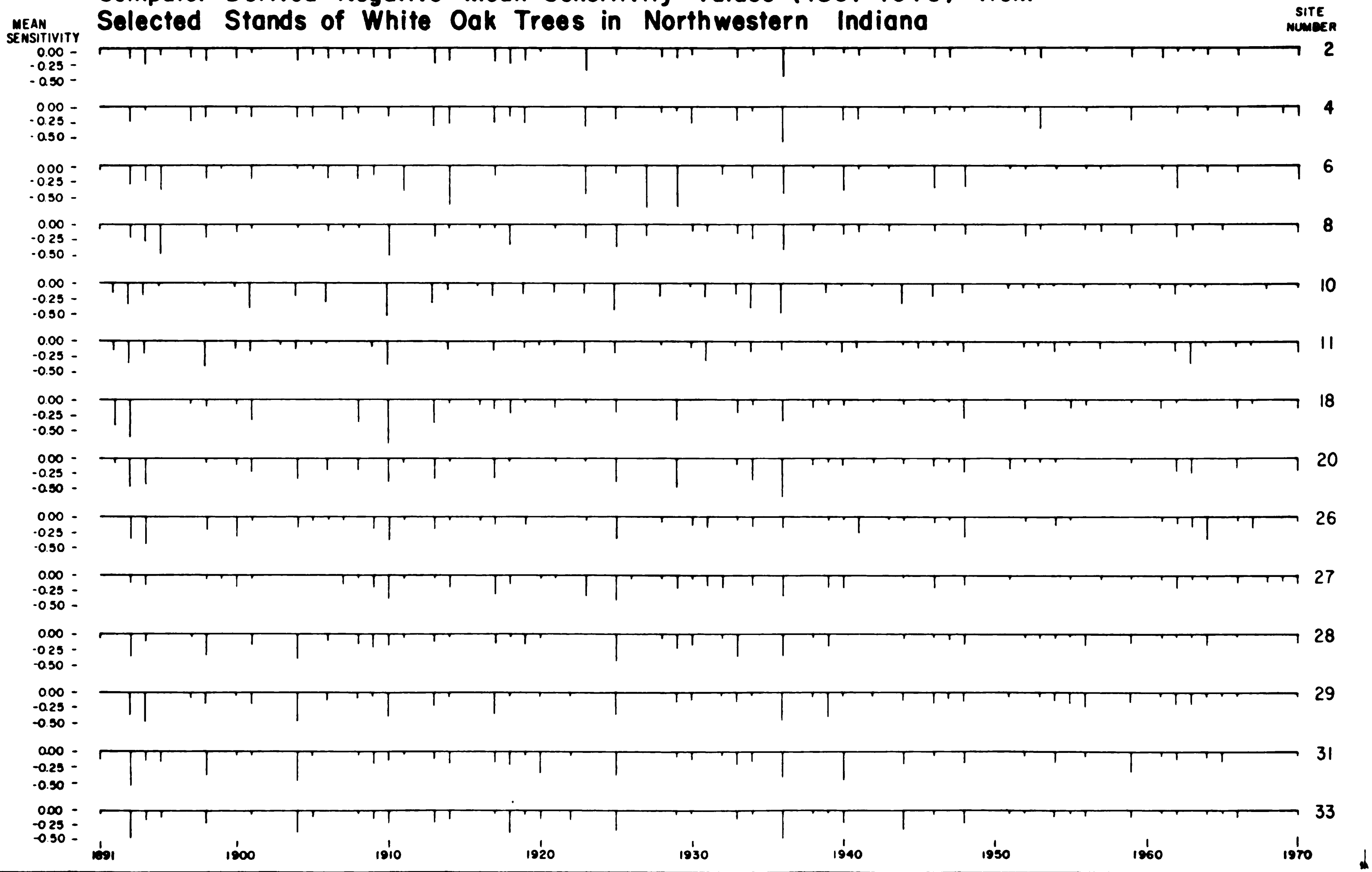
Cross-Dating With Negative Mean Sensitivity Values

In order to help determine whether or not sequences of wide and narrow rings occur in the same years among trees from different stands in northwestern Indiana, i.e., whether they display "cross-dating," computer-derived negative mean sensitivity values were plotted for the period 1890-1971. To recall, mean sensitivity is the relative first difference between any pair of adjacent tree-rings; and a negative value between two rings indicates a decrease in growth in the outermost of the two adjacent rings, usually because climate was more limiting than in the previous year. Thus, by plotting negative mean sensitivity values of stand chronologies across the study area, it was possible to determine whether woodlots were responding randomly to characteristics of individual sites, or whether these woodlots were reacting to common climatic stresses and would, therefore, display cross-dating (Fritts, 1969).

The plots from selected sites in Figure V-1 for white oak indicate that not only does valid cross-dating exist

FIGURE V-1

Computer-Derived Negative Mean Sensitivity Values (1891-1970) from Selected Stands of White Oak Trees in Northwestern Indiana



among sites at each weather station, but also that it exists between weather stations throughout the study area. For example, moisture stress was especially prominent in the years 1893, 1910, 1925, 1936, and 1948. Further, there is little apparent difference between plots of white oak and black oak (Figure V-2). The presence of cross-dating does not necessarily mean that all of the sampled forest stands in the region are responding to identical weather variables, but it does indicate that these stands have borne some similarity in their responses to common periods of climatic stress.

Correlation of Climatic Data With Tree-Ring Indices

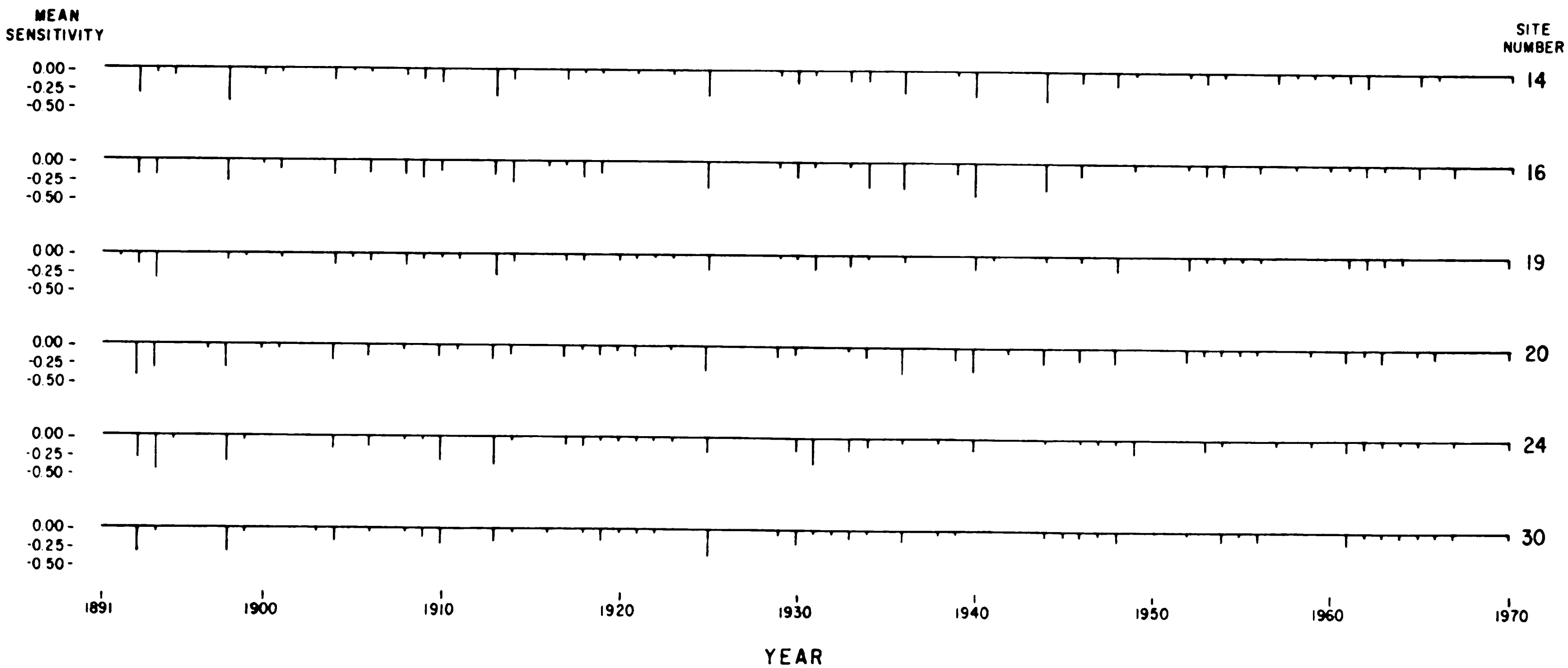
In an attempt to determine which, if any, climatic variables have been especially important to tree growth across northwestern Indiana, a stepwise multiple regression analysis program correlated selected climatic variables (Appendix IV-A) with tree-ring indices from selected stations and sites for the period 1951-1970.

Results

As indicated in Appendix IV-B, April-May precipitation of the current season appears as a significant variable at six of the twenty-two sites on both coarse-textured soils (South Bend) and fine-textured soils (Lowell and Park Forest).

FIGURE V-2

Computer-Derived Negative Mean Sensitivity Values (1891-1970) from Selected Stands of Black Oak Trees in Northwestern Indiana



With the exception of site #28 (Lowell) precipitation and tree growth were negatively related. Mean maximum April-May temperatures of the current season also were negatively related to growth at two La Porte sites.

Mean maximum June temperature of the current season was the most frequently entered variable, appearing in eight locations from Valpariso eastward on the coarser- and finer-textured sites. In each case mean maximum June temperature and tree growth were negatively related. On the other hand, total June precipitation of the current year exhibited positive correlations with ring-width at five western locations.

Climatic variables for months preceding current growth showed some importance at a few western sites. The preceding season's total June-July-August precipitation was positively associated with growth at three western sites, while October-March precipitation was negatively related at three western sites.

In overview, tree response in northwestern Indiana seems to be most closely related to climatic conditions of the current spring and early summer; June variables were especially important. These results compare favorably to a recent dendroclimatological analysis in this region by Ashby and Fritts (1972). Although the evidence is not decisive, indications are that response to moisture variables may be more direct in the western part of the study area, whereas temperature variables are more prominent in the east.

Discussion

Physiological Implications

At first glance the negative relationship between tree growth and current season April-May rainfall is surprising. But Fritts (1960) found white oak radial growth to be very sensitive to soil moisture conditions of April and May; inhibited growth accompanied arrival at field capacity, possibly because of poorer aeration and lower soil temperatures for root development. Similar reasoning may account for the negative correlations of October-March precipitation. Originally October-March precipitation was included in the analyses to determine if winter soil moisture storage, particularly in the eastern part of the region where winter snowfall is heavier (Changnon, 1968), might be important in understanding the forest transition across northwestern Indiana. However, the only influences indicated were negative, and these occurred at western sites, probably because of the high moisture holding capacity of the fine-textured soils at the three sites where this variable appears (Kramer and Kozlowski, 1960, p. 88).

Frequently in white oak (*Quercus alba*), June represents the critical point between earlywood and latewood formation (Fritts, 1958). Wetter and cooler Junes would tend to prolong production of the wider earlywood cells thereby creating wider total growth rings. The reverse would be true in Junes with high evapotranspiration rates and lower moisture availability.

Robbins (1921), Diller (1935), Freisner (1943), and Estes (1970) detected close relationships between total annual diameter growth and moisture conditions of June.

The presence of the preceding June-July-August total rainfall as a significant variable apparently demonstrates the "lag effect" described by Diller (1935), Fritts (1958), and Zahner and Donnelly (1967). If conditions are favorable late in the growing season when vegetation growth is declining, trees may manufacture and store more than normal amounts of food materials for use the next spring. If stored materials are less available to the tree in spring, the potential for growth is reduced (Kramer and Kozlowski, 1960, Ch. IV). Thus, late-season conditions often influence the size of the next year's tree-ring (Hanson, 1941; Gagnon, 1961).

Ecotonal Implications

The apparent trend to different types of significant weather variables across the study area is difficult to assess in terms of the forest gradient. Frequently, different combinations of significant variables appear on different sites around the same weather station (Appendix IV-A); this pattern may mean that soils, topography, and subsurface drainage partially decide which weather variables most highly correlate with tree response at a particular site. Thus, the higher multiple correlation coefficients and percentages of explained variability westward, and the apparent shift from temperature to precipitation variables across northwestern Indiana, could be the result of regional edaphic contrasts. If the apparent shift in climatic controls is a reality--and the data are not conclusive--at this point the significance of these findings to the forest transition is unclear.

Interpretation of the Index Program

Results

In the following analyses, a variety of figures have been derived which depict the trends of INDXA parameters across the study area on similarly textured soils. Rather than presenting data for individual woodlots as in previous diagrams, each point on a figure represents the average parameter value for all sites having approximately similar soil textures at that station. The purpose of this procedure was to reduce the wide variability often displayed among sites at most stations, in order to render general trends possibly related to climate more easily discernible. Care must be exercised in interpreting these charts because of different sample sizes represented by points and probable undetected disturbances at some sites.

The Regional Climatic Gradient

Mean ring-widths on finer-textured soils decline noticeably at the western-most sites of Lowell and Park Forest, but on coarse-textured soils any decline is very slight (Figures V-3, V-4). Westward, mean sensitivities (Figures V-5, V-6) and percentages of variance retained by groups (Figures V-7, V-8) apparently decline on finer-textured soils and rise on the coarser soils. Cross-correlation coefficients may rise toward the west on coarser soils, but the trend on finer-textured sites is indefinite (Figures V-9, V-10).

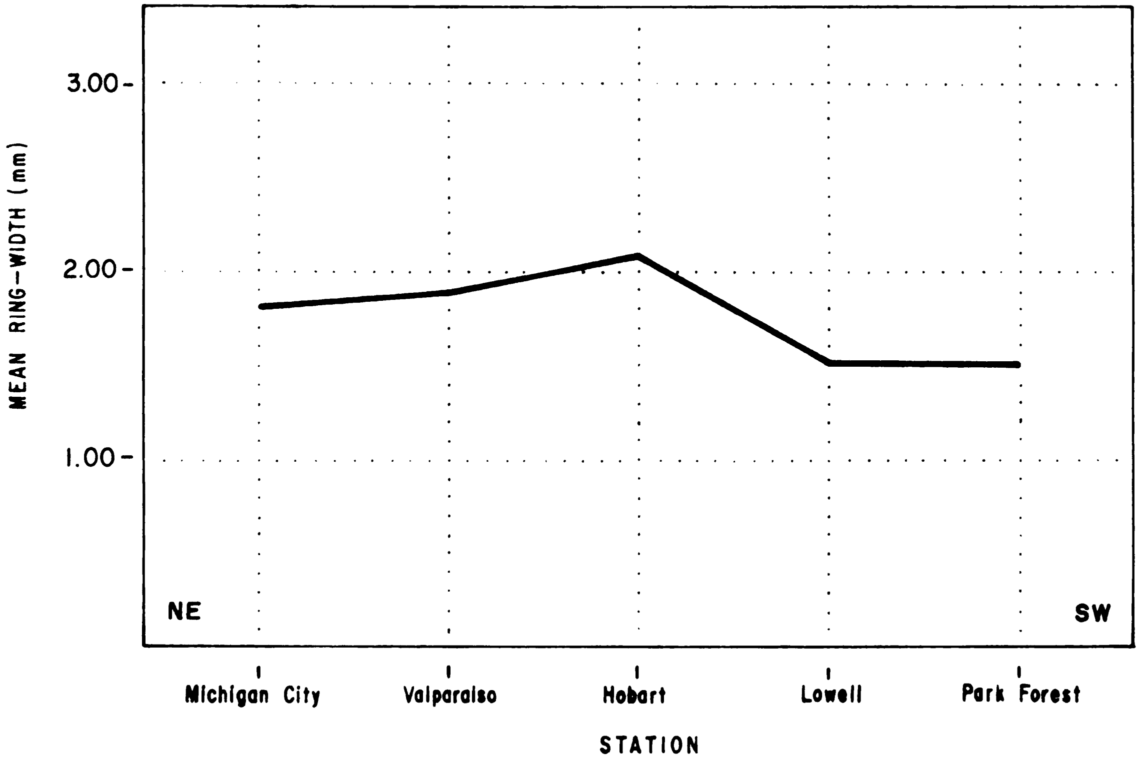
In an attempt to clarify the inconclusive, sometimes contradictory, trends in the figures described above, simple correlation techniques regressed these same chronology parameters against the distance westward of individual sites from an arbitrarily drawn line east of the study area. Significant relationships between tree-ring parameters and increasing distance westward presumably would manifest increasing climatic stress. Results of these regression analyses do not always suggest a close relationship between tree response and westward position (Table V-1). The only significant trend appeared with mean ring-widths on fine-textured soils, but the sample size of nine data points is too small to be conclusive without additional supporting evidence.

The Lake Michigan Mesoscale Climatic Gradient

A comparison of chronology parameters between coarse-textured sites from Michigan City (#9 and #11) and Hobart

FIGURE V-3

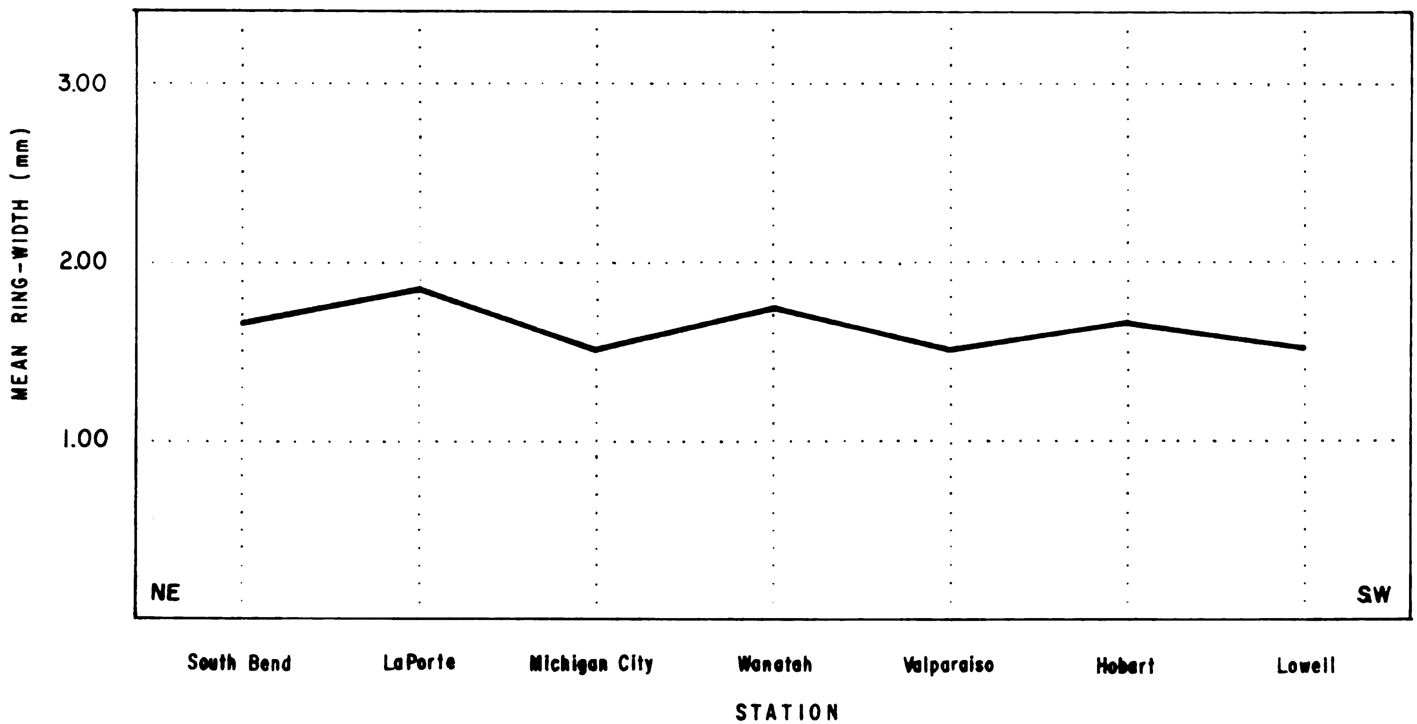
Mean Ring-Widths Among Stands of White Oak Trees on Fine-Textured* Soils at Selected Stations



* LESS THAN 50% SAND AT DEPTH OF 50 in.

FIGURE V-4

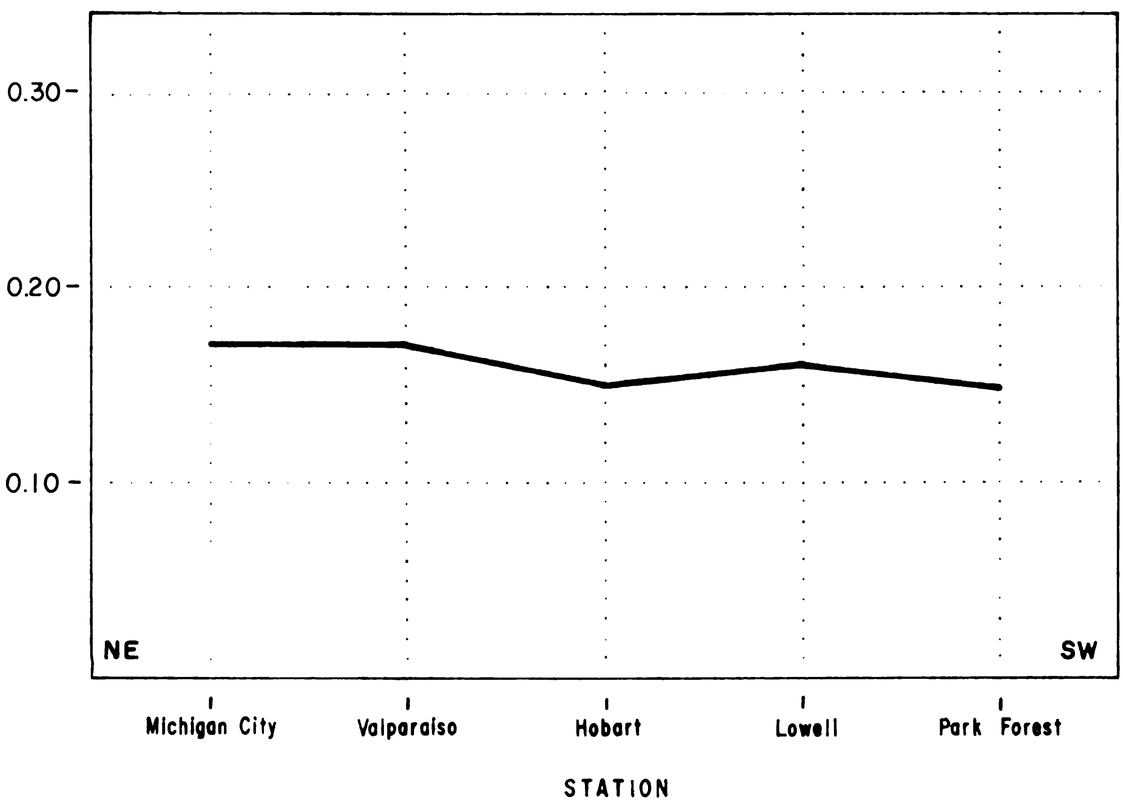
Mean Ring-Widths Among Stands of White Oak Trees on Coarse-Textured* Soils at Selected Stations



* MORE THAN 50% SAND AT DEPTH OF 50 in.

FIGURE V-5

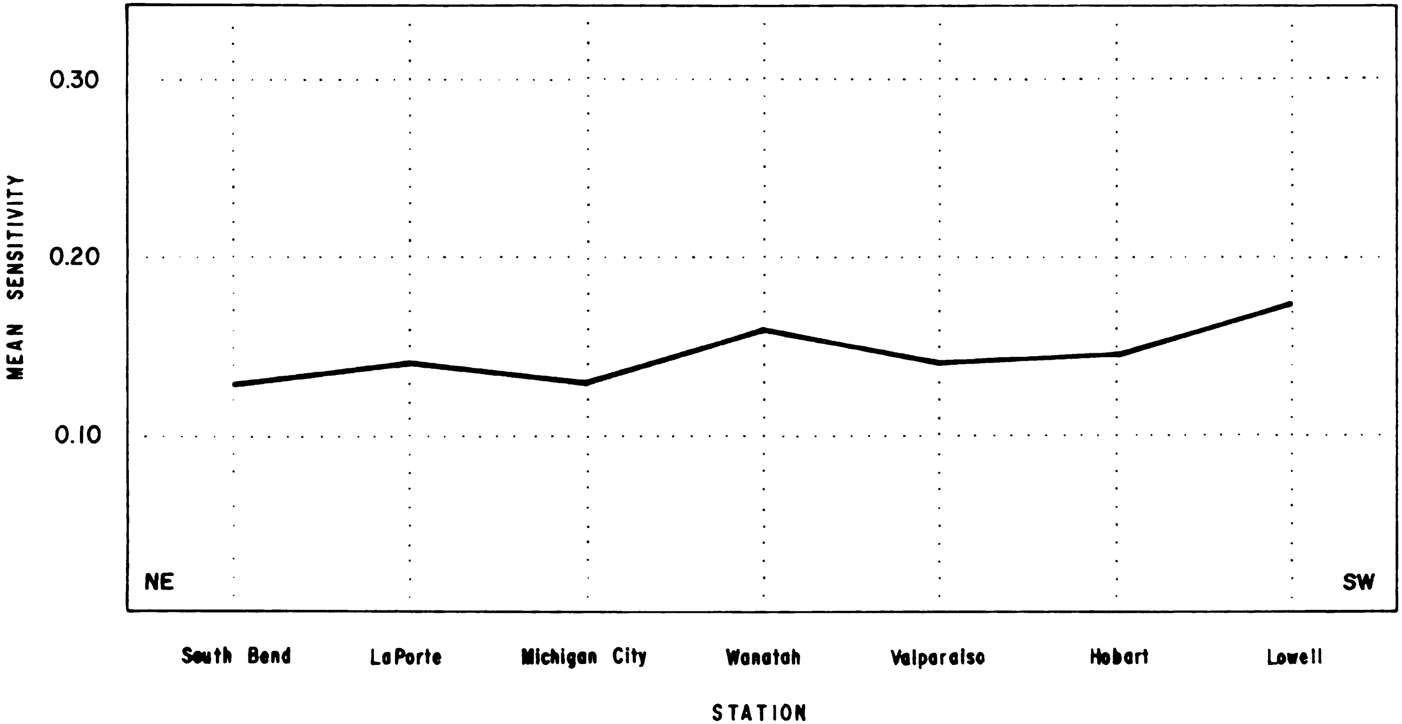
Average Mean Sensitivity Among Stands of White Oak Trees on Fine-Textured* Soils at Selected Stations



* LESS THAN 50% SAND AT DEPTH OF 50in.

FIGURE V-6

Average Mean Sensitivity Among Stands of White Oak Trees on Coarse-Textured* Soils at Selected Stations

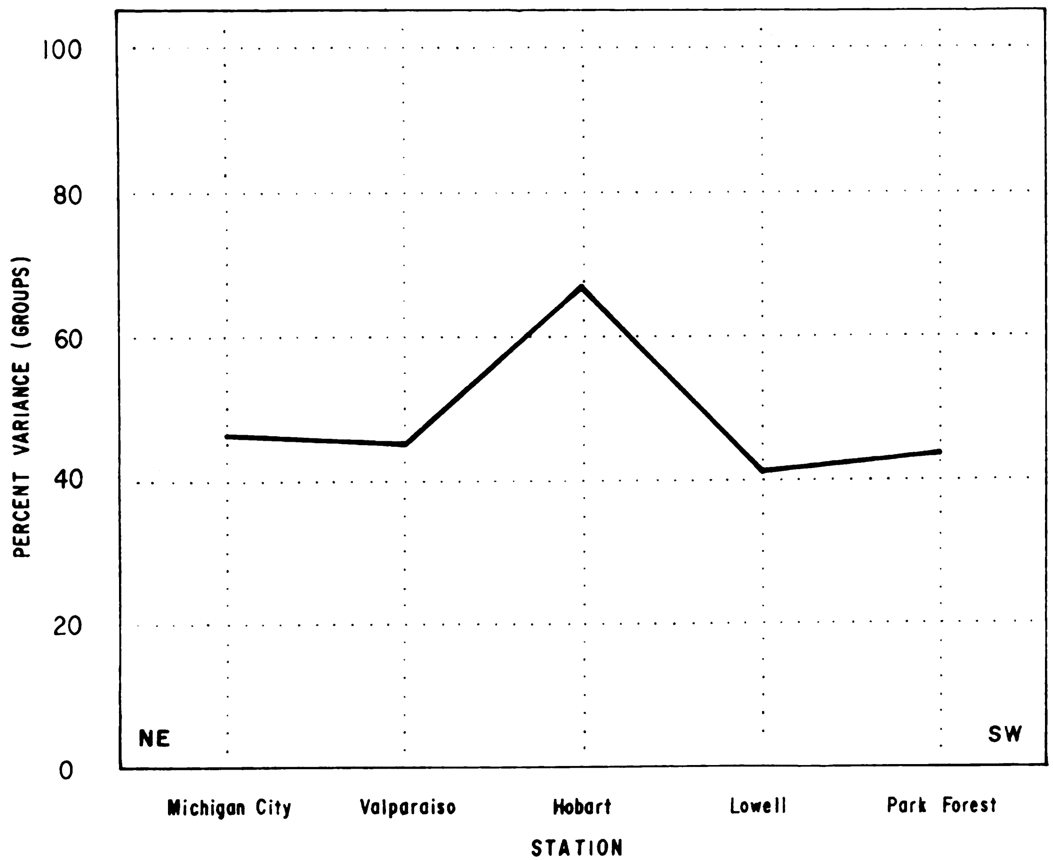


* MORE THAN 50% SAND AT DEPTH OF 50 in.

of Variance Retained by

FIGURE V-7

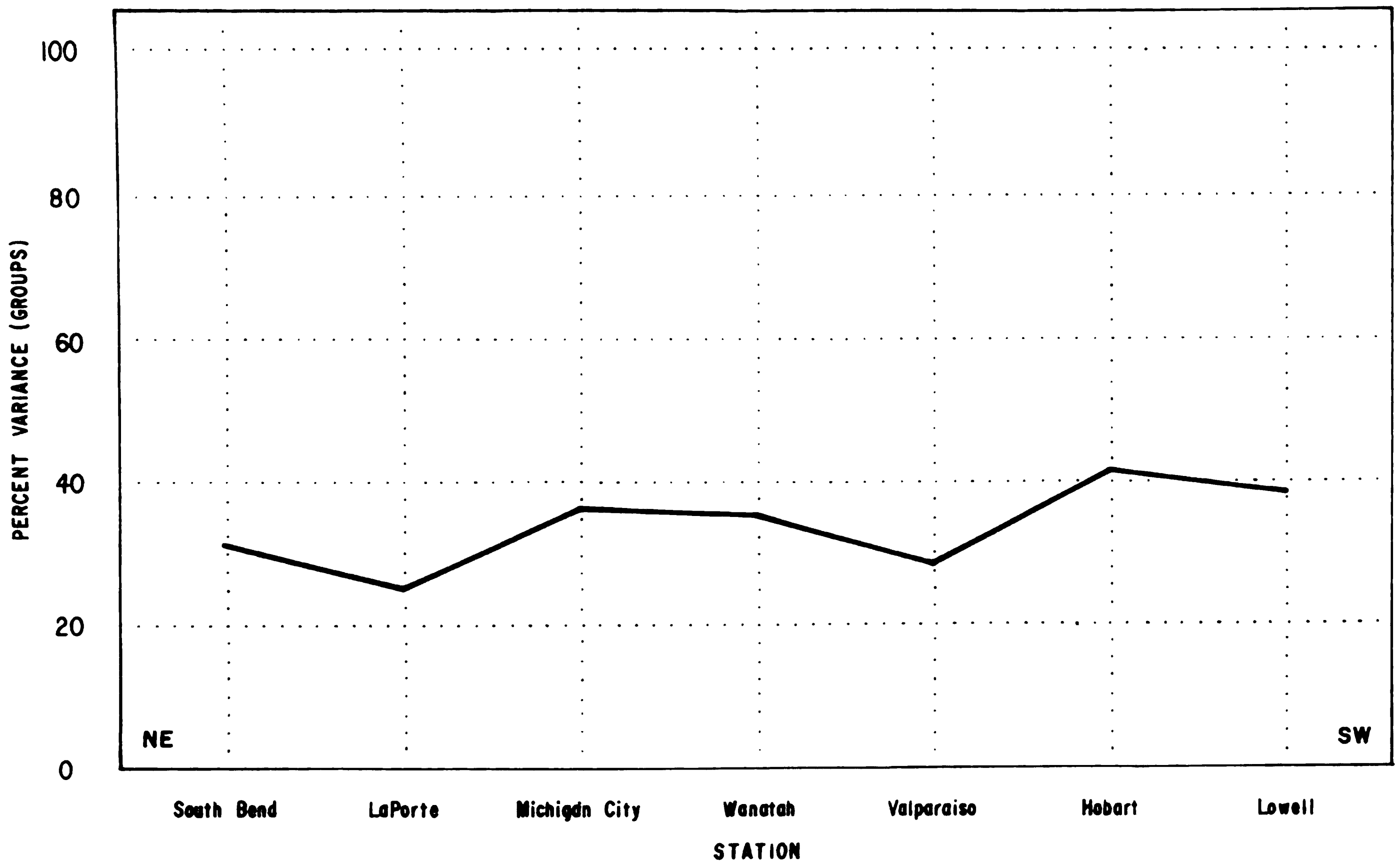
Average Percentage of Variance Retained by Groups of White Oak Trees on Fine-Textured* Soils at Selected Stations



* LESS THAN 50% SAND AT DEPTH OF 50in.

FIGURE V-8

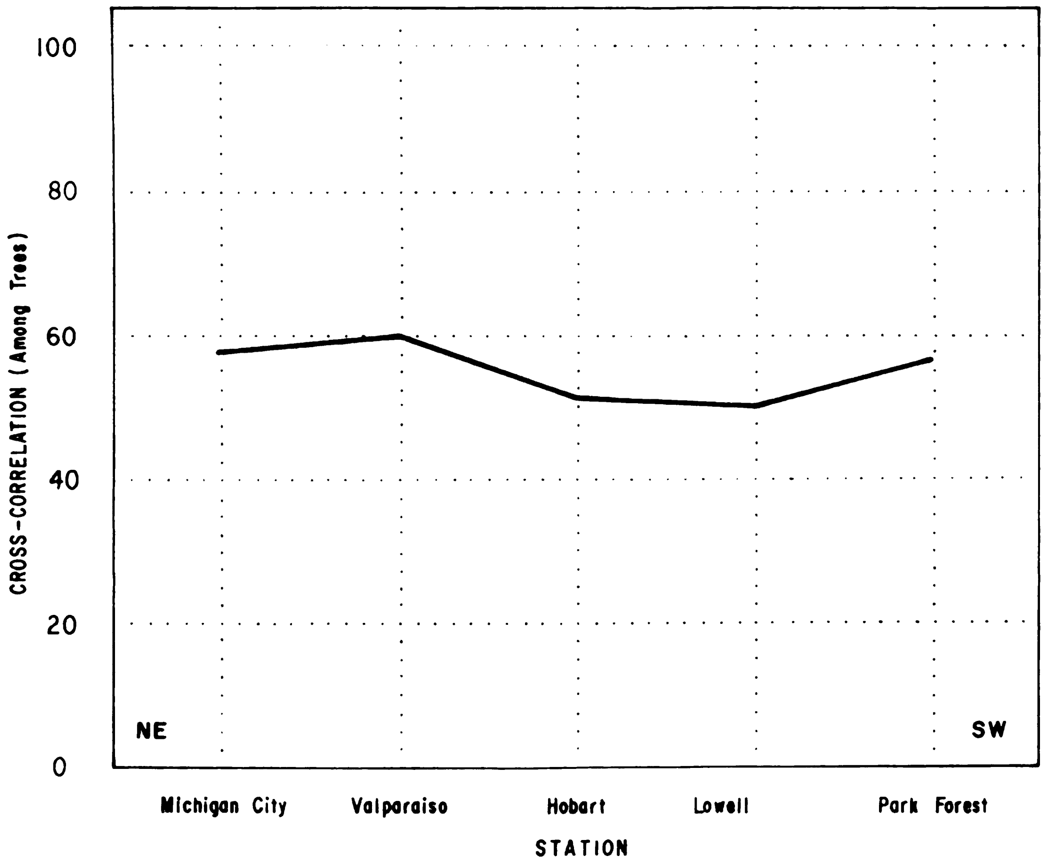
Average Percentage of Variance Retained by Groups of White Oak Trees on Coarse-Textured*Soils at Selected Stations



* MORE THAN 50% SAND AT DEPTH OF 50in.

FIGURE V-9

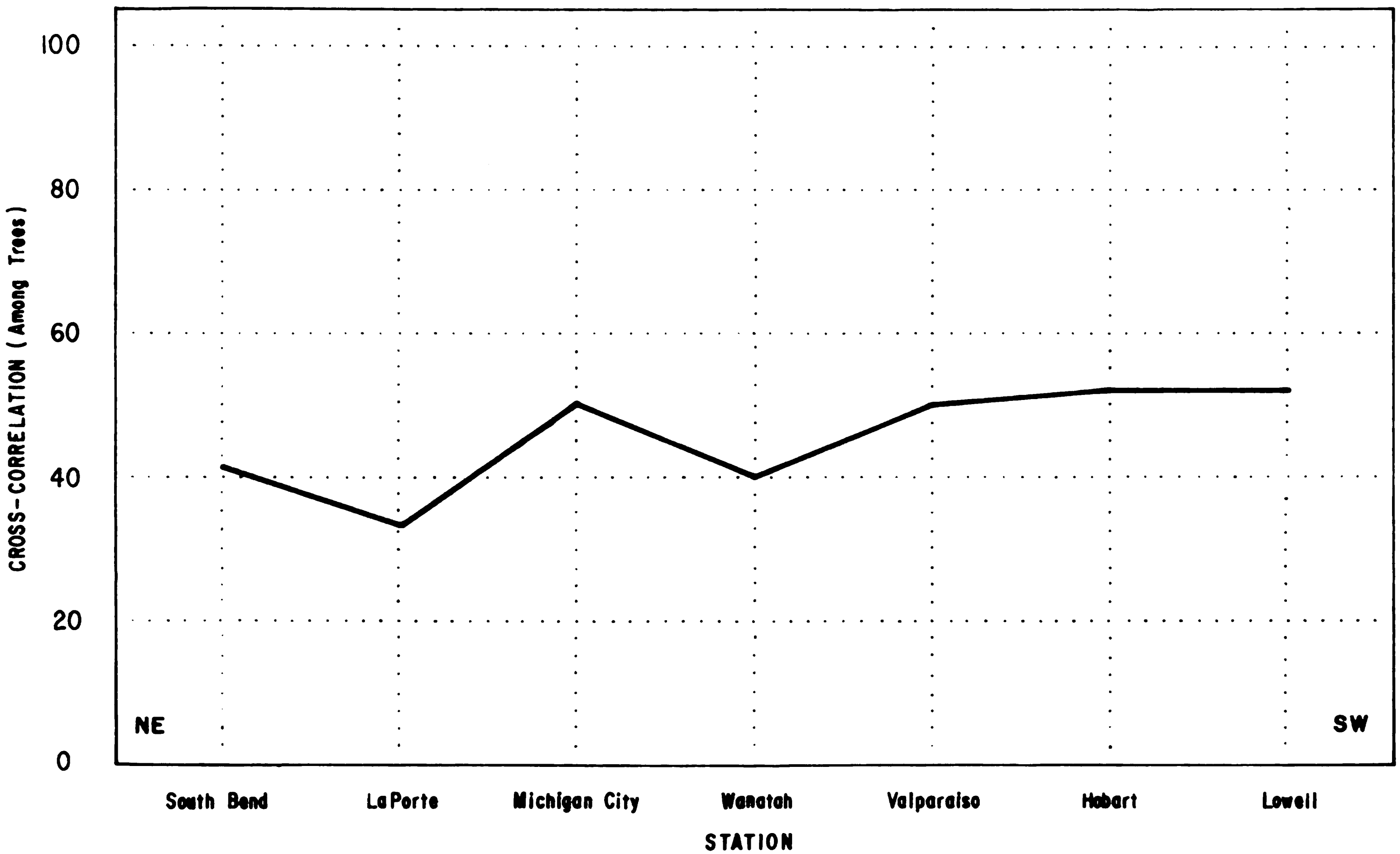
Average Cross-Correlation Among Groups of White Oak Trees on Fine-Textured* Soils at Selected Stations



* LESS THAN 50% SAND AT DEPTH OF 50 in.

FIGURE V-10

Average Cross-Correlation Among Groups of White Oak Trees on Coarse-Textured* Soils at Selected Stations



* MORE THAN 50% SAND AT DEPTH OF 50 in.

TABLE V-1. SIMPLE REGRESSIONS OF TREE-RING PARAMETERS AGAINST DISTANCE WESTWARD FROM THE INDIANA-OHIO STATE LINE

Parameter	Soil Texture	Correlation Coefficient
Mean ring-width	Coarse	-.29
Mean ring-width	Fine	-.73*
Mean sensitivity	Coarse	.29
Mean sensitivity	Fine	.47
Per cent variance-group	Coarse	.15
Per cent variance-group	Fine	-.16
Cross-correlation among trees	Coarse	.11
Cross-correlation among trees	Fine	-.29

*Value significant at .01 level.

(#26) shows similar mean ring-widths between stations, but percentages of variance (group) and cross-correlations among trees at Hobart range from about 3-8% higher than at the more easterly sites (Appendix III-A). On fine-textured soils, the percentage of variance (group) at Hobart (#27) is 19% higher than at Michigan City (#10); mean ring-widths are higher at Hobart. There are also differences in chronology parameters between Michigan City and a comparable site to the south. If only the most sensitive coarse-textured sites at Michigan City (#11) and Wanatah (#15) are compared, all chronology parameters (except mean ring-widths) are higher at Wanatah. Chronology parameters at Hobart (site #26) and Wheatfield are much alike.

Comparative Sensitivities of White and Black Oak

Appendix III-C represents the chronology parameters for white oak and black oak; each pair of samples was taken from the same forested stand. In most cases the percentage variance in groups and the cross-correlations among trees are from about 8-10% higher in black oak. The excessively well-drained site at Ogden Dunes (#25), where the percentage variances retained by the group were 41% and 30% for black and white oak, respectively, is illustrative.

Discussion

Climate and the Forest Ecotone

Considered collectively, the preceding results give little, if any, conclusive evidence for a pronounced climatic gradient across the region. Climatic gradients of a magnitude to cause an abrupt transition of major forest types probably would have left a noticeable impression in the tree-ring record. The variability of chronology parameters among sites and the inconsistency of trend lines suggests other factors are more limiting to plant response than climate. From the strong relationship between soil texture and tree response demonstrated in the previous chapter, the predominant control of the forest gradient in northwestern Indiana appears to be a function of soil texture.

However, the importance of soil texture does not mean that climate lacks phytogeographical significance in the region. A characteristic of phytogeographic tension zones is the importance of site characteristics to local plant distributions (Braun, 1960, p. 322). In the study area, the researcher observed that the beech-maple forest was restricted to coarser-textured soils, often imperfectly drained, where moisture stress is apparently moderated. On finer-textured soils sampled in this project within the mesophytic zone, beech and sugar maple were excluded from the forest canopy. Beech has been found to be sensitive to moisture stress (Spaulding, 1946); thus, the absence of beech and sugar maple on finer-textured sites suggests moisture stresses beyond the tolerances of the species. If climate were not marginal for survival of mesophytic species in the region, it seems likely that these species would occupy a greater variety of sites and soils. Beech and sugar maple usually achieve their best development on mesic sites of intermediate textures, but both species have shown a wide tolerance for many soil textures (Crankshaw, 1965).

The Lake Michigan Mesoscale Climatic Gradient

Leighly (1941), Visher (1944), Changnon (1968) and Harman (1970) have discussed a likely moderating influence of Lake Michigan at locations near the eastern and south-eastern shore of the lake (Figure I-1, p. 2), which could influence plant distributions. Suitable stands, particularly near the lake, were difficult to locate; many sites were either excessively well drained (dunes) or poorly drained. From the small number of sites available, only tentative suggestions are possible.

Higher sensitivities at the Hobart sites in relation to those at Michigan City may indicate slight climatic differences east-west between the two stations, although the difference in sensitivities on coarse-textured sites is less pronounced than on finer soils. In addition, forest composition may manifest subtle climatic changes. At Michigan City, the forest canopies on the two coarse-textured sites were mostly white oak with some black oak, over an understory of Cornus florida (flowering dogwood), Corylus americana (American hazelnut), and Hamamelis virginiana (witch hazel). Black oak with smaller numbers of white oak prevailed at Hobart, with an open understory composed mostly of grasses and some Vaccinium species. The fine-textured site at Michigan City contained white oak, red oak (Quercus rubra), and shagbark hickory (Carya ovata), whereas the site at Hobart was almost entirely white oak; Crataegus species dominated the understory at both fine-textured sites. Thus, tree-ring parameters and species composition seem to indicate that the Hobart sites are somewhat less mesic.

The evidence for a climatic gradient southward from Lake Michigan is unclear, particularly because of the varied responses at the three Wanatah sites. If the most sensitive site (#15) at Wanatah can be considered representative for the station, this higher sensitivity to the south would be anticipated if climatic conditions are moderated to the lee of Lake Michigan. Also, the negligible differences in sensitivity between Hobart and the most sensitive Wheatfield site would be expected if, as discussed above, climatic modification by the lake is less in Lake County than La Porte County. Again, the data are too few to be conclusive.

Black Oak and White Oak
In Future Research

In most cases, the parameter values for black oak are higher than for white oak. Black oak is noted for its ability to inhabit poorer, droughtier sites (Fowells, 1965, p. 559); this is dramatically evidenced by its greater responsiveness on the sand dunes near Lake Michigan, where growing conditions are stressful. In future tree-ring research, black oak, when available, may be a more useful species than white oak.

Summary

The investigation of tree-response and climatic patterns in northwestern Indiana consisted of three parts: cross-dating with negative mean sensitivity values, correlations of tree-ring indices and climatic data, and analyses of the Index Program results.

Plots of computer-derived negative mean sensitivity values indicated that valid cross-dating exists not only among well-drained sites at each station, but also among stations across the region. This fact suggests that forest stands across the region have displayed some similarity in their responses to common periods of climatic stress.

The correlation analyses raised the possibility of divergent climatic controls across the region, but the significance of this suggestion for plant distributions is unclear. An analysis of tree-ring parameters from the Index Program provided no apparent evidence of more stressful climatic conditions in the western part of the study area. Yet, the restriction of certain mesophytic species, notably

American beech (Fagus grandifolia), to favored sites where moisture stress is probably reduced, suggests that climate may be marginal for less drought-tolerant species across much of northwestern Indiana. A tentative conclusion was that the immediate control of the forest transition from mesophytic to more xerophytic species in the study area is predominantly a function of soil texture.

Based upon limited data, there is some evidence that tree-ring sensitivities are lower near the southeastern shore of Lake Michigan than at more westerly or southerly locations. These lower sensitivities may reflect a leeward mesoscale climatic modification by Lake Michigan.

Black oak appears to be a more sensitive indicator of climatic variation than white oak. In future tree-ring studies, when available, black oak may be preferable to white oak.

CHAPTER VI

THE LA PORTE PRECIPITATION ANOMALY

Review of the Literature

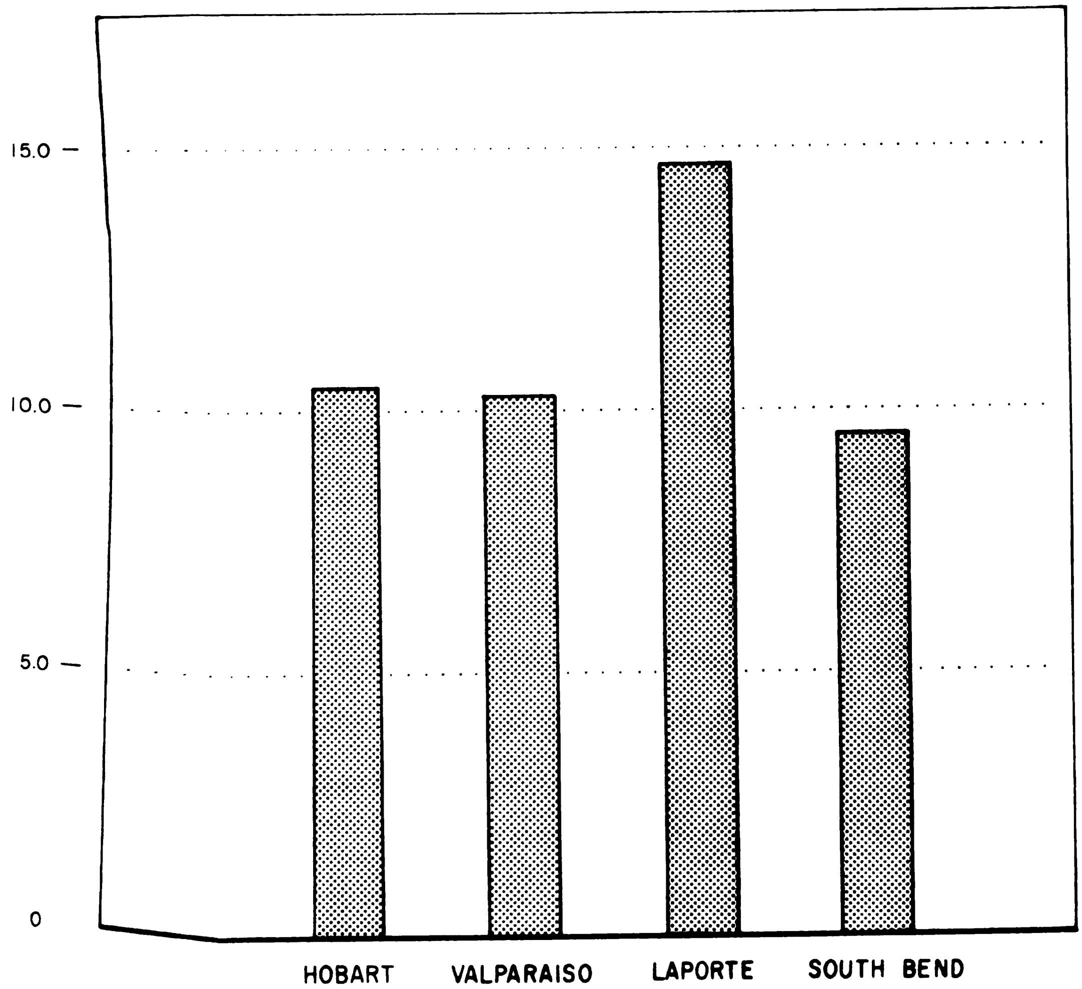
One objective of this project was to search for tree-ring evidence of an anomalous climatic pattern in the vicinity of La Porte, Indiana, described by Stout (1962) and Changnon (1968b, 1970). The published climatic record at La Porte, which stands in contrast to records at other stations in northwestern Indiana, has been intensely analyzed; yet, interested scholars still do not agree upon the validity, causes, or extent of the so-called "La Porte precipitation anomaly." Part of the current research was designed to gather data which might clarify some of the uncertainty surrounding the problem.

Indications of the anomaly appeared in several earlier studies (Visher, 1935, 1944); and an article by Stout (1962) proposed that temporal changes in the precipitation and cloud cover record at La Porte agreed with temporal changes in iron and steel production from the Chicago-Gary industrial complex. The agreement between industrial production and climatic change, and the location of La Porte approximately thirty miles downwind from the iron and steel production center, suggested a relationship between the two phenomena.

Changnon(1968b), based upon a limited number of observation stations, mapped a northeast-southwest trending, elliptical "island" of abnormally high rainfall centered on La Porte. Weather records from 1898-1968 showed that annual warm season precipitation between 1929 and 1963 at La Porte were 30-40% higher than at surrounding stations in northern Indiana; but prior to and following the period no consistent differences were recorded. For example, the average annual precipitation at La Porte from 1929-63 was over 11 inches higher than the 1964-68 years; furthermore while La Porte was experiencing apparent increases in yearly values from 1930-39, Valparaiso (20 miles upwind of La Porte) and South Bend (24 miles downwind) were showing general decreases. From 1930-39, La Porte averaged 46.3 inches per annum, whereas 38.4 inches were recorded at Valparaiso and South Bend respectively; from 1940-49, La Porte averated 55.8 inches per annum, 43% larger than Valpariso and 61% larger than South Bend (Figure VI-1). The next ten-year period produced a substantial decline in La Porte yearly precipitation totals; warm season precipitation, annual number of thunderstorm days, and annual number of hail days exhibited similar temporal distributions.

After considerable effort toward the correlation of year-to-year weather variations with the temporal distributions of steel production in the Chicago area, Changnon

FIGURE VI-1
Mean June-August Precipitation Totals
1940-1949



SOURCE: CLIMATOLOGICAL DATA

(1968b) concluded that additions of condensation and freezing nuclei, water vapor, and heat to the atmosphere were the primary causes of the La Porte rainfall anomaly. Holzman and Thom (1970), however, challenged the reality of the anomaly; subjecting the La Porte weather record to statistical analysis, they concluded that changes in observers and recording procedures produced inaccuracies in the weather data. Ogden (1969), from rainfall studies near an Australian steelworks, expressed doubt that the unusual La Porte weather record could have resulted from industrial causes. And, Elton (1970a) suggested that other factors, including synoptic conditions and lake breeze convergence, also may have been causally related to the La Porte anomaly.

After an examination of stream-flow data for the upper Kankakee River watershed, Hidore (1971) found that the flows of these streams increased substantially, especially during the warm season, and the timing of the runoff increase coincided with the proposed La Porte anomaly. Thus, Hidore's results supported the validity of the precipitation record at La Porte. But the conclusions of another hydrologic study conducted by Holzman (1971) disagreed with those of Hidore (1970).

Harman and Elton (1971) found that tree-ring variation in a stand of red oak trees near La Porte revealed patterns of cross-dating and climatic correlation which might be expected if the precipitation anomaly were a reality.

Lindsey (1969, p. 511) in support of the anomaly, reported denser shrub-layer tree reproduction in the mesic forests around La Porte than in other forests in northwestern Indiana. But Ashby and Fritts (1972) could find no evidence in white oak tree-ring records to support or refute the existence of the anomaly. However, they did suggest that some factor in the La Porte area became increasingly more limiting to tree growth than climate during the 1940-50 period, and caused a gradual reduction of growth. Toxic effects from severe air pollution correlated with high levels of smoke-haze in Chicago during the decade of the 1940's was suggested as the cause of growth reduction.

The La Porte rainfall anomaly is not only an interesting problem, but it is an important problem, for if the anomaly is real, it represents an interaction between two major problem areas of meteorology: weather modification and atmospheric pollution. And if the anomaly is fictional, serious questions about the validity and usefulness of long-term climatological records may be in order (Changnon, 1968b).

Results

Correlation of Climatic Data and Tree-Ring Indices

The stepwise multiple regression analysis procedure (STEPR) described in previous chapters was applied to climatic data and tree-ring indices for four forest stands at La Porte and one control stand at South Bend for the period 1910-69. For each stand, the climatic and tree-ring record was divided into three 20-year intervals, the purpose being to determine whether patterns of change in the statistically significant weather variables were present which might indicate temporal climatic changes.

The statistically significant variables entered into the regression equations by STEPR are presented in Appendix IV-C. At each La Porte stand, no variable was statistically significant for all three intervals at any one woodlot. At site #6, the most sensitive site at La Porte, mean maximum June temperature did appear in the first and third intervals, but other variables were entered in the second interval. Interestingly, at site #6 during the second interval (which coincides with the height of the proposed anomaly) multiple correlation coefficients and the amount of explained variability (cumulative sum of squares reduced by significant variables) are much higher than in the other two intervals. In each of the other stands at La Porte, except #8, statistical patterns are similar, although less pronounced, to those of site #6.

At site #7 different significant variables were entered in each of the first two intervals, but none were entered for the third interval. As at site #6, mean maximum June temperature of the current season appears in the first and third intervals, but not in the second; mean maximum April-May temperature of the current season was entered in the second and third intervals.

Correlations for the South Bend site indicated some changes in important variables through time, but temperature-related variables generally prevailed throughout the analysis period. An exception was current season April-May precipitation which was prominent in the second and third intervals. The explained variability and the multiple regression coefficients were in most cases higher in the second and third intervals at South Bend than in the La Porte stands. The 1930-49 interval at South Bend produced the largest number of significant variables (5), the highest explained variability (80%), and the highest correlation coefficient (87%) of the three intervals.

Analyses of Tree-Ring Chronologies

Statistical parameters for the tree-ring chronologies of the four La Porte stands are given in Appendix III-D. Each of the sites has been divided into four 20-year intervals from 1890-1969, as have control stands at South Bend, Michigan City, Wanatah, Valparaiso, and Park Forest.

Three of the La Porte sites (#5, #6, and #8) display mean ring-width characteristics which are typical of disturbed woodlots: sites #5 and #6 show persistent increases in mean ring-widths, and site #8 changes relatively little through the four intervals. Site #7 is more typical in that ring-widths decline with increasing age. Most of the control sites from other stations show generally declining mean ring-widths as the trees grow older. A notable feature of all sites across the study area (except at sites #5, #6, and #18) is the smaller mean ring-width value in the 1930-49 interval when compared to mean ring-widths in adjacent intervals.

A consideration of control site data in most instances reveals a steady decline of the group variances, percentages of variance retained by groups, cross-correlation coefficients among trees, and mean sensitivities as stand age increases, with the largest decline in parameter values usually occurring in the 1950-69 interval. The four La Porte sites follow comparable temporal chronology changes, with no consistent aberrations appearing at all four sites.

Discussion

In the current discussion it is pertinent to note that chronology parameters do not appear to remain constant through time. Lodewick (1930) and Senter (1938) reported decreasing intercorrelation as stands of southern pines became older, and Harman and Elton (1971), observing decreased intercorrelation in a stand of red oak near La Porte, have provided several possible explanations for decreasing shared sensitivity among trees. First, physiological changes within trees of increasing age may produce varying sensitivity to external environmental variation. Went (1942), and Gunckel et al. (1949), and Robbins (1957) have documented the slowing-down of life processes in aging trees. Second, maturation of the forest stand and accompanying canopy closure may have increasingly moderated the subcanopy environment, buffering the trees from macroenvironmental stresses. Estes (1970) reported decreased sensitivity in stands of pine following canopy closure. Third, early disturbances to the woodlot (grazing or frequent fires) may have brought stresses to the young stand. And, finally, the general environment may have ameliorated recently, resulting in increased independent variation among trees.

In the present project, the regular decline of chronology parameters over the past eighty-one years from widely separated sites suggests that the most probable causes are aging processes and in some cases perhaps canopy closure. Widespread climatic change across the region of a magnitude capable of substantially reducing tree sensitivities is not considered likely; and early disturbances to the woodlots under analysis is not indicated (with one possible exception to be described presently). The full significance of declining responsiveness of trees in dendrochronological research is difficult to assess. But in future studies where parameters from different forest stands are to be compared, as in studying climatic or edaphic gradients, comparable stand ages would seem to be desirable. For example, all things being equal, sensitivities in an older forest stand probably would be lower than in a younger stand. If age differences were ignored, one might erroneously conclude that environmental conditions between the two stands had been dissimilar. In the present study, the oldest stand (La Porte #5) was also the least sensitive.

The tendency for declining sensitivities with time makes interpretation of the current results difficult. Multiple correlations between tree-ring indices and climatic data at La Porte do not reveal a decline during the 1930-49 period which would be anticipated if substantial precipitation increases had occurred during that period. In fact, both multiple correlation coefficients and variability explained by statistically significant variables become larger in the 1930-49 interval at sites #5, #6, and #7, similar to responses at the South Bend site; only at site #4 is there a decrease in the second interval. And further, even though in numerous instances the significant variables change from one interval to the next, no particular pattern of change is evident. However, correlation coefficients were generally higher at the South Bend site, which could be a reflection of more stressful growing conditions, especially in the 1930-49 interval.

Chronology parameters for sites across northwestern Indiana reveal no patterns which might suggest higher rainfall at La Porte. In the La Porte chronologies, values generally decrease after 1930, but the declines are similar to those occurring in control groups away from the La Porte area. If anomalous precipitation conditions are contained in the chronology parameters, they are obscured by general decreases in sensitivity which accompany aging of stands. These results do not necessarily exclude the possibility of an anomalous rainfall record at La Porte. It should be recalled that earlier findings in this project have indicated that moisture stress is usually lower on coarser-textured soils, like those at the La Porte sites. On these coarser soils, moisture is probably sufficient for tree growth most of the time, such that shared response among trees to climate is rather low, and individual tree response to environmental factors is relatively high. Thus, the addition of more moisture at these rather insensitive sites probably would alter the chronology parameters only slightly.

The addition of more moisture might, however, promote larger growth-rings in trees. A comparison of mean ring-widths before and after 1930 for the La Porte sites and the control groups is presented in Table VI-1. As with other analyses of tree response, the results are not well-defined. The South Bend and Wanatah stands decrease noticeably after 1930 as would be expected, but the La Porte values are mixed: stands #5 and #6 increased, #7 decreased greatly, and #8 decreased slightly. The reasons for the mixed response at La Porte are not entirely clear. The owner of site #7

TABLE VI-1. CHANGES IN MEAN RING-WIDTH AFTER 1930 AT SELECTED STATIONS AND SITES IN NORTHWESTERN INDIANA

Station	Site	Soil Texture	Mean Ring-Width 1890-1929	Mean Ring-Width 1930-1969	Net Change
South Bend	2	Coarse	1.77	1.55	-.22*
La Porte	5	Coarse	1.24	1.42	+.18*
	6	Coarse	1.62	1.81	+.19*
	7	Coarse	2.67	1.64	-1.03*
	8	Coarse	2.23	2.08	-.15
Michigan City	10	Fine	1.98	1.62	-.36*
Wanatah	15	Coarse	1.70	1.44	-.26*
Valparaiso	18	Fine	2.33	1.58	-.75*

*Value significant at .01 level.

recalled that the stand had been grazed in the 1930's, the period of greatest ring-width decline. The possibility exists that water permeability and infiltration capacity of the surface soil were decreased by compaction resulting in greater runoff and moisture stress (Steinbrenner, 1951; Wilde, 1958, p. 187), and ultimately smaller ring-widths. If this stand is not representative of growth at La Porte and is omitted, then significant differences in growth patterns between La Porte and the control sites occurred. In stands #5 and #6 at La Porte the increased ring-widths for the 1930-69 period as opposed to the 1890-1929 period were statistically significant, and the slight decrease in stand #8 was not statistically significant. During the same time series, statistically significant growth decreases occurred in the 1930-69 interval at the two control sites. General canopy releases by cutting or other disturbance conceivably could have occurred in the 1930's which might have resulted in increased ring-widths at sites #5, #6, and #8, but such events were not apparent in the field or in the statistical data. Thus, the changes in mean ring-widths after 1930 at the La Porte sites (excluding #7) in comparison to control groups could be the result of higher moisture input at La Porte than at surrounding stations. Yet, even with this suggestive mean ring-width evidence, the lack of other supporting statistical data, and the uncertainty of the validity of mean ring-width values at site #7, all restrain conclusive statements concerning the reality of the La Porte precipitation anomaly.

Decreased mean ring-widths in La Porte trees during the 1940 decade were cited by Ashby and Fritts (1972) as possible evidence of the inhibiting influences of widespread air pollution downwind of the Chicago-Gary industrial complex. Their suggestion assumed that severe air pollution in the La Porte vicinity was highly correlated with high-levels of smoke-haze in Chicago during the 1940's. As a preliminary check on this assumption, hourly recordings of smoke-haze and wind data for June, July, and August of 1962 from Local Climatological Data (Supplement) (1962) at Chicago were examined.

In this examination, to qualify as a "smoke-haze day," smoke, haze, or smoke-haze must have been recorded in at least three observations during a 24-hour period; days with recorded visibility of three miles or less at some time during the day were arbitrarily considered to be severe smoke-haze days. Dominant wind directions during smoke-haze occurrences were extracted from the hourly observation records. Of 64 recorded smoke-haze days for the three month period, 47 (73%) were accompanied by surface winds with north, northeast, east, southeast, or southerly points of origin and of 30 severe smoke-haze days, 25 (83%) came with these same wind directions. Prevailing winds at Chicago for June, July, and August are listed in Climatological Data (1962) as northeast,

east, and south-southwest respectively. Thus, whether hourly observations or monthly averages are considered, days of high smoke-haze values at Chicago normally occur with surface windflow patterns which would be unlikely to advect such contaminants toward the direction of La Porte. Although the findings here are based upon only one of the latter years of the proposed precipitation anomaly, they strongly suggest that the presumed relationship between smoke-haze in Chicago and severe air pollution at La Porte may not exist. In addition, the general decrease of ring-widths in the 1930-49 period at sites other than La Porte indicates the presence of an undetermined regional influence, rather than a localized one as proposed by Ashby and Fritts (1972). This regional influence may have been the warmer, relatively dry years of the 1930's and 40's described by Wahl (1968), Wahl and Lawson (1970), and Eichenlaub (1971).

Summary

The anomalous precipitation record at La Porte, Indiana, described by Stout (1962) and Changnon (1968b, 1970) was subjected to analysis through dendrochronological techniques. Tree-ring indices from La Porte and South Bend from 1910 through 1969 were divided into three equal intervals and correlated with climatic data. Stand chronologies for four La Porte sites and five control sites were divided into four 20-year periods for analysis in the Index Computer Program.

Results of the correlation procedure revealed no decrease in correlation coefficients or explained variability at La Porte as would be expected had precipitation increased substantially during the study period. Statistical values were generally somewhat higher at the South Bend site, which may be an indication of less stressful growing conditions at La Porte.

An analysis of chronology parameters for sites across northwestern Indiana gave no indication of climatic changes or unusually high precipitation at La Porte. However, these results were not construed as a rejection of the anomaly; rather, it was suggested that the tendency for decreasing tree sensitivity with age and the ameliorating influence of the coarse-textured soils in the La Porte area probably would have obscured any changes in chronology parameters resulting from increased precipitation. An exception, however, may have been mean ring-widths. Mean ring-widths were found to have increased significantly at several La Porte sites after 1930, while decreasing significantly at control sites. Ring-width differences between the La Porte and control stands could have resulted from higher moisture inputs at La Porte. However, the inconclusiveness of much of the other statistical data did not warrant conclusive statements concerning the validity of the La Porte precipitation anomaly.

An analysis of smoke-haze data for the summer months of 1962 at Chicago indicated that a large majority of the smoke-haze observations were accompanied by winds with trajectories not conducive to severe air pollution at downwind sites, such as La Porte. It was tentatively concluded that the assumption of a close relationship between smoke-haze in Chicago and air pollution at La Porte may not be valid.

CHAPTER VII

SUMMARY AND CONCLUSIONS

I

The present study was undertaken to evaluate the general hypotheses that (1), patterns of tree-ring variation in northwestern Indiana would indicate a general westward gradient of increasing moisture stress, and (2), that local departures from the regional tree-ring chronology were present in wood samples taken from the vicinity of La Porte, Indiana. From thirty-four white oak stands and six black oak stands, tree cores were extracted and analyzed by established dendrochronological techniques.

II

A climatic gradient sufficient to control distributions of major forest types was expected to be manifested in the regional tree-ring record through steadily increasing tree-sensitivities westward across the study area. Although slight differences in types of dominant climatic variables across the study area may exist, no evidence for a climatic control of the ecotone was found. To illustrate, precipitation variables of the spring and early summer seemed to predominate in the west as opposed to temperature variables of the spring and early summer in the east, but trend lines representing tree sensitivities across the study area on similarly textured soils did not display the consistent westward decreases which would indicate increasing climatic stress. And regression analyses designed to detect a climatic gradient displayed generally insignificant relationships between tree-ring parameters and relative western position of individual sites. Yet, the restriction of drought-sensitive species such as beech (Fagus grandifolia) to favored sites where moisture stress is apparently moderated indicates that climate may be marginal to the survival of mesic species across much of northwestern Indiana. It was suggested that the immediate control of the forest ecotone is a function of soil texture, but the delimitation of potential western climatic limits for the beech-maple forest was not possible from the current data. Dendrochronological analyses of tree response in northwestern Indiana appear to support the first hypothesis, that is, that the tree-ring record indicates increasing westward moisture stress. However, this increase of moisture stress probably results more from a transition to finer-textured soils than from greater climatic stress.

III

Tree-ring indices from four La Porte stands and one South Bend site were divided into four 20-year intervals (1890-1970) and quantitatively appraised for chronology deviations which might reflect unusually large moisture inputs after 1930 (the La Porte "anomaly"). The results were mixed. The South Bend stand showed the expected regular decreases in mean ring-width accompanying aging; however, two La Porte sites exhibited statistically significant ring-width increases after 1930, and a third stand displayed no significant change. A fourth La Porte site known to have been grazed in the 1930's displayed significant ring-width decreases.

On the other hand, the decline of chronology parameters such as percentage variance (group) and cross-correlation among trees was no more than could be attributed to maturation of forest stands. Further, stepwise multiple regression analyses of selected climatic variables and tree-ring indices from 1910-69 did not reveal an anticipated decline in correlation coefficients during the 1930-49 interval (the height of the proposed anomaly). These mixed results were not considered to be a denial or a confirmation of the anomalous precipitation record at La Porte. Rather, it was suggested that possible aberrations in the tree-ring record probably would have been obscured by increasing stand age and by low sensitivity to climatic change on the coarse-textured soils around La Porte.

A preliminary examination of visibility and windflow records for June, July, and August of 1962 at Chicago indicated that days of severe smoke-haze pollution generally occur with surface windflow conditions which would be unlikely to advect such pollutants in the direction of La Porte. These findings strongly suggest that a supposed relationship between the frequency of smoke-haze conditions in Chicago and severe air pollution at La Porte may not exist.

IV

An additional research goal was to seek tree-ring evidence of any other locally important climatic patterns. Of particular interest was the suspected mesoscale climatic influences of Lake Michigan upon forests near the south-eastern shore of the lake. Tree response and general forest composition at sites near Michigan City were compared with sites further west (Hobart) and south (Wanatah). On both coarse- and fine-textured sites growing conditions appeared to be less stressful at Michigan City, which may indicate moderation of climate by Lake Michigan. Only tentative suggestions could be made, however, because of limited data.

V

One specific research aim was to assess the role of soils in producing growth stresses in plants, as evidenced by tree-ring analysis. Simple regressions of tree-ring parameters against the percentage of fine-material (silt, clay, very fine clay) in the subsoil produced highly significant correlations which suggest augmented moisture stress on finer-textured soils. In every case, percentages of variance (group) and cross-correlations among trees around individual weather stations were generally 15-20% higher on finer-textured soils than on coarser soils. Additional computer analyses revealed a positive relationship between the percentage of very fine clay in the subsoil and tree response.

Thus, the distribution of major forest types in northwestern Indiana is probably highly dependent upon soil textural variation. The westward transition from the mesophytic beech (Fagus grandifolia)--sugar maple (Acer saccharum) forest to the more xerophytic oak (Quercus spp.)--hickory (Carya spp.) forest near Valparaiso seems to coincide with a transition from coarser- to finer-textured soils. Even within the mesophytic forest, beech and sugar maple were generally excluded from sites composed of finer-textured soils.

VI

Although the findings which resulted from this project suggest that data coverage was adequate for most analyses, the prerequisites for site selection severely limited potential data sources. These constraints were necessary to permit the assumption of uniform climate for sites at each weather station; yet, it was evident that supplementary sample sites would have been helpful.

Future studies might embody the following adjustments:

(1) More emphasis should be given to locating fine-textured soils east of Valparaiso and coarse-textured soils westward. This undoubtedly would require the relaxing of distance-to-station requirements for sample sites.

(2) Additional soil samples and tree-cores west of the current study area would provide more information regarding the suspected regional climatic gradient and its influence upon tree response.

(3) Tree cores from stands of black oak around the southeastern and southern shore of Lake Michigan would furnish more conclusive evidence concerning possible mesoscale climatic influences from the lake.

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APPENDICES

APPENDIX I

FIELD INFORMATION

APPENDIX I-A. LOCATIONS OF SAMPLED FOREST STANDS

Station	Site No.	County	Congressional Land Description	Road
South Bend	1	St. Joseph	T38N, R2E	S side U.S. 20 at So. Bend Bypass
	2	St. Joseph	T38N, R2E	E side Portage Hwy. N of Brick Rd.
	3	St. Joseph	T38N, R2E	W side Portage Hwy. N of Brick Rd.
	4	St. Joseph	T38N, R2E	S side Brick Rd. E of Portage Hwy.
La Porte	5	La Porte	T36N, R3W	E side 400W S of 150N
	6	La Porte	T36N, R3W	N side State Hwy. 2 at 100S
	7	La Porte	T36N, R3W	NE Corner U.S. Hwy. 39 at McClung Rd.
	8	La Porte	T36N, R3W	S side Waverly Rd. in Soldiers Park
Michigan City	9	Porter	T37N, R5W	S side U.S. 20 at 1200W
	10	La Porte	T37N, R4W	S side 500N E of 900W
	11	La Porte	T38N, R4W	N side U.S. 20 W of St. John Rd.
	12	Porter	T37N, R5W	N side 1675N W of C & O tracks
Wanatah	13	La Porte	T34N, R4W	N side U.S. 30 E of 1200W
	14	Porter	T34N, R5W	E side 450E at N.Y.C. tracks
	15	La Porte	T34N, R4W	N side U.S. 30 W of 1100W
	16	Porter	T34N, R5W	N side 150S W of 675E
Valparaiso	17	Porter	T36N, R6W	W side Meridian Rd. N of 600N
	18	Porter	T36N, R6W	S side 700N in St. Lawrence Camp
	19	Porter	T36N, R6W	E side Meridian Rd. .3 mile N of 700N
	20	Porter	T35N, R6W	E side State Hwy. 49 .2 mile N of 450N
Wheatfield	21	Jasper	T32N, R5W	E side 100W 1.2 miles N of 1500N
	22	Jasper	T32N, R5W	W side State Hwy. 49, .2 mile N of 1600N
	23	Jasper	T32N, R6W	N side 1450N .4 mile W of 200W

Ogden Dunes	24	Porter	T37N, R7W	N side U.S. 12 W of Hillcrest
	25	Porter	T37N, R7W	W side Diana N of Indian Cp.
Hobart	26	Lake	T36N, R8W	W side Liverpool .6 mile N of E35th
	27	Lake	T36N, R7W	SW corner U.S. 6 at N. Lake
Lowell	28	Lake	T34N, R9W	Calumet at 145th - .6 mile E
	29	Lake	T34N, R9W	N side 135th W of White Oak
	30	Lake	T34N, R9W	N side 135th E of Calumet
Park Forest (Ill.)	31	Will	T34N, R13E	W side Western .3 mile S of Monee
	32	Cook	T34N, R13E	N side Sauk Rd. .5 mile E of Western
	33	Will	T34N, R13E	W side Western .4 mile S of Monee
	34	Cook	T34N, R13E	S side 26th 1.7 miles E of Western

APPENDIX I-B

FIELD DATA RECORDING FORM

Woodlot No.:_____ Location: R_____; County_______________
Twp_____;
Sec_____. Date_______________

Distance to nearest weather station_______________

Site description: Mapping Unit_______________
Parent material_______________
Topography_______________
Aspect_______________
Dominant canopy species_______________
Dominant shrub(s)_______________
Uniformly stratified stand (presence of sapling layer etc.)?_______________
Evidence of fire?_______________

Tree Record: Basal area_______________
Est. height of Canopy_________

Tree no.	1	2	3	4	5	6	7	8	9	10	11
Core											
DBH											

Soil Record:

Soil ID	Horizon	Depth	Texture	Structure T G	Reaction	Tree	Remarks

Perceptible changes in lithology?_______________

Remarks:

APPENDIX I-C

PROMINENT PLANT SPECIES OBSERVED IN SAMPLED FOREST STANDS

Trees

1. *Acer rubrum*
2. *Acer saccharum*
3. *Carya ovata*
4. *Fraxinus americana*
5. *Quercus alba*
6. *Quercus rubra*
7. *Quercus macrocarpa*
8. *Quercus velutina*

Shrubs

1. *Ceanothus ovatus*
2. *Cercis canadensis*
3. *Cornus florida*
4. *Cornus racemosa*
5. *Corylus americana*
6. *Corylus cornuta*
7. *Crataegus* spp.
8. *Hamamelis virginiana*
9. *Lonicera dioica*
10. *Prunus virginiana*
11. *Ribes* spp.
12. *Rhus copallina*
13. *Rubus* spp.
14. *Vaccinium* spp.
15. *Viburnum acerifolium*
16. *Zenobia pulverulenta*

APPENDIX I-D

SUMMARY RECORDS OF SAMPLED FOREST STANDS

Site No.	Species Sampled*	Stand Age (years)	Basal Area (Ft.^{2})	Mean DBH of Sampled Trees (inches)	Estimated Canopy Height (feet)	Evidence of Fire**	Dominant Canopy Species in Order of Occurrence***	Dominant Shrub Species***
1	WO	130	140	20.3	70	No	5,6,3	5,10
2	WO	130	110	17.3	55	No	5,8	7,10
3	WO	125	120	18.2	55	No	5,8	7,8
4	WO	130	100	18.8	60	Yes	8,5	3,8
5	WO	180	110	24.0	65	No	6,5	4,11
6	WO	120	130	19.6	60	No	5,4,2	6,7
7	WO	130	110	19.1	50	No	5,8,1	7,10
8	WO	120	110	23.2	50	No	6,5	7,10,15
9	WO	115	110	18.3	60	No	5,8,1	3,6,8
10	WO	110	110	19.1	60	No	6,5,3	7
11	WO	120	120	18.5	55	Yes	5	8,14
12	WO	95	130	16.1	55	Yes	8,5,1	4,8,14

13	WO	120	120	20.3	50	No	8,6,5	8,10
14	WO	115	100	17.8	60	Yes	8,5	3,4,9,10
	BO	115	100	18.2	60			
15	WO	120	110	19.9	65	No	8,5	4,7
16	WO	105	100	17.5	55	No	8,5	3,7,10
	BO	105	100	20.9	55			
17	WO	105	110	16.9	50	No	5,6	3,8,14
18	WO	160	100	17.9	50	No	5,6,3	4,7,10
19	WO	115	110	14.1	55	No	8,5	2,3,7,8,14
	BO	115	110	14.8	55			
20	WO	110	110	16.7	55	No	5,8	7,10
	BO	100	110	16.7	55	No		
21	WO	95	100	17.6	50	No	8,5	13,14
22	WO	105	100	19.9	40	Yes	8,5,7	13,14
23	WO	100	110	17.1	55	No	5,8	7,14
24	WO	105	100	12.0	35	Yes	8,5	1,12,14
25	WO	95	90	13.5	45	Yes	8,5	2,8,12,14
	BO	90	90	14.6	45	Yes		
26	WO	100	100	16.9	55	Yes	5,8	12,13,16
27	WO	120	110	17.4	60	No	5,6	7,12
28	WO	110	110	17.7	60	NO	5,8,3	7,13
29	WO	115	110	17.9	50	No	5,8	4,7,11
30	WO	120	100	18.1	50	No	5,3,8	4,7,11
	BO	110	100	17.8	50			
31	WO	115	110	18.6	65	No	5,7,3,8	2,5,7
32	WO	115	110	18.5	55	No	5,8,3,7	2,7
33	WO	105	120	19.4	55	No	5,7,3	2,5,7
34	WO	120	100	18.5	50	No	5,8,7	4,7

*WO = white oak; BO = black oak; **From charred remains, damaged boles, and/or fire-scarred tree cores; ***See Appendix I-C.

APPENDIX II

SOILS INVESTIGATIONS

APPENDIX II-A. COMPARATIVE PERCENTAGES OF SAND, SILT, CLAY, AND VERY FINE CLAY IN PAIRS OF SOIL SAMPLES FROM SELECTED SITES IN NORTHWESTERN INDIANA

Site No.	A Horizon				B Horizon				Fifty-Inch Depth			
	Sand	Silt	Clay	Very Fine Clay	Sand	Silt	Clay	Very Fine Clay	Sand	Silt	Clay	Very Fine Clay
1	64.2	26.4	4.8	4.6	72.2	13.3	4.8	9.6	81.2	10.4	1.8	6.6
	62.2	24.4	6.6	6.2	66.4	12.2	4.8	16.6	79.2	9.8	3.4	7.6
2	75.4	16.0	4.0	4.6	81.2	11.2	2.6	5.0	86.2	7.2	3.0	3.6
	78.8	15.6	3.0	2.6	82.2	12.2	3.0	2.6	89.4	4.0	2.0	4.6
5	68.4	25.0	2.0	4.6	69.4	29.0	1.0	0.6	87.4	7.0	0.0	5.6
	75.4	18.0	2.0	3.6	71.4	15.0	2.0	11.6	84.4	7.0	1.0	7.6
6	49.4	37.0	5.0	8.6	41.4	40.0	5.0	13.6	69.4	24.0	3.0	3.6
	46.4	39.0	5.0	9.6	41.4	43.0	6.0	9.6	75.4	14.0	2.0	7.6
9	90.4	6.0	1.0	2.6	94.4	2.0	1.0	2.6	85.2	8.2	2.0	4.6
	89.2	6.6	2.0	2.6	90.1	4.3	1.0	4.6	96.1	0.3	1.0	2.6
10	32.4	49.0	8.1	12.3	20.8	28.0	13.1	38.2	18.8	43.0	11.1	27.1
	28.3	45.0	9.8	16.1	16.0	35.1	6.9	42.1	16.0	49.1	6.0	28.9

APPENDIX II-B. AVERAGE PERCENTAGES OF SAND, SILT, CLAY, AND VERY FINE CLAY IN SOIL SAMPLES FROM SURVEYED FOREST STANDS

Site No.	A Horizon Sand	A Horizon Silt	A Horizon Clay	A Horizon Very Fine Clay	B Horizon Sand	B Horizon Silt	B Horizon Clay	B Horizon Very Fine Clay	Fifty-Inch Depth Sand	Fifty-Inch Depth Silt	Fifty-Inch Depth Clay	Fifty-Inch Depth Very Fine Clay
1	63.2	25.9	5.7	5.7	68.5	12.3	4.8	13.1	80.2	10.1	2.6	7.1
2	76.9	15.8	3.5	3.6	81.6	11.7	2.5	3.8	87.8	5.6	2.6	4.1
3	83.7	12.2	1.2	3.5	83.4	9.5	2.4	4.7	92.4	5.7	2.0	3.6
4	71.6	22.5	2.5	3.1	68.4	25.5	6.0	7.8	87.9	7.0	1.5	3.6
5	71.9	22.5	2.0	4.1	70.4	22.0	1.5	6.0	85.9	7.0	0.5	6.6
6	47.6	38.0	5.0	9.1	41.4	41.5	5.5	11.6	72.4	19.0	2.5	5.6
7	62.4	29.4	3.0	5.1	62.4	22.0	4.0	11.6	74.9	14.0	2.5	8.6
8	61.2	26.2	2.5	5.1	63.0	30.4	4.5	7.1	79.2	11.7	2.5	6.1
9	89.8	6.3	1.5	2.6	92.3	3.2	1.0	3.6	90.7	4.3	1.5	3.6
10	30.4	47.0	8.9	14.2	18.4	31.6	10.0	40.2	17.4	46.0	8.6	28.0
11	86.9	7.0	1.5	4.1	89.9	5.5	1.0	3.6	97.4	1.0	0.0	1.6
12	84.9	10.5	1.0	3.6	87.4	7.5	1.0	4.1	92.9	2.5	0.5	4.1
13	67.4	32.6	3.0	5.6	72.4	17.0	4.0	8.6	75.4	12.0	3.0	9.6
14	78.4	14.0	3.0	4.6	77.4	12.0	2.0	8.6	90.4	4.0	1.0	4.6
15	67.4	33.0	3.0	6.6	65.4	21.0	3.0	10.6	81.4	9.0	1.0	8.6
16	68.4	22.0	3.0	6.6	77.4	13.0	2.0	7.6	77.8	16.6	1.0	4.6
17	61.3	28.3	5.2	5.2	51.2	34.3	10.0	4.5	62.4	19.9	14.0	4.2
18	32.8	48.0	6.0	13.2	20.8	34.0	6.0	39.2	13.6	39.2	12.0	35.2
19	83.0	11.4	1.0	4.6	84.4	9.0	2.0	4.6	67.2	29.2	0.0	3.6
20	38.8	44.0	8.0	9.2	36.8	30.0	6.0	27.2	34.8	35.0	8.0	22.2

21	92.0	3.4	1.6	3.0	92.0	3.4	0.6	4.0	97.4	1.0	1.0	0.6
22	93.4	3.0	1.6	2.0	95.4	1.0	0.6	3.0	96.4	0.0	0.6	3.0
23	85.4	9.0	2.6	3.0	91.4	3.0	0.8	4.8	96.4	1.0	1.8	0.8
24	94.4	2.0	1.0	2.6	95.4	2.0	1.0	1.6	98.4	0.0	0.0	1.6
25	96.4	1.0	1.0	1.6	97.4	0.0	1.0	1.6	97.4	0.0	0.0	2.6
26	88.4	6.0	2.0	3.6	95.4	1.0	1.0	2.6	96.4	1.0	1.0	1.6
27	52.4	32.4	6.0	9.2	30.4	36.4	4.0	29.2	28.4	36.4	10.0	25.2
28	44.0	36.8	7.2	12.0	36.0	24.8	5.2	34.0	28.8	28.8	9.2	34.0
29	55.4	35.0	3.6	6.0	61.4	23.0	2.6	1.0	61.4	24.0	1.6	13.0
30	30.4	48.4	7.2	14.0	30.4	28.4	5.2	36.0	8.4	46.4	9.2	36.0
31	24.8	50.0	11.6	13.6	17.2	27.6	9.6	45.6	17.2	31.6	13.6	37.6
32	38.8	40.0	9.6	11.6	43.6	17.2	7.6	31.6	21.2	35.6	11.6	31.6
33	25.2	49.6	9.6	15.6	17.6	29.2	9.6	43.6	17.6	33.2	9.6	39.6
34	28.8	50.0	5.6	15.6	23.2	39.6	3.6	33.6	30.8	30.0	15.6	23.6

APPENDIX II-C. PERCENTAGE DISTRIBUTIONS OF SAND FRACTIONS IN COARSE-TEXTURED SOILS FROM NORTHWESTERN INDIANA*

Site No.	A Horizon					B Horizon					Fifty-Inch Depth				
	Very Coarse 2.0-1.0mm	Coarse 1.0-.5mm	Medium .5-.25mm	Fine .25-.10mm	Very Fine .10-.05	Very Coarse 2.0-1.0mm	Coarse 1.0-.5mm	Medium .5-.25mm	Fine .25-.10mm	Very Fine .10-.05	Very Coarse 2.0-1.0mm	Coarse 1.0-.5mm	Medium .5-.25mm	Fine .25-.10mm	Very Fine .10-.05
1	1.0	5.0	26.0	26.0	8.0	0.5	5.0	28.0	26.0	7.0	1.0	5.0	33.0	36.0	5.0
2	1.0	6.0	43.0	25.0	2.8	0.5	4.5	42.0	31.0	2.0	6.0	15.0	37.0	28.0	2.0
3	2.0	7.0	39.0	25.0	4.0	2.0	9.0	43.0	26.0	2.0	2.0	8.0	48.0	30.0	3.0
4	1.0	4.0	35.0	25.0	4.0	1.0	3.0	36.0	24.0	5.0	2.0	9.0	50.0	25.0	2.0
5	2.0	5.0	33.0	23.0	8.0	2.0	7.0	35.0	22.0	5.0	3.0	9.0	43.0	28.0	4.0
6	0.1	4.0	19.0	15.0	9.0	1.0	4.0	17.0	13.0	7.0	2.0	8.0	36.0	20.0	6.0
7	0.1	2.0	24.0	27.0	8.0	1.0	3.0	23.0	26.0	9.0	1.5	7.0	47.0	17.0	3.0
8	2.0	7.0	28.0	18.0	6.0	2.0	5.0	30.0	21.0	4.0	3.0	11.0	33.0	26.0	3.0
9	0.0	0.5	16.5	70.5	3.0	0.0	0.2	15.5	79.5	2.0	0.0	1.5	28.3	59.0	6.5
11	0.2	2.3	30.0	53.3	4.0	0.2	2.5	31.0	60.5	2.0	0.0	0.9	24.5	67.0	0.8
12	0.5	0.4	12.5	65.5	9.0	0.1	0.7	13.5	69.0	8.0	0.0	0.2	4.5	67.5	14.5
13	0.1	3.5	37.5	26.0	6.0	0.0	2.0	30.0	38.0	8.0	1.0	12.0	47.0	19.0	6.0
14	0.0	1.0	35.5	39.0	4.0	0.0	1.0	34.0	41.5	4.0	0.1	2.0	48.0	39.0	4.5
15	0.0	3.5	41.0	33.0	15.0	0.0	2.0	38.0	26.5	21.0	0.8	10.0	59.5	16.0	4.0
16	0.0	1.0	31.5	31.0	14.5	0.1	2.0	33.5	31.0	7.0	0.7	7.0	48.5	20.0	5.0
17	2.0	5.0	21.0	30.5	6.0	2.0	4.0	19.5	22.0	5.0	3.0	6.5	19.0	28.5	7.0
19	0.0	2.0	40.0	39.5	9.5	0.0	2.5	40.0	39.5	9.0	0.1	2.0	26.5	40.0	10.5
21	0.0	6.5	68.5	21.0	3.0	0.1	6.0	68.0	23.5	1.0	0.1	4.5	63.5	33.0	2.5
22	0.0	2.5	64.0	27.0	3.5	0.0	3.5	66.5	29.0	3.5	0.0	3.5	72.5	23.5	3.0
23	0.1	5.0	61.5	28.0	3.0	0.1	4.0	61.5	29.5	2.5	0.1	3.0	58.5	35.0	3.5
24	0.0	0.1	13.0	82.0	2.5	0.0	0.2	12.5	87.0	1.0	0.0	0.1	16.5	82.5	0.6
25	0.0	0.2	24.5	74.0	1.2	0.0	0.5	28.5	70.5	1.0	0.0	1.0	26.5	73.0	0.5
26	0.0	0.2	5.5	73.5	13.0	0.0	0.5	5.3	76.5	16.0	0.0	0.1	1.5	81.5	17.5
29	0.3	4.0	24.5	22.0	7.0	1.0	5.5	26.5	23.0	7.5	4.0	9.5	33.0	17.5	2.5

*Determined by Cenco-Meinzer Sieve Shaker (U.S. Standard Sieve Series)

APPENDIX II-D. STEPWISE MULTIPLE REGRESSION ANALYSIS CORRELATIONS BETWEEN SOIL TEXTURE CHARACTERISTICS AND TREE RESPONSE*: STATIONS 5 THROUGH 10 INCLUDED

Total Sum of Squares	Sum of Squares Reduced This Step	Proportion Reduced	Cumulative Sum of Squares Reduced	Cumulative Proportion Reduced	Multiple Correlation (Adjusted for Degrees of Freedom)	Variable Entered
2044	677	.33	677	.33	.58	Very Fine Clay at 50"**
	255	.13	932	.46	-.65	Very Fine Clay in A Horizon
	114	.06	1046	.51	.66	Clay at 50"
	97	.05	1203	.55	-.67	Silt in A Horizon
	60	.03	1106	.59	-.69	Sand in B Horizon

*Represented by percent of variance retained by the group at each site.

**Value significant at the .05 level.

APPENDIX II-E. STEPWISE MULTIPLE REGRESSION ANALYSIS CORRELATIONS BETWEEN SOIL TEXTURE CHARACTERISTICS AND TREE RESPONSE*: STATIONS 1 THROUGH 10 INCLUDED

Total Sum of Squares	Sum of Squares Reduced This Step	Proportion Reduced	Cumulative Sum of Squares Reduced	Cumulative Proportion Reduced	Multiple Correlation (Adjusted for Degrees of Freedom)	Variable Entered
2654	935	.35	935	.35	.59	Very Fine Clay at 50"**
	265	.10	1199	.45	-.65	Very Fine Clay in A Horizon
	59	.02	1259	.47	-.65	Sand in B Horizon
	221	.08	1480	.56	.70	Sand in A Horizon
	71	.03	1551	.59	.71	Silt in A Horizon
	103	.04	1655	.62	.72	Clay in A Horizon
	41	.02	1696	.64	.72	Clay in B Horizon

*Represented by percent of variance retained by the group at each site.

**Value significant at .05 level.

APPENDIX III

CHRONOLOGY INVESTIGATIONS

APPENDIX III-A. CHRONOLOGY PARAMETERS FOR AN 81-YEAR ANALYSIS OF VARIANCE PERIOD (1890-1970) FOR STANDS OF WHITE OAK IN NORTHWESTERN INDIANA

			Chronology Parameters									
									Percent of Total Variance			Cross-Correlation
Weather Station	Site No.	Soil Texture: 50 inches	Mean Ring-Width	Serial Correlation	Mean Sensitivity	Standard Deviation	Error of Y	Group Variance (Y)	Group (Y)	Trees (YT)	Radii (YCT)	Among Trees
South Bend	1	Loamy Sand	1.65	.49	.13	.18	.070	.027	30	24	45	.40
	2	Sand	1.66	.47	.13	.16	.052	.023	35	24	42	.46
	3*	Sand	1.85	.77	.12	.23	.070	.051	46	27	26	.59
	4	Sand	1.72	.27	.14	.15	.058	.019	32	28	38	.40
La Porte	5	Sand	1.50	.37	.11	.13	.087	.011	10	30	59	.16
	6	Loamy Sand	1.62	.49	.19	.24	.079	.053	38	28	34	.50
	7	Loamy Sand	2.14	.49	.14	.19	.076	.031	26	35	40	.32
	8	Loamy Sand	2.14	.32	.15	.15	.065	.020	29	32	37	.39
Michigan City	9	Sand	1.47	.64	.11	.16	.051	.023	35	16	49	.50
	10	Clay Loam	1.80	.38	.17	.19	.052	.033	47	21	32	.58
	11	Sand	1.66	.50	.14	.18	.057	.029	38	22	40	.51
	12*	Sand	2.15	.81	.13	.28	.078	.075	51	18	30	.66
Wanatah	13*	Sandy Loam	1.94	.69	.18	.32	.078	.097	52	18	29	.62
	14	Sand	1.74	.49	.15	.17	.052	.021	31	26	42	.37
	15	Loamy Sand	1.58	.72	.17	.28	.075	.073	47	14	38	.61
	16	Loamy Sand	1.86	.42	.16	.20	.097	.031	21	58	21	.25
Valparaiso	17	Sandy C.L.	1.63	.65	.17	.28	.127	.065	26	40	33	.31
	18	Clay Loam	1.95	.70	.17	.28	.071	.073	53	22	25	.62
	19	Sandy Loam	1.44	.72	.14	.23	.087	.047	29	24	48	.37
	20	Clay Loam	1.88	.53	.17	.24	.082	.049	37	39	25	.57
Wheatfield	21	Sand	1.85	.32	.19	.22	.079	.040	31	28	41	.38
	22	Sand	1.81	.53	.15	.21	.103	.035	22	50	29	.22
	23	Sand	1.42	.17	.21	.21	.063	.040	43	32	26	.52
Ogden Dunes	24	Sand	1.32	.71	.12	.19	.101	.026	17	50	33	.21
	25	Sand	1.27	.36	.15	.17	.065	.025	30	25	44	.44
Hobart	26	Sand	1.67	.69	.14	.22	.068	.044	42	23	34	.53
	27	Clay Loam	2.01	.83	.15	.35	.065	.115	66	16	18	.76
Lowell	28	Clay	1.47	.38	.17	.21	.060	.039	43	27	30	.53
	29	Sandy Loam	1.55	.77	.14	.28	.101	.068	37	28	33	.46
	30	Silty Clay	1.44	.63	.15	.24	.083	.051	39	36	25	.48
Park Forest	31	Clay	1.54	.50	.16	.22	.056	.046	51	20	28	.62
	32	Clay	1.42	.48	.15	.19	.045	.031	43	19	40	.57
	33	Clay	1.72	.56	.15	.21	.056	.043	53	26	21	.60
	34	Clay Loam	1.20	.36	.16	.18	.059	.029	30	14	57	.47

*Severely disturbed forest stand.

APPENDIX III-B. COMPARISONS OF CHRONOLOGY CHARACTERISTICS ON CONTRASTING SOIL TEXTURES AT SELECTED WEATHER STATIONS IN NORTHWESTERN INDIANA

Weather Station	Site No.	Soil Texture	Serial Corre-lation	Mean Sensi-tivity	Cross-Corre-lation Among Trees	Percent of Total Variance			Actual Group Variance (Y)
						Group (Y)	Trees (YT)	Radii (YCT)	
Michigan City	9	Coarse	.64	.11	.50	35	16	49	.023
	10	Fine	.38	.17	.58	47	21	32	.033
	11	Coarse	.50	.14	.51	38	22	40	.029
Valparaiso	17	Coarse	.65	.17	.31	26	40	33	.065
	18	Fine	.70	.17	.62	53	22	25	.073
	19	Coarse	.72	.14	.37	29	24	48	.047
	20	Fine	.53	.17	.57	37	39	25	.049
Hobart	26	Coarse	.69	.14	.53	42	23	34	.044
	27	Fine	.83	.15	.76	66	16	18	.115
Lowell	28	Fine	.38	.17	.53	43	27	30	.039
	29	Coarse	.77	.14	.46	37	28	33	.068
	30	Fine	.63	.15	.48	39	36	25	.051

APPENDIX III-C. COMPARISONS OF WHITE OAK AND BLACK OAK CHRONOLOGY PARAMETERS FROM SITES IN NORTHWESTERN INDIANA

Station	Site	Species	Mean Ring-Width (mm)	Serial Corre-lation	Mean Sensi-tivity	Group Vari-ance (Y)	Percent Variance by Group (Y)	Error of Y	Cross-Corre-lation Among Trees
Wanatah	14	WO	1.74	.49	.15	.021	31	.051	.37
		BO	1.87	.46	.14	.023	21	.076	.35
	16	WO	1.86	.42	.16	.030	21	.097	.25
		BO	2.06	.49	.15	.031	37	.066	.49
Valparaiso	19	WO	1.44	.72	.14	.047	29	.087	.37
		BO	1.60	.67	.11	.024	40	.045	.50
	20	WO	1.88	.53	.17	.049	37	.081	.57
		BO	2.16	.54	.15	.041	38	.077	.45
Ogden Dunes	25	WO	1.27	.36	.15	.024	30	.065	.44
		BO	1.53	.63	.13	.033	41	.59	.52
Lowell	30	WO	1.44	.63	.15	.051	39	.083	.48
		BO	1.41	.71	.11	.040	47	.059	.57

WO = White Oak
BO = Black Oak

APPENDIX III-D. CHRONOLOGY PARAMETERS FOR 20-YEAR ANALYSIS OF VARIANCE PERIODS FROM SELECTED STATIONS AND SITES IN NORTHWESTERN INDIANA

				Chronology Parameters									
										Percent of Total Variance			
Station	Site No.	Analysis of Variance Period	Gross Soil Texture	Mean Ring-Width	Serial Corre-lation	Mean Sensi-tivity	Standard Deviation	Error of Y	Group Variance (Y)	Group (Y)	Trees (YT)	Radii (YCT)	Cross-Corre-lation Among Trees
South Bend	2	1890-1909	Coarse	1.84	.31	.15	.20	.033	.024	45	5	52	.65
		1910-1929		1.59	.15	.14	.16	.042	.018	38	13	49	.55
		1930-1949		1.44	-.12	.14	.12	.043	.016	35	30	36	.44
		1950-1969		1.77	.33	.08	.12	.035	.007	29	26	45	.38
La Porte	5	1890-1909	Coarse	1.18	.52	.13	.17	.044	.025	31	7	65	.93
		1910-1929		1.30	.25	.10	.12	.062	.009	12	18	70	.19
		1930-1949		1.35	-.55	.15	.10	.058	.007	13	31	57	.18
		1950-1969		1.49	.20	.06	.07	.041	.003	8	19	74	.14
	6	1890-1909	Coarse	1.58	.68	.20	.34	.217	.070	32	60	9	.58
		1910-1929		1.66	.36	.28	.29	.059	.081	56	10	35	.70
		1930-1949		1.76	.26	.19	.22	.065	.045	47	19	32	.63
		1950-1969		1.84	.30	.09	.10	.047	.008	24	15	57	.41
	7	1890-1909	Coarse	2.88	.21	.21	.22	.094	.039	28	52	19	.36
		1910-1929		2.46	-.25	.16	.13	.039	.015	35	23	44	.46
		1930-1949		1.62	-.35	.12	.11	.040	.010	26	21	56	.35
		1950-1969		1.65	.43	.07	.09	.036	.006	24	30	46	.32
	8	1890-1909	Coarse	2.32	.43	.19	.19	.067	.033	39	33	27	.55
		1910-1929		2.13	-.07	.16	.14	.050	.017	36	29	34	.49
		1930-1949		1.98	-.47	.16	.12	.035	.012	37	7	57	.53
		1950-1969		2.17	.28	.09	.09	.042	.007	20	24	56	.25
Michigan City	10	1890-1909	Fine	2.13	.39	.18	.21	.054	.043	52	18	29	.67
		1910-1929		1.82	-.16	.20	.16	.038	.024	50	10	40	.64
		1930-1949		1.43	-.59	.22	.15	.046	.020	41	19	39	.56
		1950-1969		1.81	.41	.06	.07	.041	.004	14	32	54	.21
Wanatah	15	1890-1909	Coarse	1.65	.47	.21	.24	.069	.057	45	10	43	.64
		1910-1929		1.84	.53	.16	.21	.057	.043	45	5	50	.63
		1930-1949		1.15	-.11	.18	.14	.062	.016	25	30	44	.37
		1950-1969		1.66	.61	.14	.19	.064	.031	37	14	47	.48
Valparaiso	18	1890-1909	Fine	2.45	.67	.25	.44	.054	.183	45	12	38	.71
		1910-1929		2.21	.26	.17	.18	.054	.031	51	9	41	.68
		1930-1949		1.61	-.03	.15	.14	.057	.018	40	19	41	.57
		1950-1969		1.55	.16	.08	.08	.042	.004	18	25	59	.28
Park Forest	1	1890-1909	Fine	1.81	.38	.22	.27	.051	.071	66	14	21	.76
		1910-1929		1.52	.44	.17	.21	.046	.042	59	13	27	.74
		1930-1949		1.39	.12	.16	.18	.094	.029	54	6	38	.73
		1950-1969		1.43	.42	.10	.12	.039	.013	40	26	34	.51

APPENDIX IV

CLIMATIC INVESTIGATIONS

APPENDIX IV-A. SELECTED VARIABLES FOR CLIMATIC ANALYSES

Variable	Identification Number
Total April-May Precipitation--Current Season	1
Total June Precipitation--Current Season	2
Total July Precipitation--Current Season	3
Total August Precipitation--Current Season	4
Total April-August Precipitation--Current Season	5
Total April-May Precipitation--Preceding Season	6
Total June-July-August Precipitation--Preceding Season	7
Total September Precipitation--Preceding Season	8
Total October-March Precipitation--Preceding Season	9
Mean Maximum April-May Temperature--Current Season	10
Mean Maximum June Temperature--Current Season	11
Mean Maximum July Temperature--Current Season	12
Mean Maximum August Temperature--Current Season	13
Mean Maximum June-July Temperature--Preceding Season	14
Mean Maximum August-September Temperature--Preceding Season	15

APPENDIX IV-B. STEPWISE MULTIPLE REGRESSIONS OF WHITE OAK TREE-RING INDICES AGAINST SELECTED CLIMATIC VARIABLES (OF THE CURRENT AND PRECEDING SEASONS) FROM STATIONS AND SITES IN NORTHWESTERN INDIANA--1951-1970

		Precipitation									Temperature						Stepwise Multiple Regression Analysis Values		
		Current					Preceding				Current				Preceding				
Station	Site	Apr.-May	June	July	August	Apr.-Aug.	Apr.-May	June-July-August	September	Oct.-Mar.	Apr.-May	June	July	August	June-July	September	Multiple Correlation	Sum of Squares	Cumulative Proportion Reduced
South Bend	1				-							-					.48	.35	.23
	2	-										-				+	.73	.17	.59
	3*																---	---	---
	4	-										-					.49	.17	.22
La Porte	5										-	-					.58	.17	.36
	6				-							-					.53	.34	.28
	7*																---	---	---
	8										-	-					.73	.17	.57
Valparaiso	17*																---	---	---
	18											-					.31	.14	.18
	19						+					-					.68	.57	.50
	20																---	---	---
Wheatfield	21*																---	---	---
	23		+														.65	.23	.42
Hobart	24			+				+									.63	.79	.43
	27												-				.55	.33	.31
Lowell	28	+												+			.65	.74	.46
	29						-										.49	.26	.24
	30	-		+						-							.69	.25	.53
Park Forest	31	-	+					+		-							.64	.22	.44
	32		+	+													.85	.39	.77
	33	-	+					+		-							.64	.69	.45

*No significant variable entered.

+Positive correlation, statistically significant at .05 level.

-Negative correlation, statistically significant at .05 level.

APPENDIX IV-C. STEPWISE MULTIPLE REGRESSIONS OF WHITE OAK TREE-RING INDICES AGAINST SELECTED CLIMATIC VARIABLES FROM SOUTH BEND AND LA PORTE FOR THE PERIOD 1910-1969

Station	Site No.	Time Interval	Sum of Squares	Cumulative Proportion Reduced	Multiple Correlation (Adjusted for D.F.)	Sign	Variable* No.
South Bend	2	1910-29	.193	.19	.43	+	10
		1930-49	.349	.35	.59	-	12
				.54	.72	-	1
				.66	.79	-	10
				.74	.83	+	3
				.80	.87	+	11
		1950-69	.173	.25	.50	-	1
				.47	.66	-	11
				.59	.73	+	15
La Porte	5	1910-29	.371	.19	.43	+	14
		1930-49	.221	.25	.46	-	6
				.40	.60	-	4
		1950-69	.170	.22	.47	-	7
				.37	.58	-	10
	6	1910-29	.221	.20	.44	-	5
		1930-49	.798	.98	.99	+	2
				.99	.99	-	13
		1950-69	.339	.28	.53	-	6
	7	1910-29	.425	.32	.57	-	11
		1930-49	.181	.25	.50	-	6
				.42	.63	+	8
		1950-69**	--	--	--	--	--
	8	1910-29	.372	.26	.51	+	14
				.55	.72	-	11
		1930-49	.222	.26	.51	-	10
		1950-69	.174	.46	.68	-	2
				.57	.74	-	10

*All variables significant at .01 level; **No significant variable entered.