AN ECOLOGICAL STUDY OF THE COMPOSITION, STRUCTURE AND DISTURBANCE REGIMES OF THE PRE-EUROPEAN SETTLEMENT FORESTS OF WESTERN CHIPPEWA COUNTY, MICHIGAN

By

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ABSTRACT

AN ECOLOGICAL STUDY OF THE COMPOSITION, STRUCTURE AND DISTURBANCE REGIMES OF THE PRE-EUROPEAN SETTLEMENT FORESTS OF WESTERN CHIPPEWA COUNTY, MICHIGAN

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To successfully implement ecosystem management an understanding must be achieved regarding how different forest communities and ecosystems function and interrelate at the landscape level. This study explores the composition, structure and disturbance patterns of the pre-European settlement forests of eastern upper Michigan, by reconstruction of the forests from General Land Office Survey notes. Results suggest that the pre-European settlement landscape was a vast array of irregular patches, composed of different successional stages and forest associations of different age and size classes. The composition and structure of the forest was driven by fire, windthrow, insect related mortality and beaver (Castor canadensis) floodings. Hemlock (Tsuga canadensis) was a dominant species in the landscape. The results of the study provide a foundation for understanding how today's forests differ from those that dominated the landscape before Europeans began to harvest timber.

This thesis is dedicated to Stephanie.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Professional and public concern regarding the long-term health, sustainability and diversity of forests and other natural resources has initiated a movement away from established, conventional management techniques, toward a landscape or ecosystem oriented approach to management of resources. Simultaneous and ever increasing demands upon our remaining resources by many disparate user groups continues to necessitate multiple-use management objectives for these resources. Management for multiple-use has been a central objective of forest management plans for many years. While sound in principle, management for multiple-use has retained a rather narrow focus upon management of forests at the population and community levels. Moreover, incorporating all management objectives into concrete management plans has become increasingly problematic, with limited scientific data concerning ecosystem processes on which to base these plans. Relatively recent discussions by Brown and Maurer (1989) and by Holling (1992) have stressed the urgency of expanding the spatial and temporal scale of research efforts in contemporary ecology beyond the population and community levels, to the ecosystem and biome levels. Viewing forest populations and communities within the context of how they integrate into their surrounding ecosystem or landscape has useful implications for forest management. Attempting to manage a population or community for a particular narrow attribute, while ignoring or not fully understanding the larger ecosystem of which it is a functional part, may have a detrimental impact upon other attributes of the ecosystem. This may ultimately hinder the achievement of multiple-use objectives rather than facilitate them. Consequently, the concept of an ecosystem approach to management is now receiving serious attention at national, state and even local levels. In 1992, the U.S. Forest Service announced a commitment to ecosystem management as the framework in which to achieve multiple-use management of national forests and grasslands (Robertson 1992a, 1992b). The Nature Conservancy has also recognized the importance of maintaining sustainable ecosystems. It is now focusing upon the preservation and maintenance of intact, functioning ecosystems as a more broad approach to its primary goal concerning the preservation of threatened or endangered habitats for plant and animal species.

To successfully implement ecosystem management an understanding must first be gained regarding how different populations, communities and ecosystems function and interrelate at the landscape and biome level. One method that ecologists have used to expand our knowledge of how different ecosystems function is to observe ecosystems as they exist in their primal state. To this end, examples of naturally functioning, relatively undisturbed ecosystems are frequently studied with the ultimate objective of identifying significant natural principles upon which sound management practices may be founded. Remnants of intact, relatively undisturbed ecosystems in the eastern United States are few, most having been "preserved" in protected parks, designated wilderness areas or other types of reserves. It must be recognized that despite our best intentions, even these preserved examples of undisturbed ecosystems have been affected (on local to global scales and with varying degrees of impact) by human activity, both within preserves and especially in the landscape surrounding preserves. Human impacts include recreational use, exclusion of natural disturbance regimes (particularly fire), inadvertent or deliberate introduction of exotic plant and animal species and disease pathogens, intentional manipulation of flora and fauna, pollution in the form of gaseous compounds, particulate matter and acid deposition, and global climate change to name but a few. However, research of relatively undisturbed and naturally functioning ecosystems can continue to provide valuable knowledge concerning the function and structure of managed ecosystems, provided that these adverse impacts are taken into consideration.

Compared to the western regions of the United States, large remnants of relatively undisturbed, virgin forest are rare in the Great Lakes region. That the state of Michigan was the largest producer of timber in the United States from 1870 to 1890 (Benson 1976) explains this paucity. So complete was the devastation of the pre-European forest, that by 1929 there were actual doubts as to the former existence of the once vast pine forests of Michigan (Weaver and Clements 1929). Similar over-exploitation occurred in the neighboring Lake States of Wisconsin and Minnesota. The Boundary Waters Canoe Area of Minnesota is the largest remaining example (215,000 ha/ 531,000 ac) of a virgin ecosystem in the Great Lakes region, but even it has not escaped human exploitation.

The state of Michigan is itself unique among the eastern states in that it is covered by approximately 7.3 million ha (18.0 million ac) of forest land, much of it in the public domain. Included in this figure are three major National Forests, one National Park, two National Lakeshores, and an extensive State Park and Forest system. The state is quite diverse, and can be divided into four distinct regional landscape ecosystems (Albert et al. 1986): I. southern lower Michigan, II. northern lower Michigan, III. eastern upper Michigan and IV. western upper Michigan. The overwhelming majority of the forest land in the public domain is concentrated in regions II through IV. Most of this land reverted to the public domain through tax delinquency, following attempts at agriculture in the aftermath of the unrestricted logging of the late nineteenth and early twentieth centuries. Hence, only minor remnants of the vast historical forest ecosystems of Michigan remain somewhat intact today.

Significant forest remnants in regions II through IV include the Porcupine Mountains Wilderness State Park (14,500 ha/35,800 ac), the McCormick Wilderness Area (6,900 ha/17,000 ac), the Sylvania Wilderness Area (6,000 ha/14,800 ac), a tract in the Huron Mountains area (2,500 ha/6,200 ac), the Roscommon Red Pines Study Area (65 ha/160 ac) and the Hartwick Pines State Park (20 ha/50 ac). A few other smaller fragments also exist. Although these areas have been and continue to be extensively studied, their limited size places serious spatial constraints on many conclusions we might discern regarding the composition, structure and dynamic processes of primal ecosystems. Secondly, because all communities and ecosystems possess some properties of composition, structure and internal processes that are inherent functions of their unique environments, knowledge from one particular community or ecosystem may not be universally applicable to all other communities or ecosystems. The alternative study of second growth forest ecosystems is much more limited by the often severe nature of past human disturbance and continuing direct and indirect adverse impacts upon these ecosystems. Any theory derived from these studies must also be applied with great caution.

Fortunately, other sources of information do exist that can be utilized to study the primal forest ecosystems of Michigan. These include pollen from core samples of bogs, varves from lake bottom sediment cores and historical records. Of the latter, General Land Office (GLO) survey records have been most commonly used in scientific studies. The use of original land survey records for scientific study of the primal ecosystems of Michigan offer several advantages: 1) they are available for the entire state, 2) they were conducted in the field according to a predetermined plan, 3) they constitute a definitive sample of the forest tree species, and 4) they are thus usable for quantitative and qualitative analysis of primal ecosystems (Bourdo 1956). Most importantly, the surveys were for the most part completed before the large scale exploitation of Michigan's virgin forests began in the mid to late 1800's.

Some of the first uses of GLO survey records involved the reconstruction of the general boundaries of pre-European settlement forest types in the form of simple maps (Sears 1925, Marshner 1930, Veatch 1959, Findley 1976). The first study to investigate the suitability of survey records for use in analysis of pre-European settlement forests was by Bourdo (1954, 1956). These studies and subsequent studies by Lorimer (1977, 1980a), Canham (1978), Canham and Loucks (1984), and Whitney (1986, 1987) were important in describing the uses of GLO survey records in reconstructing pre-European settlement forests, and in providing critiques of the methods used. More recent research for selected areas in Michigan includes the studies by Whitney (1986, 1987) and Palik and Pregitzer (1992). These studies have gone beyond merely reconstructing the pre-European settlement composition of forests and have sought to derive insight into the structure, function and dynamics of these forests.

One function of forested ecosystems that has been the focus of considerable study is disturbance. Disturbance in the form of windthrow and/or fire, extensive mortality due to insect outbreaks, and beaver floodings have a direct and significant influence upon the composition and structure of forested ecosystems. Two projects investigating natural disturbance regimes of forests have occurred in Michigan. The first was Whitney's 1986 study of the relation of pre-European settlement pine forests to substrate and disturbance history in the region II counties of Roscommon and Crawford. The second was a study by Frelich and Lorimer (1991) which described the disturbance regimes of the three relatively large preserves of northern hardwood forests in region IV. The former study was based upon GLO survey records, while the latter study was conducted in remnant old-growth forests as they presently exist.

The purpose of the present study was to integrate data from GLO survey notes with the C-MAP vector-based geographic information system to determine the composition, structure and disturbance regimes of the pre-European settlement forests of western Chippewa county, in Michigan's region III (Albert et al. 1986).

The objectives of the study were to:

1. Determine the composition, structure and successional status of the pre-European settlement forests of western Chippewa County, Michigan.

2. Determine the types, frequencies and return intervals of the natural disturbance regimes of the pre-European settlement forest types.

3. Provide comparisons of pre-European settlement forest cover type to the 1978 Michigan Resource Information System (MIRIS) forest cover types.

The following hypotheses were tested:

1. Even-aged stands in pre-European settlement forests were primarily composed of jack pine.

2. Northern conifer forests were fire dependent ecosystems, with fire intervals less than the maximum potential lifespans of the tree species.

3. Old-growth northern conifer forests existed in a shifting-mosaic steady state.

4. Northern hardwood and mixed swamp conifer forests were windthrow dependent ecosystems, with disturbance intervals greater than the maximum potential lifespans of the tree species.

5. Old-growth northern hardwood forests existed in a shifting-mosaic steady state.

STUDY AREA

History and Location

Chippewa County is the eastern-most county in region III of Michigan. The study area consists of all townships west of the Michigan Meridian, which falls in the eastern third of the county and bisects the city of Sault Ste. Marie. Sections 1 and 2 of Township 47 North, Range 1 West, which were outlying disturbed areas of Sault Ste. Marie in the 1840's, have been excluded from the study area. The study area thus encompasses a total of thirty-five townships covering an area of approximately 273,237 ha (674,660 ac). It can be divided into two districts (13 and 14) and four subdistricts (13.1, 13.2, 14.1 and 14.2) according to Albert et al. (1986) (Figure 1). Most of the study area falls within subdistricts 13.2 and 14.2, with a modest representation of subdistrict 14.1 and only a slight representation of subdistrict 13.1.

Chippewa County has a long and rich history. Native-americans were occupying the region long before the discovery of North America by European cultures. The major native-American villages in eastern upper Michigan were located at present day Sault Ste. Marie and St. Ignace. Three smaller villages and three sugar camps were noted on

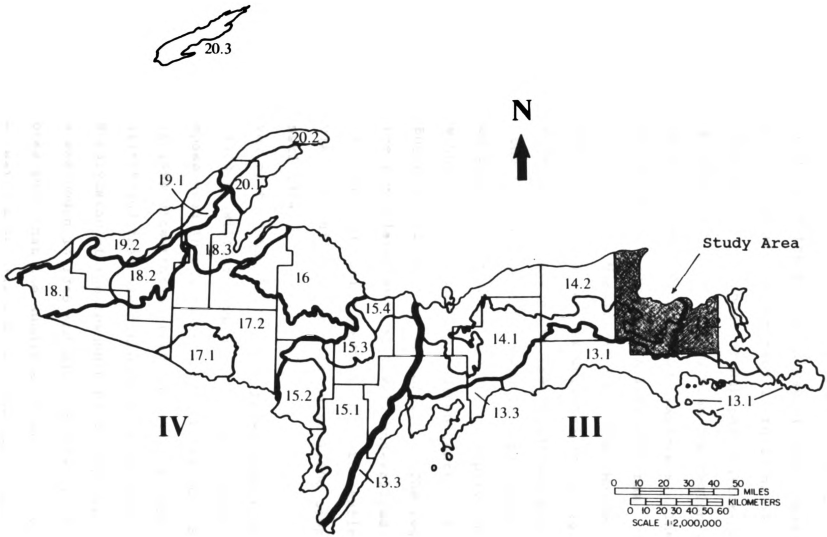

Figure 1. Regional Landscape Ecosystems of Upper Michigan, Regions III and IV.

the surveyor's township plat maps of the study area along the south shoreline of the Whitefish Bay of Lake Superior. The extent of the villages ranged from 24 to 41 ha (60 to 100 ac). The first influences of European culture can be traced back to the early 17th century when the region was first penetrated by French trappers and explorers. The first European settlement occurred in 1668 with the establishment of a Jesuit Mission at Sault Ste. Marie. A second missionary settlement was established in St. Ignace in 1671. The region remained under French influence until the close of the French and Indian wars in 1763, when England gained control of much of the French empire in North America. The United States in turn, gained control of the region from England following the War of 1812. The region remained sparsely populated and relatively undeveloped until the mid-1800's. The non-native population of the entire Upper Peninsula of Michigan was estimated at 1,300 people in 1840 (Karamanski 1989).

The survey of township lines in Chippewa County was conducted in 1840 by William Austin Burt, the inventor of the solar compass used in the surveys of the period. Bourdo reports in his 1954 dissertation that Burt's work "was of excellent quality" and that his "integrity is beyond question". Subdivision of the township by surveys of the section lines was begun in 1845 and was complete by 1850. The survey notes show that the subdivision surveyors were Harvey Mellon, Wells Burt, James H. Mullett and Henry

Brevoort.

The first sawmill in the Upper Peninsula was established in Sault Ste. Marie in 1822 for the construction of Fort Brady. By 1835, when the sawmill was leased to the American Fur Company, limited logging had progressed to encompass an area only 8 km (5 mi) from the town (Karamanski 1989). At some date between 1846 and 1849, James P. Pendill constructed a sawmill 40 km (25 mi) west of Sault Ste. Marie where the creek that bears his name enters Whitefish Bay. When Harvey Mellon's survey team reached the site of the sawmill on September 14, 1849, he noted that an area encompassing only 101 ha (250 ac) had been disturbed by logging. When Wells Burt was likewise subdividing the farthest township on Whitefish Point on 29 June, 1849, he made note of the new lighthouse that became active earlier in that same year. An area of approximately 22 ha (55 ac) was potentially disturbed by the establishment of the lighthouse.

By 1850 the non-native population of the Upper Peninsula reached approximately 6,000 persons, with the greatest concentrations probably occurring at Sault Ste. Marie and the copper ranges of the Keweenaw Peninsula. In 1855 the first canal and locks were completed in the St. Marys river at Sault Ste. Marie, and in June of that year commercial logging began on the southern shore of Lake Superior from the Whitefish Bay to Grand Island at present day Munising (Karamanski 1989).

Based upon this chronology, I have concluded that the study area was relatively undisturbed by any major logging before 1850, when the subdivision surveys of the townships were completed. Furthermore, none of the townships in the study area were subsequently found to be fraudulent and thus required re-survey at a later date. Therefore, I have also concluded that the surveys of the study area are at a minimum comprehensive and accurate in scope.

Environmental Characteristics

Climate

Bounded by Lake Superior to the north, and Lakes Michigan and Lake Huron to the south, region III has a cool lacustrine climate. The most pronounced effect of the lakes is to moderate the climate such that warming is retarded in the spring and cooling is retarded in the fall. Hence, the growing season is relatively long, although maximum summer temperatures are depressed. Average climatic data for Chippewa County is presented in Table 1. The presence of the lakes also reduces the severity of summer thunderstorms, reduces the frequency of tornadoes to rare occurrences and causes considerable lake effect snow in the winter.

Landform and soils

The region encompassing the study area has, like all of Michigan, been distinctly influenced by the Wisconsinan period of the Pleistocene glaciation. It is primarily

Table 1. Average climatic data for Chippewa County.

Growing season length (days)	135
Growing season heat sum, base 7.2 C, April-October (°C-days)	1860
Total annual precipitation (mm)	787
Annual average temperatures (°C)	5.0
July average daily max temperature (°C)	24.4
January average daily minimum temperature (°C)	-13.1

Barnes and Wagner (1981), Albert et al. (1986)

characterized by low elevations and flat lake plain topography, with a relatively young bedrock of limestone and dolomite. The following subdistrict descriptions are summaries of Albert et al. (1986):

13.1 St. Ignace Subdistrict. The subdistrict is characterized by sand lake plains and limestone bedrock at or near the surface, with occasional areas of rolling ground moraines and large ridges. Elevations range from 175-315 m (580-1040 ft). The sand lake plain is characterized by both poorly drained depressions and by excessively drained ridges. Drainage is poor where the limestone bedrock is near the surface.

13.2 Rudyard Subdistrict. The subdistrict is characterized by flat, post-glacial clay lake plains, with some areas of ground moraine and sand lake plain. Elevations range from 175-245 m (580-800 ft). The soils of the clay lake plains are generally poorly drained. The ground moraines are well drained, and the sand lake plains are often excessively drained.

14.1 Seney Subdistrict. The subdistrict is characterized by flat, poorly drained sand lake plain. There are also occasional narrow ridges or dunes with excessively drained sand soils. Elevations range from 180-270 m (600-880 ft). Areas of limestone bedrock and moderately sloping ground moraines, as found in the St. Ignace Subdistrict, are lacking.

14.2 Grand Marais Subdistrict. The subdistrict is characterized by sand end moraine ridges, outwash plains and lake plains. Elevations range from 185-380 m (602-1240 ft), with the highest elevations in the western side of the subdistrict. The well drained end moraines are steep and irregular 30-61 m (100-200 ft) ridges, interspersed with kettle lakes and poorly drained swamps. The eastern edge of the subdistrict is the outwash Raco Plain, with excessively drained sand soils. The steep topography of the subdistrict is in sharp contrast with the flat Seney and Rudyard Subdistricts to the south and east respectively.

Vegetation

Following the retreat of the Wisconsinan glaciers regions III and IV were reforested by migration of species from refugia in the south. Boreal species such as white spruce (Picea glauca), black spruce (Picea mariana), alder (Alnus spp.), eastern larch (Larix laricina), jack pine (Pinus banksiana) and balsam fir (Abies balsamea) migrated into region III approximately 10,000 years ago. White pine (Pinus strobus) entered the region approximately 2,000 years later. Late successional species such as maple (Acer spp.) eastern hemlock (Tsuga canadensis) and American beech (Fagus grandifolia) entered the region approximately 7,000, 5,000 and 4,000 years ago respectively (Davis 1981).

The tree species currently found in Chippewa County are a direct function of past exploitation and subsequent management practices. Northern hardwood forests are dominated by sugar maple (*Acer saccharum*) and American beech and yellow birch (*Betula alleghaniensis*), with smaller components of red maple (*Acer rubrum*), balsam fir, black cherry (*Prunus serotina*), basswood (*Tilia americana*) ironwood (*Ostrya virginiana*) and eastern hemlock. There are extensive pine plains, with many intensively managed plantations of jack pine, red pine (*Pinus resinosa*) and white pine. Smaller components of the pine plains are white birch (*Betula papyrifera*), bigtooth aspen (*Populus grandidentata*), trembling aspen (*Populus tremuloides*) and northern red oak (*Quercus rubra*). Extensive areas of mixed swamp conifers are dominated by northern white cedar (*Thuja occidentalis*), white and black spruce and eastern larch, with smaller proportions of white pine and white birch.

METHODS

GLO Surveys

The surveys of Michigan followed the 1833 instructions of the Surveyor General for the States of Ohio and Indiana, and the Territory of Michigan, and the 1850 instructions for the states of Ohio, Indiana and Michigan (White 1984). In addition to recording the position, species and diameter of corner and line bearing trees (hereafter referred to simply as bearing trees), the surveyors were required to note the "face of the country", the character of the soil, the most prevalent timber and undergrowth species, the occurrence of windfalls and swamps, and the occurrence of burned land. The instructions also specified that the surveyors were to draw a plat map of each township, scaled at two inches per mile. This plat map was to be drawn in the field as the survey progressed, to ensure completeness and accuracy. Surveyors were required to draw "the crossing and courses of all streams of water, the intersection, situation and boundaries of all prairies, marshes, swamps, lakes, hills and all other things mentioned in (the) field notes" (White 1984, pages 299 and 370). This included the boundaries of forest types and the location of disturbances noted on the survey lines.

Both the 1833 and 1850 instructions specified that four bearing trees be established at all township corners and at all section corners on range or township lines. However, only two bearing trees were required for the interior corners which subdivided each township into sections. Surveyors were required to record a minimum of one line tree per section line (White 1984). Table 2 lists the tree species used by surveyors as bearing trees in the study area. The surveyors did not differentiate between some species, such as white and black spruce, bigtooth and trembling aspen and species of willow. Consequently, I will also refer to them as simply spruce, aspen and willow. Some species were referred to by names that are not commonly recognized today, and are listed by other surveyor names in the second column of Table 2. It is probable that surveyor references to black oak were actually pertaining to red oak, and I have recorded them as such.

The primary concern in the use of GLO survey records in forest reconstruction is the degree of bias present in the sample. There are two biases of concern, the surveyor's choice of tree species and preference for specific diameter classes for use as bearing trees. Biases are evident by over-representation of tree species and diameter classes, and when bearing trees are consistently reported in opposite quadrants with only two trees established per corner. In general, biases are not present in even-aged stands, but there are usually biases toward medium sized trees in all-

Table 2. Species used by surveyors for bearing trees.

Common Name	Other Surveyor Name	Scientific Name
American elm	Elm	*Ulmus americana*
Balsam poplar	Balm-of-Gilead	*Populus balsamifera*
Basswood	Lynn	*Tilia americana*
Beech		*Fagus grandifolia*
Bigtooth aspen	Aspen	*Populus grandidentata*
Black ash		*Fraxinus nigra*
Black spruce	Spruce	*Picea mariana*
Bur oak	Swamp oak	*Quercus macrocarpa*
Cottonwood		*Populus deltoides*
Balsam fir	Fir	*Abies balsamea*
Hemlock		*Tsuga canadensis*
Ironwood		*Ostrya virginiana*
Jack pine	Spruce pine Norway pine	*Pinus banksiana*
Mountain ash		*Sorbus americana*
Northern red oak	Black oak	*Quercus rubra*
Northern white cedar		*Thuja occidentalis*
Red maple	Maple	*Acer rubrum*
Red pine	Yellow pine	*Pinus resinosa*
Speckled alder	Alder	*Alnus rugosa*
Sugar maple	Sugar	*Acer saccharum*
Tamarack		*Larix laricina*
Trembling aspen	Aspen	*Populus tremuloides*
White birch		*Betula papyrifera*
White pine	Pine	*Pinus strobus*
White spruce	Spruce	*Picea glauca*
Willow		*Salix* spp.
Yellow birch	Birch Yellow birch	*Betula alleghaniensis*

aged stands. Smaller diameter trees were generally biased against because space was required to blaze and carve the required township, range and section data. Bourdo (1956) noted that the primary concern is not whether bias is present, but whether it will significantly impact quantitative analysis.

The presence of bias can be identified by quadrant analysis of bearing trees and by analysis of mean distances from corner posts to their respective bearing trees (Bourdo 1956). Quadrant analysis will reveal the presence of bias, but cannot differentiate between diameter and species bias. Quadrant analysis of bearing trees is based upon the principle that the tree nearest the corner may occur with equal probability in any of four quadrants. If surveyors expressed no bias toward a particular species or diameter in choosing a bearing tree, then the frequency with which each quadrant was chosen should be nearly equal. Analysis of mean bearing tree distances can be used to detect both diameter and species bias. Detection of diameter bias by analysis of mean bearing tree distances involves computing the mean distances from corner posts to their respective bearing trees for each two inch diameter class within a forest type. For a given type, bearing trees of every diameter class should be located a similar mean distance from corner posts. If bias toward a particular diameter class occurred, then that diameter class will have a higher or lower mean distance than other diameter classes and wide variation in these mean distances would be expected. Detection of species bias by analysis of mean bearing tree distances is similarly accomplished by computing the mean distances from corner posts to their respective bearing trees for each tree species occurring in a forest type.

There are other potential sources of error that may impact quantitative analysis of survey data. The diameter of bearing trees recorded by surveyors may be considered suspect. Surveyors were only required by the instructions to estimate, rather than measure, bearing tree and line tree diameters (White 1984). The experience of the surveyor thus determined the relative accuracy of reported diameters. A "good tape measure" was listed among the equipment required for surveyors in the field (White 1984), but it is unknown whether the tape was used by surveyors to periodically check their diameter estimates. One must also accept the reported diameter of bearing trees as a close approximation of diameter at breast height (1.4 m or 4.5 ft). The surveyors probably estimated diameter at the height at which they blazed and recorded township, range and section corner data, which depending upon the height of the surveyor, would coincidentally be close to 1.4 m. The reported distances from corner posts to their respective bearing trees can also be a potential source of error. The chainage from the corner being established to the more distant bearing trees was documented by Bourdo (1956) to sometimes be paced or guessed, even though the instructions specified that they were to be measured. Bourdo documented this by actual measurement of original bearing trees in western upper Michigan. He found that where pacing or guessing was evident, it occurred primarily for bearing trees greater than 6.0 m (19.8 ft) from corner posts. Thus, the accuracy of bearing tree distances was very much dependent upon the integrity of the surveyor.

In summary, it is known that: 1) the quality of survey work varied depending upon surveyor integrity, 2) the surveys do not constitute a truly random sample, 3) some degree of surveyor bias may be present in the selection of bearing trees, and 4) one must acknowledge some inaccuracies of reported bearing tree diameters and distances. Despite these limitations, the historical data contained in the GLO surveys can still reveal a wealth of information concerning the composition, structure and function of pre-European settlement forests. Previous investigations have concluded that the GLO survey records can be used to reconstruct pre-European settlement forests (Bourdo 1956, Kilburn 1958, Curtis 1959).

Data Collection

GLO survey notes are held at the State Archives of Michigan, in Lansing. Data was collected from microfiche copies of the transcribed GLO survey records of Chippewa County, and entered by township into FOXPRO database files using a General Land Office Vegetation Entry (GLOVE) program developed by the Center for Remote Sensing at Michigan State University. A dictionary of codes used in each data field of the GLOVE program is presented in Appendix A. The following information from the GLO survey records was entered into the database files, and served to reference subsequent attribute point data:

1) Township number.
2) Section number.
3) The reference corner of the section line along which the surveyor was traversing.
4) The bearing in which the surveyor was traversing.
5) The distance in chains (to the hundredth decimal place) from the reference corner that the surveyor traversed before setting a line or corner post.
6) The bearing and distance in links from a line or corner post to the post's bearing trees.

The following attribute data from the GLO survey records were then entered into the database files:

1) The bearing tree species.
2) The bearing tree diameter (in inches).
3) The year in which the survey was conducted.
4) The presence and orientation of disturbances noted by the surveyors.
5) The topography of the section line, as noted by the surveyor.
6) Notes of the species of trees as observed by the surveyor in order of predominance.

Thirty-five database files were created using the GLOVE program, one for each township in the study area.

Data Analysis

Use of the C-MAP Geographic Information System

C-MAP 2.1.1 is a vector-based geographic information system (GIS) developed for use on personal computers by the Center for Remote Sensing at Michigan State University. C-MAP is specifically designed for use with federal databases in ARC/info and the GIS data formats of the State of Michigan, which include the Michigan Resource Information System (MIRIS). The C-MAP programs offer several capabilities which include creating thematically shaded maps, running statistical and data grouping operations, performing database queries on object attributes and measuring and spatially analyzing feature distributions.

Point data referenced in the FOXPRO database files required conversion into state plane coordinates before it could be used by C-MAP. Data conversion into state plane coordinates was performed by a conversion program called LOCTREE, also developed by the Center for Remote Sensing. Some error was induced in the conversion of point data to state plane coordinates. The error occurred because point data was placed by true north, south, east and west vectors originating from the referenced section corners. Such referencing did not take the convergence of lines of longitude into account (Figure 2). However, for the purposes of this study where data was sampled on a transect grid with spacing of approximately 1.61 km (1 mi) between transects, the amount of error induced by non-convergence of a vector over a maximum distance of 1.61 km can be considered negligible. A future version of LOCTREE will convert point data in the Universal Transverse Mercator system, thus eliminating convergence error.

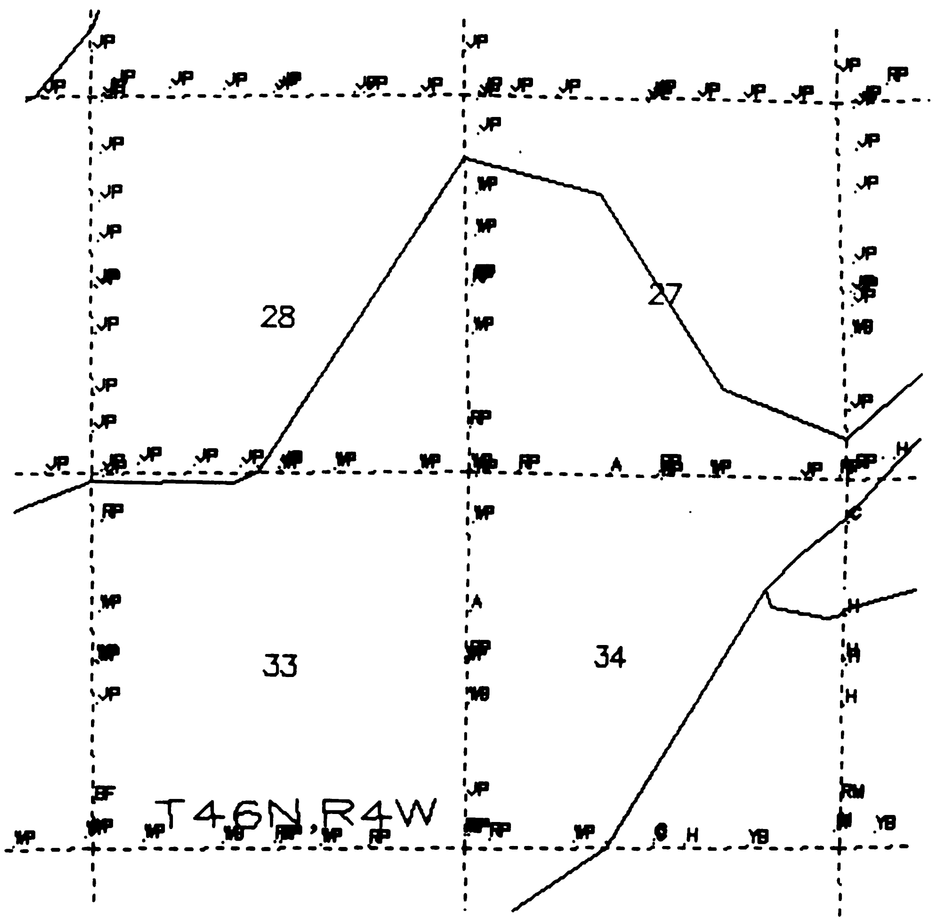

Figure 2. Example C-MAP plot of bearing trees and digitized forest type boundaries.

Once converted into state plane coordinates, tree species and topography point data were displayed by C-MAP. The topography data indicated changes in forest type as recorded by the surveyors, and tree species were used as indicators of expected forest types (See Appendix A for tree species and topography codes used). A forest type map of the study area (Figure 2) was created with the on-screen digitizing program in C-MAP, using the displayed tree species and topography point data and printed copies of the surveyor plat maps (on which the surveyors drew general forest type boundaries) to determine the placement of my forest type boundaries. Delineation of forest types was made to the greatest detail possible, based upon the criteria outlined above. In some cases the presence of a single tree indicator species (such as a single red pine in a mixed conifer swamp) provided sufficient evidence to define a forest type boundary. The resultant type map was then cleaned to correct for topological inconsistencies and the topological files were built to represent forest type polygons (defined contiguous areas). Point data were labeled by forest type using the overlay function of C-MAP, and then used for analysis of composition and structure and disturbance according to forest type.

Composition and Structure

Analysis of composition and structure was conducted on a sub-sample of the study area. The sub-sample consists of eight adjacent townships in the interior of the study area: Townships 45 north Ranges 3-6 west, and Townships 46 north Ranges 3-6 west. The sub-sample was chosen for two reasons. The first is that human influences in the study area were concentrated along the shorelines. This is to be expected since travel by water was the most expedient mode of transportation during the era. Thus, the forest in the interior can be expected to be much less perturbed by human activity, and more representative of the pre-European forests of the region. The second reason for the location of the sub-sample is that it contained substantial areas of each forest type found in the overall study area, and thus represented a sample of each. Point data for the sub-sample were exported to Quattro Pro for composition and structure analysis.

Methods for estimating density, relative density, basal area and relative dominance from GLO survey data are reviewed in Bourdo (1954) and Cottam and Curtis (1956). Two methods are described by Cottam and Curtis: 1) point to plant methods and 2) plant to plant methods. The former methods rely upon measured distances from a point to the nearest tree(s). The later methods rely upon measured distances between two trees that are nearest to each other, and not necessarily those trees nearest to a point. The 1833 and 1850 survey instructions specify that only those trees nearest to the corner being established shall be chosen as bearing trees. Trees selected as bearing trees may or may not be those trees that are closest to each other. Thus, the plant to plant methods are not suitable for use with GLO survey data.

Point to plant methods are better suited for use with GLO survey data, but have been used with varying success. The closest individual method is the simplest to use with survey data. The method is based upon the mean area (M) occupied by a tree. The square root of M is a direct indication of the spacing between trees. Thus with this method, the distances measured by surveyors from corner posts to bearing trees can be used to estimate tree density. For the closest individual method the distance from the corner post to the single closest tree is required. The mean of all measured distances has been found to equal 50% of the square root of the mean area M (Cottam et al. 1953, Morisita 1953). This method, therefore, requires multiplication of the average distance by a correction factor of 2.0, before squaring to obtain M. The mean area M can then be divided into the unit area to yield the number of trees per unit area.

In order to obtain accurate estimates of tree density using the closest individual method, the tree being sampled must be the nearest tree to the corner being established. Although surveyors were instructed to utilize the nearest trees as bearing trees when establishing a corner, there is no assurance that this was always done. Subjective biases can severely distort the results of point to plant methods.

As previously discussed, bias may be expressed by surveyor preference toward particular tree species and toward certain diameter classes of trees. The closest individual method is particularly susceptible to these biases because only one tree per point is used in calculations. To obtain estimates within 10% of true densities, the closest individual method requires a minimum of 150 sample corners. Furthermore, when trees are clumped together with open spaces between groups, the closest individual method will not yield accurate estimates of stand density (Cottam and Curtis 1956).

Spurr (1952) devised a fixed diameter method of estimating basal area, which was reviewed by Bourdo (1954). This method is well suited for use when diameter class bias is present, because it can utilize this bias to an advantage. Spurr determined that a single, randomly chosen tree from a series of plots could be used to determine basal area, according to the equation:

$$\text{(1)} \qquad \text{Basal area/acre} = \frac{(4)(302.5)\ D^{2}}{R^{2}}$$

where D equals half the diameter of the tree (in inches), R equals the plot radius (in feet, to the center of the tree) and 302.5 is a constant. Because survey trees are reported in quadrants, a multiplication factor of 4 is required so that the estimate represents all quadrants.

Bourdo (1954) found that Spurr's formula could be used, with the most frequently selected tree diameter class as D and the mean distance from the corner post for that class as R, to yield good approximations of basal area per acre. Bourdo reasoned that the diameter class most frequently chosen by surveyors as bearing trees was the most representative diameter of the forest type. The process is thus highly dependent upon determining the diameter class that is indeed most representative of the forest type. There are four methods of doing this. The most obvious is a simple count of the number of trees to determine the most frequently represented diameter class. Two other methods are determining the average diameter and the median diameter of all trees of all diameter classes. The fourth method is to determine the mean diameter based upon the mean basal area of all trees in all diameter classes. By using all four of these methods the most representative diameter class can be determined with confidence. As a further precaution against error, Spurr's formula may be applied to the three most representative diameter classes. When this is done the most representative diameter class must be used as the middle value, and the contribution of all diameter classes to basal area must be weighted by their representation in the type. Bourdo (1954) compared basal area estimates obtained using Spurr's formula to actual basal area measurements in residual old growth northern hardwoods, and concluded that good estimates of basal area per acre can be determined by using the principles defined by Spurr. Thus, Bourdo confirmed that Spurr's formula is based upon sound scientific theory.

Because all GLO surveys are probably affected to some degree by diameter class bias, I have used Spurr's formula for estimation of basal area per acre in each forest type. With basal area known, density was estimated by dividing the basal area per unit area by the mean basal area per tree. Relative density was calculated by dividing the number of individuals of any species by the total number of individuals of all species, and then multiplying by 100. Relative dominance was calculated by dividing the total basal area of a species by the total basal area of all species, and again multiplying by 100.

Disturbance Regimes

The main limitation in the use of GLO survey records for the estimation of disturbance frequencies and return intervals is that direct evidence of blowdowns and burned over land becomes blurred once forest canopy closure occurs after approximately fifteen years (Lorimer 1980a, Canham and Loucks 1984). Thus, any reference by surveyors to blowdowns and burned over land would indicate that the disturbance has probably occurred within the previous fifteen years. Fifteen years is a fairly narrow period on which to base estimates of disturbance frequency. However, given the range of approximately fifteen years over which the survey and examinations (checks for accuracy and completeness of survey work) of Chippewa County were conducted, direct evidence of blowdowns and fires may potentially be distinguished in the survey records over a thirty year period. Therefore, meaningful estimates of disturbance frequencies and return intervals can potentially be derived from GLO survey records.

The GLO surveys represent a systematic sample of Chippewa County. Surveyors were required by the 1833 and 1850 instructions to record the distance along a transect at which they encountered and departed any disturbance, and to plot its location on the township plat map. I cross-checked the plotted location of each disturbance on the plat map with the associated survey notes for each township in the study area, and found the location of each disturbance to be accurate. The most expedient method of analyzing disturbances would be to simply digitize the area of each individual disturbance event from the plat maps. There is a problem with this approach. The location along a section line and the bearing in which an individual disturbance event was running was the only information available to surveyors when drawing the location of disturbances upon the plat maps. Because the survey section lines were 1.61 km (1 mi) apart, the area of each disturbance could confidently be estimated and drawn only for disturbances large enough to intersect a survey line in at least two different locations. Other than deviating from the survey lines, surveyors had no way of knowing the course of disturbances within the interior of sections. Surveyors were not able to draw the boundaries of small disturbances when they covered less than one section in area, and intersected survey lines in only one location. Additionally, any small disturbances that were less than 2.27 km (1.41 mi) in length could potentially remain undetected by surveyors. I attempted to retroactively estimate the area of such disturbances, but concluded that areas cannot be estimated with sufficient accuracy or reliability to be used with any degree of confidence in analysis of disturbance. For these reasons, I have not used area as a basis for analysis of disturbance regimes. I have alternatively conducted analysis of disturbance by measurement of the total length of survey lines impacted by different disturbance regimes, within the different forest types.

Area line transect sampling theory was used to estimate the total number of disturbances less than 1.41 km in length from the actual number observed by the surveyors (Canham and Loucks 1984, Canham 1978, Devries 1974, Warren and Olsen 1964). If a transect of length L is placed through a population of randomly distributed disturbances, then the estimated number of disturbances (X) in each forest type can be calculated by summing sections of size s:

$$X = 0.7854 \sum_{i=1}^{n} \frac{1}{y} \tag{2}$$

where n = the number of times disturbances were noted to intercept a transect.
y = the length of the i'th intercepted disturbance (measured in miles).

0.7854 = a constant simplifying the area relationship s/2L where the grid system of survey lines provides an average of L=2 miles (3.22 km) of survey lines for the area s=1 mi^2 (2.59 km^2) in each section.

Distances are in English units for convenience of calculation only. The only information required for use of equation 2 is the length of each individual disturbance encountered along a transect.

Analysis of disturbance regimes was conducted on the entire study area. Disturbance data were segregated by forest type prior to disturbance analysis. This step was necessary because the type, frequency and scale of disturbance is dependent upon the pre-existing stand composition and structure. Disturbance lengths were determined by screen digitizing disturbance point data, merging the resultant disturbance arcs with the forest type arcs and then reading the lengths of disturbance arcs within each forest type after the resultant file was cleaned.

Equation 2 allows subdivision of disturbances into size classes. Disturbances were classified as those greater in length than 50 m, 100 m, 200 m, etc., up to a maximum of 12,800 m. The estimated total number of disturbances in each size class, with mean length less than 1600 m (one mile), were calculated using equation 2. The numbers of disturbances with lengths greater than 1600 m were determined from the numbers actually recorded in the surveyor notes. The estimated total length of section line in each size class that was affected by disturbance was

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calculated by multiplying the number of estimated disturbances by the mean length of the disturbances actually observed in each size class, and then adding the result to the total length of those disturbances actually observed.

Analysis of disturbance regimes involves the calculation of disturbance frequencies, disturbance return intervals and areas of annual disturbance. Disturbance frequency is defined as the number of disturbances per unit time in a designated area. The actual number of disturbances observed by surveyors in each forest type, were added to the additional estimated number of non-observed disturbances to yield the total number of disturbances that I used in the frequency calculations. The disturbance frequency was estimated by dividing this total number of disturbances by the number of years over which these disturbances were observed. Disturbance return intervals are defined as the number of years between two successive disturbance events in a designated area (Romme 1980), or the number of years that it would take for an entire landscape to be disturbed. It must be emphasized that the concept of return intervals can be misleading. One must recognize the heterogeneous nature of landscapes and realize that some portions of a landscape are more prone to disturbance than others. In other words, different parts of a landscape are subject to different types, combinations and rates of disturbance. Disturbance return intervals were estimated by calculating the percent distance of surveyors lines in each forest type that were affected by a particular disturbance regime over a fifteen and thirty year survey period. The annual percent affected was then divided into 100 to yield an estimate of the disturbance interval (Whitney 1986). The fifteen year interval is probably conservative with respect to disturbance frequencies and return intervals, and the thirty year interval is probably high. Both recording intervals will be reported in calculations of disturbance frequencies and return intervals. The area of annual disturbance was estimated for each forest type and disturbance regime by dividing the area of each forest type by the return interval for each disturbance regime.

RESULTS AND DISCUSSION

Surveyor Bias

Quadrant analysis of bearing trees at 343 corners in four townships (Townships 45 north, Ranges 5-6 west and Townships 46 north, Ranges 5-6 west) shows that 83, 89, 96 and 75 trees were located in the northeast, northwest, southeast and southwest quadrants of those corners respectively. If bearing trees were chosen randomly, with no bias toward diameter or species, then one would expect to find 85.75 trees in each quadrant. A chi square analysis shows that a hypothesis of random departures of the observed bearing tree counts in each quadrant from the expected value of 85.75 trees cannot be rejected (X^2=2.7843, 3 df, P > 0.3). Quadrant analysis of bearing trees thus reveals no indication of bias toward specific diameter classes or tree species.

In the northern hardwood, mixed conifer/deciduous upland and mixed conifer swamp forest types the low variances of mean bearing tree distances indicates that there was little bias toward either specific diameters or tree species (Tables 3-5).

Initial analysis of the diameter class distribution of the mixed pine forest type showed that the 10, 15 and 20 cm

Table 3. Analysis of mean distances of bearing trees for diameter and species bias in the northern hardwood forest type.

Diameter Class[1] (cm)	Tree Count	Mean Distance (m)	Species[2]	Tree Count	Mean Distance (m)
15	13	7.7	BE	19	8.2
20	15	8.6	H	58	9.2
25	23	8.6	RM	11	9.7
30	24	8.7	SM	45	9.0
35	23	8.2	YB	25	7.5
40	21	10.0			
45	13	9.5			
50	11	7.9			
Sum	143			158	
Mean		8.7			8.7
Std Dev		0.8			0.9
Variance		0.6			0.8

[1] Diameter classes range from 10 to 90 cm, but outlying diameter classes were excluded due to under-representation.

[2] BE = Beech, H = hemlock, RM = red maple, SM = sugar maple, YB = yellow birch.

Table 4. Analysis of mean distances of bearing trees for diameter and species bias in the mixed conifer/deciduous upland forest type.

Diameter Class[1] (cm)	Tree Count	Mean Distance (m)	Species[2]	Tree Count	Mean Distance (m)
10	11	8.8	BF	11	10.2
15	24	8.3	H	32	8.5
20	24	7.0	RM	8	8.6
25	18	7.2	SM	6	8.8
30	16	10.0	SP	36	7.6
35	13	9.8	WP	24	8.5
			YB	12	7.4
Sum	106			129	
Mean		8.5			8.5
Std Dev		1.3			0.9
Variance		1.6			0.8

[1] Diameter classes range up to 100 cm, but outlying diameter classes were excluded due to under-representation.

[2] BF = balsam fir, H = hemlock, RM = red maple, SM = sugar maple, SP = spruce, WP = white pine, YB = yellow birch.

Table 5. Analysis of mean distances of bearing trees for diameter and species bias in the mixed conifer swamp forest type.

Diameter Class[1] (cm)	Tree Count	Mean Distance (m)	Species[2]	Tree Count	Mean Distance (m)
5	6	8.8	C	77	7.6
10	46	9.0	H	8	10.3
15	82	8.2	JP	15	8.5
20	46	8.3	SP	83	7.5
25	39	8.0	T	67	9.8
30	28	8.5	WP	8	8.2
35	9	7.8			
Sum	256			264	
Mean		8.4			8.7
Std Dev		0.4			1.2
Variance		0.2			1.3

[1] Diameter classes range up to 90 cm, but outlying diameter classes were excluded due to under-representation.

[2] C = cedar, H = hemlock, JP = jack pine, SP = spruce, T = tamarack, WP = white pine.

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diameter classes represented the three highest densities of all the diameter classes. Table 6 shows that the 10, 15 and 20 cm diameter class bearing tree distances can also be considered a sub-sample of the entire diameter class distribution. The 10 through 20 cm diameter classes are grouped around a mean sub-sample distance of 9.2 meters, with a standard deviation and variance of 0.5 and 0.3 respectively. The bearing tree distances of diameter classes 25 through 50 are closely grouped around a mean of 13.0 meters, with a standard deviation of 0.6 and a variance of 0.3. Table 6 also shows the mean bearing tree distance of jack pine to be 8.9 meters. Given the seral nature of jack pine, its dependence upon periodic stand replacing fires for regeneration and the relatively small diameter distribution characteristic of nearly pure jack pine forests, I have separated the mixed pine forest type into a subtype of nearly pure jack pine and a subtype of mixed white and red pine (of which I retain the name of "mixed pine"). Subsequently, the low variances of mean bearing tree distances indicate that there is no bias toward either specific diameter classes or species in the mixed pine or jack pine forest types.

The mixed conifer/deciduous lowland forest type shows some moderate bias toward the 15 and 20 cm diameter classes, but there is no indication of any significant bias toward a specific tree species (Table 7). The diameter class bias may also result from a difference in stand structure. If

Table 6. Analysis of mean distances of bearing trees for diameter and species bias in the mixed pine and jack pine forest types.

Diameter Class[1] (cm)	Tree Count	Mean Distance (m)	Species[2]	Tree Count	Mean Distance (m)
10	27	9.0	JP	71	8.9
15	46	8.8			
20	28	9.8			
Sum	101			71	
Mean		9.2			8.9
Std Dev		0.5			0
Var		0.3			0
25	18	12.7	RP	63	12.5
30	30	13.2	WP	80	11.7
35	13	13.0			
40	9	13.9			
45	17	12.9			
50	9	12.2			
Sum	96			143	
Mean		13.0			12.1
Std Dev		0.6			0.6
Variance		0.3			0.3

[1] Diameter classes range from 5 to 75 cm, but outlying diameter classes were excluded due to under-representation.

[2] JP = jack pine, RP = red pine, WP = white pine.

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Table 7. Analysis of mean distances of bearing trees for diameter and species bias in the mixed conifer/deciduous lowland forest type.

Diameter Class[1] (cm)	Tree Count	Mean Distance (m)	Species[2]	Tree Count	Mean Distance (m)
10	8	7.0	BF	6	10.1
15	8	11.7	H	5	9.6
20	10	11.7	SP	10	8.3
25	6	7.9	T	11	8.2
30	3	6.7	WP	4	7.1
35	4	8.7			
Sum	39			40	
Mean		9.0			8.7
Std Dev		2.2			1.2
Variance		5.0			1.4

[1] Diameter classes range from 2 to 40 inches, but outlying diameter classes were excluded due to under-representation.

[2] BF = balsam fir, H = hemlock, SP = spruce, T = tamarack, WP = white pine.

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the 15 and 20 cm diameter classes were statistically the two most numerous classes in the type, then one would expect these classes to be used as bearing trees with a greater frequency than other classes.

In summary, the only evidence of bias was toward the 15 and 20 cm diameter classes in the mixed conifer/deciduous lowland forest type. This bias is of a moderate nature. Therefore, I have concluded that the GLO surveys for the study area are mostly free of bias toward any specific diameter classes or tree species.

Forest Composition and Structure

Six distinct forest types (Figure 3) were discernable from the tree species and topography data grid of the study area:

1) Northern Hardwoods
2) Mixed Pine
3) Jack Pine
4) Mixed Conifer/Deciduous Upland
5) Mixed Conifer/Deciduous Lowland
6) Mixed Conifer Swamp

The forest types are accurate to the scale of 1.61 km (1 mile). This seemingly coarse scale is unavoidable due to the nature of survey records, where the survey represents a sample grid with a distance interval of 1.61 km between transects. While the broad patterns of forest types are essentially accurate to within less than 1.61 km, one must recognize that a transition zone often (but not always) exists between two adjacent forest types. Thus, these rather coarse-scaled forest type boundaries are actually

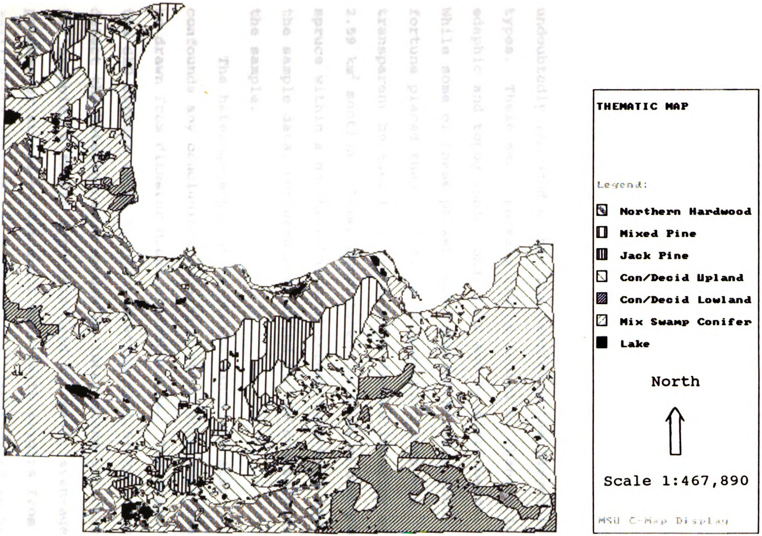

Figure 3. Pre-European settlement forest types of western Chippewa County, Michigan.

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represented by transition zones. C-MAP 2.1.1 does not have the capability to define and separate out these transition zones and I deemed it too laborious a task to digitize them by hand. Consequently, transition zones exist, but are not visible in the forest type boundaries. Another consequence of the coarse scale of the forest types is that a complete picture of the heterogeneous nature of the landscape is not obtained. Some small pockets of different forest types are undoubtedly imbedded within the fabric of the larger forest types. These small pockets can be caused by changes in edaphic and topographic conditions and by disturbance. While some of these pockets are apparent because good fortune placed them on a survey transect, others are transparent because they are located in the interior of a 2.59 km^2 section. Thus, inconsistencies such as red pine or spruce within a northern hardwood forest type were found in the sample data, but were attributed to the coarse scale of the sample.

The heterogeneous nature of the landscape also confounds any conclusions regarding stand structure that may be drawn from diameter class distributions. The scale of the GLO surveys (with transect spacing of 1.61 km) cannot detect the heterogeneous nature of inter-stand structure. For example, a forest type comprised of small, even-aged patches or stands of different ages (with origins from small-scale disturbances) could be misinterpreted as being uneven-aged when diameter data is taken across all patches a

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and then viewed from a landscape perspective. The only forest type where heterogeneity may not confound diameter class distribution is the jack pine type, where large scale fire disturbance probably resulted in a more homogeneous landscape.

Maps detailing the forest cover types in each township of the study area are presented in Appendix B. Density, basal area and mean DBH estimates for each forest type are shown in Table 8. Discussion of each forest type follows below.

The Northern Hardwood Forest Type

The northern hardwood type had the highest basal area and density values of all the forest types (35 m^2/ha and 348 TPH). Table 9 and Figures 4 and 5 show the relative density and dominance of the tree species in the northern hardwood forest type. The virgin northern hardwood forests of the sub-sample study area were dominated by eastern hemlock and sugar maple in both density and basal area. Hemlock was predominant in terms of basal area (9.8 m^2/ha), while sugar maple was dominant in density (99 TPH). Yellow birch and beech were also relatively important in the forest type, but beech (2.1 m^2/ha) was not nearly as dominant as yellow birch (6.0 m^2/ha). Other indicator species of a northern hardwood forest such as balsam fir, basswood and ironwood were also present as minor components in the sub-sample area. An understory of hazel was sometimes noted by surveyors in the

Table 8. Basal area, density and mean DBH estimates for the pre-European settlement forest types of western Chippewa County, Michigan.

Forest Type	Estimated Density (TPH)	Estimated BA (m^2/ha)	Mean DBH (cm)
Northern Hardwood	348 (141)[1]	35 (154)	33 (13)
Mixed Pine	81 (33)	8 (36)	31 (12)
Jack Pine	326 (132)	8 (33)	18 (7)
Mixed Conifer/ Decid. Upland	287 (116)	21 (92)	28 (11)
Mixed Conifer/ Decid. Lowland	269 (109)	15 (66)	23 (9)
Mixed Conifer Swamp	314 (127)	14 (60)	20 (8)

[1] Numbers in parentheses are density in trees/acre, basal area in ft^2/acre and DBH in inches.

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Table 9. Relative density and dominance of tree species in the northern hardwood forest type.

Species[2]	Tot #	Relative Density	Trees Per Hectare	Total Basal Area (m^2)	Relative Dominance	BA per Hectare (m^2/ha)
A	6	0.7	2.5 (1.0)[1]	0.2 (2.0)	0.2	0.1 (0.3)
BE	86	10.4	36.1 (14.6)	5.0 (53.6)	5.9	2.1 (9.1)
BF	55	6.6	23.2 (9.4)	2.0 (21.2)	2.3	0.8 (3.6)
BO	2	0.2	0.7 (0.3)	0.6 (5.9)	0.7	0.2 (1.0)
BW	4	0.5	1.7 (0.7)	0.5 (5.4)	0.6	0.2 (0.9)
H	170	20.5	71.7 (29.0)	23.5 (252.3)	27.8	9.8 (42.9)
IW	3	0.4	1.2 (0.5)	0.1 (0.7)	0.1	0.02 (0.1)
RM	68	8.2	28.7 (11.6)	3.3 (35.5)	3.9	1.4 (6.0)
RP	2	0.2	0.7 (0.3)	0.3 (3.5)	0.4	0.1 (0.6)
SM	235	28.4	98.8 (40.0)	19.2 (206.1)	22.8	8.0 (35.0)
SP	30	3.6	12.6 (5.1)	2.0 (21.3)	2.4	0.8 (3.6)
WB	9	1.1	3.7 (1.5)	0.7 (7.1)	0.8	0.3 (1.2)
WP	42	5.1	17.8 (7.2)	12.7 (136.7)	15.1	5.3 (23.2)
YB	116	14.0	48.9 (19.8)	14.4 (154.7)	17.1	6.0 (26.3)
Sum	828	100	348 (141)	84 (906)	100	35 (154)

[1] Numbers in parentheses are trees/acre, ft^2 and ft^2/acre respectively.

[2] A = aspen, BE = beech, BF = balsam fir, BO = black/red oak, BW = basswood, H = hemlock, IW = ironwood, RM = red maple, RP = red pine, SM = sugar maple, SP = spruce, WB = white birch, WP = white pine, YB = yellow birch.

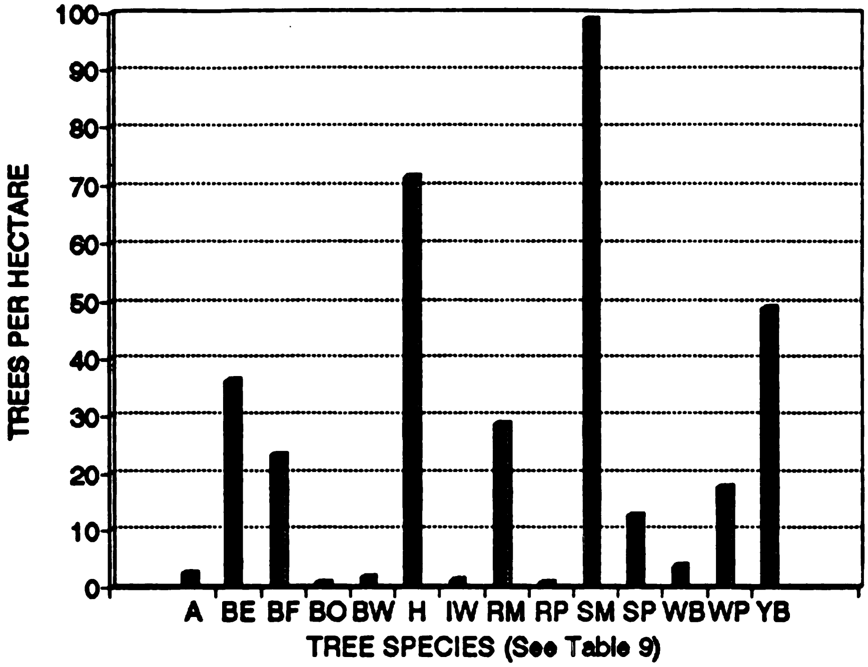

Figure 4. Density of tree species in the northern hardwood forest type.

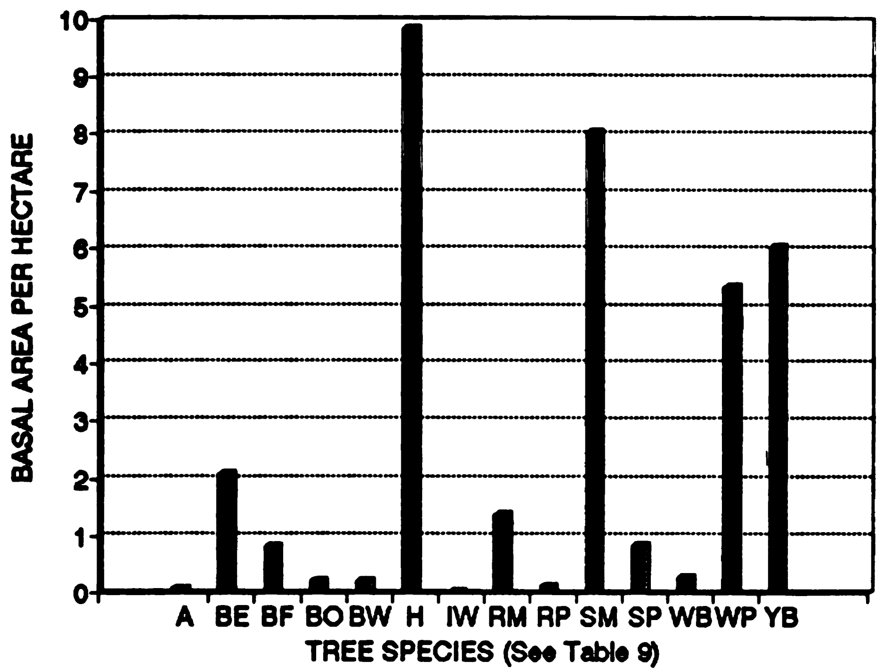

Figure 5. Basal area of tree species in the northern hardwood forest type.

northern hardwood forest type.

There was also a white pine component in the northern hardwood forest type. Although low in density (18 TPH), white pine was a dominant in terms of basal area (5.3 m^2/ha). The two northern red/black oak trees in the sub-sample study area were 51 and 66 cm in diameter. Thus, oak was a minor component in this forest type. The early-successional species aspen and white birch were also present within the forest type. Diameters for aspen ranged from 15 to 31 cm. Diameters for white birch ranged from 13 to 56 cm.

A diameter class distribution of the northern hardwood forest type is presented in Figure 6. Appendix C contains

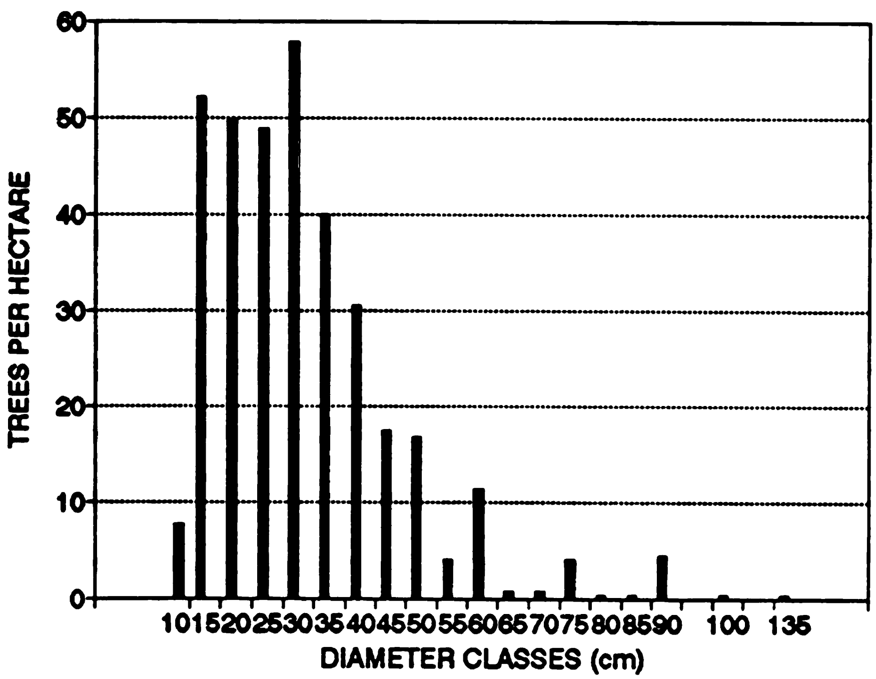

Figure 6. Diameter distributions of tree species in the northern hardwood forest type.

diameter class distribution graphs for all of the significant species in the northern hardwood forest type. It is evident from the diameter class distributions that some very large trees occurred within the forest type. The mean and median diameters of all sample trees was in the 30 cm class. The mean diameter based upon the mean basal area per tree was 36 cm. Diameter classes less than 15 cm were under-represented in the sample because very small trees were unsuitable for blazing and recording of township, range and section corner data. I believe that it is highly probable that advance regeneration of tolerant species was occurring in the understory of the virgin northern hardwood forests of the sub-sample area. Due to landscape heterogeneity I cannot definitively conclude from the diameter class distributions that the northern hardwood forests of the study area were uneven-aged. Disturbance, ranging in size from individual tree fall gaps to larger windfall events, probably created a mosaic of forest patches or stands. The presence of seral aspen, oak, white birch and red pine, and mid-tolerant white pine provide evidence of the heterogeneous nature of the landscape. The composition of stands probably ranged from even-aged seral species to uneven-aged or possibly even-aged late successional species. Therefore, the northern hardwood forest type cannot be broadly classified as uneven-aged, although large patches of it undoubtedly were.

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The Mixed Pine Forest Type

The mixed pine type had a very low density (81 TPH), and a basal area similar to the jack pine type (8 m^2/ha). Table 10 and Figures 7 and 8 show the relative density and dominance of tree species in the mixed pine forest type. For convenience, both the mixed pine and jack pine forest types are shown in Table 10. The mixed pine type was dominated in both density and basal area by white and red pine. White pine exhibited a density of 36 TPH and a basal area of 5.2 m^2/ha. Red pine had a density of 27 TPH and a basal area of 2.4 m^2/ha. Minor components of the mixed pine forest included aspen, balsam fir, northern red/black oak, eastern hemlock, red maple, spruce, white birch and yellow birch. Both large and small areas of disturbance that were thickly stocked with seral aspen and white birch saplings were noted by the surveyors. The oak component was also seral, with the two sampled individuals being 8 and 10 cm in diameter. The mid to late-successional species balsam fir, hemlock, red maple, spruce and yellow birch were found either in the understory, or more likely in small pockets on more fertile sites. Some of these better sites where white pine dominated may have been converting to the northern hardwood forest type.

Figure 9 shows the diameter class distribution of the mixed pine forest type. Appendix D contains the diameter class distributions of significant species found in the mixed pine forest type. Once again, any conclusions

Table 10. Relative density and dominance of tree species in the mixed pine and jack pine forest types.

Species[2]	Tot #	Relative Density	Trees Per Hectare	Total Basal Area (m^2)	Relative Dominance	BA per Hectare (m^2/ha)
A	25	3.2	2.7 (1.1)[1]	0.6 (6.4)	0.8	0.1 (0.3)
BF	12	1.6	1.2 (0.5)	0.3 (3.1)	0.4	0.02 (0.1)
BO	2	0.3	0.2 (0.1)	0.01 (0.1)	0.02	0.002 (0.01)
C	3	0.4	0.2 (0.1)	0.2 (1.6)	0.2	0.02 (0.1)
H	20	2.6	2.2 (0.9)	1.7 (18.0)	2.2	0.2 (0.8)
RM	1	0.1	0.1 (<0.1)	0.1 (0.8)	0.1	0.01 (0.03)
RP	255	32.9	26.7 (10.8)	22.8 (245.0)	29.8	2.4 (10.7)
SP	42	5.4	4.4 (1.8)	0.9 (9.4)	1.1	0.1 (0.4)
T	7	0.9	0.7 (0.3)	0.2 (1.8)	0.2	0.02 (0.1)
WB	56	7.2	5.9 (2.4)	0.9 (9.3)	1.1	0.1 (0.4)
WP	339	43.7	35.6 (14.4)	48.4 (520.0)	63.2	5.2 (22.8)
YB	14	1.8	1.5 (0.6)	0.7 (7.1)	0.9	0.1 (0.3)
Sum	776	100	81 (33)	77 (823)	100	8 (36)
JP	378	100	326 (132)	8.85 (95.11)	100	8 (33)

[1] Numbers in parentheses are trees/acre, ft^2 and ft^2/acre respectively.

[2] A = aspen, BF = balsam fir, BO = black/red oak, C = cedar, H = hemlock, JP = jack pine, RM = red maple, RP = red pine, SP = spruce, T = tamarack, WB = white birch, WP = white pine, YB = yellow birch.

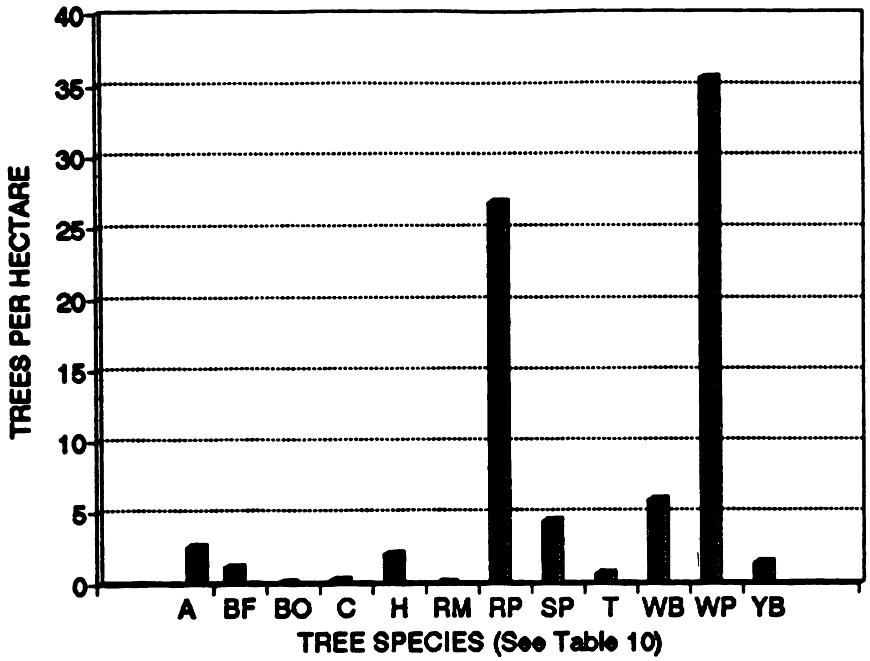

Figure 7. Density of tree species in the mixed pine forest type.

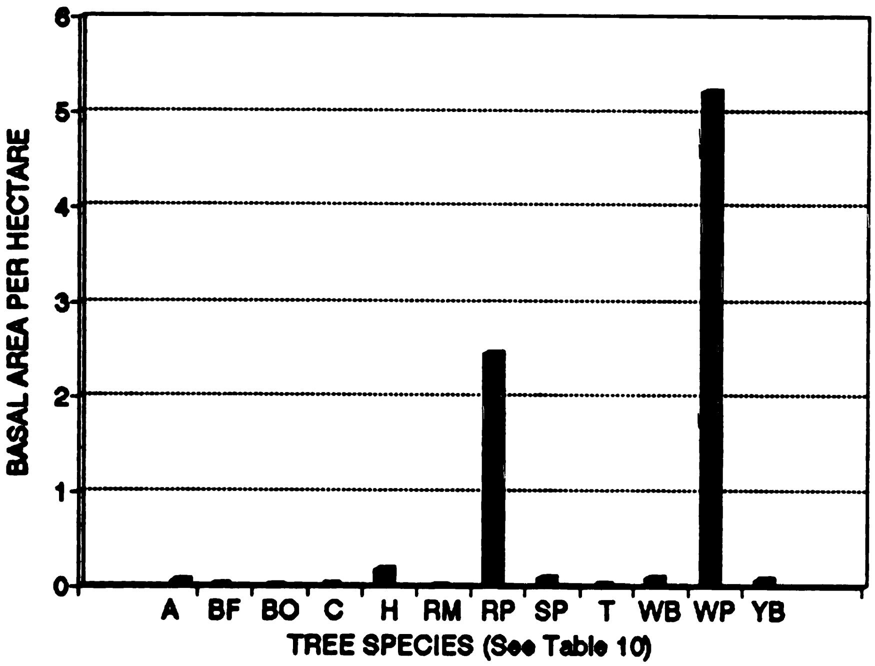

Figure 8. Basal area of tree species in the mixed pine forest type.

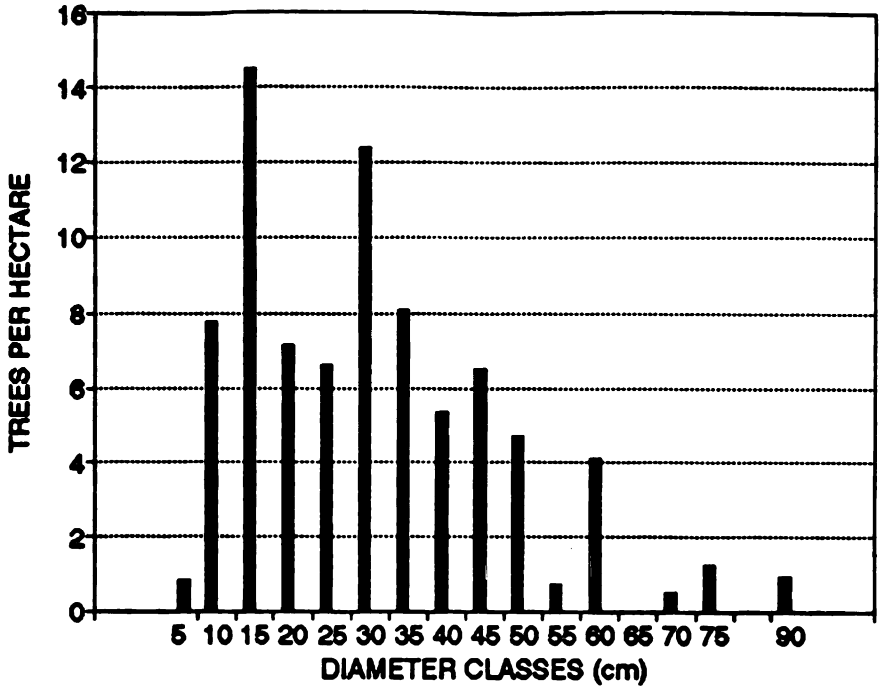

Figure 9. Diameter distributions of tree species in the mixed pine forest type.

regarding age structure are confounded by the heterogeneous nature of the landscape. The long right hand tail of the diameter class distribution (Figure 9) may indicate residual survivors of disturbance. The very low density of 81 TPH suggests that the virgin mixed pine forest of the study area had a very open, park-like structure. Numerous groves of white and red pine were noted by the surveyors. The surveyors frequently referred to areas of mixed pine as "openings", which lends further credence to an open, park-like structure. No understory or ground flora data were recorded in these groves and the pole size diameter classes are probably under-represented in Figure 9, so the degree to which advance regeneration was occurring is unknown.

However, the thick bark of mature pine in these groves would be very resistant to the periodic fires which occurred within this forest type, while high mortality would be expected in the seedling and pole size classes. Consequently, one would expect the diameter distributions of white and red pine to show large numbers of mid to large sized trees, some very large monarchs and relatively few smaller diameter trees. Indeed, the mean and median diameters of all sample trees in the mixed pine forest type were in the 30 cm class. The mean diameter based upon the mean basal area per tree was 36 cm.

I theorize that hemlock may have occurred within the groves of white and red pine noted by the surveyors, and given its shade tolerance was probably uneven-aged in distribution. Since hemlock has very exacting moisture requirements for seed maturation and germination, many of the groves where hemlock was present were probably located in the ravines of stream bottoms, where more moist and favorable microclimates existed. These are also the probable sites in which spruce was located. I suspect that significant regeneration of hemlock in the 5 and 10 cm classes was present in these more fire resistant habitats within the mixed pine forest type, but was not reported due to lack of suitability as bearing trees.

Seral aspen and white birch probably existed in even-aged patches within the mixed pine landscape. Large areas of windthrow were noted by the surveyors within the mixed pine forest type, and in addition to the remnant white and red pine it was reported to be thickly stocked with aspen and white birch saplings. This fact, together with the open park-like structure, the tendency of white and red pine to occur in groves, the fire resistant nature of mature pine and the ravine microclimates, suggest that the mixed pine forest type was very heterogeneous. This heterogeneity was probably manifested in a mosaic of both even and uneven-aged stands within the forest type.

The Jack Pine Forest Type

The jack pine forest type was often referred to as thickets by the surveyors. The density of the forest type confirms why jack pine stands were referred to as thickets. They had a high density of 326 TPH and a low basal area of 8 m^2/ha, and were comprised of nearly pure jack pine (Table 10). The very few monarch red and white pine that occurred within the jack pine forest type were excluded from the density and basal area calculations.

Figure 10 shows the diameter class distribution of the jack pine forest type. I do not believe that landscape heterogeneity has confounded the diameter class distribution to a significant degree, and an even-aged distribution is suggested. An even-aged structure is expected given the seral nature of jack pine, its predisposition for stand replacing fires and its dependence upon fire for regeneration. The mean and median diameter of all sampled

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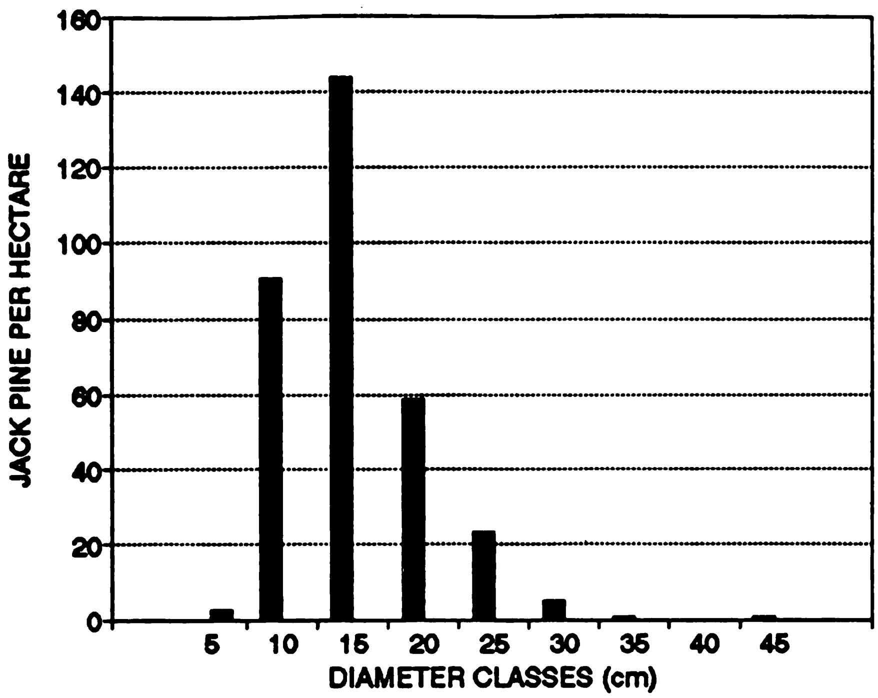

Figure 10. Diameter distributions of tree species in the jack pine forest type.

jack pine trees was in the 15 cm class. The mean diameter based upon the mean basal area per tree was also in the 15 cm class. Very few jack pine apparently survived periodic fire disturbance to reach the larger diameter classes, and the jack pine landscape appears to have been quite homogeneous.

The Mixed Conifer/Deciduous Upland Forest Type

The mixed conifer/deciduous upland forest type also has a relatively high density (287 TPH), but a significantly lower basal area (21 m^2/ha) than the northern hardwood type (35 m^2/ha). Table 11 and Figures 11 and 12 show the relative density and dominance of tree species in the mixed

Table 11. Relative density and dominance of tree species in the mixed conifer/deciduous upland forest type.

Species[2]	Tot #	Relative Density	Trees Per Hectare	Total Basal Area (m^2)	Relative Dominance	BA per Hectare (m^2/ha)
A	12	1.6	4.50 (1.8)[1]	0.5 (5.1)	0.9	0.2 (0.8)
BA	8	1.1	3.00 (1.2)	0.3 (3.0)	0.5	0.1 (0.5)
BE	2	0.3	0.7 (0.3)	0.1 (0.9)	0.2	0.02 (0.1)
BF	78	10.2	29.4 (11.9)	2.8 (30.2)	5.0	1.1 (4.6)
C	64	8.4	24.0 (9.7)	3.5 (38.1)	6.3	1.3 (5.8)
H	131	17.2	49.2 (19.9)	13.7 (146.7)	24.3	5.1 (22.4)
JP	31	4.1	11.6 (4.7)	1.0 (10.2)	1.7	0.4 (1.6)
RM	38	5.0	14.3 (5.8)	2.2 (23.8)	3.9	0.8 (3.6)
RP	11	1.4	4.2 (1.7)	1.1 (11.6)	1.9	0.4 (1.8)
SM	25	3.3	9.4 (3.8)	1.4 (15.4)	2.6	0.5 (2.4)
SP	151	19.8	56.8 (23.0)	5.7 (61.2)	10.1	2.1 (9.3)
T	38	5.0	14.3 (5.8)	1.3 (14.1)	2.3	0.5 (2.2)
WB	21	2.8	7.9 (3.2)	0.9 (10.0)	1.7	0.3 (1.5)
WP	83	10.9	31.1 (12.6)	15.7 (168.8)	28.0	5.8 (25.7)
YB	70	9.2	26.2 (10.6)	6.0 (64.2)	10.6	2.2 (9.8)
Sum	763	100	287 (116)	56 (603)	100	21 (92)

[1] Numbers in parentheses are trees/acre, ft^2 and ft^2 /acre respectively.

[2] A = aspen, BA = black ash, BE = beech, BF = balsam fir, C = cedar, H = hemlock, JP = jack pine, RM = red maple, RP = red pine, SM = sugar maple, SP = spruce, T = tamarack, WB = white birch, WP = white pine, YB = yellow birch.

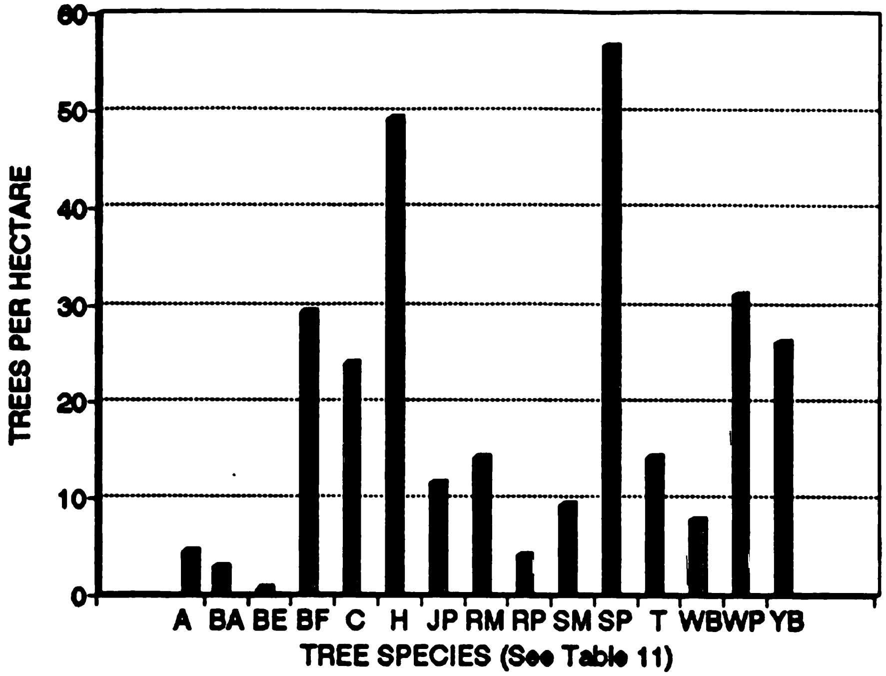

Figure 11. Density of tree species in the mixed conifer/deciduous upland forest type.

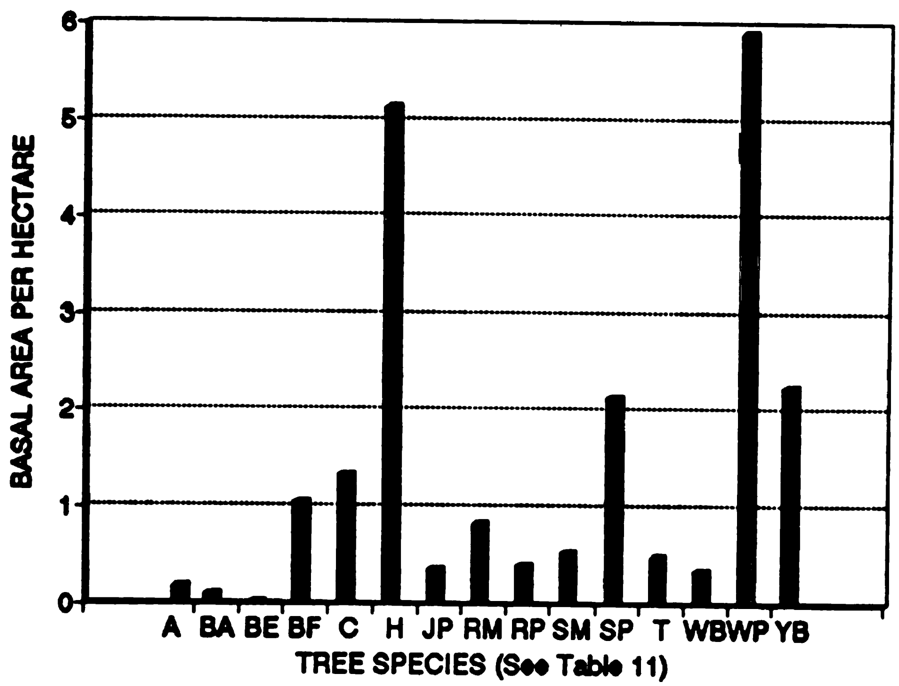

Figure 12. Basal area of tree species in the mixed conifer/deciduous upland forest type.

conifer/deciduous upland forest type. Spruce, eastern hemlock, white pine, balsam fir and yellow birch were the predominant tree species of this forest type, with red maple also present in significant proportions. White pine and hemlock were dominant in terms of basal area (5.8 and 5.1 m^2/ha respectively). Spruce and hemlock had the greatest densities of any species in the forest type (57 and 49 TPH respectively). Other species that were found within the forest type were aspen, beech, jack pine, red pine, sugar maple and white birch. The mixed conifer/deciduous upland forest type was apparently a mosaic of poorly drained, well drained and excessively drained soils, with well drained sites predominating. This would explain the black ash, cedar and tamarack, versus the jack and red pine components of the forest type, which typically occur upon poorly and excessively sites drained respectively.

The diameter distribution of the mixed conifer/deciduous upland forest type is shown in Figure 13. Appendix E contains diameter distribution graphs for the most significant species in the forest type. The smaller diameter classes are probably under-represented in the sample due to non-suitability as bearing trees. The diameter distribution is again confounded by the spatial heterogeneity of the landscape, thus precluding any definitive conclusions regarding stand structure. The mean and median diameters of all sample trees was in the 25 cm class. The mean diameter based upon the mean basal area per

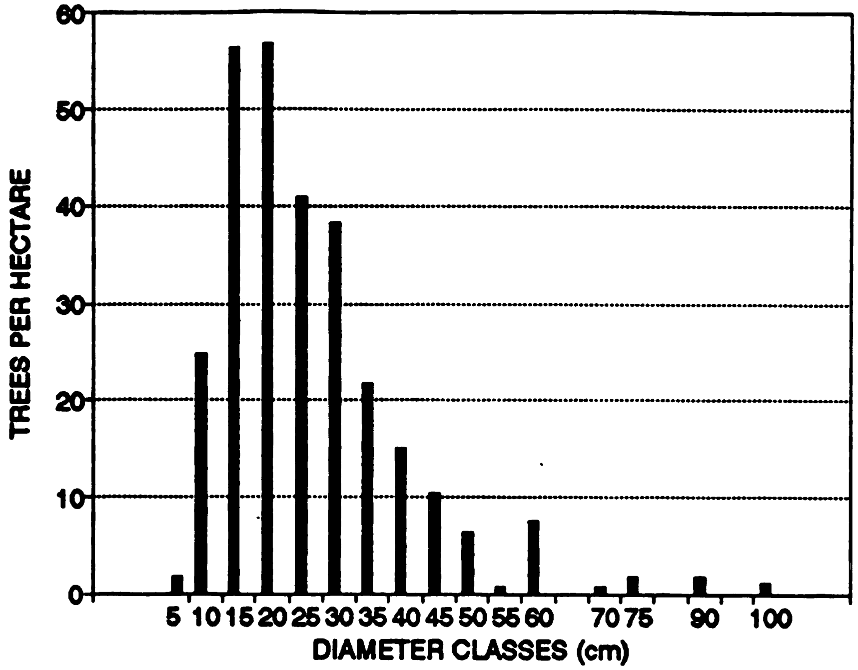

Figure 13. Diameter distributions of tree species in the conifer/deciduous upland forest type.

tree was 30 cm. It is evident from the diameter class distributions that some very large trees occurred within the mixed upland type.

Since hemlock often occurs in groves and has very exacting regeneration requirements it is possible that some hemlock existed in stratified cohorts, with at least two distinct canopy classes. These cohorts may have been even-aged. However, hemlock is very tolerant, grows extremely slowly in its early growth stages and can persist in a suppressed canopy position for up to 200 years (Tubbs 1977). Thus, any apparent even-agedness of the stratified canopy layers may be deceiving, and some of the hemlock stands were, therefore, probably uneven-aged.

Red pine and jack pine probably existed in even-aged cohorts on smaller pockets of excessively drained soil within the mixed upland forest type. Cedar and tamarack probably occurred upon poorly drained microsites within the mixed upland forest type. Sugar maple probably occurred upon well drained, morainal features throughout the forest type, as a late successional species. Aspen was probably predominant within areas of disturbance as a seral species, in even-aged cohorts. Overall, the wide variety of tree species (each with very different physiological characteristics and site requirements) suggest that the mixed conifer/deciduous upland forest type was quite heterogeneous in composition and structure across the landscape in which it occurred, probably being a compilation of even-aged and uneven-aged stands of various combinations of species.

The Mixed Conifer/Deciduous Lowland Forest Type

The mixed conifer/deciduous lowland type has a slightly higher basal area (15 m^2/ha), but is also less dense (269 TPH) than the mixed conifer swamp type. Table 12 and Figures 14 and 15 show the density and dominance of tree species in the forest type. The dominant species in the forest type were white pine, spruce and tamarack. White pine was the clear dominant, with almost twice the basal area (4.6 m^2/ha) of any other species in the forest type. Spruce and tamarack were dominant in terms of density with

Table 12. Relative density and dominance of tree species in the mixed conifer/deciduous lowland forest type.

Species[2]	Tot #	Relative Density	Trees Per Hectare	Total Basal Area (m^2)	Relative Dominance	BA per Hectare (m^2/ha)
A	10	5.2	14.1 (5.7)[1]	0.3 (2.9)	2.5	0.4 (1.7)
BA	2	1.0	2.7 (1.1)	0.04 (0.4)	0.4	0.1 (0.2)
BF	18	9.4	25.2 (10.2)	0.5 (5.0)	4.4	0.7 (2.9)
BR	1	0.5	1.5 (0.6)	0.01 (0.1)	0.1	0.02 (0.1)
C	17	8.9	24.0 (9.7)	1.0 (10.9)	9.4	1.4 (6.2)
H	12	6.3	16.8 (6.8)	1.0 (10.3)	8.9	1.3 (5.9)
RM	4	2.1	5.7 (2.3)	0.2 (1.8)	1.5	0.2 (1.0)
RP	5	2.6	6.9 (2.8)	0.8 (8.8)	7.6	1.1 (5.0)
SM	2	1.0	2.7 (1.1)	0.2 (1.6)	1.4	0.2 (0.9)
SP	57	29.7	80.1 (32.4)	1.9 (20.0)	17.3	2.6 (11.4)
T	39	20.3	54.6 (22.1)	1.3 (13.7)	11.8	1.8 (7.8)
WB	3	1.6	4.2 (1.7)	0.1 (1.5)	1.3	0.2 (0.9)
WP	17	8.9	24.0 (9.7)	3.3 (35.7)	30.8	4.6 (20.3)
YB	5	2.6	6.9 (2.8)	0.3 (3.1)	2.7	0.4 (1.8)
Sum	192	100	269 (109)	11 (116)	100	15 (66)

[1] Numbers in parentheses are trees/acre, ft^2 and ft^2/acre respectively.

[2] A = aspen, BA = black ash, BF = balsam fir, BR = bur oak, C= cedar, H = hemlock, RM = red maple, RP = red pine, SM = sugar maple, SP = spruce, T = tamarack, WB = white birch, WP = white pine, YB = yellow birch.

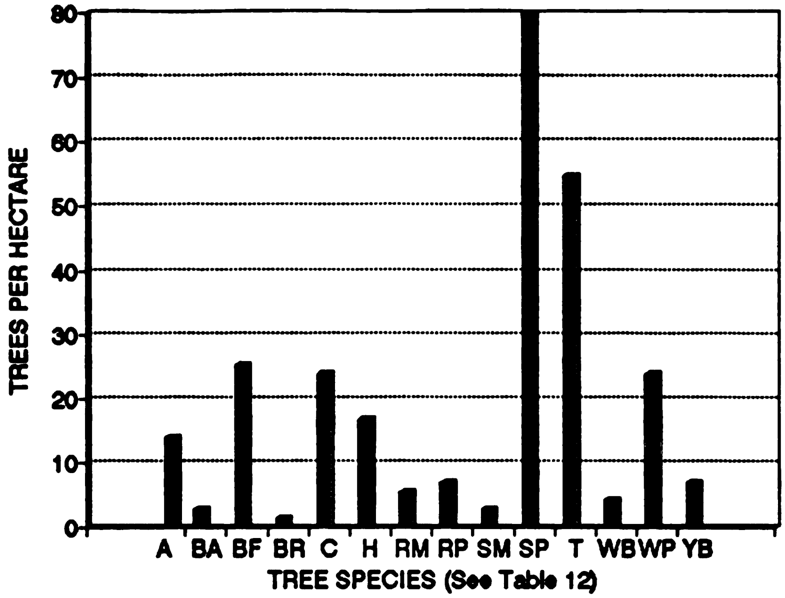

Figure 14. Density of tree species in the mixed conifer/deciduous lowland forest type.

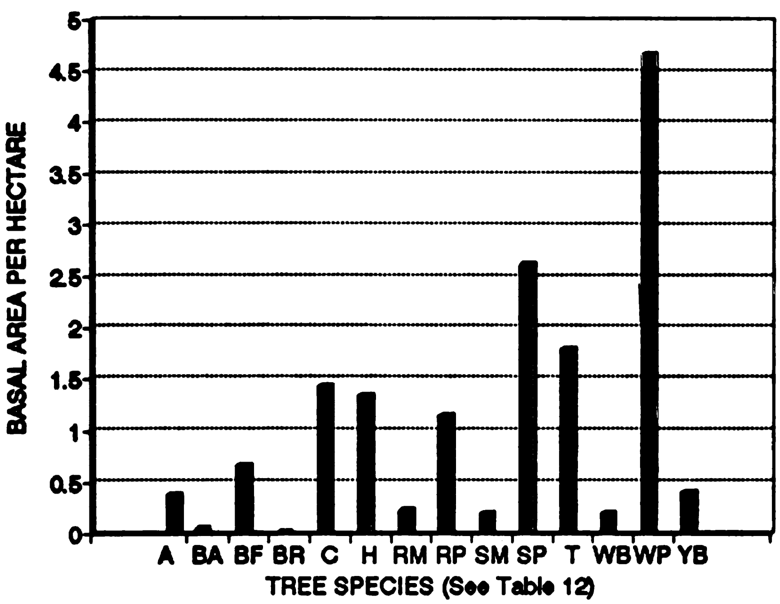

Figure 15. Basal area of tree species in the mixed conifer/deciduous lowland forest type.

80 and 55 TPA respectively. Northern white cedar, balsam fir and eastern hemlock also occurred in significant densities. Other species that occurred within the forest type were aspen, black ash, bur oak, red maple, sugar maple, white birch and yellow birch. Aspen, yellow birch and red maple were the most significant of these minor species.

The major difference between the mixed conifer/deciduous lowland and mixed conifer swamp forest type was not the species composition of the types. Both forest types were composed of similar species, with the jack pine component of the mixed conifer swamp being absent in the mixed conifer/deciduous lowland type. The major difference between the two forest types was the relative proportions of species within both types. There was much greater parity in the density of species in the mixed conifer/deciduous upland forest type. Cedar was not nearly as dominant, and hemlock and balsam fir were relatively more dominant in terms of density and basal area. Most significantly, the relative density of the hardwood deciduous component of the forest type was much higher than in the mixed conifer swamp forest type.

Figure 16 shows the diameter class distribution of the mixed conifer/deciduous lowland forest type. The moderate bias toward trees in the 15 and 20 cm diameter classes is evident in the distribution. Appendix F contains the diameter class distributions of significant species within the forest type. The smaller diameter classes are again

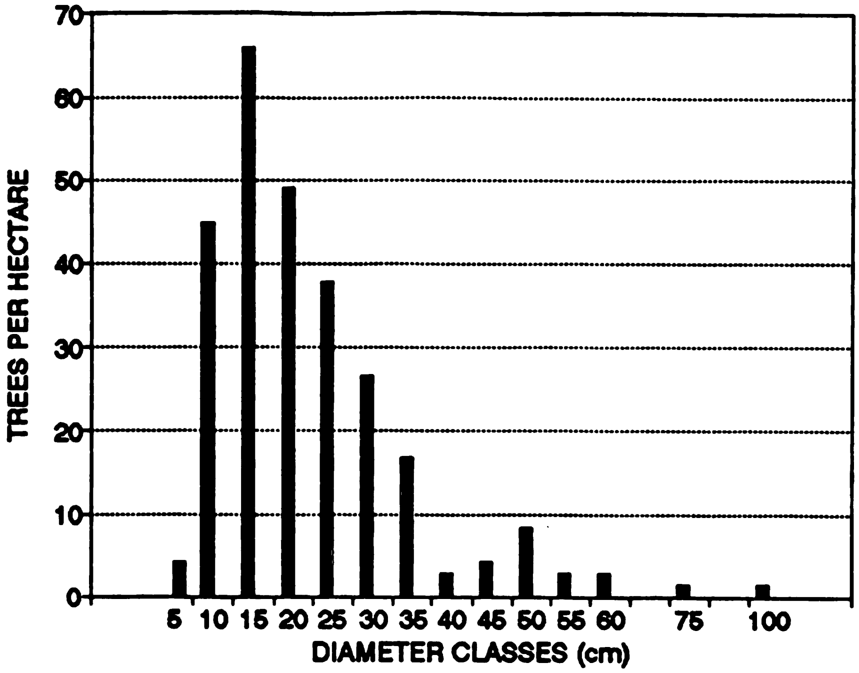

Figure 16. Diameter distributions of tree species in the conifer/deciduous lowland forest type.

under-represented in the diameter distributions due to non-suitability as bearing trees. It is evident that some very large trees were present in the mixed lowland forest type. The mean and median diameters of all sample tree species within the forest type were 23 and 20 cm respectively. The mean diameter based upon the mean basal area of all trees was 25 cm.

The wide variety of sample tree species indicate that the mixed lowland forest type was probably very heterogeneous in structure. The dominant species, white pine, spruce, tamarack, cedar and balsam fir probably existed in uneven-aged and even-aged patches scattered throughout the landscape. Seral aspen likely occurred in even-aged patches. Hemlock may again have existed in stratified, uneven-aged and even-aged stands. Red pine probably occurred upon small, excessively to well drained upland islands, while mesic species such as sugar maple and yellow birch occurred upon well drained, more fertile sites imbedded within the overall landscape.

The Mixed Conifer Swamp Forest Type

The mixed conifer swamp forest type had a moderate basal area (14 m^2/ha), but was quite dense (314 TPH). Table 13 and Figures 17 and 18 show the density and dominance of the tree species in this forest type. The forest type was dominated by northern white cedar, spruce, tamarack and white pine in terms of both basal area and density. Cedar had the highest basal area (4.0 m^2/ha), and spruce had the highest density (97 TPH) of all species in the forest type. Of the dominant species, white pine had a relatively low density (15 TPA), but had a relatively high basal area (2.5 m^2/ha). Other species occurring within the forest type were aspen, black ash, balsam fir, eastern hemlock, jack pine, red maple, white birch and yellow birch. Of these species, only hemlock and balsam fir were significant in terms of density and basal area. Alder and briars were sometimes noted by the surveyors in the mixed conifer swamp forest type.

Figure 19 shows the diameter class distribution of the mixed conifer swamp forest type. The diameter class

Table 13. Relative density and dominance of tree species in the mixed conifer swamp forest type.

Species[2]	Tot #	Relative Density	Trees Per Hectare	Total Basal Area (m^2)	Relative Dominance	BA per Hectare (m^2/ha)
A	6	0.5	1.5 (0.6)[1]	0.8 (8.4)	1.5	0.2 (0.9)
BA	6	0.5	1.5 (0.6)	0.2 (1.7)	0.3	0.1 (0.2)
BF	40	3.4	10.6 (4.3)	1.0 (11.2)	2.0	0.3 (1.2)
BO	1	0.1	0.3 (0.1)	0.02 (0.2)	0.04	0.01 (0.02)
C	292	24.7	77.3 (31.3)	15.0 (161.7)	29.0	4.0 (17.4)
H	29	2.5	7.7 (3.1)	2.0 (21.2)	3.8	0.5 (2.3)
JP	55	4.7	14.6 (5.9)	1.1 (12.1)	2.2	0.3 (1.3)
RM	8	0.7	2.2 (0.9)	0.3 (2.9)	0.5	0.1 (0.3)
RP	11	0.9	3.0 (1.2)	0.7 (7.2)	1.3	0.2 (0.8)
SP	366	30.9	97.1 (39.3)	11.2 (120.0)	21.5	2.9 (12.9)
T	287	24.2	76.1 (30.8)	9.3 (99.9)	17.9	2.4 (10.7)
WB	16	1.4	4.2 (1.7)	0.6 (6.7)	1.2	0.2 (0.7)
WP	58	4.9	15.3 (6.2)	9.5 (101.7)	18.2	2.5 (10.9)
YB	9	0.8	2.5 (1.0)	0.3 (3.4)	0.6	0.1 (0.4)
Sum	1184	100	314 (127)	52 (558)	100	14 (60)

[1] Numbers in parentheses are trees/acre, ft^2 and ft^2/acre respectively.

[2] A = aspen, BA = black ash, BF = balsam fir, BO = black/red oak, C = cedar, H = hemlock, JP = jack pine, RM = red maple, RP = red pine, SP = spruce, T = tamarack, WB = white birch, WP = white pine, YB = yellow birch.

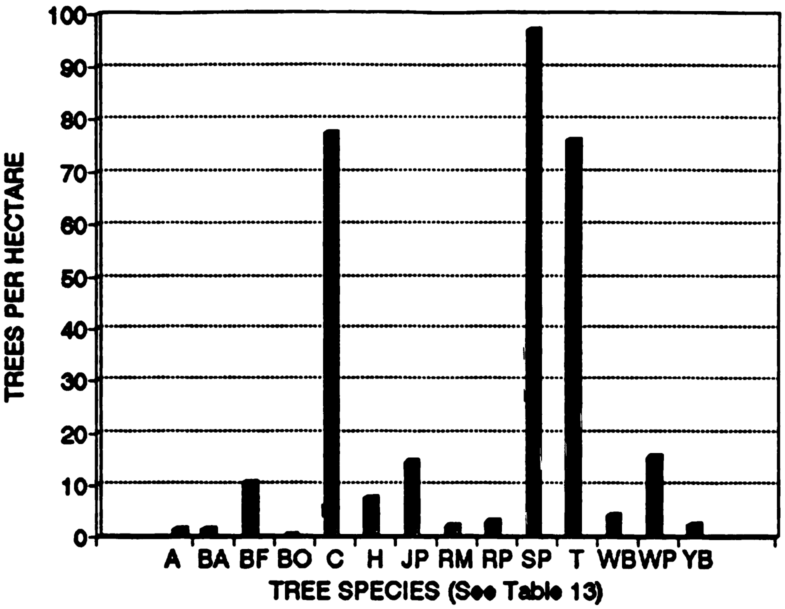

Figure 17. Density of tree species in the mixed conifer swamp forest type.

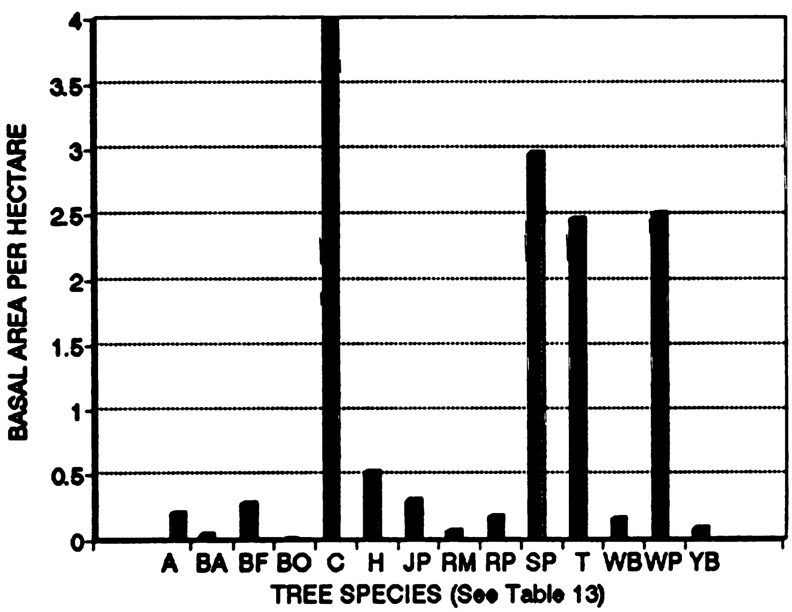

Figure 18. Basal area of tree species in the mixed conifer swamp forest type.

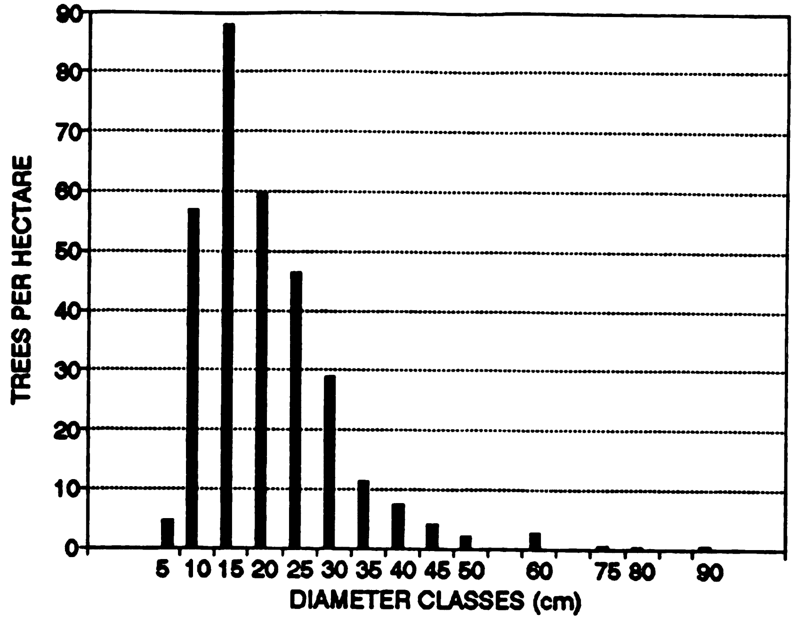

Figure 19. Diameter distributions of tree species in the mixed conifer swamp forest type.

distributions of the individual species within the forest type are presented in Appendix G. The smaller diameter classes are again mis-represented due to their lack of suitability as bearing trees. The mean and median diameter of all tree species in the sample was in the 20 cm class. The mean diameter based upon the mean basal area per tree was 23 cm. There did not appear to be many very large trees within the mixed conifer swamp forest type. Landscape heterogeneity again confounds the diameter class distributions, precluding any definitive conclusions regarding stand structure. However, many of the stands within the mixed conifer swamps may have been of fire origin, and were probably even-aged in structure. It is highly probable that almost pure patches of jack pine became established on upland islands after significant fire events within the forest type, and were almost certainly even-aged. Remnant white pine may have added a dimension of uneven-agedness to the structure of the mixed swamp type, due the fire resistant bark of the mature trees.

Disturbance Regimes

Disturbance regimes noted by surveyors in the study area were fire, windthrow, fire associated with windthrow, dead timber from unknown cause (possibly insect related mortality) and beaver floodings (ponds or meadows). There were 285 individual disturbance events recorded by the surveyors in the study area. Figure 20 shows the distribution of all survey lines affected by these disturbance events. The thickness of the affected survey lines are exaggerated for purposes of clarity. Figure 21 shows a very approximate estimation of the total area covered by these disturbance events in the study area. It is immediately apparent from these figures that natural disturbance affected large portions of the study area. The widespread, and in several cases very extensive, occurrence of disturbance clearly played an important role in regulating the composition and structure of every forest type. Tables 14 and 15 show the distribution of these events by forest type and disturbance regime. Table 14 lists only those disturbance events actually observed by the

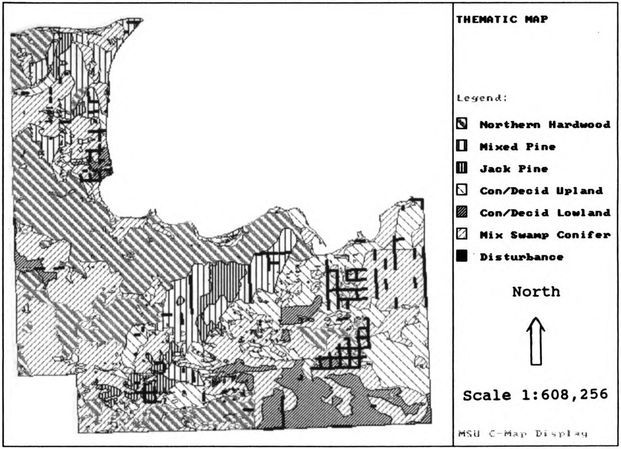

Figure 20. Survey lines affected by disturbance events in western Chippewa County, Michigan from 1840 to 1854.

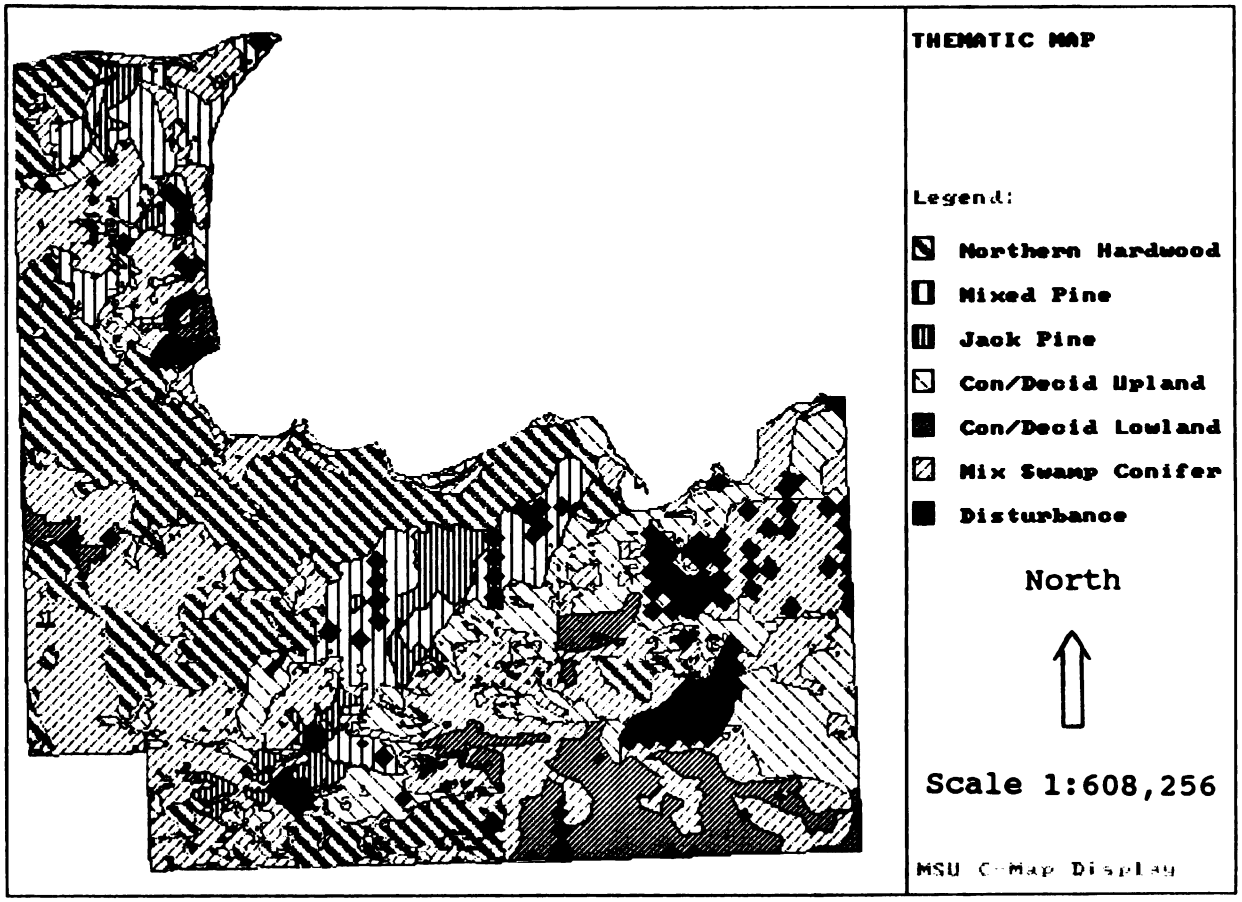

Figure 21. Estimated areas of disturbance in western Chippewa County, Michigan from 1840 to 1854.

Table 14. Number of individual disturbances events observed by surveyors in each forest type.

	North Hdwds	Mixed Pine	Jack Pine	Mixed Upland	Mixed Lowland	Mixed Swamp	Total	%
Area (ha)	66,129	27,490	9,632	44,585	21,974	103,427		
Total Transect Length (km)	898	378	121	657	314	1,407		
Fire	4	12	7	14	9	24	70	24.6
Wind	6	6	-	33	3	39	87	30.5
Wind/ Fire	2	1	1	30	16	35	85	29.8
Insect	-	5	4	3	-	14	26	9.1
Beaver Flooding	1	-	-	8	1	7	17	6.0
Totals	13	24	12	88	29	119	285	100
%	4.6	8.4	4.2	30.9	10.2	41.7	100	

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Table 15. Total number of estimated individual disturbance events in each forest type.

	North Hdwds	Mixed Pine	Jack Pine	Mixed Upland	Mixed Lowland	Mixed Swamp	Total	%
Area (ha)	66,129	27,490	9,632	44,585	21,974	103,427		
Total Transect Length (km)	898	378	121	657	314	1,407		
Fire	48	56	59	131	56	139	489	24.1
Wind	58	8	-	196	19	131	412	20.4
Wind/ Fire	53	1	5	186	83	227	555	27.4
Insect	-	15	8	51	-	121	196	9.6
Beaver Flooding	25	-	-	206	15	128	374	18.5
Totals	184	80	72	770	173	746	2025	100
%	9.1	4.0	3.6	38.0	8.5	36.8	100	

surveyors of the study area. Table 15 lists the observed disturbances plus an additional number of estimated disturbances that the surveyors did not detect in section interiors. All of these estimated disturbances are smaller than 1600 m in length. Given the large number of disturbances actually observed by the surveyors and equally impressive area covered by these disturbances, I believe the total estimated number of disturbances in Table 15 to be reasonably accurate. The overwhelming number of disturbance events occurred within the mixed conifer/deciduous upland (38.0 percent) and mixed conifer swamp (36.8 percent) forest types. The northern hardwood (9.1 percent) and mixed conifer/deciduous lowland (8.5 percent) forest types were approximately equal in their proportion of disturbance events. The mixed pine and jack pine forest type had 4.0 and 3.6 percent of all disturbance events respectively.

Windthrow was the dominant disturbance regime in the study area landscape. Figures 22 and 23 show the incidence of windthrow (without subsequent fire) in the study area, and Figures 24 and 25 show the incidence of windthrow with associated fire. Windthrow (without subsequent fire) accounted for 20.4 percent of all disturbances, but this figure increased to 47.8 percent when additional windthrow events that subsequently burned were also taken into account. Since it is logical that windfall events created heavy fuel loads on or near the forest floor, I have assumed that fires occurred subsequent to the incidence of

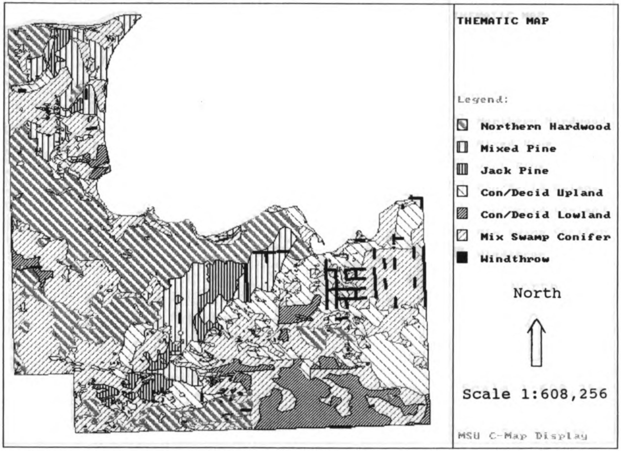

Figure 22. Survey lines affected by windthrow in western Chippewa County, Michigan from 1840 to 1854.

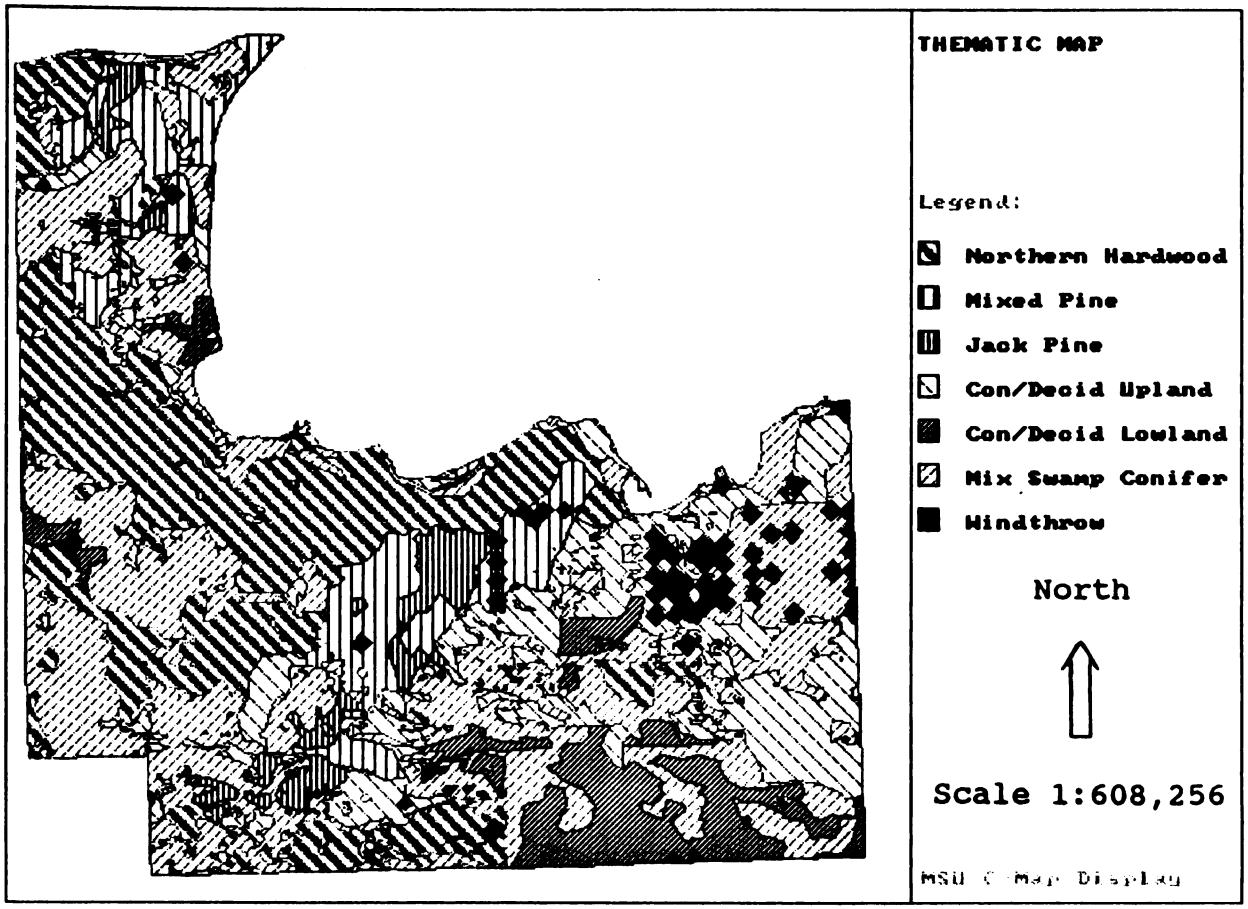

Figure 23. Estimated area impacted by windthrow in western Chippewa County, Michigan from 1840 to 1854.

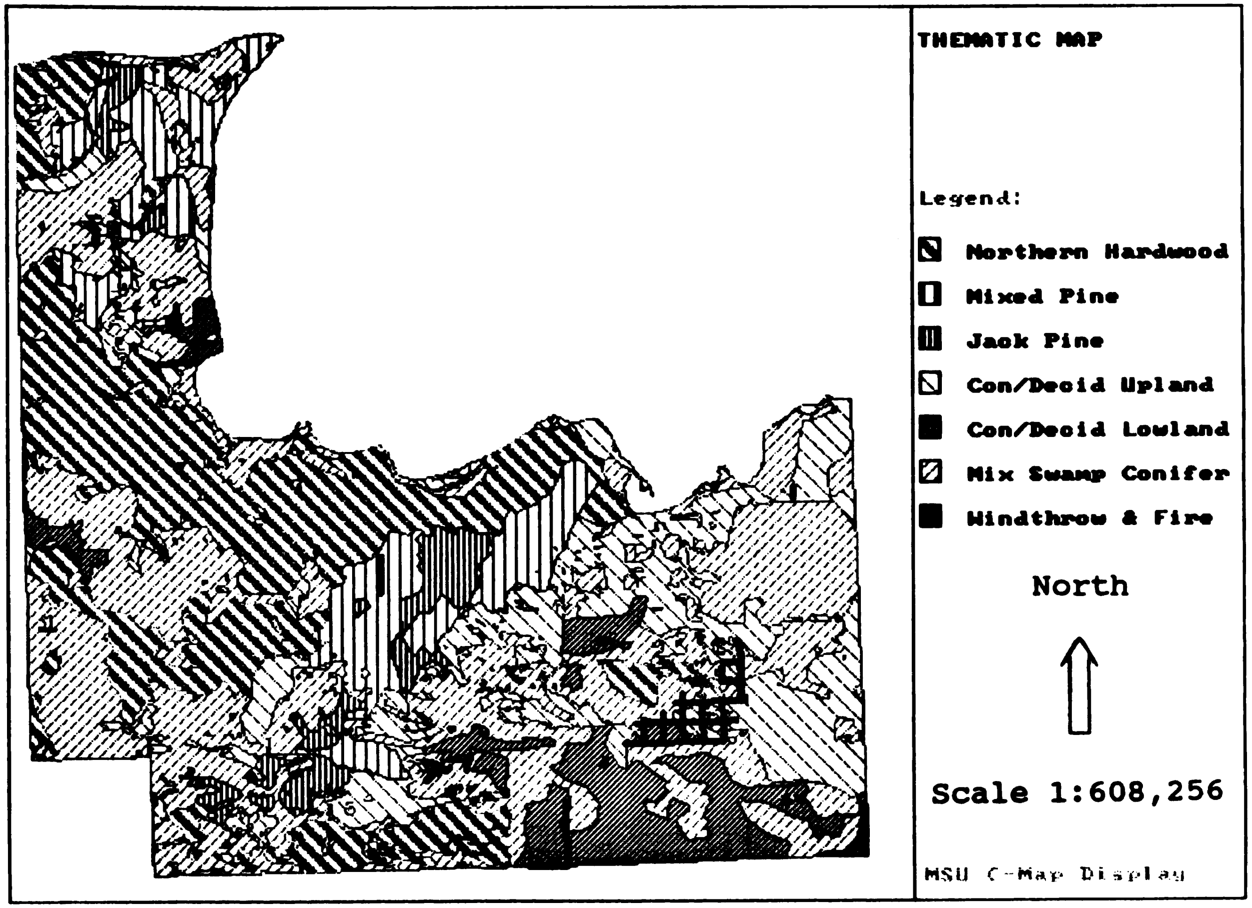

Figure 24. Survey lines affected by windthrow and fire in western Chippewa County, Michigan from 1840 to 1854.

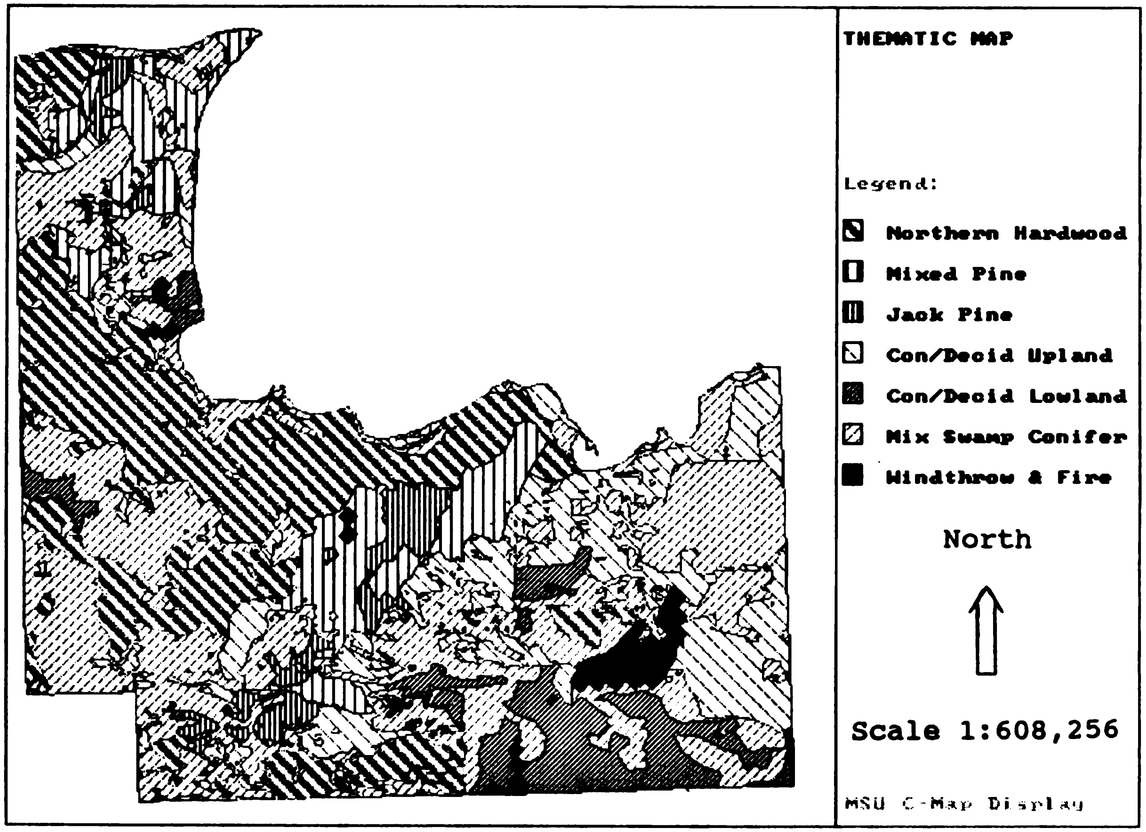

Figure 25. Estimated area impacted by windthrow and fire in western Chippewa County, Michigan from 1840 to 1854.

windthrow, rather than vice a versa. I do recognize that down-drafts caused by large crown fires can also result in fallen timber, but the impact of this phenomenon is impossible to determine. Two very large windthrow events were observed by the surveyors in the study area, with one of these events apparently burning after it blew down. Figures 22 and 24 show that these events occurred across two to three adjacent forest types. The greatest incidence and extent of windthrow was in the mixed conifer/deciduous upland and mixed conifer swamp forest types, with significant numbers of events also occurring within the northern hardwood and mixed conifer/deciduous lowland forest types. Relatively few windthrow events occurred in the mixed pine and jack pine forest types. It is interesting to note that windthrow disturbance appeared to be associated with the proximity to the shoreline of Lake Superior. There was a pronounced lack of windthrow events in the southwest portion of the study area, in the lee of the landmass to the west of Whitefish Point. An analysis of historic wind patterns and velocities would undoubtedly prove interesting, if a positive correlation existed between the wind patterns and this observed "snapshot" of windfall disturbance. Some windthrow events can likely be attributed to severe thunderstorms and tornadoes, although the incidence of such storms is suppressed in the region due to the moderating effect of the Great Lakes. Snow and ice loads from winter storms may also contribute to downed woody debris within the forests of the study area.

The survey records show that fires not associated with windthrow accounted for an additional 24.1 percent of all disturbances within the study area landscape. Figures 26 and 27 show the incidence of fire in the study area. Fires were most common in the mixed conifer swamp and mixed conifer/deciduous upland forest types, with fire also occurring within the jack pine, mixed pine, mixed conifer/deciduous lowland and northern hardwood forest types (Table 15). In the northern portions of Michigan it is not uncommon for organic matter decomposition to be greatly reduced due to the cold climate, thus sometimes resulting in significant accumulations of organic matter on forest floors. Such accumulations can, over time, result in high fuel loads, which increase the chance of fire occurrence. There are many factors which play a role in determining the degree to which a particular forest type, or stand within a forest type, is susceptible to fire. The length of time since the last fire event is the most important, since time has a direct influence on successional status, the degree of biomass accumulation, the presence of fuel ladders, the incidence of natural mortality and the probability of other disturbance such as windthrow and insect or disease related mortality creating increased fuel loads. Another factor is anthropogenic influences. It is impossible to determine from the surveyor records the influence of the native-American population upon the incidence of fire in the study

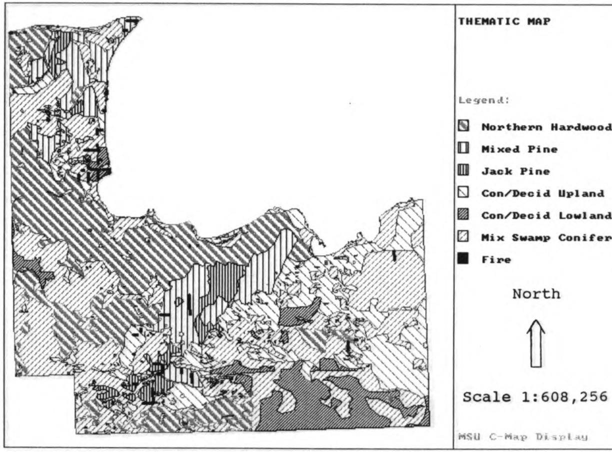

Figure 26. Survey lines affected by fire in western Chippewa County, Michigan from 1840 to 1854.

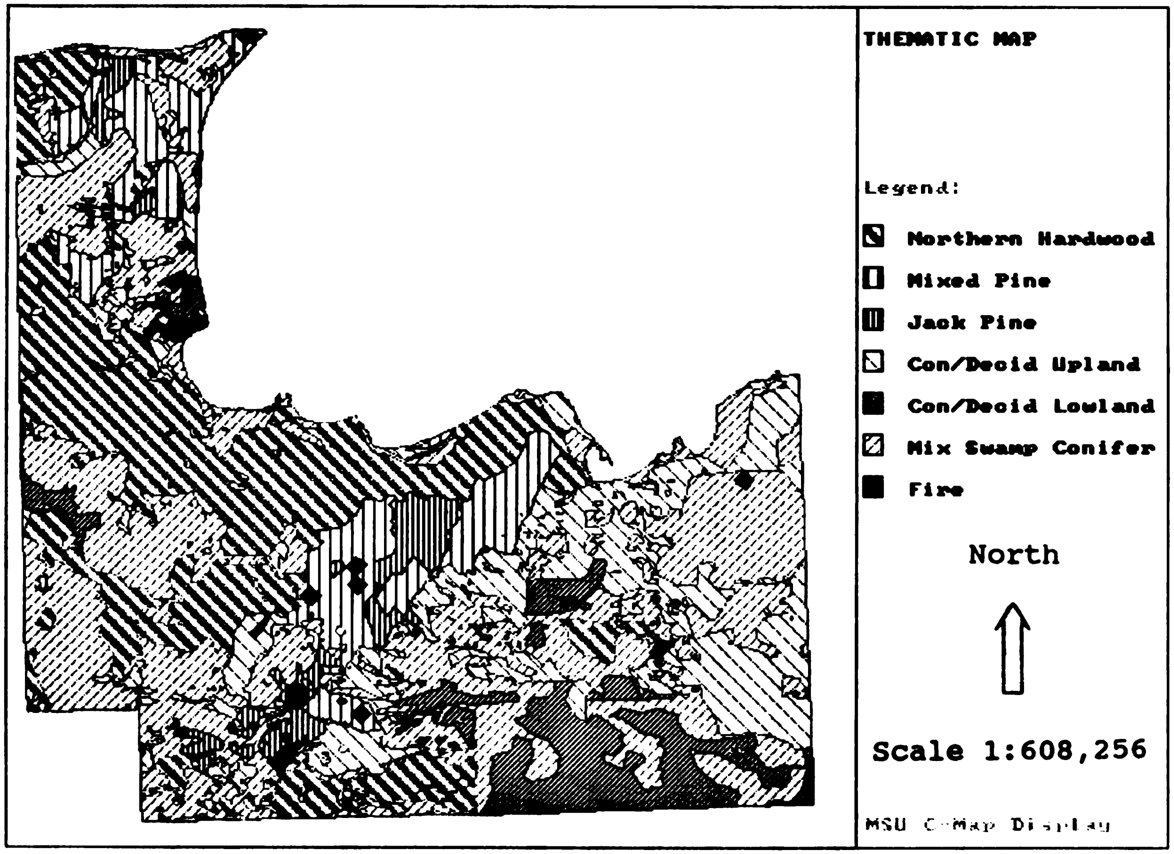

Figure 27. Estimated area impacted by fire in western Chippewa County, Michigan from 1840 to 1854.

area. It is possible that some fire events were deliberately initiated by native-Americans to improve game habitat for hunting purposes. I cannot discount the possibility that they may have had a significant impact upon the frequency and magnitude of fire disturbance in portions of the study area.

Areas of dead timber accounted for 9.6 percent of all disturbance events in the study area landscape. Figures 28 and 29 show the areas of dead timber noted by the surveyors. The most significant number of events occurred within the mixed conifer swamp forest type, with additional numbers of events occurring within the mixed conifer/deciduous upland, mixed pine and jack pine types (Table 15). No incidents of dead timber were noted in the northern hardwood or mixed conifer/deciduous lowland forest types. Tree mortality may have been caused by induced stresses from endemic insect infestations. Insects such as the spruce budworm (<u>Choristoneura fumiferana</u>), jack pine budworm (<u>Choristoneura pinus</u>) and the eastern larch beetle (<u>Dendroctonus simplex</u>) may have been the causal agents of stress. Balsam fir and white spruce are the preferred tree species of the spruce budworm, although they will also secondarily feed on black spruce, tamaracks, hemlock and pines if they are growing nearby. The jack pine budworm will also feed on red and white pine if they are growing under or adjacent to an infested area of jack pine. The eastern larch beetle primarily affects tamarack (Wilson 1977). Insect induced

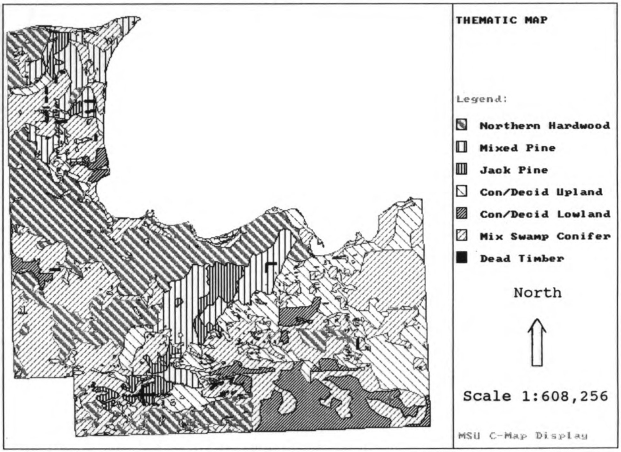

Figure 28. Survey lines affected by dead timber in western Chippewa County, Michigan from 1840 to 1854.

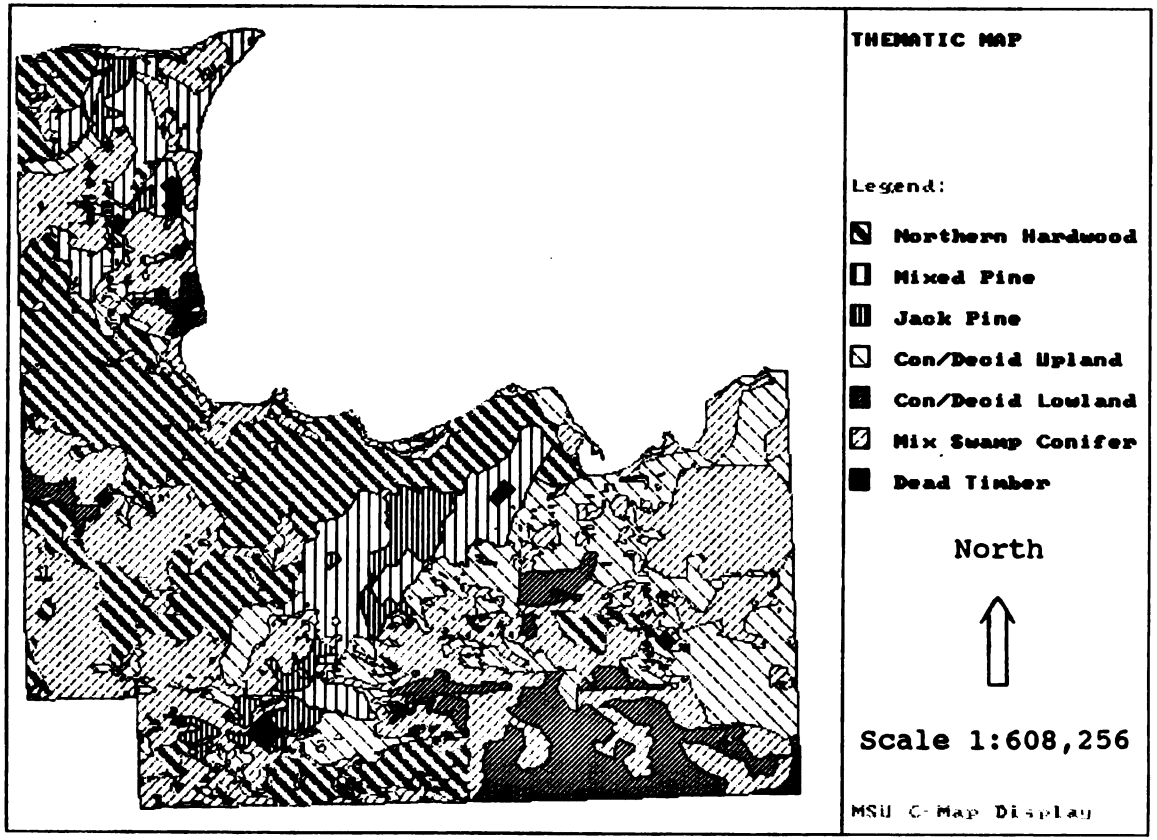

Figure 29. Estimated area impacted by dead timber in western Chippewa County, Michigan from 1840 to 1854.

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mortality can be widespread during major outbreaks, but outbreaks are typically patchy in nature, affecting small stands or portions of stands throughout a landscape. Because the recorded instances of dead timber were observed in forest types dominated by tree species that are susceptible to insect infestation, I have concluded that such areas of tree mortality probably resulted from insect infestation. All subsequent discussion of dead timber will be referred to as insect induced mortality.

Areas affected by beaver (Castor canadensis) floodings accounted for 18.5 percent of all disturbance events in the study area. Beaver disturbance events were noted by surveyors as ponds or meadows. The felling of trees for use as food and dam building material is also a factor in beaver related disturbance, but no mention of this was made in the survey notes. The areas affected by beaver flooding are shown in Figure 30, but are hard to distinguish due to their small size. The greatest number of events occurred within probable imperfectly drained depressions and streams in the mixed conifer/deciduous upland forest type, with a significant number also occurring within the mixed conifer swamp forest type (Table 15). Some beaver disturbance was noted in the northern hardwood and mixed conifer/deciduous lowland forest types, but no events were recorded in the mixed pine or jack pine forest types. By the period in which the surveys of the study area occurred, the incidence of beaver related disturbance was probably significantly

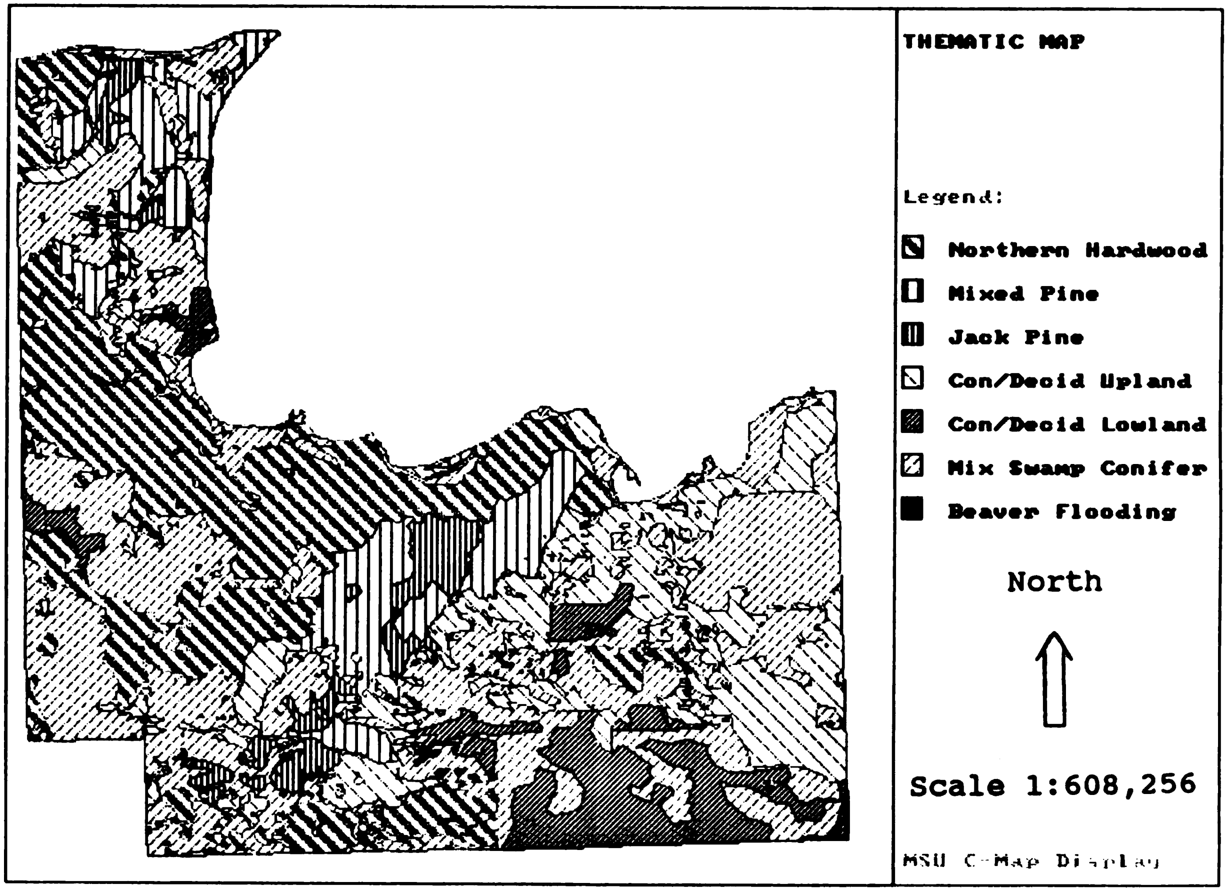

Figure 30. Estimated area impacted by beaver flooding in western Chippewa County, Michigan from 1840 to 1854.

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less than its original extent. This was due to the fashion trends of the era, and the resultant demand for and harvest of beaver skins.

Estimates of disturbance frequencies are based upon 15 and 30 year recording intervals. Disturbance frequencies for each regime in each forest type are shown in Table 16. The estimated return intervals and areas of annual disturbance for each forest type are also based upon 15 and 30 year recording intervals, and are shown in Tables 17 and 18 respectively. Return intervals have no meaning for beaver floodings because floodings are restricted to riparian areas, and cannot possible occur over an entire landscape. Therefore, return intervals for beaver floodings were not calculated.

Table 16. Disturbance frequencies[1] (events/year) by forest type and disturbance regime, based upon 15 and 30 year recording intervals.

	North Hdwds	Mixed Pine	Jack Pine	Mixed Upland	Mixed Lowland	Mixed Swamp
Area (ha)	66,129	27,490	9,632	44,585	21,974	103,427
Total Transect Length (km)	898	378	121	657	314	1,407
	Freq	Freq	Freq	Freq	Freq	Freq
<u>Fire</u>						
15 yr	3.2	3.7	3.9	8.7	3.7	9.3
30 yr	1.6	1.9	2.0	4.4	1.9	4.6
<u>Wind</u>						
15 yr	3.9	0.5	-	13.1	1.3	8.7
30 yr	1.9	0.3		6.5	0.6	4.4
<u>Wind/Fire</u>						
15 yr	3.5	0.1	0.3	12.4	5.5	15.1
30 yr	1.8	0.0	0.2	6.2	2.8	7.6
<u>Insect</u>						
15 yr	-	1.0	0.5	3.4	-	8.1
30 yr		0.5	0.3	1.7		4.0
Beaver <u>Flooding</u>						
15 yr	1.7	-	-	13.7	1.0	8.5
30 yr	0.8			6.9	0.5	4.3
<u>Totals</u>						
15 yr	12.3	5.3	4.7	51.3	11.5	49.7
30 yr	6.1	2.7	2.5	25.7	5.8	24.9

[1] Frequencies are representative of the entire area of each forest type within the study area.

Table 17. Estimated return intervals (years) for disturbances in each forest type, based upon 15 and 30 year recording intervals.

		North Hdwds	Mixed Pine	Jack Pine	Mixed Upland	Mixed Lowland	Mixed Swamp
Area (ha)		66,129	27,490	9,632	44,585	21,974	103,427
Total Transect Length (km)		898	378	121	657	314	1,407
<u>Fire</u>	15 Yr	2252	247	142	429	292	490
	30 Yr	4504	493	283	858	585	979
<u>Wind</u>	15 Yr	1387	284	-	145	633	231
	30 Yr	2778	568		291	1266	463
Wind/	15 Yr	5128	1760	1133	180	122	314
<u>Fire</u>	30 Yr	10204	3521	2266	359	243	628
<u>Insect</u>	15 Yr	-	451	218	2119	-	835
	30 Yr		901	435	4237		1672
Beaver	15 Yr	N/A	N/A	N/A	N/A	N/A	N/A
<u>Flood</u>	30 Yr						

Table 18. Estimated areas of annual disturbance (ha/yr) and percentage of total area affected in each forest type, based upon 15 and 30 year recording intervals.

	North Hdwds	%	Mixed Pine	%	Jack Pine	%
Area (ha)	66,129		27,490		9,632	
Total Transect Length (km)	898		378		121	
Fire						
15 yr	30 (73)[1]	0.04	111 (275)	0.41	68 (167)	0.70
30 yr	15 (36)	0.02	56 (138)	0.20	34 (84)	0.35
Wind						
15 yr	48 (118)	0.07	97 (239)	0.35	-	
30 yr	24 (59)	0.04	49 (120)	0.18	-	
Wind/Fire						
15 yr	13 (32)	0.02	16 (39)	0.06	9 (21)	0.09
30 yr	6 (16)	0.01	8 (19)	0.03	4 (10)	0.04
Insect						
15 yr	-	0	61 (151)	0.22	44 (109)	0.46
30 yr	-	0	30 (75)	0.11	22 (55)	0.23
Beaver Flooding						
15 yr	6 (16)	0.01	-	0	-	
30 yr	3 (8)	0.005	-	0	-	
Totals						
15 yr	97 (239)	0.14	285 (704)	1.04	121 (297)	1.25
30 yr	48 (119)	0.07	143 (352)	0.52	60 (149)	0.62

[1] Numbers in parentheses are areas expressed in ac/yr.

Table 18 (Cont'd). Estimated areas of annual disturbance (ha/yr) and percentage of total area affected in each forest type, based upon 15 and 30 year recording intervals.

	Mixed Upland	%	Mixed Lowland	%	Mixed Swamp	%
Area (ha)	44,585		21,974		103,427	
Total Transect Length (km)	657		314		1,407	
<u>Fire</u>						
15 yr	104 (257)[1]	0.23	75 (186)	0.34	211 (521)	0.20
30 yr	52 (128)	0.12	38 (93)	0.17	106 (261)	0.10
<u>Wind</u>						
15 yr	307 (759)	0.69	35 (86)	0.16	448 (1106)	0.43
30 yr	153 (378)	0.34	17 (43)	0.08	224 (552)	0.22
<u>Wind/Fire</u>						
15 yr	248 (612)	0.56	180 (445)	0.82	329 (813)	0.32
30 yr	124 (307)	0.28	90 (223)	0.41	165 (407)	0.16
<u>Insect</u>						
15 yr	21 (52)	0.05	-	0	124 (306)	0.12
30 yr	11 (26)	0.02	-	0	62 (153)	0.06
<u>Beaver Flooding</u>						
15 yr	49 (122)	0.11	6 (16)	0.03	48 (119)	0.05
30 yr	25 (61)	0.05	3 (8)	0.01	24 (59)	0.02
<u>Totals</u>						
15 yr	729 (1802)	1.64	296 (733)	1.35	1160 (2865)	1.12
30 yr	365 (900)	0.81	148 (367)	0.67	581 (1432)	0.56

[1] Numbers in parentheses are areas expressed in ac/yr.

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The Northern Hardwood Forest Type

Disturbance regimes noted by surveyors in the northern hardwood forest type were fire, windthrow, windthrow with subsequent fire and beaver flooding. Six to twelve disturbance events occurred per year in the forest type (Table 16). The transect size class distribution for the estimated total number of disturbance events in the northern hardwood forest type is shown in Table 19. As expected, windthrow and windthrow events associated with fire were the dominant disturbance regimes in the forest type, accounting for 60.3 percent of all disturbances in the type. Fire was associated with windthrow in 28.8 percent of the disturbance events. Fire (not associated with windthrow) accounted for 26.1 percent of all disturbance events within the forest type. The three smallest size classes (< 200 m in length) accounted for 91.9 percent of all disturbances events.

Disturbance frequencies for windthrow events in the study area were estimated to be between 4 and 8 events per year (Table 16). This estimate does not take individual tree fall gaps into account, since such small events were not recorded and were probably ignored by the surveyors. Half of the windfall events burned subsequent to the windthrow. Most windthrow events were also in the three smallest size classes, with occasional events occurring in the larger size classes, up to 1600 m in length. The estimated return interval for windthrow events (not associated with fire) was between 1389 and 2778 years, with

Table 19. Estimated total number of disturbance events for each size class and disturbance regime in the northern hardwood forest type.

Transect Size Class (m)	Fire	Wind	Wind/ Fire	Insect	Beaver Flood	Total	%
< 50	-	30	30	-	-	60	32.6
50-100	25	-	23	-	25	73	39.7
100-200	19	17	-	-	-	36	19.6
200-400	-	6	-	-	N/A	6	3.3
400-800	4	3	-	-	N/A	7	3.8
800-1600	-	2	-	-	N/A	2	1.1
Totals	48	58	53	0	25	184	100
%	26.1	31.5	28.8	0.0	13.6	100	

an estimated area of annual disturbance between 24 and 48 ha per year (Tables 17 and 18). The return interval for my study area is slightly longer than that in the pre-European settlement northern hardwood forests of Roscommon and Crawford Counties (1220-2439 yrs) in the lower peninsula (Whitney 1986). The estimate is similar to the 1210-2420 year estimate calculated by Canham and Loucks (1984) for the hemlock-northern hardwood forests of northeastern Wisconsin. The return interval for windthrow followed by fire was between 5128 and 10,204 years, with an area of annual disturbance between 6 and 13 ha per year. Overall, between 0.05 and 0.09 percent of the total northern hardwood forest was impacted by windfall on an annual basis (Table 18).

Eastern hemlock was a dominant in both density and basal area in the forest type and is known to be shallow-rooted and much less wind firm than other species in the northern hardwood type. Many hemlock trees were dominants in the canopy, and probably tended to grow singly or in small groves. It is possible that many of the smaller disturbances in the size classes less than 100 m in length occurred in hemlock groves.

Fires not associated with windthrow occurred at less than half (2-3 events per year) the frequency of windthrow events (Table 16). Figure 27 shows that the fire events observed by the surveyors in the northern hardwood forests of the study area occurred in the transition zone adjacent to more fire prone forest types. Most fire events occurred in the 50 to 200 meter size classes, with a few in the 400 to 800 m size class (Table 19). The estimated area of annual disturbance was between 15 and 30 ha per year (Table 18). The return interval for fire in the northern hardwood forest was between 2252 and 4504 years (Table 17). This is much longer than Whitney's (1986) interval for Roscommon and Crawford Counties (1389-2778 yrs). Overall, the results indicate that most fire events in the northern hardwoods were small in size, and occurred primarily in the transition zones adjacent to other forest types. This might be expected in a forest type that is relatively fire resistant in nature.

Beaver flooding was a relatively minor disturbance regime in the northern hardwood forest type. The area of annual disturbance was a very low 3 to 6 ha per year (Table 18). In most occurrences, it is probable that beaver related disturbances did not physically occur within what would be considered northern hardwoods, but rather were restricted to small pockets of lowland types imbedded within the overall northern hardwood forest type. Even so, this reenforces an overall pattern of landscape heterogeneity within the northern hardwood forest type.

Overall, disturbance affected only 0.07 to 0.14 percent of the northern hardwood forest on an annual basis. This was the lowest percentage of any forest type. Windthrow and fire were the dominant disturbance regimes, with fire occurring in the transition zones between northern hardwood and other, more fire prone, forest types. Smaller events less than 200 m in length were most common, with larger events much less frequent in occurrence. The return intervals for disturbance were much longer than the maximum potential lifespans of the dominant tree species within the northern hardwood forest. The shortest estimated return interval was 1387 years for windthrow. The maximum potential lifespans for sugar maple, eastern hemlock, beech and yellow birch are 300-400 years (Godman, Yawney and Tubbs 1990), 400-990 years (Godman and Lancaster 1990), 370 years (Tubbs and Houston 1990), and 300-370 years (Erdmann 1990) respectively. Consequently, once succession to the northern hardwood forest type occurred on a favorable site, the forest type was likely to persist and dominate the site through the natural recruitment of its component species. This does not mean that disturbance had no impact upon the composition and structure of the northern hardwood forest. Small disturbance events created pockets where seral forest types could compete within the overall northern hardwood forest matrix. I believe that small windthrow events and occasional burns helped to perpetuate the existence of hemlock and yellow birch in the northern hardwood forest type. Both species regenerate well on windthrow hummocks and where burns severely reduce impenetrable, desiccating litter layers or expose mineral soil (Godman and Lancaster 1990, and Erdmann 1990).

The Mixed Pine Forest Type

Disturbance regimes observed by the surveyors within the mixed pine forest type were fire, windthrow, windthrow with subsequent fire and insect induced mortality. Three to five events occurred per year in the forest type (Table 16). The transect size class distribution for the estimated disturbance events in the mixed pine forest type is shown in Table 20. As expected, fire was the dominant disturbance regime in this forest type, accounting for 70.0 percent of all disturbance events. Insect induced mortality accounted for 18.7 percent of all disturbances. Windthrow accounted for 11.3 percent of all disturbances, with only 1.3 percent of windfall events also associated with subsequent fire.

Table 20. Estimated total number of disturbance events for each size class and disturbance regime in the mixed pine forest type.

Transect Size Class (m)	Fire	Wind	Wind/ Fire	Insect	Beaver Flood	Total	%
< 50	-	-	-	-	-	0	0.0
50-100	-	-	-	-	-	0	0.0
100-200	31	-	-	8	-	39	48.8
200-400	14	-	-	-	N/A	14	17.5
400-800	6	-	-	-	N/A	6	7.5
800-1600	2	5	-	7	N/A	14	17.5
1600-3200	2	1	-	-	N/A	3	3.8
3200-6400	1	2	1	-	N/A	4	5.0
Totals	56	8	1	15	0	80	100
(%)	70.0	10.0	1.3	18.7	0.0	100	

The disturbance frequency for fire in the mixed pine forest type was estimated to be between 2 to 4 events per year (Table 16). Most fires occurred in the 100 to 800 m size classes, with some larger events being observed in the 800 to 6400 m size classes (Table 20). The return interval for fire was short, at 247 to 493 years (Table 17). Whitney's (1986) estimates for fire return intervals in the pre-European settlement mixed pine forests of Roscommon and Crawford Counties were between 129 and 258 years. Fires in my study area therefore occurred with almost half the frequency of fires on outwash plains in the northern lower peninsula. The estimated area of annual disturbance was between 56 and 111 ha per year, representing between 0.20 and 0.41 percent of the forest type per year (Table 18). This was the highest rate of any disturbance regime in the mixed pine forest type. Heinselman's (1973) classic study of fire in the mixed pine forests of Minnesota's Boundary Waters Canoe Area showed that 0.82 percent of the virgin forests burned on an annual basis. Heinselman estimated a return interval of approximately 100 to 200 years for mixed pine stands (1981a). Again, this indicates a rate of fire disturbance at least twice that of my study area. However, it must be recognized that Heinselman's estimate is based upon physical fire scar evidence over a 141 year period from 1727 to 1868, which included five exceptional fire years. Exceptional fire years occurred in 1727, 1759, 1801, 1824 and 1864 (Heinselman 1973). During these exceptional years

Heinselman documented that fires consumed areas ranging from 8.3 to 44.1 percent of the virgin forest. The thirty year period from 1824 to 1854 encompassed only one exceptional fire year (1824), the least severe of all the exceptional years during the period of 1727 to 1868 (Heinselman 1973). By the years 1845 to 1850, when the subdivision surveys of my study area were completed, any evidence of fires that occurred in the 1824 exceptional fire year would be 20 to 25 years old, and rapidly fading if evident at all. Seral forest cover would be well developed after 20 to 25 years. The primary evidence of large scale fire events in 1824 would be substantial areas of pole sized timber, as typified by the pure, even-aged stands of jack pine on the Raco outwash plains. The 15 cm mean and median diameters of these stands suggest that they could possibly have their origin after the 1824 exceptional fire year.

Incidents of insect induced mortality in the mixed pine forest type occurred at a low rate of 1 or fewer events per year (Table 16). The estimated return interval was between and 451 and 901 years (Table 17). The area of annual disturbance was between 30 and 61 ha per year, representing 0.11 to 0.22 percent of the forest type on an annual basis (Table 18). Insect related disturbance events occurred in two classes, the 100-200 m and 800-1600 m size classes (Table 20). A likely causal agent of extensive areas of mortality in the mixed pine forest type is the jack pine budworm. Presently, small outbreaks of jack pine budworm occur frequently in the Lake States. They attack jack pine of all sizes, preferring trees with abundant male flowers (Wilson 1977). They will also attack adjacent stands of red and white pine. From the evidence presented, it appears that insect infestation caused infrequent, and moderate areas of tree mortality in the mixed pine type.

Windthrow occurred with a frequency of less than 1 event every two years (Table 16). The return interval of windthrow alone was rather short, estimated at 284 to 568 years, with an area of annual disturbance between 49 and 97 ha per year (Tables 17 and 18). Whitney's (1986) return interval estimate for windfall in the virgin mixed pine forests in Roscommon and Crawford Counties was much longer at 1587 to 3174 years. This indicates that windfall events were much more extensive in my study area, as shown in Figures 22 and 23. The area of annual disturbance represented 0.18 to 0.35 percent of the forest type on an annual basis. Windthrow events were quite large, with all events falling within the 800 to 6400 m size classes (Table 20). Thus, although windthrow events in the mixed pine forest type were not very frequent, they were typically large in extent.

The return interval for windthrow with subsequent fire was between 1760 and 3521 years. Table 18 shows that the estimated area of annual disturbance of windthrow events with subsequent fire was between 8 and 16 ha per year, representing a small proportion of the forest type area, between 0.03 and 0.06 percent annually. Only one windthrow event with subsequent fire occurred in the mixed pine forest type, but it was in the 3200-6400 m length class (Table 20).

Overall, disturbance affected 0.52 to 1.04 percent of the mixed pine forest on an annual basis. This was a moderate rate of disturbance, with 3 to 5 events occurring per year. Fire, windthrow and probable insect induced mortality were the dominant types of disturbance, with fire and windthrow affecting the greatest annual percentage of the forest type. Mid-sized events between 100 and 1600 m in length were the most common, with larger events much less frequent in occurrence. The return intervals for fire (247-493 yrs) and windthrow (284-569 yrs) were less than the maximum potential lifespans of the two most dominant tree species in the forest type. The maximum potential lifespans for white and red pine are 450 years (Wendel and Smith 1990) and 300-400 years (Rudolf 1990) respectively. Thus, regeneration of tree species within the mixed pine forest type was potentially dependent upon disturbance. Fire and windthrow, rather than species recruitment as in the northern hardwood forest type, had the capacity to regulate the composition and structure of the mixed pine forest type. However, species recruitment still played a role in the regulation of forest composition. Major fire events scarified the soil by burning away much of the organic matter covering mineral soil. Such scarification provided an excellent seedbed for the germination and growth of white and red pine via seed dispersal from residual trees (Wendel and Smith 1990, Rudolf 1990). Conversely, windthrow favored the growth of seral species such as bigtooth aspen, trembling aspen and white birch which have high potential asexual reproduction rates, and did not have to depend upon favorable seedbed conditions for sexual reproduction.

The Jack Pine Forest Type

Disturbances noted by the surveyors in the jack pine forest type were fire, windfall with subsequent fire and insect induced mortality. Only 3 to 5 disturbance events occurred per year in the forest type (Table 16). The transect size class distribution for the estimated disturbance events in the jack pine forest type is shown in Table 21. As expected, fire was the dominant form of disturbance within this forest type, accounting for a total of 81.9 percent of all disturbance events. Insect induced mortality and windfall with subsequent fire represented only 11.1 and 6.9 percent of all disturbance events respectively.

Fire occurred with a frequency of 2 to 4 events per year in the jack pine forest type (Table 16). The estimated return interval for fire was 142 to 283 years (Table 17). This interval compares favorably with Whitney's (1986) estimate of 83 to 167 years for Roscommon and Crawford Counties. Heinselman (1973) estimated a return interval of approximately 50 to 100 years for jack pine stands in the Boundary Waters Canoe Area in Minnesota. The estimated area

Table 21. Estimated total number of disturbance events for each size class and disturbance regime in the jack pine forest type.

Transect Size Class (m)	Fire	Wind	Wind/ Fire	Insect	Beaver Flood	Total	%
< 50	-	-	-	-	-	0	0.0
50-100	47	-	-	-	-	47	65.3
100-200	-	-	-	-	-	0	0.0
200-400	-	-	5	-	N/A	5	6.9
400-800	6	-	-	3	N/A	9	12.5
800-1600	6	-	-	4	N/A	10	13.9
1600-3200	-	-	-	1	N/A	1	1.4
Totals	59	0	5	8	0	72	100
(%)	81.9	0.0	6.9	11.1	0.0	100	

of annual disturbance was 34 to 68 ha per year, representing 0.35 to 0.70 percent of the forest type annually (Table 18). This was the second highest percentage of any disturbance regime in any forest type in the study area, indicating the importance of fire in the jack pine forest type. The vast majority of fires in the jack pine forest were in the 50-100 m length class, with a significant number of events in the 400 to 1600 m size classes (Table 21). Figures 26 and 27 show that most of the area affected by fire could be attributed to the larger size classes. My results show that large areas of the jack pine forest type burned on a regular basis, resulting in a very low return interval. The 15 cm mean and median diameters of jack pine, and the even-aged diameter distribution of the forest type suggest that the fires in jack pine were stand-replacing in severity. My results support the hypothesis that fire dependent communities burn more frequently and with greater severity than do other communities, because natural selection has forced evolution of physiological characteristics in their component vegetation that make them inherently more flammable (Mutch 1970). Jack pine has evolved physiological attributes such as early maturation and persistent, serotinous cones that enable it to thrive as a species on the xeric, fire prone sites of the Raco Plains.

Insect induced mortality occurred at a rate of approximately 1 event every two years within the jack pine forest type (Table 16). The jack pine budworm was probably the causal agent of this type of disturbance in the forest type. The estimated return interval for jack pine budworm infestation was only 218 to 435 years (Table 17). The area of annual disturbance was between 22 and 44 ha per year, or at the high rate of 0.23 to 0.46 percent of the forest type annually (Table 18). Table 20 shows that all of the budworm disturbance events occurred in the largest size classes (400 to 3200 m in length). The results indicate that although the frequency of jack pine budworm outbreaks was relatively low, the events were typically large in scale. I have no method of determining whether areas of dead jack pine were positively correlated with the frequency of fire within the jack pine forest type. However, I hypothesize that extensive patches of stressed, dying or dead jack pine would have dramatically increased the fuel load in large areas of the jack pine forest type, increasing the intensity and probably the frequency of fire within the type.

Windthrow with subsequent fire occurred at a very infrequent rate (<1 event every 3 years), and affected only moderately sized areas (between 4 and 9 ha/yr) and a very low percentage of the jack pine forest type annually (0.04 to 0.09 percent). The few windfall events may have served to increase fuel loads in small pockets, and may have had an effect on fire frequency. However, I have concluded that windfall with subsequent fire was a relatively minor disturbance mechanism in the jack pine forest type.

Overall, disturbance impacted 0.62 to 1.25 percent of the jack pine forest on an annual basis. This was a high rate of disturbance. Jack pine equaled the mixed pine forest type for the lowest frequency of disturbance of any forest type, at 3 to 5 events per year. Fire and probable insect induced mortality were the dominant disturbance events. Small-sized events in the 50-100 m length class were the most common, with larger fire and insect infestations much less frequently recorded. The return interval for fire (142-283 yrs), which was the most dominant mode of disturbance, was less than the 185-230 year maximum potential lifespan of jack pine (Rudolph and Laidly 1990). Thus, regeneration of the jack pine forest type appears to have been dependent upon disturbance. Fire drove the life cycle of jack pine, and was the dominant regulator of the composition and structure of the forest. Major destructive fire events opened the persistent, serotinous cones of jack pine, and exposed the mineral soil to provide a seedbed for copious jack pine reproduction. Fire allowed jack pine to persist and dominate on more xeric sites that were predisposed to fire.

The Mixed Conifer/Deciduous Upland Forest Type

Disturbance regimes noted by surveyors in the mixed conifer/deciduous upland forest type were fire, windthrow, windthrow with subsequent fire, insect induced mortality and beaver flooding. Twenty-six to fifty-one disturbance events occurred within the forest type per year (Table 16). The transect size class distribution for the estimated disturbance events in the mixed upland forest type is shown in Table 22. Windthrow was the dominant form of disturbance within this forest type, accounting for a total of 49.6 percent of all disturbance events. Beaver floodings and fire were also significant disturbance regimes within the mixed upland forest type, representing 26.8 and 17.0 percent of all disturbance events, respectively. Insect induced mortality accounted for only 6.6 percent of all disturbance events. Smaller size classes of disturbance were dominant within the forest type, with lengths of less than 400 m accounting for 87.9 percent of all events.

Table 22. Estimated total number of disturbance events for each size class and disturbance regime in the mixed conifer/deciduous upland forest type.

Transect Size Class (m)	Fire	Wind	Wind/ Fire	Insect	Beaver Flood	Total	%
< 50	49	30	-	-	83	162	21.0
50-100	14	36	50	48	101	249	32.3
100-200	30	60	65	-	22	177	23.0
200-400	23	29	37	-	N/A	89	11.6
400-800	12	19	19	3	N/A	53	6.9
800-1600	3	17	15	-	N/A	35	4.6
1600-3200	-	4	-	-	N/A	4	0.5
3200-6400	-	1	-	-	N/A	1	0.1
Totals	131	196	186	51	206	770	100
%	17.0	25.4	24.2	6.6	26.8	100	

Windthrow occurred with a total frequency of between 12 and 25 events per year, the largest frequency value of disturbance in any forest type (Table 16). Fire occurred subsequent to windthrow in about half of these events. The return intervals of windthrow were among the lowest of any disturbance regime in any forest type. The return interval for windthrow was only 145 to 291 years (Table 17). The area of annual disturbance was between 153 and 307 ha per year, and represented a very high 0.34 to 0.69 annual percent of the forest type area (Table 18). The return interval for windthrow followed by fire was slightly greater at 180 to 359 years, with an area of annual disturbance between 124 and 248 ha per year. The areas represented slightly lower annual values of 0.28 to 0.56 percent of the forest type. Windthrow events were distributed in the smaller size classes, with most occurring in the 50 to 400 m classes (Table 22). A few large windthrow events occurred in the larger (1600 to 6400 m) size classes. Spruce and eastern hemlock were dominant in density in this forest type. Both species, but especially hemlock, are shallow-rooted and subject to windthrow. Thus, many smaller to moderately sized windthrow events occurred within the mixed upland forest type, with about half of the events subsequently burning. Some windfall events were quite large.

Beaver floodings were also very frequent in the mixed upland forest type. Although beaver floodings are restricted to riparian areas, they occurred in the upland type with a frequency of 7 to 14 events per year. This frequency was the highest of any forest type. The estimated area of annual disturbance for beaver floodings was between 25 and 49 ha per year, representing between 0.05 and 0.11 percent of the forest type area on an annual basis (Table 18). Not surprisingly, most beaver floodings were less than 100 m in length (Table 22). White birch, aspen and red maple are well represented within the forest type, and are also preferred for food and construction material by the beaver. This fact, as well as a greater proportion of stream habitat within the forest type, may explain the high incidence of beaver flooding found here.

Fire (not associated with windthrow) also occurred quite frequently within the mixed upland forest type, at a rate of 4 to 9 events per year (Table 16). The return interval for fire was 429 to 858 years. The area of annual disturbance was between 52 and 104 ha per year, or 0.12 to 0.23 percent of the area on an annual basis (Table 18). Most of the fire events occurred in size classes less than 400 m in length, but a few were as large as 800-1600 m in length (Table 22).

Insect induced mortality occurred at a low rate of 2 to 3 events per year in the mixed upland forest type, and affected only 0.02 to 0.05 percent of the forest type annually. The causal agent of timber mortality in the forest type may have been the spruce bud worm, since spruce was a dominant in both density and basal area within the type. Tamarack and jack pine were also present within the forest type, so the eastern larch beetle and the jack pine budworm may have been contributing factors to small pockets of tree mortality.

The mixed conifer/deciduous upland forest type had the highest frequency of disturbance of any forest type, at 26 to 51 events per year. Disturbance affected 0.81 to 1.64 percent of the forest on an annual basis, the highest percentage of any forest type. Windthrow, with or without subsequent fire, and beaver floodings were the dominant types of disturbance. Smaller sized events, less than 400 m in length were the most common, with larger events occurring with rapidly decreasing frequency. The return interval for windthrow, between 145 and 359 years, was less than the maximum potential lifespans of the dominant tree species. The maximum potential lifespans for hemlock, white spruce and white pine are 400-990 years, 250-300 years (Nienstaedt and Zasada 1990) and 450 years respectively. Thus, windthrow had the potential to regulate the composition and structure of the mixed upland forest type. Regeneration of tree species within the mixed upland forest type was potentially dependent upon disturbance. Windthrow events which were not associated with fire probably favored the reproduction of spruce, aspen and white birch. Exposed mineral soil from windthrows provide one of the best seed beds for white spruce regeneration and can result in stocking levels approaching 100 percent (Nienstaedt and Zasada 1990). As discussed previously, aspen and white birch have a competitive advantage due to their asexual reproduction capacities. When fire followed windthrow events the reproduction of white pine and hemlock and spruce were probably favored on the exposed mineral soil, especially when subsequent moisture conditions were favorable for seed germination and seedling growth.

The Mixed Conifer/Deciduous Lowland Forest Type

Disturbance regimes observed by the surveyors within the mixed conifer/deciduous lowland forest type were fire, windthrow, windthrow with subsequent fire and beaver floodings. Six to twelve disturbance events occurred within the forest type per year (Table 16). The transect size class distribution for the estimated disturbance events in the mixed lowland forest type is shown in Table 23. Windthrow and fire were the dominant modes of disturbance within the forest type, accounting for 59.0 and 32.4 percent of all disturbances respectively. Windthrows associated with fire accounted for 48.0 percent of all disturbance events. Beaver floodings represented the remaining 8.7 percent of all disturbance events. Disturbance events with lengths between 50 and 800 m accounted for 90.2 percent of all events. The 50-100 m size class was dominant, representing nearly half of all events.

Windthrow events occurred at a rate of 3 to 7 events

Table 23. Estimated total number of disturbance events for each size class and disturbance regime in the mixed conifer/deciduous lowland forest type.

Transect Size Class (m)	Fire	Wind	Wind/ Fire	Insect	Beaver Flood	Total	%
< 50	-	-	-	-	-	0	0.0
50-100	31	16	23	-	15	85	49.1
100-200	-	-	37	-	-	37	21.4
200-400	14	-	4	-	N/A	18	10.4
400-800	7	-	9	-	N/A	16	9.3
800-1600	4	2	6	-	N/A	12	6.9
1600-3200	-	-	3	-	N/A	3	1.7
3200-6400	-	1	-	-	N/A	1	0.6
6400-12800	-	-	1	-	N/A	1	0.6
Totals	56	19	83	0	15	173	100
%	32.4	11.0	48.0	0.0	8.7	100	

per year, with fire following windthrow in every 3 to 5 events (Table 16). The return interval for windthrow alone was between 633 and 1266 years (Table 17). The area of annual disturbance was between 17 and 35 ha per year, representing 0.08 to 0.16 percent of the forest type on an annual basis (Table 18). With fire subsequent to windthrow the return interval was an extremely low 122 to 243 years (Table 17). The area of annual disturbance was between 90 and 180 ha per year, representing a substantial 0.41 to 0.82 percent of the forest type. All together, windthrow affected between 0.49 and 0.98 percent of the mixed lowland forest type annually. Most (90.2 percent) disturbance events occurred in the 50 to 800 m size classes, with the size class distribution rapidly decreasing above 800 m (Table 23). The largest single length of disturbance of any regime in any forest type, was a windthrow and burn in the 6400-12800 m size class. Spruce, northern white cedar and eastern hemlock are significantly represented in density and basal area within the forest type. These species are also shallow rooted and prone to windthrow, and may account for many of the windthrow events within the forest type. Apparently fire followed windthrow in most windthrow events. These events occurred in small to medium sized patches throughout the mixed lowland forest type, and affected moderately large areas.

Fire events not directly associated with windthrow occurred with a frequency of 2 to 4 events per year in the mixed lowland forest type (Table 16). The estimated return interval for fire was a relatively short 292 to 585 years (Table 17). The area of annual disturbance was between 38 and 75 ha per year, representing 0.17 to 0.34 percent of the forest type on an annual basis (Table 18). Almost half of all burn events occurred in the 50-100 m size class, with significant numbers also occurring in the 200 to 1600 m size classes (Table 23). Thus, burns occurred regularly in the mixed lowland forest type, but were moderate in size and probably somewhat patchy in distribution.

Beaver floodings occurred at a rate of 1 per year in the mixed lowland forest type (Table 16). The estimated area of annual disturbance was a very low 3 to 6 ha per year, representing an equally low 0.01 to 0.03 percent of the mixed lowland forest type (Table 18). All flooding events occurred in the 50-100 m size class (Table 23), although this estimate is based upon only one observed event.

Overall, disturbance affected 0.67 to 1.35 percent of the mixed conifer/deciduous lowland forest on an annual basis. Windthrow and fire were the dominant types of disturbance. Mid-sized events between 50 and 1600 m in length were the most common, with large to very large events much less frequent in occurrence. Windthrow associated with subsequent fire accounted for almost half of all disturbance events, and the annual area of disturbance was more than twice that of the other types of disturbance in the type.

The return interval for windthrow with subsequent fire was between 122 and 243 years, and the interval for fire was between 292 and 585 years. The maximum potential lifespan of black spruce, tamarack, white pine and northern white cedar are 200-280 years (Vireck and Johnston 1990), 150-240 years (Johnston 1990b), 450 years and 400 years (Johnston 1990a) respectively. The return intervals are less than or equal to the maximum potential lifespan of the four most dominant tree species in the forest type. Thus, regeneration of tree species within the mixed conifer/deciduous lowland forest type was probably dependent upon disturbance. Windthrow and fire had the potential to regulate the composition and structure of the mixed lowland forest type. Complete removal of organic surface layers and exposure of mineral soil by windthrow and fire favors the successful regeneration of black spruce, tamarack, white pine and cedar (Viereck and Johnston 1990, Johnston 1990b, Wendel and Smith 1990 and Johnston 1990). Thus, windthrow and fire were probably dominant factors in the perpetuation of forested wetlands.

The Mixed Conifer Swamp Forest Type

Disturbance regimes observed by the surveyors within the mixed conifer swamp forest type were fire, windthrow, windthrow with subsequent fire, insect induced mortality and beaver floodings. Twenty-five to fifty disturbance events occurred per year in the forest type (Table 16). The dominant mode of disturbance in the type was windfall, accounting for 48.0 percent of all events. Fire, insect induced mortality, and beaver floodings were approximately equal in representation, accounting for 18.6, 16.2 and 17.2 percent of all events respectively. The transect size class distribution for the estimated disturbance events in the mixed conifer swamp forest type is shown in Table 24. The smaller size classes less than 800 m were dominant in the forest type, accounting for 89.6 percent of all events.

Windthrow occurred with a frequency of 12 to 24 events per year (Table 16). Windfall with subsequent fire accounted for two-thirds of these events. The estimated return interval for windfall alone was a short 231 to 463 years (Table 17). This return interval is almost one-sixth of the 1316 to 2632 year interval calculated by Whitney (1986) for the pre-European settlement swamp conifer forests of Roscommon and Crawford Counties in northern lower Michigan. The return interval for windfall with subsequent fire was longer at 314 to 628 years. This indicates that windfall was much more prevalent in the wetlands of Chippewa county. The area of annual disturbance for windfall was large, at 224 to 448 ha per year, representing 0.22 to 0.43 percent of the mixed conifer swamp forest type on an annual basis. This was the highest area of annual disturbance for any regime in any forest type. For windthrow with subsequent fire the area of annual disturbance was smaller, between 165 and 329 ha per year, or 0.16 to 0.32 percent

Table 24. Estimated total number of disturbance events for each size class and disturbance regime in the mixed conifer swamp forest type.

Transect Size Class (m)	Fire	Wind	Wind/ Fire	Insect	Beaver Flood	Total	%
< 50	-	-	35	71	26	132	17.7
50-100	18	14	53	19	94	198	26.5
100-200	62	22	53	-	8	145	19.4
200-400	34	36	34	7	N/A	111	14.9
400-800	13	22	38	10	N/A	83	11.1
800-1600	11	28	10	12	N/A	61	8.2
1600-3200	1	6	4	2	N/A	13	1.7
3200-6400	-	3	-	-	N/A	3	0.4
Totals	139	131	227	121	128	746	100
%	18.6	17.6	30.4	16.2	17.2	100	

annually. Windthrow events occurred in every size class (Table 23). Most windfall events fell within the 100 to 1600 m size classes, with some events up to 3200-6400 m in length (Table 24). Windfall events with subsequent fire were well distributed throughout all size classes less than 800 m, with the largest events occurring in the 1600-3200 m size class. It appears that fire followed windfall with a high frequency, affecting slightly less area and occurring in somewhat smaller patches than windfalls not associated with fire.

Fire (not associated with windthrow) occurred at a rate of 5 to 9 events per year in the mixed swamp forest type (Table 16). The estimated return interval was between 490 and 979 years (Table 17). The estimated return interval of fire in the virgin conifer swamp forests of Roscommon and Crawford Counties was 2959 to 5917 years (Whitney 1986), again indicating a much greater impact of fire in my study area. The area of annual disturbance was 106 to 211 ha per year, representing 0.10 to 0.20 percent of the forest type per year (Table 18). Almost all of the fire events occurred in the 50 to 1600 m size classes (Table 24). The one exception was an event in the 1600-3200 m size class. Upland islands of jack and red pine often occurred within mixed conifer swamps in the central portion of the study area. In the late summer and early autumn the mixed conifer swamps and these upland islands can become very fire prone, especially in years characterized by drought. It is therefore very plausible that relatively large and frequent fires occurred within the mixed conifer swamp forest type, affecting both small and mid-sized patches of the forest.

Disturbance by beaver flooding in the mixed conifer swamp forest type occurred at a rate of 4 to 9 events per year (Table 16). The estimated area of annual disturbance was between 24 and 48 ha per year, representing a low 0.02 to 0.05 percent of the forest type annually (Table 19). All events were less than 200 m in length, with most occurring in the 50-100 m size class (Table 24). There were almost half as many beaver flooding events as occurred in the mixed conifer/deciduous upland forest type. This can probably be attributed to the lesser density of preferred food and building material tree species (white birch, aspen and red maple) in the mixed conifer swamp forest type, rather than a lack of suitable riparian habitat.

The incidence of insect induced mortality in the mixed conifer swamp forest type occurred at a moderately high rate of 4 to 8 events per year (Table 16). The spruce budworm and the eastern larch beetle were the probable causal agents of extensive tree mortality within the forest type. The estimated return interval for insect infestation was between 835 and 1672 years (Table 17). Smaller pockets of infestation were most common and may have been the result of relatively minor insect outbreaks, or may have simply occurred in areas with high densities of spruce or tamarack. The occasional larger areas of tree mortality are likely the result of more severe insect infestations. In general, insect infestations occurred with a moderately high frequency. Although the area of annual disturbance was moderate in size, the total annual percentage of the mixed conifer swamp forest type that was affected by insect infestation was rather low.

With the exception of the mixed conifer/deciduous upland forest type, the mixed swamp conifer forest type had the second highest rate of disturbance, at 25 to 50 events per year. However, disturbance impacted only a moderate 0.56 to 1.12 percent of the mixed conifer swamp forest on an annual basis. Windthrow and fire were the dominant disturbance regimes, with fire occurring subsequent to windthrow in two-thirds of all windthrow events. Relatively small-sized events less than 800 m in length were the most common, with larger events progressively less frequent in occurrence. With the exception of northern white cedar, the return intervals for disturbance in the mixed conifer swamp forest type were greater than the maximum potential lifespans of the dominant species in the forest type. The lowest return interval was for windthrow at 231 to 463 years. The return interval for windthrow with subsequent fire was longer (314 to 628 years). The maximum potential lifespans for black spruce, northern white cedar and tamarack are 200-280, 400 and 150-240 years respectively.

Forest Comparisons - Past and Present

Various means of comparison may be used to examine the differences between the pre-European settlement forests and the forests that exist today in western Chippewa County. I will discuss differences in terms of area coverage, composition, structure and disturbance. I have classified the pre-European settlement forests into six distinct forest ecosystem types. These were the northern hardwood, mixed pine, jack pine, mixed conifer/deciduous upland, mixed conifer/deciduous lowland and mixed conifer swamp forest types discussed above. Each of these ecosystems differed in terms of composition, structure and disturbance frequency. Although beyond the scope of my study, I believe that other internal functions such as carbon and nutrient cycling were also undoubtedly different among the six different ecosystems. The variation observed among the six ecosystems probably stemmed from inherent differences in the edaphic characteristics of the soils on which the ecosystems occurred. Edaphic characteristics would at a minimum include substrate composition, acidity, cation exchange capacity, nutrient availability and water retention capacity. Further examination of the study area for correlations between the forest types and edaphic soil characteristics would undoubtedly prove interesting.

Forest Composition

Changes in land use, forest composition and the impacts of human manipulation upon the landscape are readily apparent by comparisons of the area covered by each forest ecosystem. I have compared the areas of my six forest types to the land use areas contained in the 1978 MIRIS survey, which was based upon aerial photography. Some error in scale is present between my data and the MIRIS survey data, as is evident from the difference in total area reported. This misregistration error may have been due to distortions in the aerial photos. A more serious source of error in the MIRIS survey data is inaccuracies concerning photo-interpretation of the different land use types. The Land and Water Management division of the Michigan DNR has indicated that wetland and lowland forest types were often very difficult to distinguish from upland forest types. Consequently, the reported area coverages can only be considered as rough estimates, with an unknown degree of error. For lack of a better data source, I have proceeded with using the MIRIS data for my analysis. I acknowledge that some comparisons may be rough in nature, but general trends are still apparent. I have made comparisons of composition and area by comparing the percentage of area covered, thus minimizing the error associated with scale.

Pre-European settlement forest type areas (minus the area of lakes in the study area) are shown in Table 25. The 1978 MIRIS cover type areas are shown in Table 26. The impact of human manipulation upon the landscape is readily apparent. Nearly 2 percent of the study area is now

Table 25. Pre-European settlement forest type areas.

MIRIS Code	Forest Type	Area (ha)	Percent
411	Northern Hardwoods	65,590	24.21
421	Mixed Pine	27,393	10.11
4213	Jack Pine	9,622	3.55
		37,015	13.66
414	Mixed Conifer/ Deciduous Lowland	21,917	8.09
422	Mixed Conifer/ Deciduous Upland	44,245	16.33
423	Mixed Conifer Swamp	102,112	37.70
Sum		270,879	100

Table 26. MIRIS (1978) cover type areas.

Miris Code	Forest Type	Area (ha)	Percent	Percent Change
31	Open Herbaceous	3,485	1.31	+1.31
32	Open Shrub	6,836	2.57	+2.57
100	Urban	4,998	1.88	+1.88
200	Agriculture	26,153	9.84	+9.84
411	Northern Hardwoods	70,929	26.70	+2.49
413	Aspen/White Birch	13,001	4.89	+4.89
414	Lowland Hardwood	9,815	3.69	-4.40
421	Pine	50,538	19.02	+5.36
422	Other Upland Conifers	17,362	6.54	-9.79
429	Christmas Tree Plantation	36	0.01	+0.01
423	Lowland Conifers	33,072		
612	Shrub Wetlands	14,971		
621	Aquatic Bed Wetlands	823		
622	Emergent Wetlands	13,634		
		62,500	23.53	-14.17
Sum		265,653	100	0.0

classified as urban, whereas only 0.04 percent of the study area was occupied by indian villages in the 1840's. Almost 10 percent of the study area is now under conventional agriculture, or in Christmas tree plantations. An additional 4 percent is classified as open herbaceous or shrub land. An aspen/white birch association now covers almost 5 percent of the landscape. These early successional species became more predominant after the widespread exploitation of timber in the study area, particularly in the pine and mixed upland ecosystems. Portions of the study area are maintained in this early successional state by intensive management of jack pine and aspen for pulpwood. There has been an estimated 14 percent loss of wetlands in the study area (where wetlands are defined by my mixed conifer swamp and the MIRIS cover types), and over a 4 percent estimated loss in the mixed conifer/deciduous lowland forest type. It is estimated that almost 10 percent of the original mixed conifer upland forest type has been lost. Some of the swamps, mixed lowlands and mixed uplands may have been converted to urban areas and agriculture. The percentage of northern hardwoods actually increased by over 2 percent, possibly through succession on some of the better sites previously occupied by pine or mixed uplands that were not extensively logged. There has also been an increase of over 5 percent in the area covered by pine. It is likely that some of the mixed upland forest type has been converted to pine plantations. Large areas were aggressively afforested with pine in the 1930's, and continue to be managed as pine plantations by the U.S. Forest Service and the Michigan Department of Natural Resources. Since the MIRIS survey did not differentiate between the species of pine, I cannot determine what changes have occurred in the percentage of area covered by mixed pine and jack pine.

Other than the genesis of the aspen/white birch forest type, the most striking change in the composition of the forest within the study area is the pronounced decline in the dominance of eastern hemlock. Hemlock has been severely reduced from its position as a dominant tree species in the northern Lake States, and now occupies a mere 0.5 percent of the landscape (Eckstein 1980). I do not have definitive data on present day densities of hemlock in the study area, but from extensive personal observation I know that hemlock is not present at anywhere near the densities that I have calculated. I have found that hemlock was formerly a dominant (and possibly <u>the</u> dominant) species in both the northern hardwood and mixed conifer/deciduous upland forest types of my study area (Tables 9 and 11).

There are several reasons for the decline of hemlock. Hemlock was logged heavily in the region both for lumber and for its bark, which contained the tannin used for many years in the leather tanning process (Karamanski 1989). This heavy cutting and the frequent highly destructive fires that followed in the wake of lumbering severely reduced residual seed sources. Hemlock also has rather exacting germination requirements. Hemlock seeds and seedlings are highly susceptible to desiccation, and do not survive without forest cover that is at least pole sized in growth (Jordan and Sharp 1967). As discussed previously, fire that exposes mineral soil can enhance hemlock regeneration. Hough and Forbes (1943) described some hemlock stands that were of clear fire origin. Hemlock regeneration also occurs on decaying nurse logs and stumps, and upon windthrow hummocks where warmer surface temperatures and better moisture regimes exist (Godman and Lancaster 1990). However, the second-growth forests of today have not yet matured to the point where large amounts of fallen and decaying material are again present upon the forest floor, and present day fire suppression policies severely restrict the scale of fire in all forest types. Mladenoff and Sterns (1993) hypothesized that fire suppression has created almost pure deciduous forests, which have resulted in the replacement of conifer litter nutrient cycles by deciduous litter nutrient cycles that discourage the regeneration of hemlock, and provide a positive feedback that favors the regeneration of deciduous species. Mladenoff and Sterns also suggest that browsing by the current high population densities of white tailed deer (Odocoileus virginianus) is not the critical factor suppressing the regeneration of hemlock. They theorize that regeneration is prevented by the previously discussed inhibiting factors, and therefore renders the issue of browsing moot.

I believe that the lack of residual seed sources is a primary factor inhibiting the regeneration of hemlock, because without seed sources regeneration cannot possibly occur. Where significant seed sources do exist the above discussed problems affecting regeneration then become a concern. Perhaps when second growth forests mature to the point where natural mortality and windthrow again produce significant quantities of down and decaying material and windthrow hummocks on the forest floor, within range of residual hemlock seed sources, significant hemlock regeneration will occur. Management practices which encourage down and decaying material, the use of prescribed burns near residual seed sources and downward pressure upon deer populations can assist hemlock regeneration. Regardless, it will take hundreds of years (if it is even possible at all) for hemlock to regain the predominance that it once possessed in the northern hardwood and mixed upland forests of my study area.

Forest Structure

Changes in forest structure are also apparent. Table 27 shows the estimated basal area, density and mean DBH for the pre-European and present day forests of the study area. The basal area and mean DBH data are from 1994 U.S. Forest Service compartment records. Estimates of density were not readily available, and were calculated as described in the methods section above. The resultant densities for the

Table 27. Estimates of basal area, density and mean DBH for pre-European settlement and present day forest types.[1]

Forest Type	Basal Area (m^2/ha)		Estimated Density (TPH)		Mean DBH (cm)	
	1850	1994	1850	1994	1850	1994
Northern Hardwood	35 (154)[2]	21 (92)	348 (141)	563 (228)	33 (13)	23 (9)
Mixed Pine	8 (36)	15 (67)	81 (33)	570 (231)	31 (12)	18 (7)
Jack Pine	8 (33)	15 (64)	326 (132)	854 (346)	18 (7)	15 (6)
Aspen/ White Birch	N/A	16 (68)	N/A	681 (276)	N/A	18 (7)
Mixed Conifer Upland	21 (92)	17 (75)	287 (116)	578 (324)	28 (11)	18 (7)
Mixed Conifer Lowland	15 (66)	21 (92)	269 (109)	528 (214)	23 (9)	23 (9)
Mixed Conifer Swamp	14 (60)	17 (74)	314 (127)	963 (390)	20 (8)	15 (6)

[1] Present day estimates are based upon 1994 U.S. Forest Service Compartment Records.

[2] Numbers in parentheses are basal area in ft^2/ac, density in trees/ac and DBH in inches.

northern hardwood and jack pine forest types compared favorably with figures achieved using stocking curves (Tubbs 1977, Benzie 1977), so I believe that the procedure used to calculate the densities is accurate.

The structural data of the present forests in Table 27 was compared to the data of the pre-European settlement forests in Table 8. The density of every forest type is significantly higher in the present day forests of the study area. The mean DBH is significantly less in every type except the jack pine and mixed conifer lowland types, which are only slightly less. The estimates of basal area per hectare were significantly higher in the northern hardwood and mixed conifer upland types of the pre-European settlement forests. The higher densities and lower basal areas and diameters in the present day northern hardwood and mixed upland types are indicative of forests that are still relatively young. This would be expected in the second growth forests of the study area, where all stands are probably much less than 100 years old. Somewhat higher basal areas were found in the mixed pine, jack pine, mixed conifer lowland and mixed conifer swamp types of the present-day forests of the study area. These small increases in basal area can be attributed to the tremendous increases in density and associated smaller diameters within these forest types. Few truly mixed pine stands exist in the present day forests of the study area. Most white pine, and particularly red and jack pine stands are intensively managed in plantations, where densities far exceed even the dense pre-European settlement jack pine stands. Although the mixed conifer lowland and mixed conifer swamp forest types are not nearly as intensively managed as the pine types, high natural densities have occurred in the regenerated stands.

In contrast, the pre-European settlement forests of the study region were characterized by large and dominant trees of several species, relatively low tree densities associated with relatively high basal areas, probable multi-layered canopies, and widespread windthrow events which created dead snags, large fallen logs, windfall hummocks and variably sized pockets of seral species. In the northern hardwood forests of the study area seral species such as aspen, oak, white birch and white pine made up only 6.9 percent of the bearing trees selected. All of these characteristics are rare or lacking in young second growth forests, and they can be considered indicators of old growth forests.

Disturbance Regimes

Disturbance regimes are very different in the present day forests of the study area. The pre-European settlement forests of my study area were disturbance driven and dependent ecosystems. Disturbance by fire, windthrow, insect related mortality and beaver flooding had profound impacts on both the composition and structure of the pre-European forest. Disturbance does not have nearly the same impact today.

Since the 1930's wildfire has been rigorously suppressed in the study area. Some controlled burning has been utilized in recent years, to assist in the regeneration of jack pine for instance. However, the widespread and catastrophic fires that frequently occurred, particularly in the pine forest types, are likely never to be experienced again. Interests concerned with the protection of private property have greater political weight than forest professionals in determining fire suppression policies. Bormann and Likens (1979) reported the present-day incidence of fire in both the eastern and western halves of the Hiawatha National Forest. On a one-million acre (405,000 ha) basis, an average of 19.5 fire events occurred per year. Of these, 2.5 events were caused by lightning, and 17 events were caused by humans. Weighting the total number of events, to take the acreage of the study area into account, yielded a present day average of 13 fire events per year in the study area. This is significantly less than the estimated 16 to 32 fire events and 19 to 37 windthrow and fire events per year for all pre-European settlement forest ecosystems combined (Table 16). Furthermore, the average area burned in the present-day forests is only 65 ha per year. The estimated area of annual disturbance for fire in all pre-European settlement forest types combined was between 296 and 591 ha per year. For windthrow with subsequent fire the area of annual disturbance was even greater at 392 to 783 ha per year (Table 18). Thus, fire plays an insignificant role in determining the composition and structure of the present day forests of the study area, as compared to the forests of the 1840's.

Management practices of forestry professionals have taken the place of fire in regulating the composition and structure of the present day forests. I believe that the exclusion of fire has altered many facets of the original forests of the study area, particularly the composition of the forest. Today's white and red pine plantations on the better sites of the Raco outwash plains often have deciduous components in their understory. Bigtooth aspen and red maple are present in jack and red pine stands in densities that could not have existed in the virgin forests (Palik and Pregitzer 1992). I believe that the mixed conifer/deciduous lowland forest type has a much greater relative density of hardwood species in its present day composition, hence it is referred to in the MIRIS codes as lowland hardwoods. In the pre-European settlement forests these deciduous species, and seedling and pole sized conifers as well, were periodically destroyed by fire. Fire reduced competition by deciduous species in forest types dominated by conifers, or essentially every type but the northern hardwoods. Such a regime favored the survival and growth of tree species that were adapted to periodic disturbance by fire, such as the pines, hemlock, the spruces, cedar and tamarack.

Data on the present day frequency and scale of windthrow events in the study area are not available. However, an excellent study of natural windthrow patterns in the hemlock-hardwood preserves of the Porcupine Mountains, Sylvania Wilderness Area and the Huron Mountains in western upper Michigan was conducted by Frelich and Lorimer (1991). Their estimates of return intervals range from as low as 69 years for events with more than 10 percent canopy removal, to a high of 1920 years for events with greater than 60 percent canopy removal. This return interval is within that calculated for the virgin northern hardwood forests of my study area (1387-2778 years). It must be emphasized that these results apply to virgin, old growth northern hardwood forests. The relatively young second growth forests currently in my study area do not have the same structure as old growth forests, and I suspect that they therefore are not impacted by the same intensity of windthrow disturbance. From personal observation, I certainly have not seen any evidence of windthrow events anywhere near the frequency, size and scale of those noted by the surveyors in the virgin forests of my study area. Windfall is likely a moderate disturbance regime in the present day forests of the study area. However, I believe that the impact of windthrow will increase as more forest area matures and begins to develop old growth structural characteristics. A field study to determine the current extent of windthrow in my study area would undoubtedly be very useful in assessing the current impact of windthrow upon the composition and structure of the forest types of the area.

Despite the best efforts of forest managers, insect related mortality remains a dominant influence upon forest composition and structure, especially in conifer dominated types. It is very likely that insects have a greater role and have more impact (relative to other disturbance regimes) in regulating the composition and structure of today's forests, than they did in the virgin forests of the study area. There are several reasons why I believe this is true. The 5.4 percent increase in the area covered by pine provides more forest area that can potentially be impacted by insect outbreaks that favor such tree species. The predominantly pure composition, and unnaturally dense structure of many pine stands provide few effective buffers to slow and disrupt the dispersal of insects. In the case of jack pine, current management practices exclude fire with the objective of artificially extending the lifespan so as to produce merchantable timber. Such stands are much more dense and older than historic stands and therefore more susceptible to stresses such as those induced by insect infestation. Consequently, when such infestations occur they tend to be severe and devastating in scale. In 1991 the jack pine budworm defoliated approximately 20,250 ha in the Upper Peninsula of Michigan (USDA 1993). The Raco outwash plains of my study area has, in a two year period since 1991, experienced extensive jack pine bud worm defoliation on over 6,480 ha of forest land. Typical mortality rates are between 10 and 40 percent, and will result in 648 to 2592 ha of dead timber. This is a rate of between 324 and 1296 ha per year, far exceeding the estimated 55-109 ha per year area of annual disturbance calculated for the pre-European settlement jack pine forests of the study area. The incidence of insect related mortality in the present-day lowland hardwoods and lowland conifers may not be as extensive as in the virgin forests due to the severe reduction of their area coverage.

I know of no data regarding the current impact of beaver floodings upon my study area. The genesis of the aspen/paper birch forest type may provide more suitable habitat for beaver. The decline of the fur industry has simultaneously reduced the negative pressure that for so many years repressed the populations of beaver. Given these facts, I suspect that the incidence of beaver flooding in the study area is increasing. A field study to determine the current extent of beaver floodings in the study area would be very useful in assessing the current impact of flooding upon the composition and structure of the forest types of the area.

SUMMARY AND CONCLUSIONS

It is important to realize that this study represents a mere snapshot in time. Despite this fact, some relevant conclusions regarding the composition, structure and disturbance dynamics of the study area may still be drawn. I believe that the overall structure of the pre-European forests of western Chippewa County fit the shifting-mosaic steady state model of Bormann and Likens (1979). The landscape was essentially a vast array of irregular patches, composed of different successional stages and tree species associations of different age and size classes. The forest ecosystems were variable in scale, and also contributed to the heterogeneity of the landscape. They were also variable in composition and structure, probably being a compilation of uneven-aged and even-aged stands. The jack pine ecosystem probably had an even-aged structure. The composition and structure of the forests were driven by disturbance. Disturbance regimes in the study area were fire, windthrow, insect related mortality and beaver floodings. The northern hardwood ecosystem was a windthrow-dependent system. The mixed pine, and jack pine ecosystems were fire dependent. The mixed conifer/deciduous upland, mixed conifer/deciduous lowland and mixed conifer swamp ecosystems were windthrow and fire dependent systems. The northern hardwood and mixed conifer swamp ecosystems had disturbance return intervals that were greater than the maximum potential lifespans of their dominant tree species. The mixed pine, jack pine, mixed conifer/deciduous upland and mixed conifer/deciduous lowland ecosystems had return intervals less than the maximum potential lifespans of their dominant tree species. The regeneration and persistence of these forest types were probably dependent upon stand-replacing disturbance.

The pre-European settlement forests of the study area were characterized by large and dominant trees of several species, relatively low tree densities with relatively high basal areas, probable multi-layered canopies, and widespread windthrow events which created dead snags, large fallen logs, windfall hummocks and variably sized pockets of seral species. All of these features are characteristics of old-growth forests. I do not use the term old-growth to imply that each forest type was homogeneously dominated by late-successional "climax" species associations. It is clear that disturbance regimes caused seral heterogeneity within every forest type. Such heterogeneity varied in scale, from relatively small patches in the northern hardwood forests to large-scale patches of seral jack pine on the Raco outwash plains. The area within each forest type possessing old-growth characteristics was likewise variable, ranging from large contiguous areas in the northern hardwood type to essentially none within the jack pine type.

The composition, structure and predominant modes of disturbance have changed dramatically since the period of the GLO land surveys in the 1840's. Most notable is the decline of hemlock from its dominant status in the northern hardwood and mixed conifer/deciduous upland forest types. A greater percentage of the landscape is now covered by seral species, such as the aspen/white birch association. The forests of today are characterized by very high densities, lower mean diameters and relatively lower basal areas. Because of active suppression, fire is no longer a significant factor in regulating the composition and structure of forest ecosystems. The impact of windfall has been reduced as well, probably by changes in forest structure. The timber harvesting aspect of forest management, and insect related mortality have become the dominant disturbance regimes in the study area.

Since it is highly unlikely that large areas of western Chippewa County will be designated wilderness areas and be allowed to grow and function according the natural processes, forest management will continue to be the dominant influence upon the composition and structure of the forests. Gaining an understanding of how the ecosystems of the study area were once structured and naturally functioned is paramount to the attainment of a managed condition which maintains the long-term health and sustainability of these ecosystems. Management must begin at the landscape and ecosystem levels, and then filter down to the community and stand levels. In order to successfully implement ecosystem management as the broad framework in which to manage the forest resources of the study area for multiple-use, while also maintaining the long term integrity, health, productivity and biodiversity of the forest ecosystems, we must recognize the role that disturbance has historically played in the function of the ecosystems. We must understand the role that disturbance played in regulating the composition and structure of the forest ecosystems if we can ever hope to successfully emulate the disturbance regimes through ecologically sound management practices. Management practices can be implemented at the stand level. However, such actions must be taken with a full understanding of how individual stand dynamics interrelate with overall community, ecosystem and landscape structure and dynamics. I believe that the historic composition, structure and disturbance dynamics revealed by this study can provide a substantial foundation upon which sound ecosystem management practices may be based, not only for the study area, but also for much of eastern upper Michigan.

APPENDIX A

A dictionary of data field codes used in the General Land Office Vegetation Entry (GLOVE) program.

ASPECT	A two digit character field available for recording slope aspect data.
B1	A one digit character field (associated with DIST1) recording the bearing (N or S) from a line or corner post to a bearing tree.
B2	A one digit character field (associated with DIST2) recording the bearing (N or S) from a line or corner post to a bearing tree.
CNTY	A two digit numeric code representing the county in Michigan to which subsequent field data pertains.
CSE	A two digit numeric code representing the orientation (or course) of any disturbance event recorded by surveyors, where: 1 = North-South 3 = East-West 2 = Northwest-Southeast 4 = Northeast-Southwest
DIA	A two digit numeric field recording the bearing tree diameter (in inches).
DIR	A one digit character field recording the bearing (N, S, E or W) in which the surveyor was traversing.
DIST	A six digit, 2 decimal numeric field recording the distance (in chains) from the reference corner that the surveyor traversed before setting a line or corner post.
DIST1	A five digit, one decimal numeric field recording the first distance (in links) from a line or corner post to a bearing tree.

DIST2 — A five digit, one decimal numeric field recording the second distance (in links) from a line or corner post to a bearing tree.

DRNG — A two digit character field available for recording soil drainage data.

DSTRB — A two digit numeric code recording the presence of any disturbance noted by the surveyors, where:

92 = Fire	95 = Beaver Pond
93 = Dead & Windthrown	97 = Dead Timber
94 = Beaver Meadow	98 = Burned & windthrown

GEOL — A two digit character field available for recording quaternary geological data.

NOTES — A text memo field for recording any supplemental data of interest.

RECNUM — A sequential numbering of records in the database.

REF — A two digit character field referencing the section corner (NE, NW, SE or SW) from which the surveyor was traversing.

SEC — A two digit numeric field for the section (1-36) to which subsequent field data pertains.

TOPO — A two digit character field representing the general topography of a section line, where:

ES = Enter Swamp Depression
SD = Swamp Depression
LS = Leave Swamp Depression
EB = Enter Alder Bottoms
SB = Stream Bottom
LB = Leave Alder Bottoms
EM = Enter Marsh
OM = Open Marsh
LM = Leave Marsh
LP = Level Plains
WP = Wet Level Plains
SR = Side of Ridge
TR = Top of Ridge
RU = Rolling Uplands
FU = Flat Uplands
SW = Swale
EO = Enter Open Pine Land
LO = Leave Open Pine Land
EG = Enter Pine Grove
LG = Leave Pine Grove
ET = Enter Jack Pine Thicket
LT = Leave Jack Pine Thicket

TREE A two digit character field recording the bearing tree species, where:

A = Aspen	IW = Ironwood
AL = Alder	JP = Jack Pine
BF = Balsam Fir	BP = Balsam Poplar
BW = Basswood	MA = Mountain Ash
BE = Beech	RM = Red Maple
BA = Black Ash	RO = Red Oak
BC = Black Cherry	RP = Red Pine
BO = Black Oak	SP = Spruce
BR = Bur Oak	SM = Sugar Maple
C = Cedar	T = Tamarack
CW = Cottonwood	WB = White Birch
E = Elm	WP = White Pine
GA = Green Ash	W = Willow
H = Hemlock	YB = Yellow Birch

TWP A six digit alpha-numeric field recording the township tier and range (ie. 40N10W) to which subsequent field data pertains.

YR A two digit numeric field recording the year (ie. 40 = 1840) in which the survey was conducted.

APPENDIX B

Township forest cover type maps of western Chippewa County, Michigan.

APPENDICES

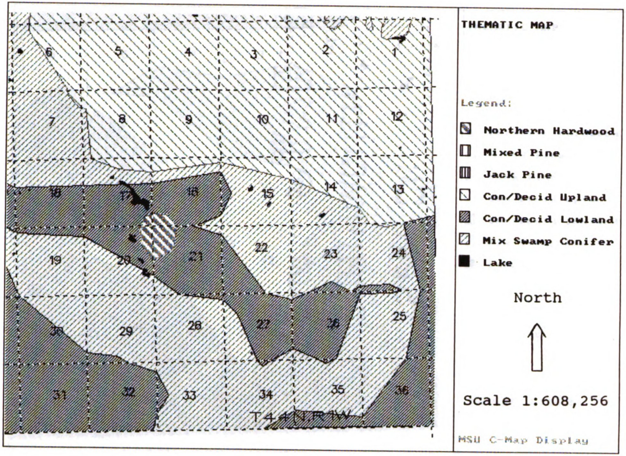

Figure B.1. **Pre-European settlement forest cover types for Township 44 North, Range 1 West.**

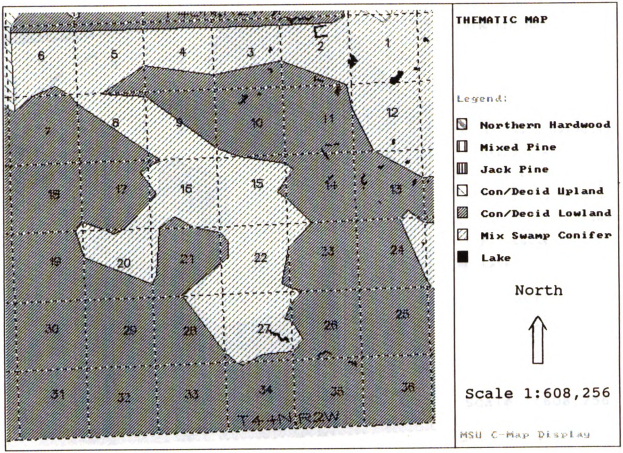

Figure B.2. **Pre-European settlement forest cover types for Township 44 North, Range 2 West.**

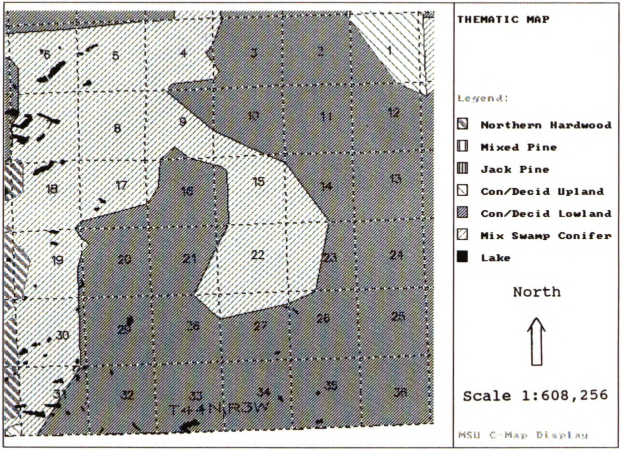

Figure B.3. **Pre-European settlement forest cover types for Township 44 North, Range 3 West.**

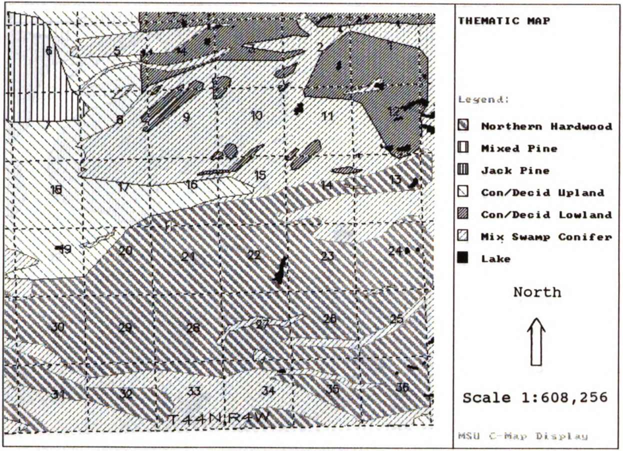

Figure B.4. Pre-European settlement forest cover types for Township 44 North, Range 4 West.

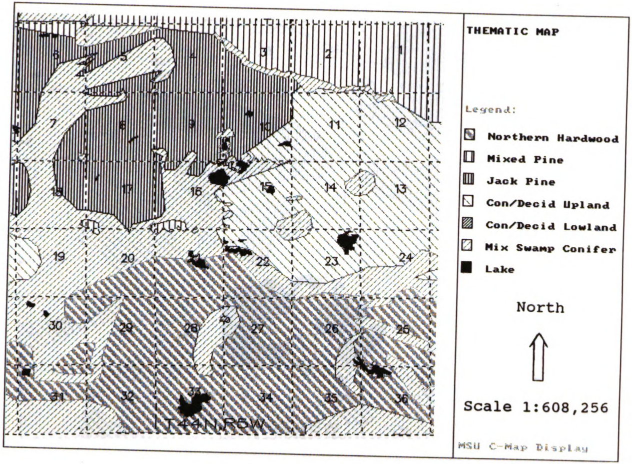

Figure B.5. **Pre-European settlement forest cover types for Township 44 North, Range 5 West.**

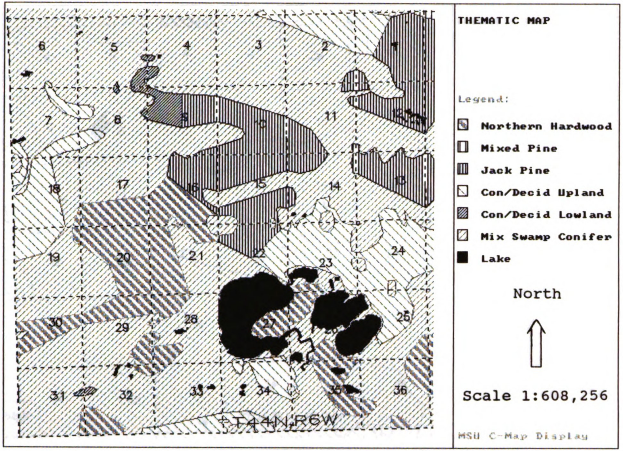

Figure B.6. Pre-European settlement forest cover types for Township 44 North, Range 6 West.

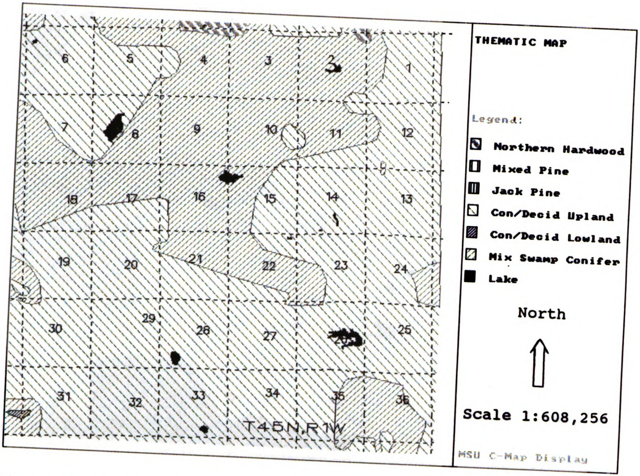

Figure B.7. Pre-European settlement forest cover types for Township 45 North, Range 1 West.

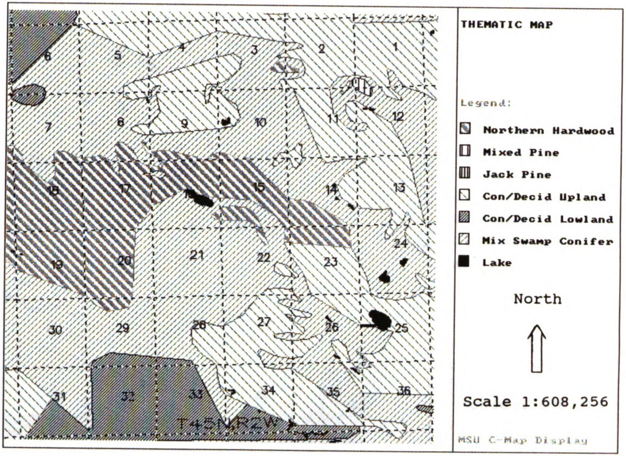

Figure B.8. Pre-European settlement forest cover types for Township 45 North, Range 2 West.

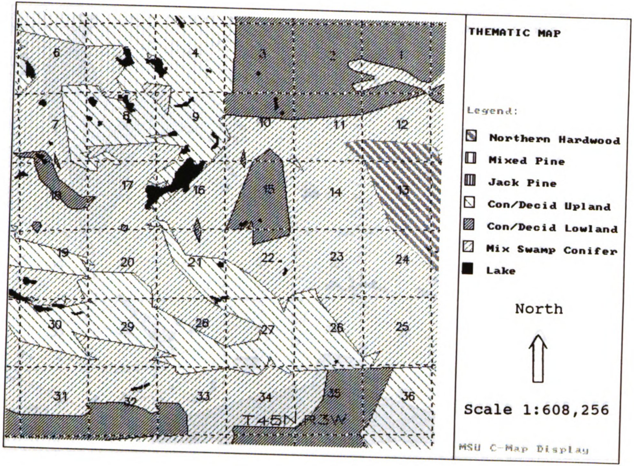

Figure B.9. **Pre-European settlement forest cover types for Township 45 North, Range 3 West.**

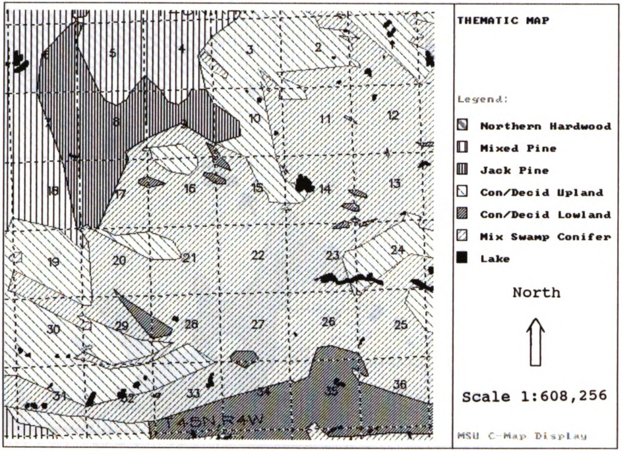

Figure B.10. Pre-European settlement forest cover types for Township 45 North, Range 4 West.

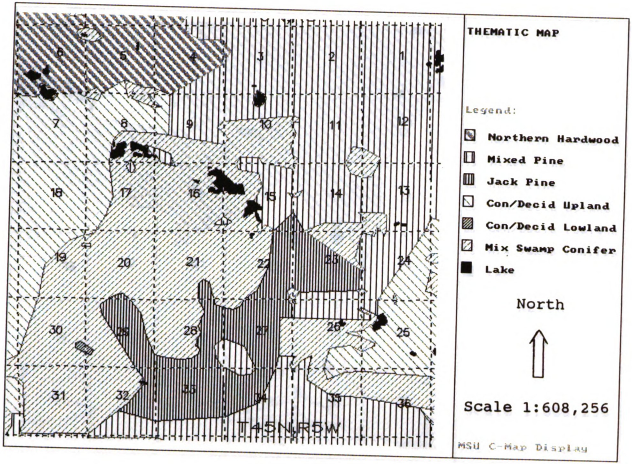

Figure B.11. Pre-European settlement forest cover types for Township 45 North, Range 5 West.

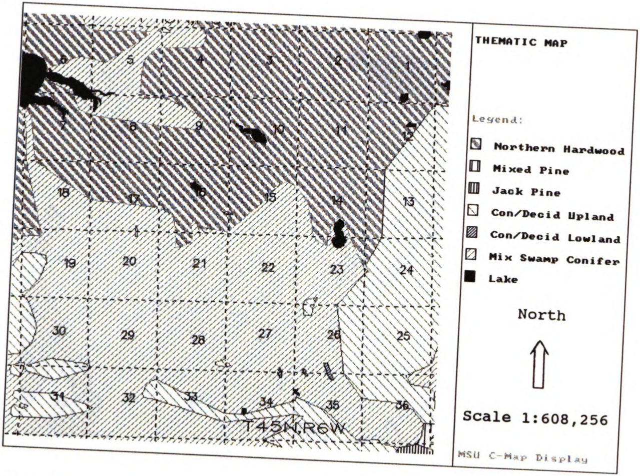

Figure B.12. Pre-European settlement forest cover types for Township 45 North, Range 6 West.

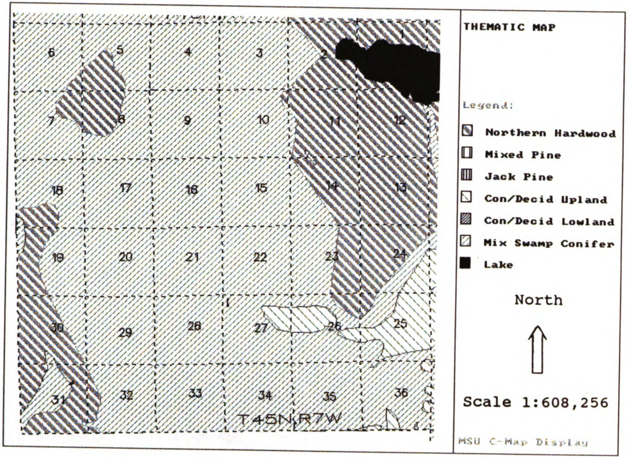

Figure B.13. Pre-European settlement forest cover types for Township 45 North, Range 7 West.

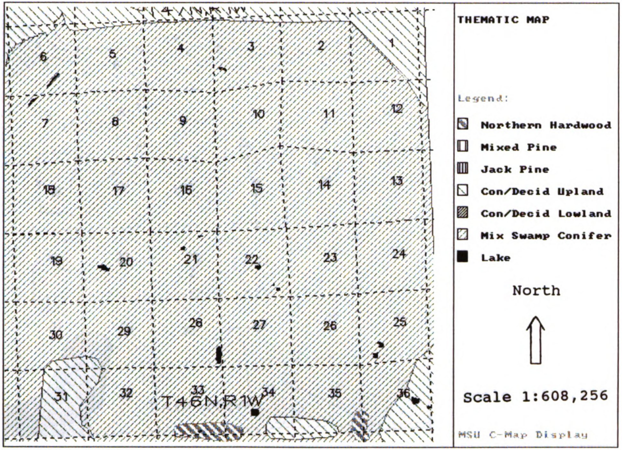

Figure B.14. Pre-European settlement forest cover types for Township 46 North, Range 1 West.

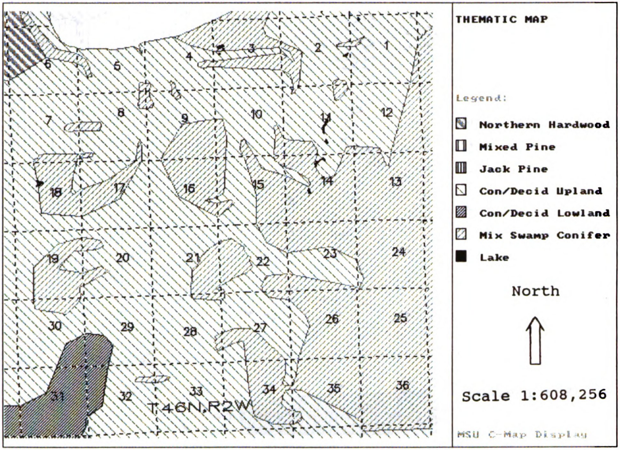

Figure B.15. Pre-European settlement forest cover types for Township 46 North, Range 2 West.

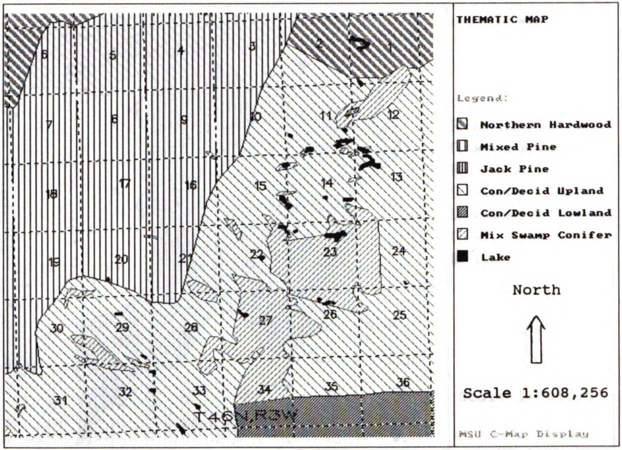

Figure B.16. Pre-European settlement forest cover types for Township 46 North, Range 3 West.

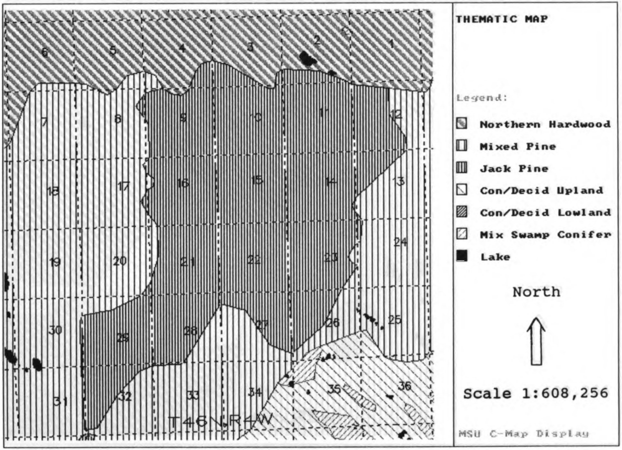

Figure B.17. Pre-European settlement forest cover types for Township 46 North, Range 4 West.

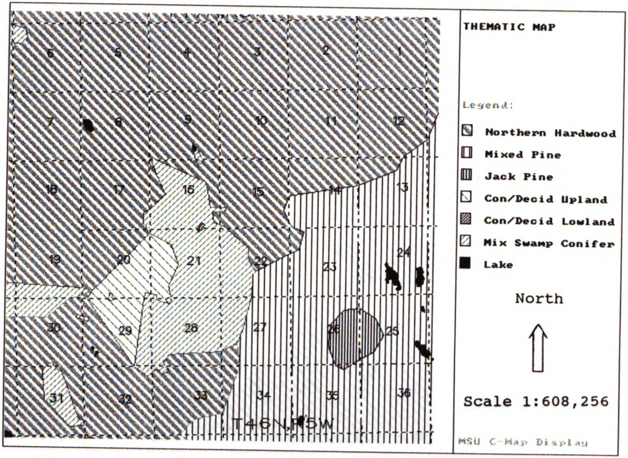

Figure B.18. Pre-European settlement forest cover types for Township 46 North, Range 5 West.

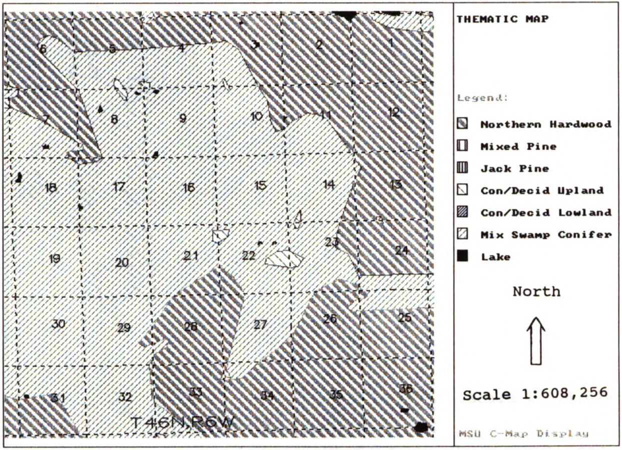

Figure B.19. Pre-European settlement forest cover types for Township 46 North, Range 6 West.

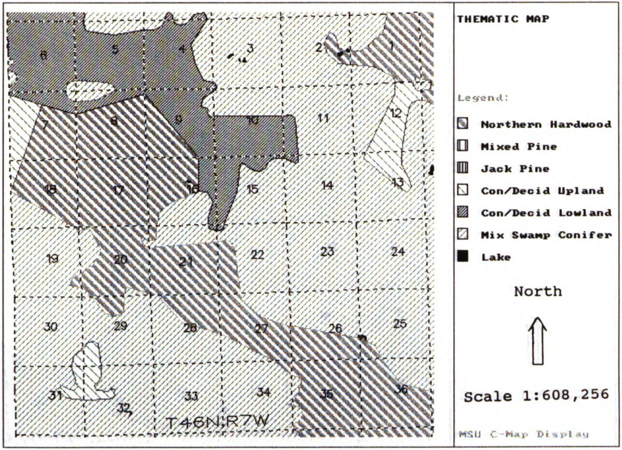

Figure B.20. Pre-European settlement forest cover types for Township 46 North, Range 7 West.

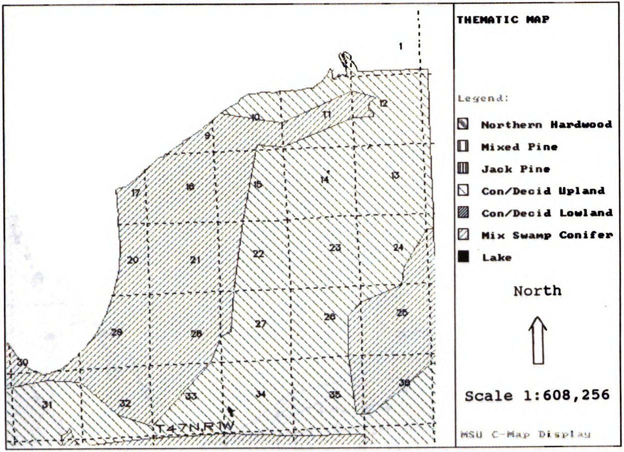

Figure B.21. Pre-European settlement forest cover types for Township 47 North, Range 1 West.

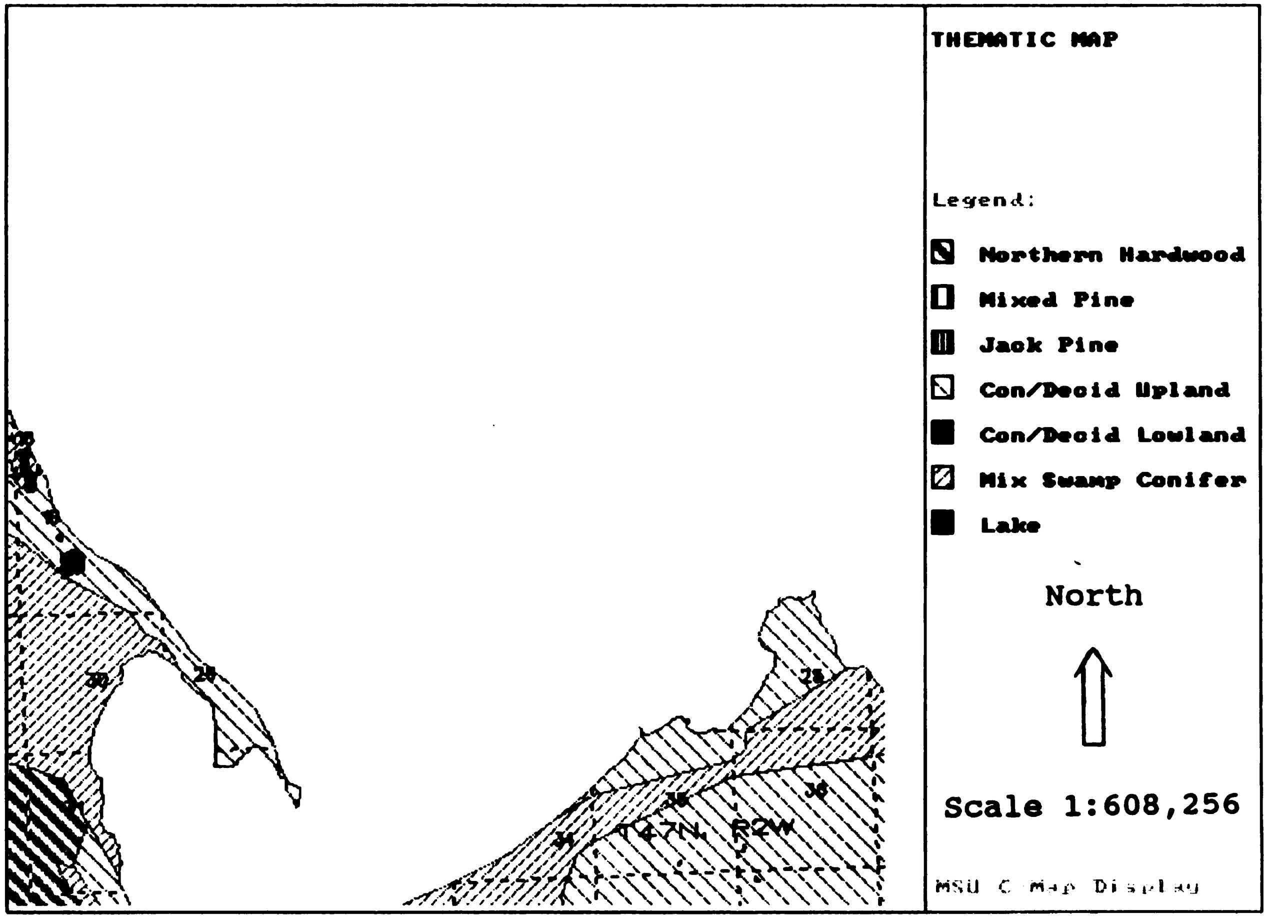

Figure B.22. Pre-European settlement forest cover types for Township 47 North, Range 2 West.

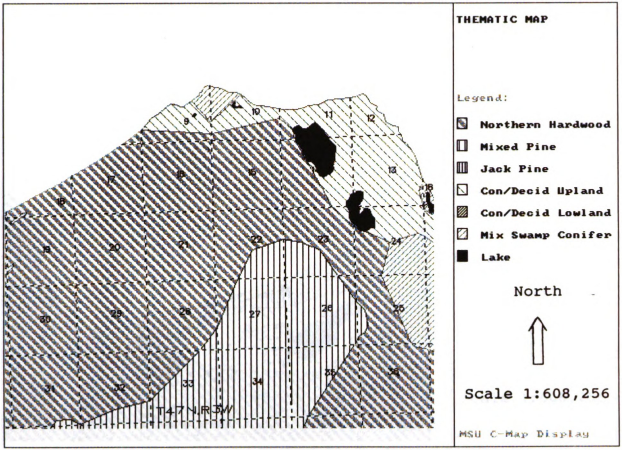

Figure B.23. Pre-European settlement forest cover types for Township 47 North, Range 3 West.

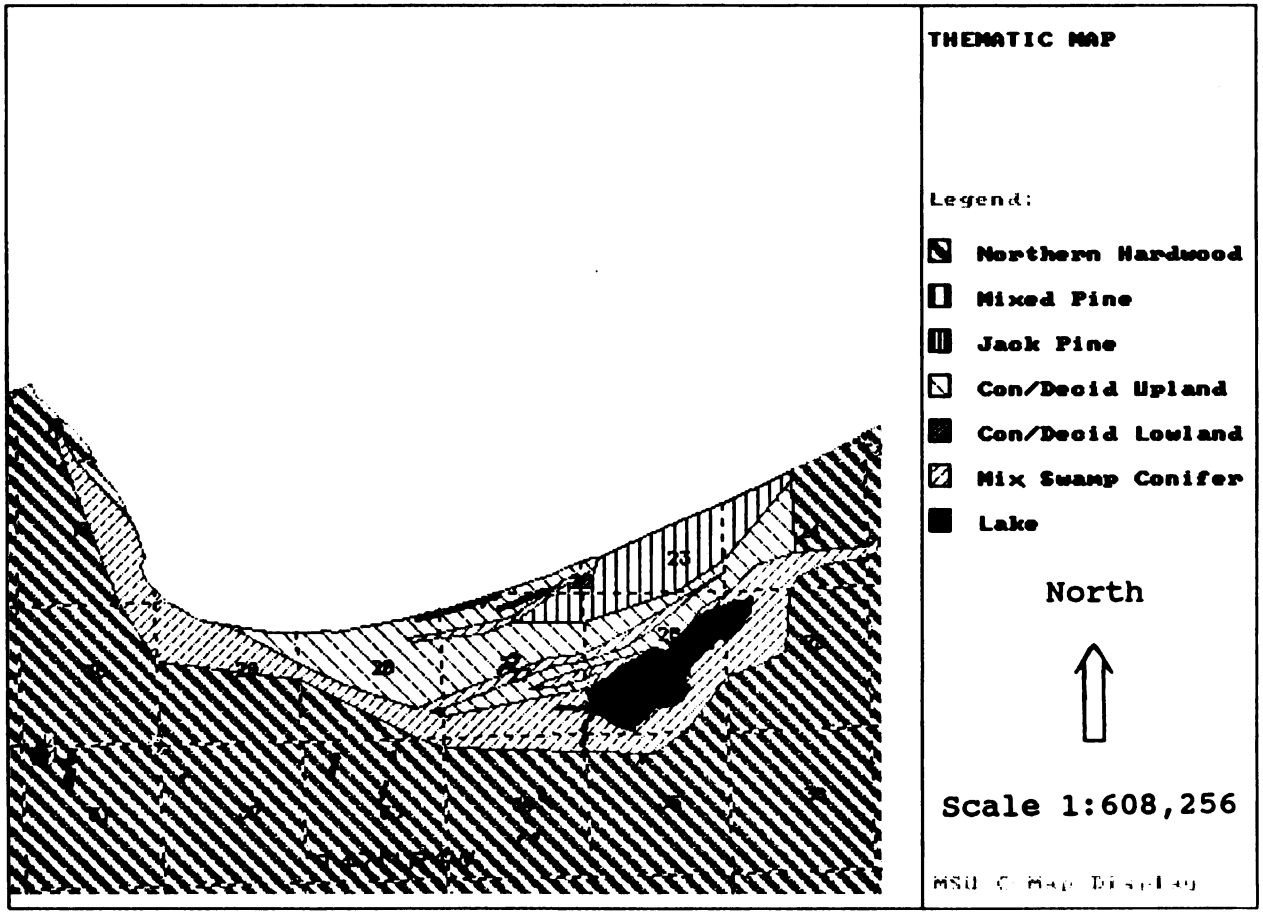

Figure B.24. Pre-European settlement forest cover types for Township 47 North, Range 4 West.

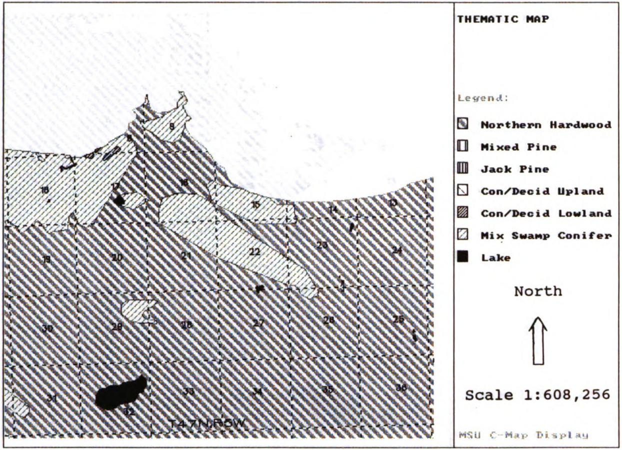

Figure B.25. Pre-European settlement forest cover types for Township 47 North, Range 5 West.

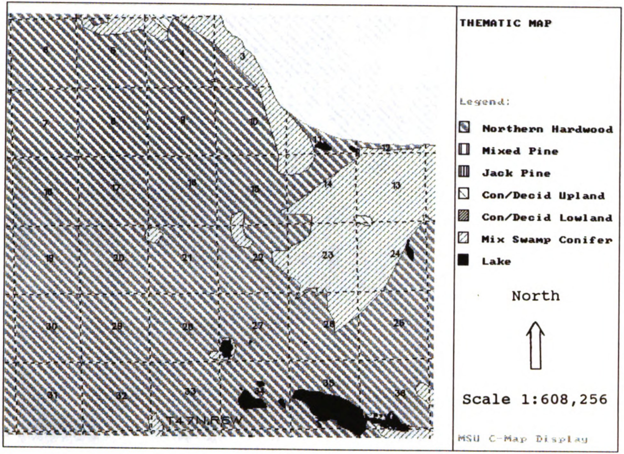

Figure B.26. Pre-European settlement forest cover types for Township 47 North, Range 6 West.

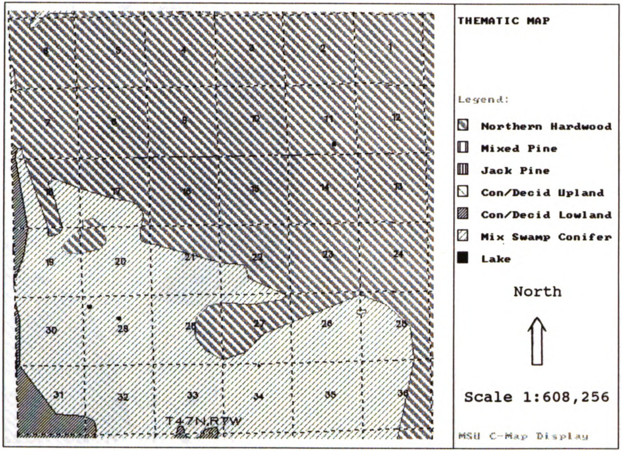

Figure B.27. Pre-European settlement forest cover types for Township 47 North, Range 7 West.

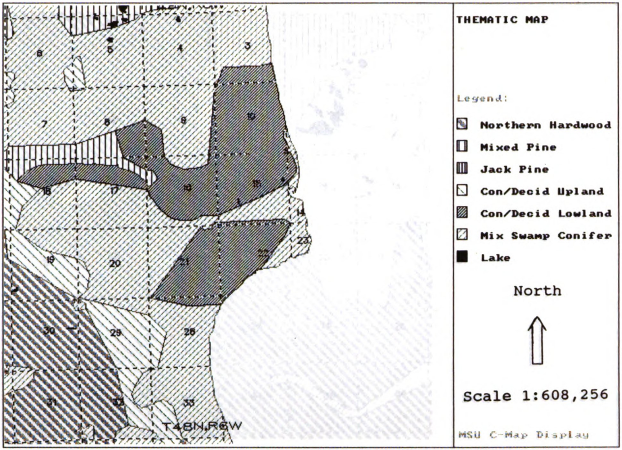

Figure B.28. Pre-European settlement forest cover types for Township 48 North, Range 6 West.

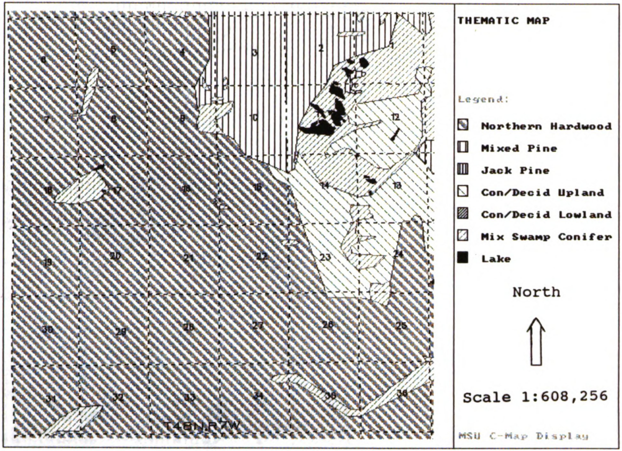

Figure B.29. Pre-European settlement forest cover types for Township 48 North, Range 7 West.

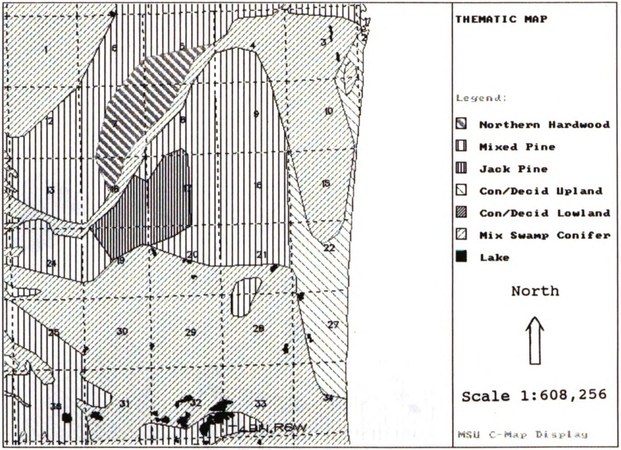

Figure B.30. Pre-European settlement forest cover types for Township 49 North, Range 6 West.

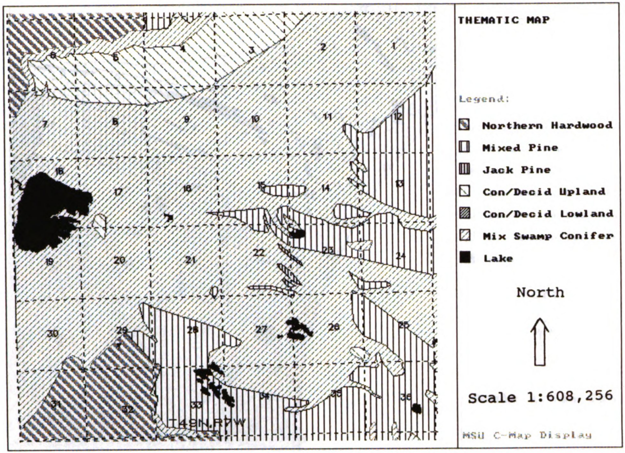

Figure B.31. Pre-European settlement forest cover types for Township 49 North, Range 7 West.

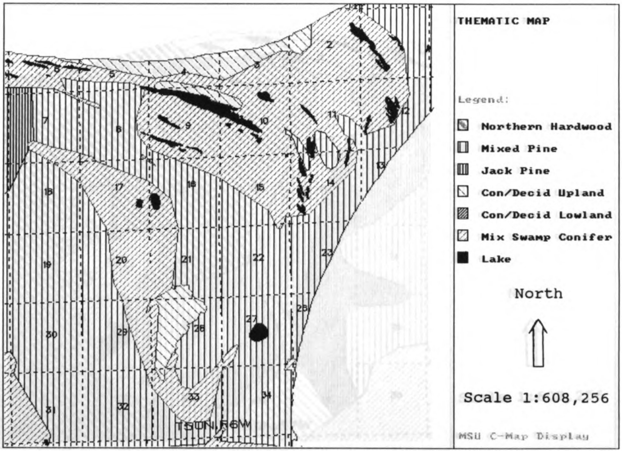

Figure B.32. Pre-European settlement forest cover types for Township 50 North, Range 6 West.

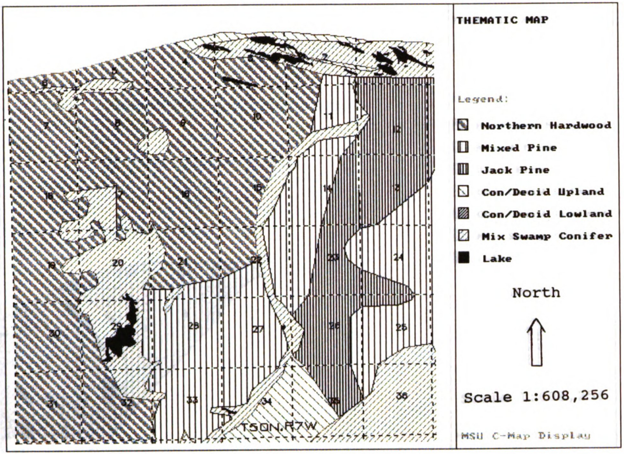

Figure B.33. Pre-European settlement forest cover types for Township 50 North, Range 7 West.

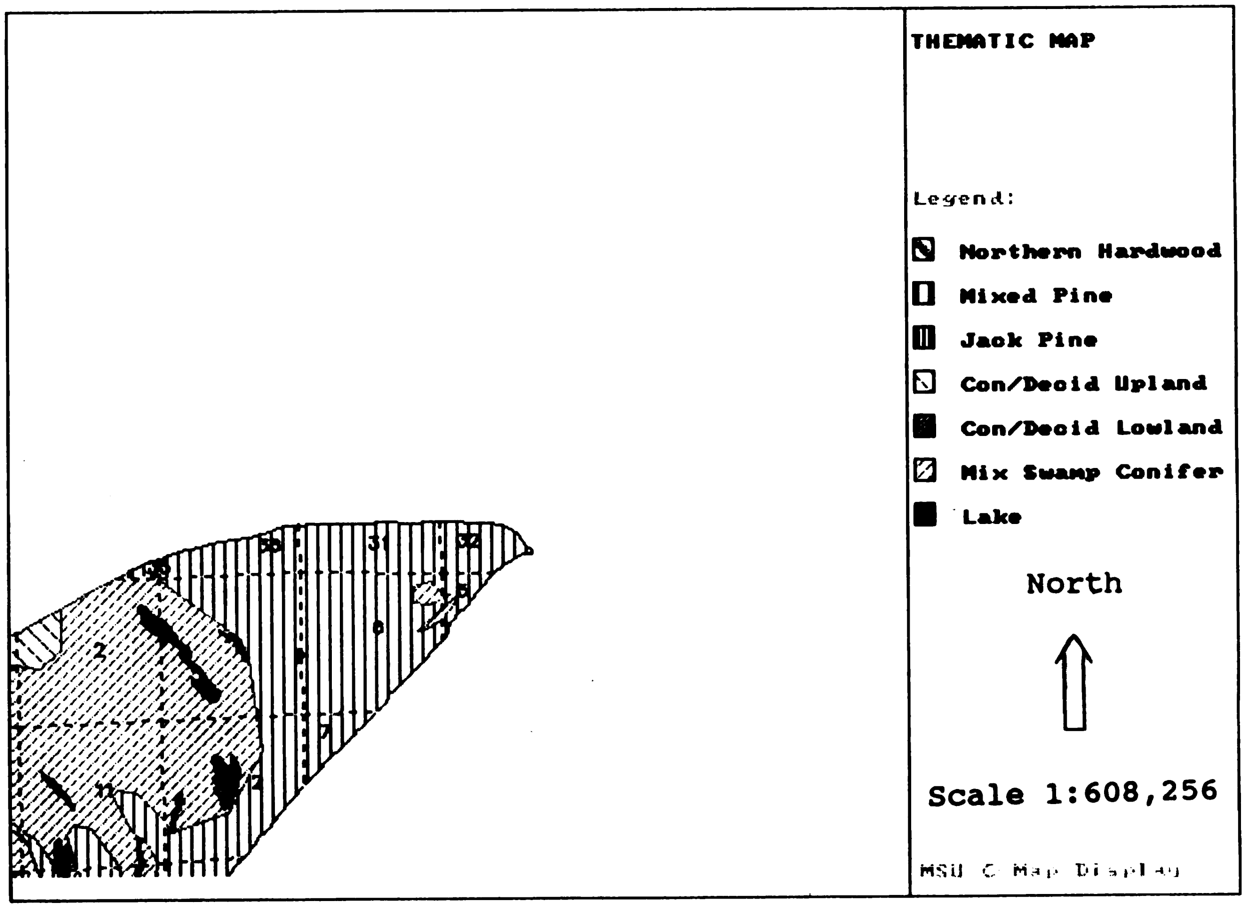

Figure B.34. Pre-European settlement forest cover types for Township 50 North, Range 5 West, and Townships 51 North, Ranges 5-6 West.

APPENDIX C

Diameter distribution graphs for significant tree species in the northern hardwood forest type.

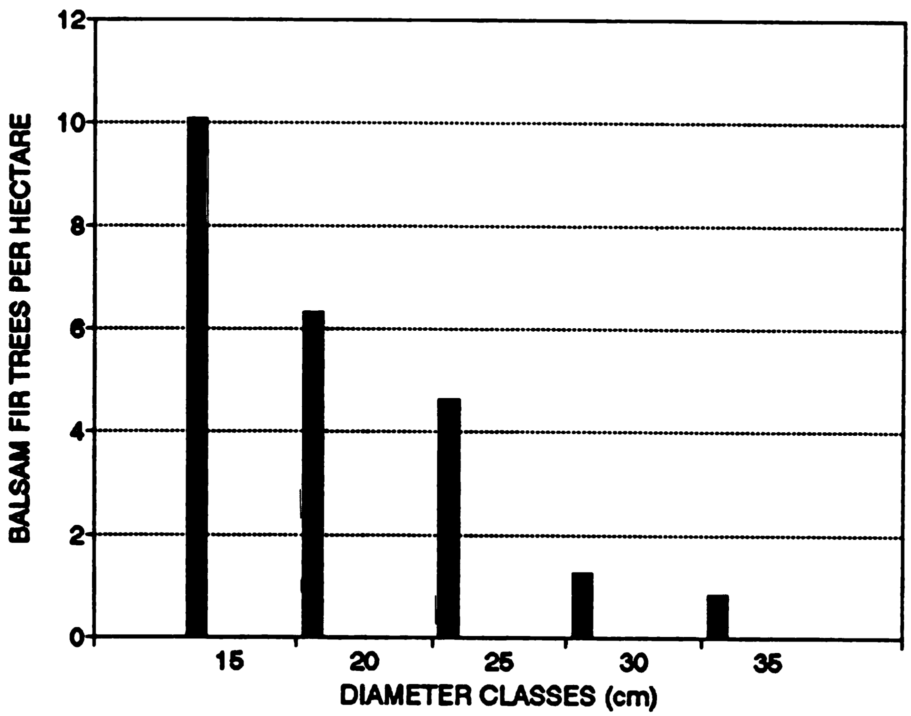

Figure C.1. Diameter distribution of balsam fir in the northern hardwood forest type.

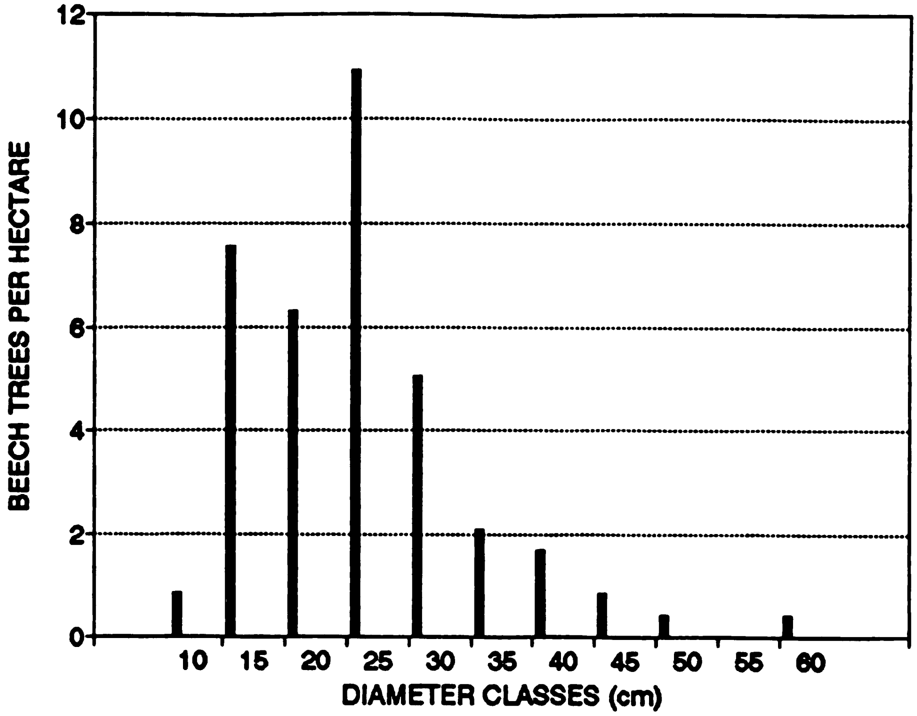

Figure C.2. Diameter distribution of beech in the northern hardwood forest type.

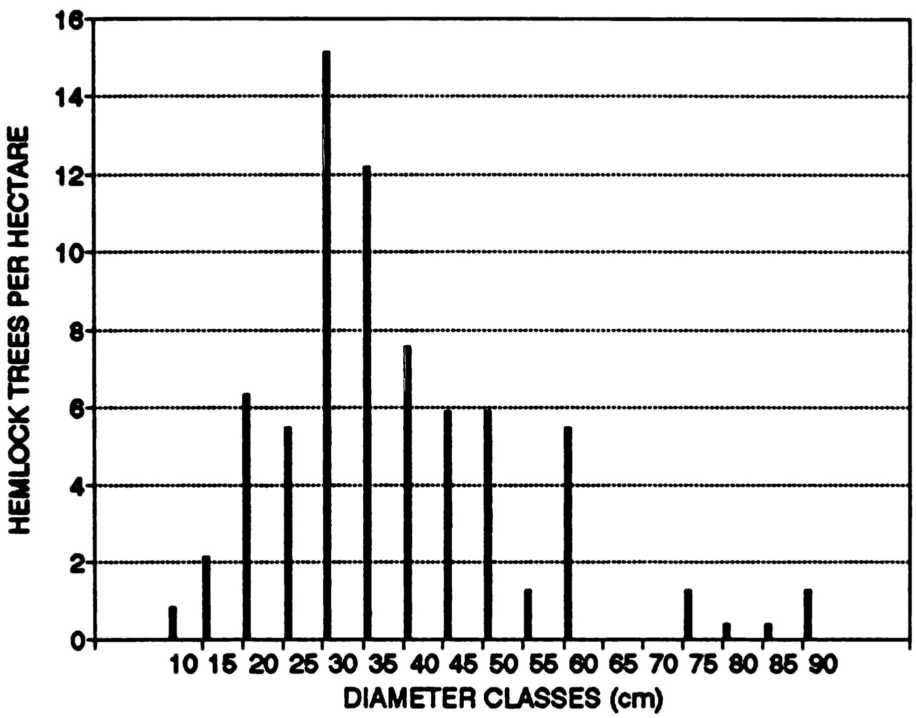

Figure C.3. Diameter distribution of eastern hemlock in the northern hardwood forest type.

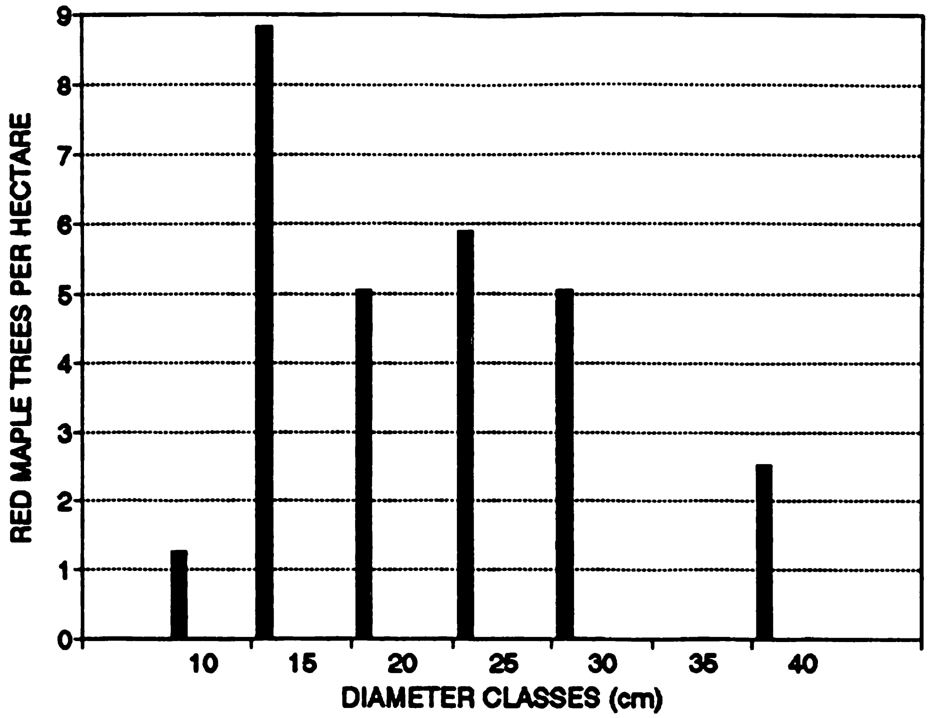

Figure C.4. Diameter distribution of red maple in the northern hardwood forest type.

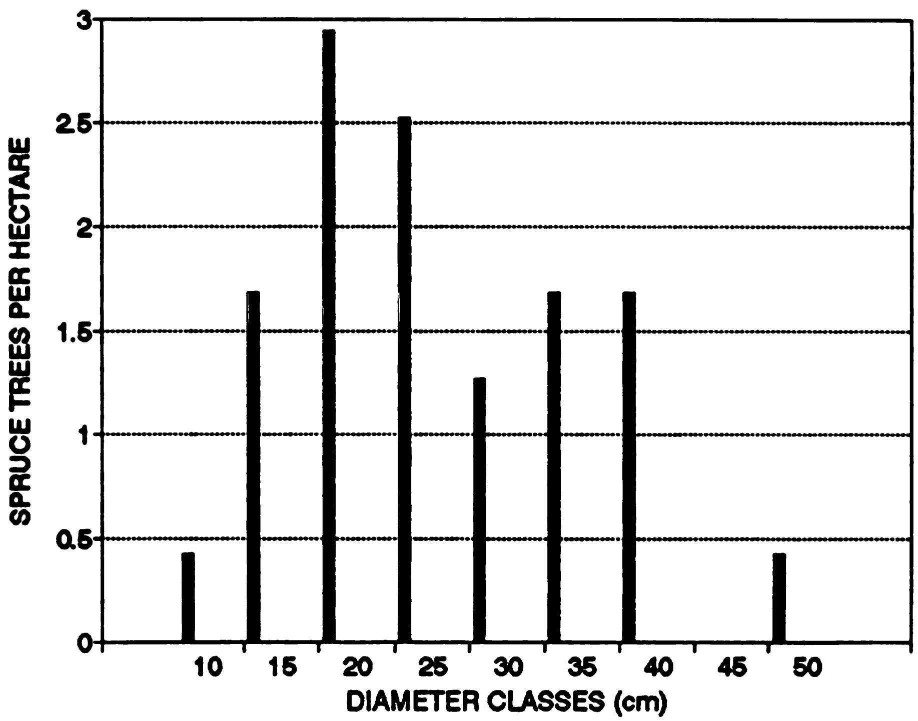

Figure C.5. Diameter distribution of spruce in the northern hardwood forest type.

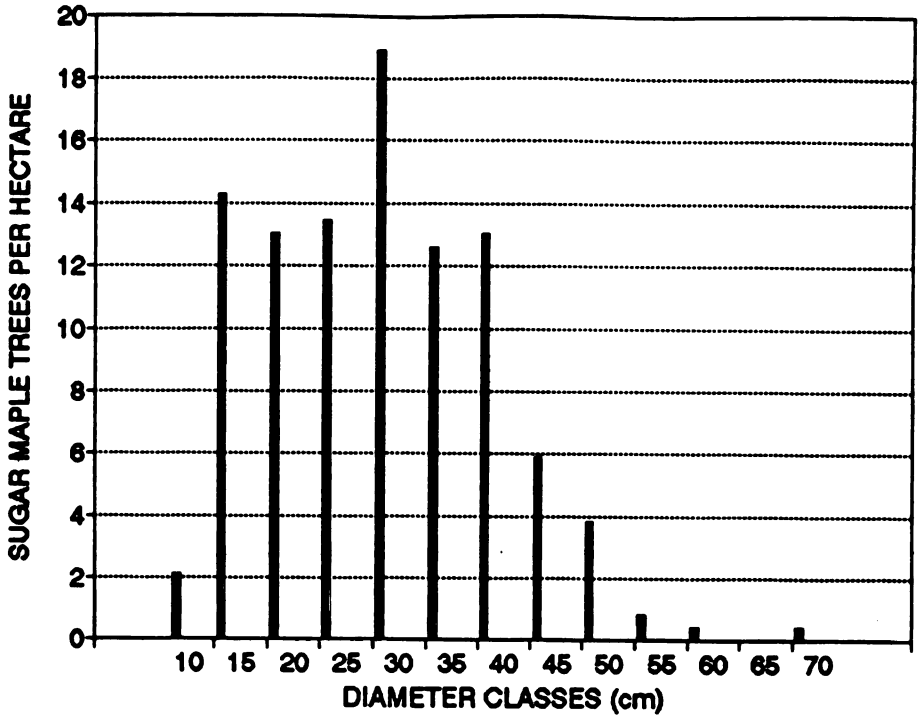

Figure C.6. Diameter distribution of sugar maple in the northern hardwood forest type.

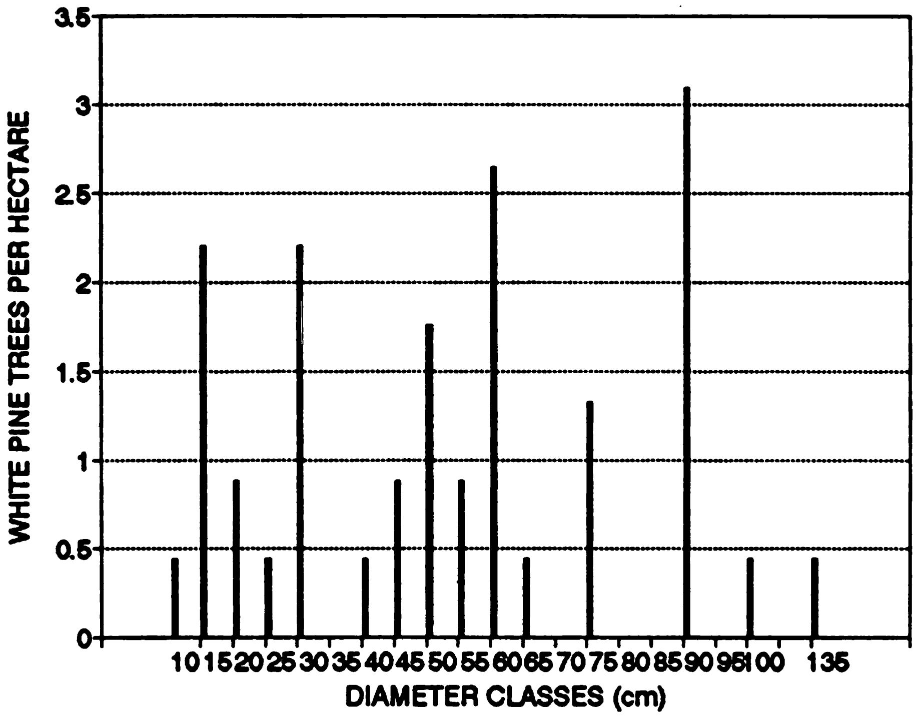

Figure C.7. Diameter distribution of white pine in the northern hardwood forest type.

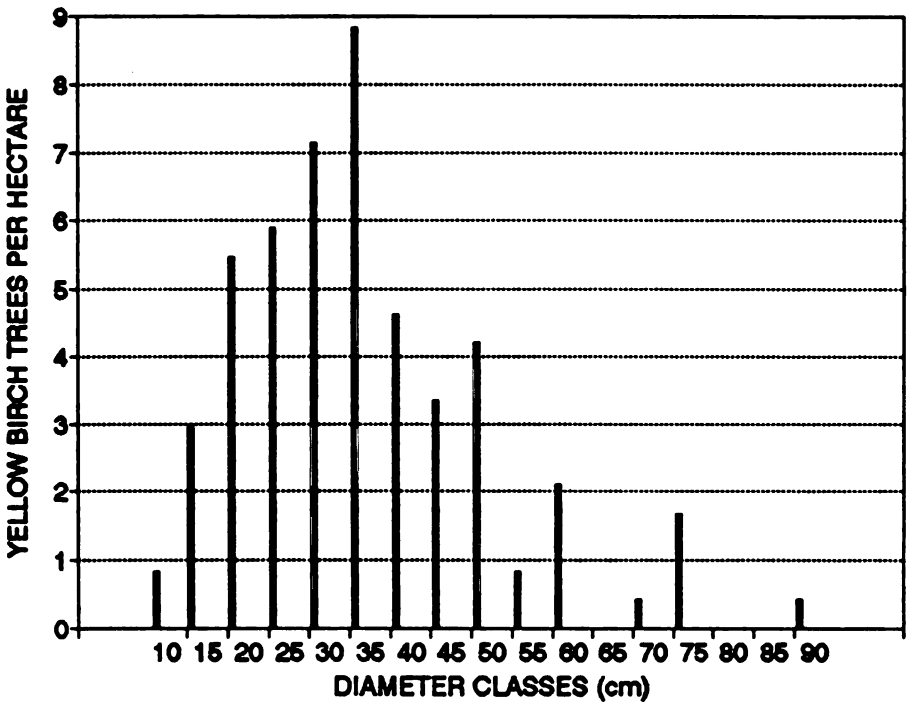

Figure C.8. Diameter distribution of yellow birch in the northern hardwood forest type.

APPENDIX D

Diameter distribution graphs for significant tree species in the mixed pine forest type.

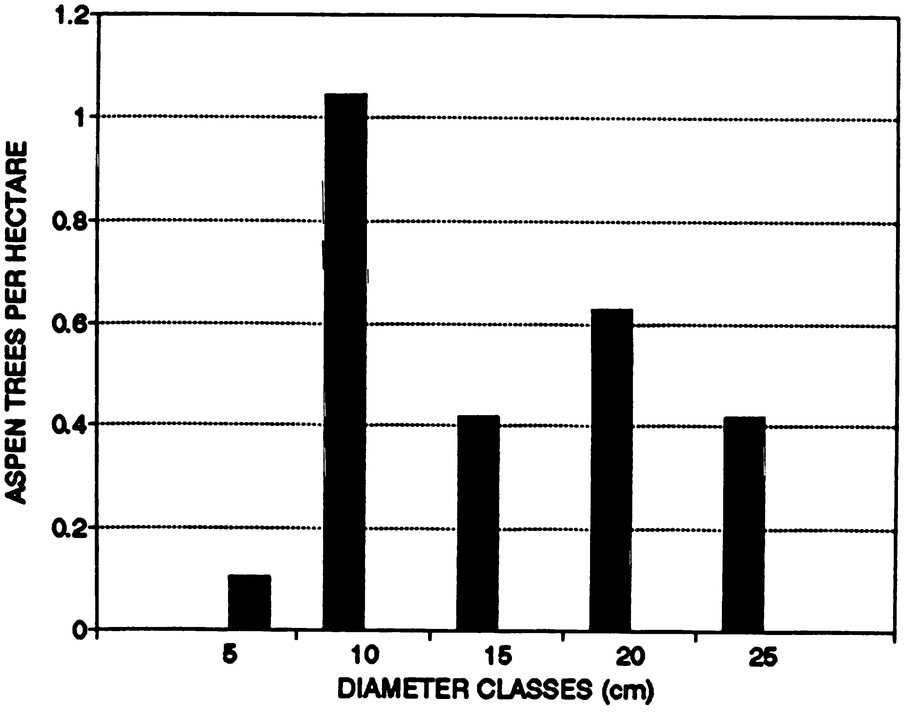

Figure D.1. Diameter distribution of aspen in the mixed pine forest type.

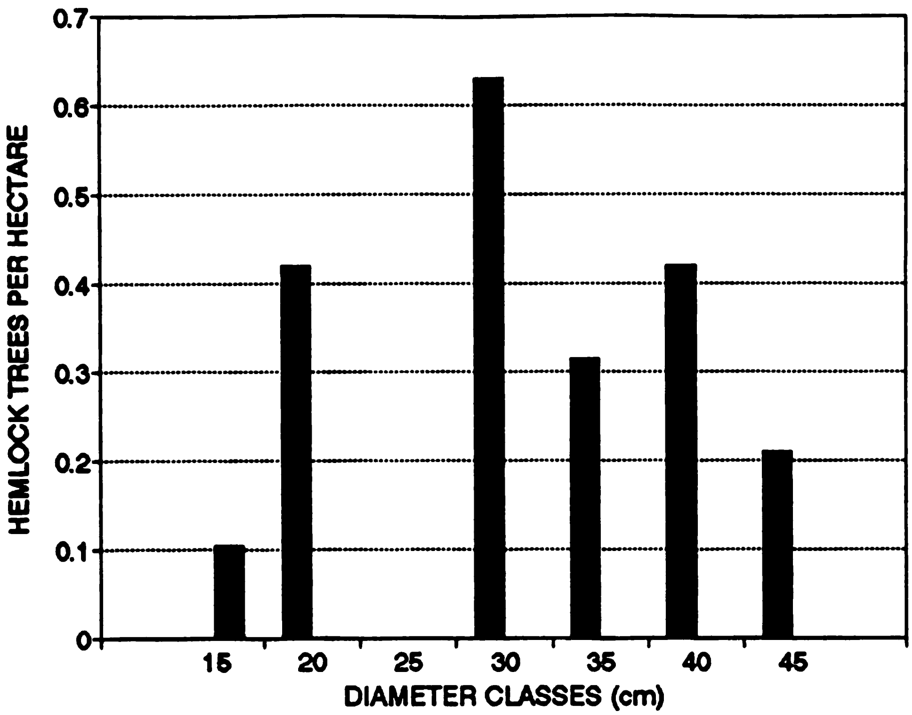

Figure D.2. Diameter distribution of eastern hemlock in the mixed pine forest type.

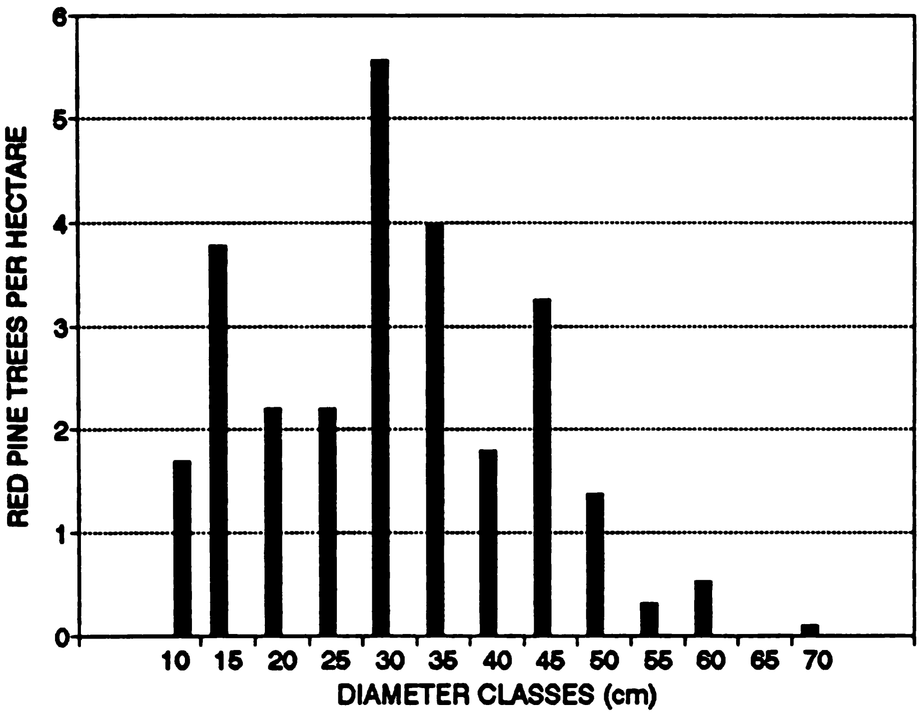

Figure D.3. Diameter distribution of red pine in the mixed pine forest type.

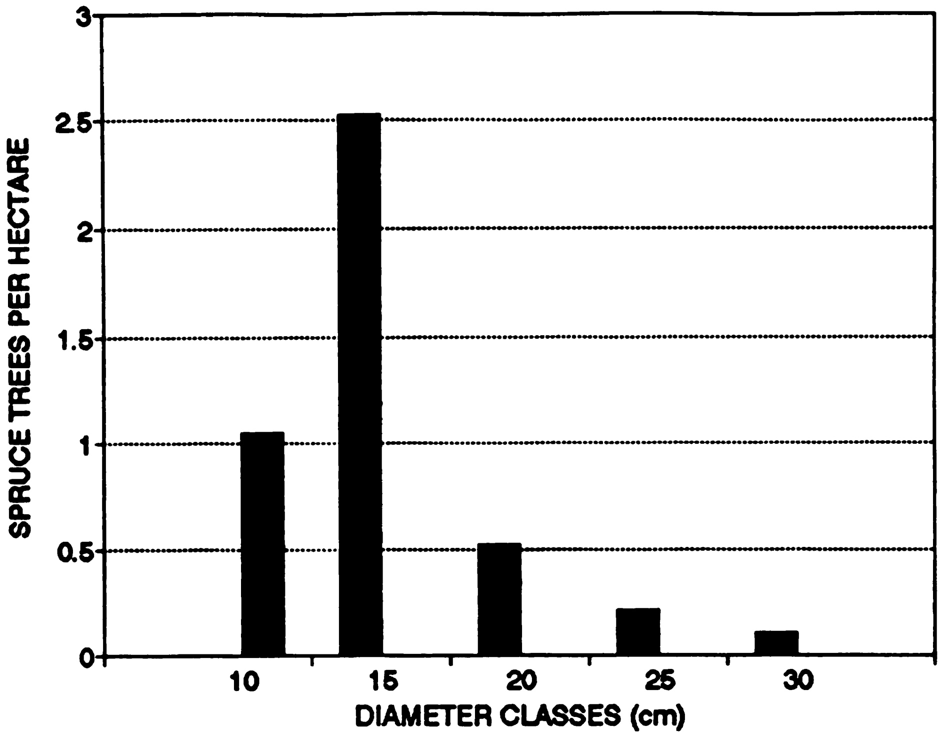

Figure D.4. Diameter distribution of spruce in the mixed pine forest type.

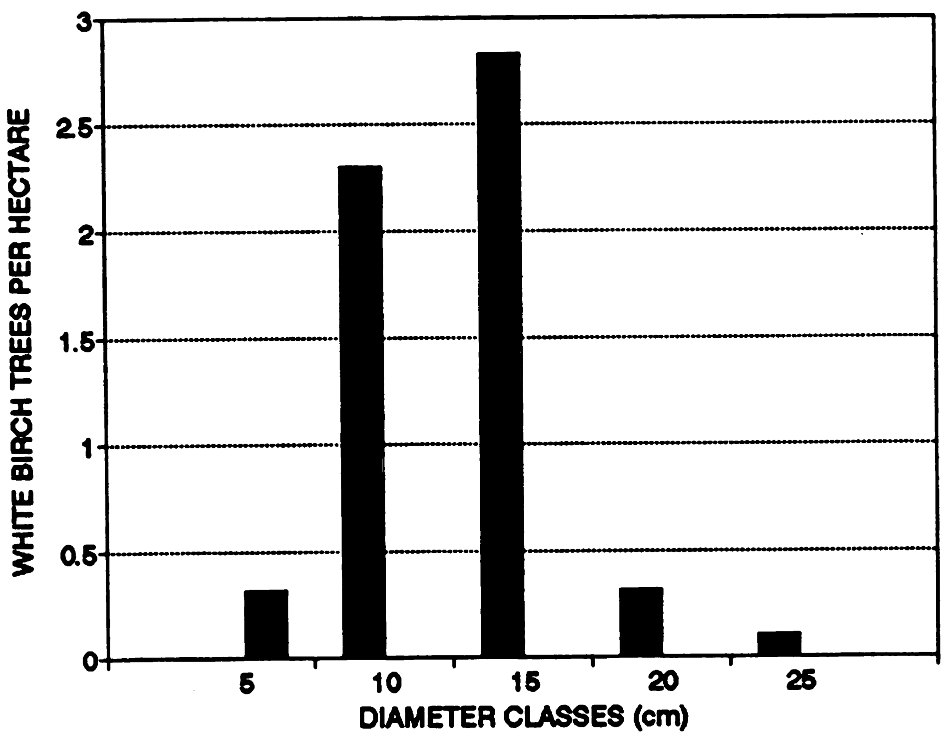

Figure D.5. Diameter distribution of white birch in the mixed pine forest type.

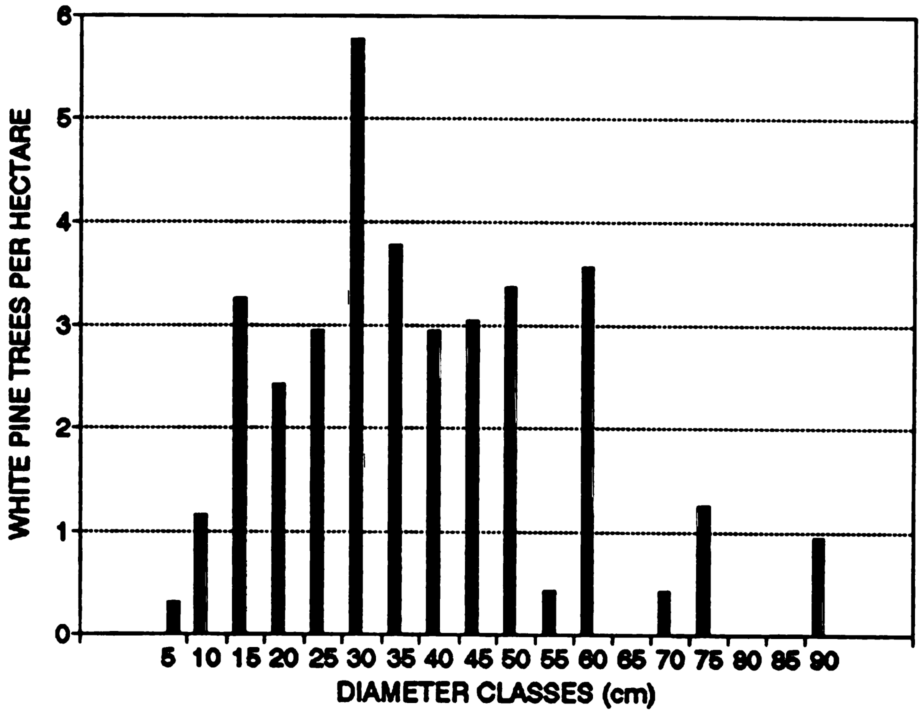

Figure D.6. Diameter distribution of white pine in the mixed pine forest type.

APPENDIX E

Diameter distribution graphs for significant tree species in the mixed conifer/deciduous upland forest type.

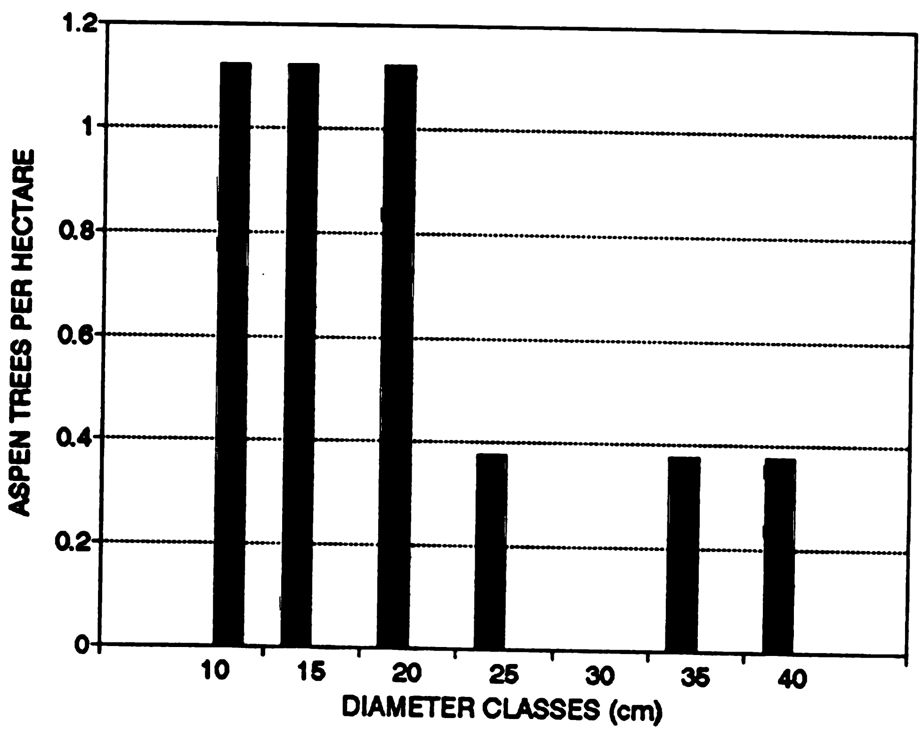

Figure E.1. Diameter distribution of aspen in the mixed conifer/deciduous upland forest type.

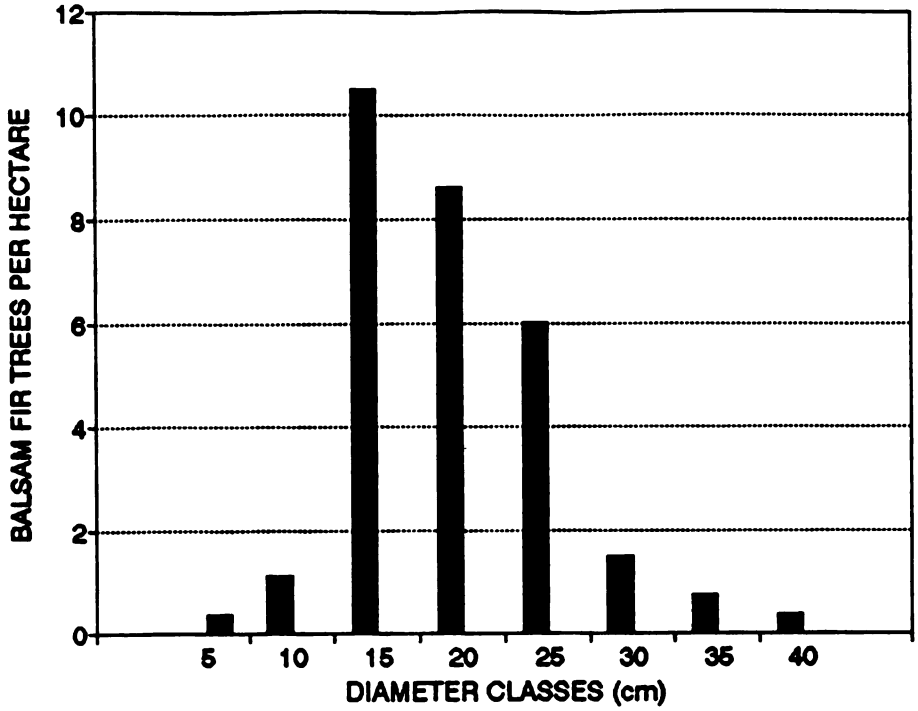

Figure E.2. Diameter distribution of balsam fir in the mixed conifer/deciduous upland forest type.

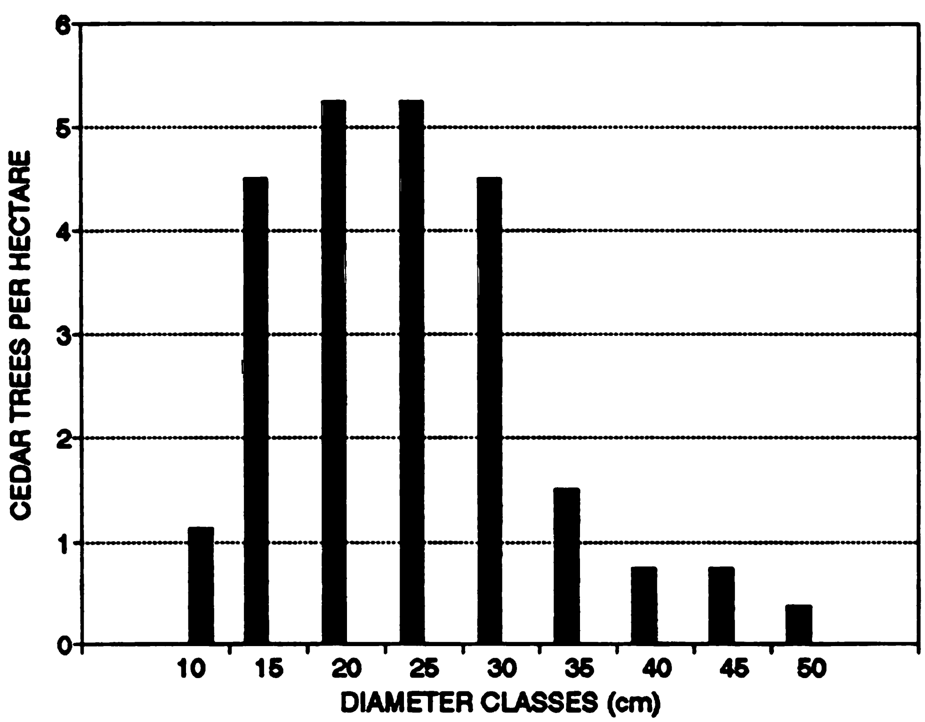

Figure E.3. Diameter distribution of northern white cedar in the mixed conifer/deciduous upland forest type.

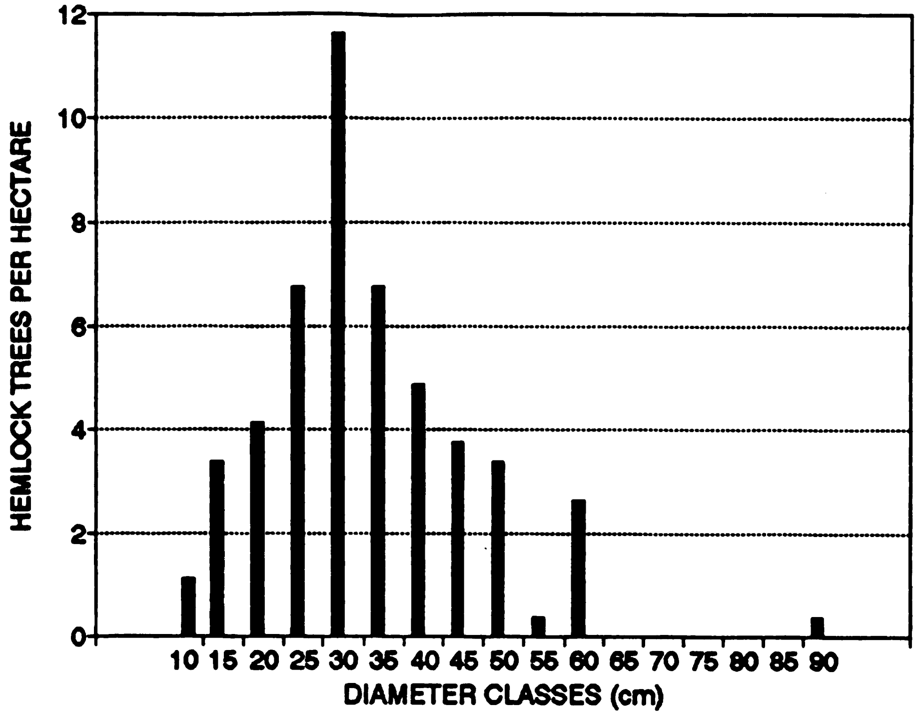

Figure E.4. Diameter distribution of eastern hemlock in the mixed conifer/deciduous upland forest type.

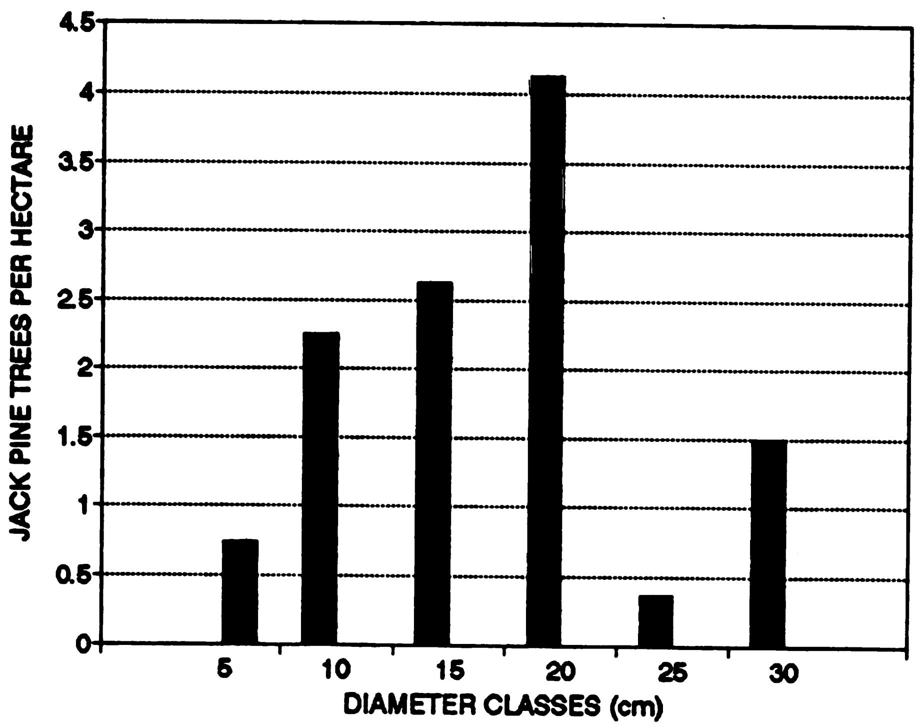

Figure E.5. Diameter distribution of jack pine in the mixed conifer/deciduous upland forest type.

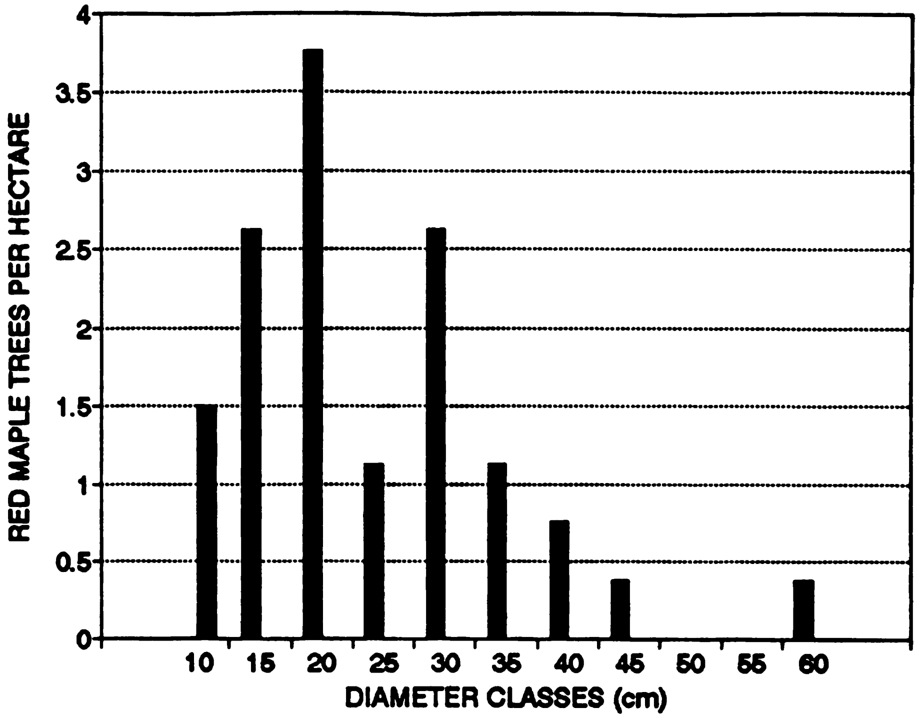

Figure E.6. Diameter distribution of red maple in the mixed conifer/deciduous upland forest type.

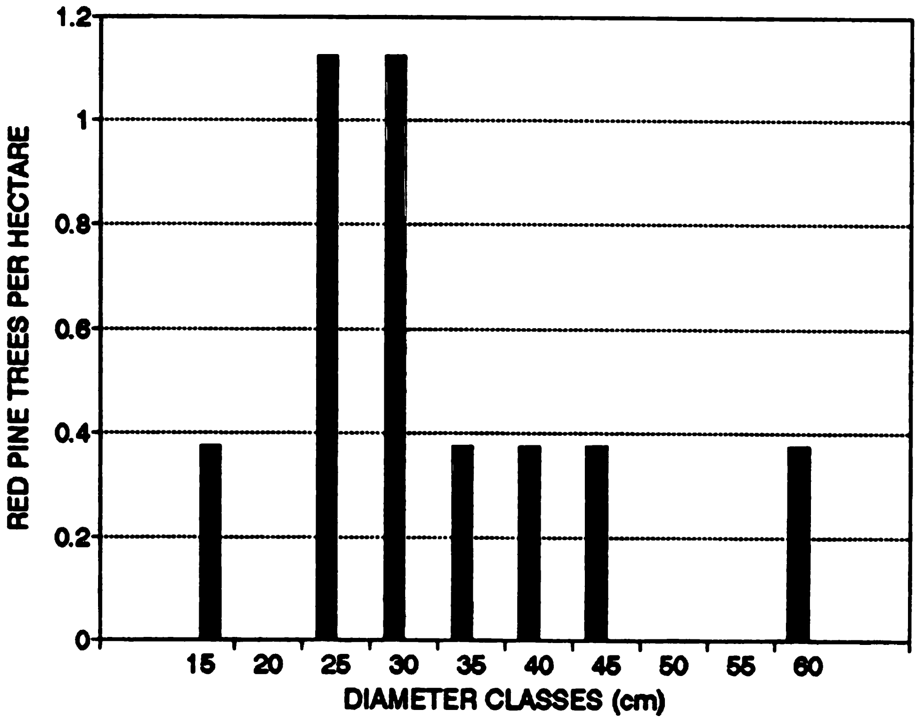

Figure E.7. Diameter distribution of red pine in the mixed conifer/deciduous upland forest type.

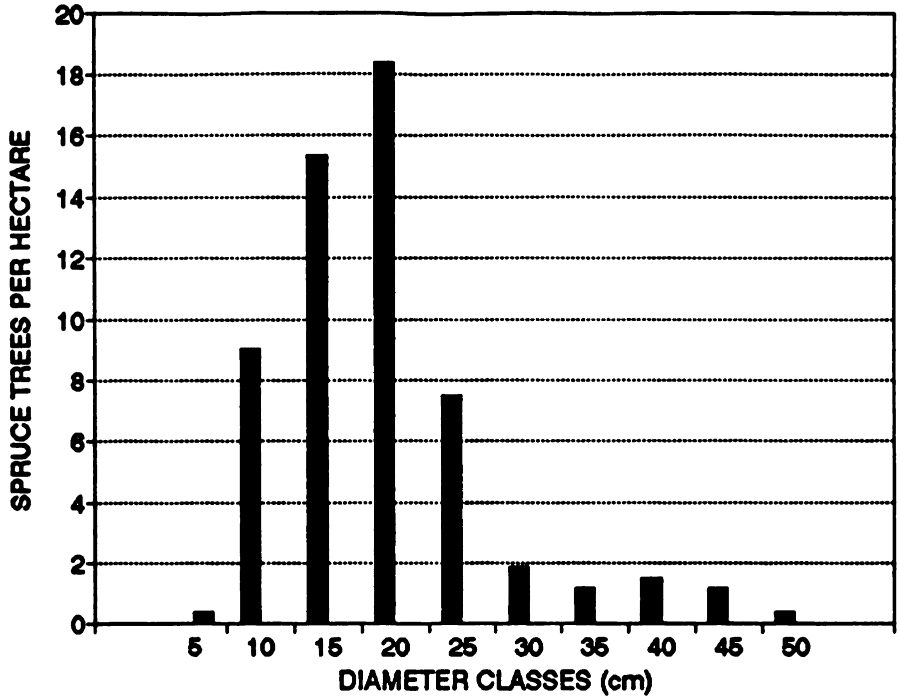

Figure E.8. **Diameter distribution of spruce in the mixed conifer/deciduous upland forest type.**

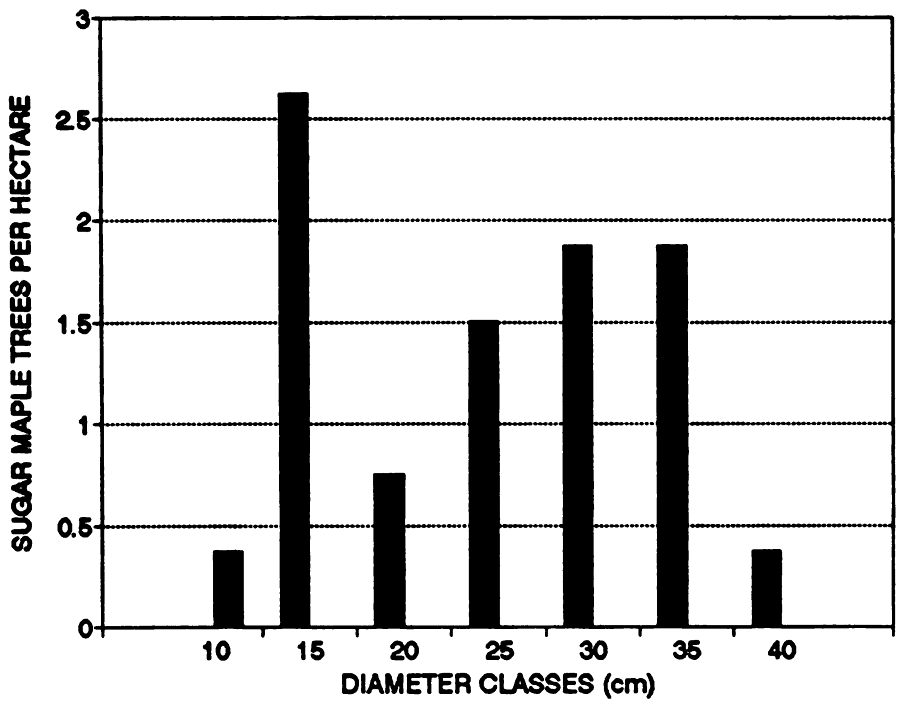

Figure E.9. **Diameter distribution of sugar maple in the mixed conifer/deciduous upland forest type.**

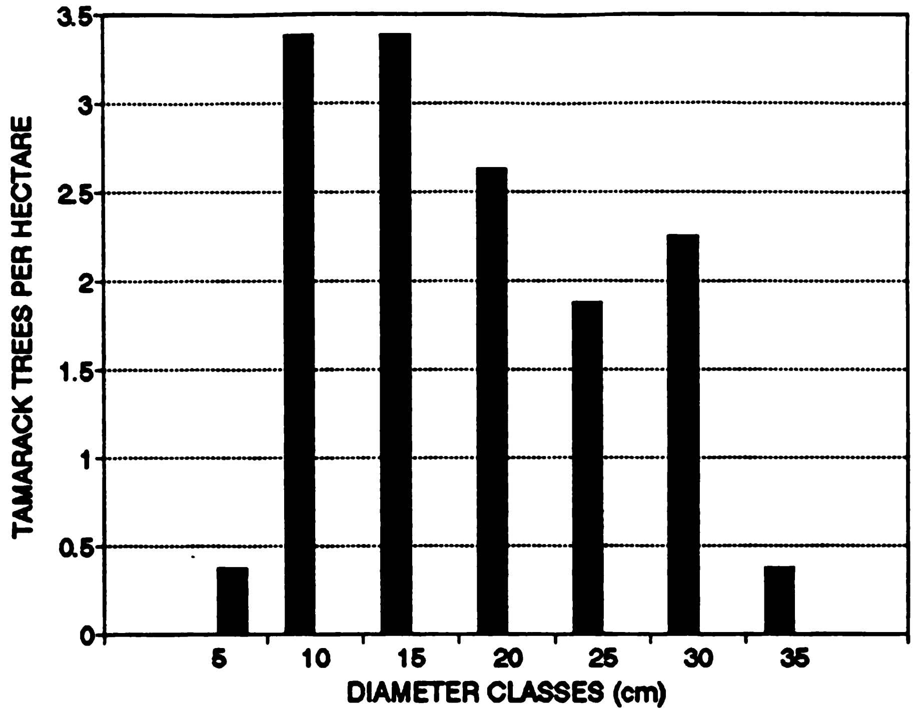

Figure E.10. Diameter distribution of tamarack in the mixed conifer/deciduous upland forest type.

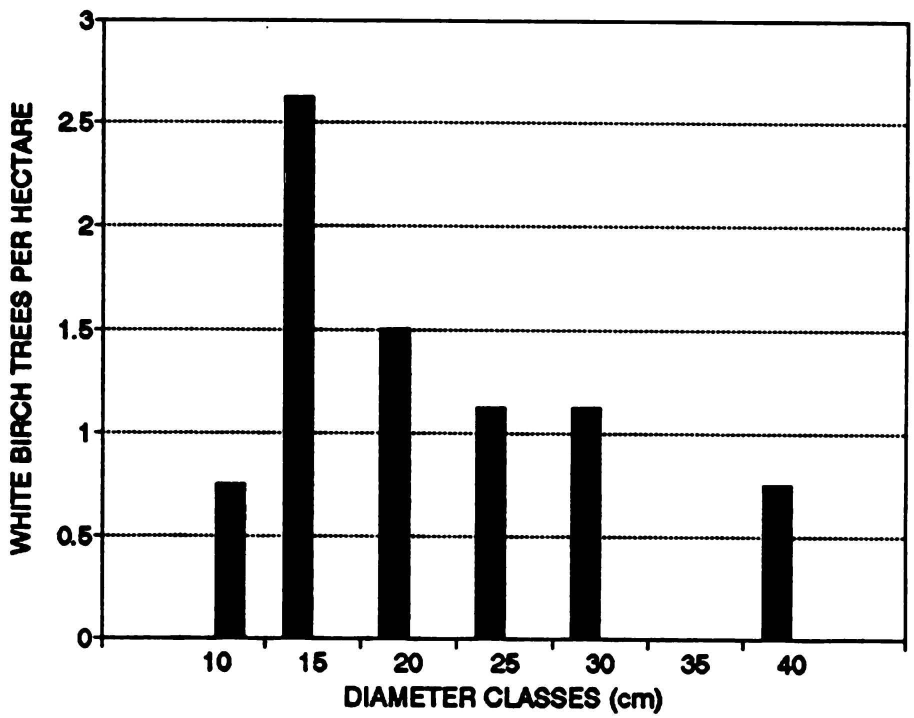

Figure E.11. Diameter distribution of white birch in the mixed conifer/deciduous upland forest type.

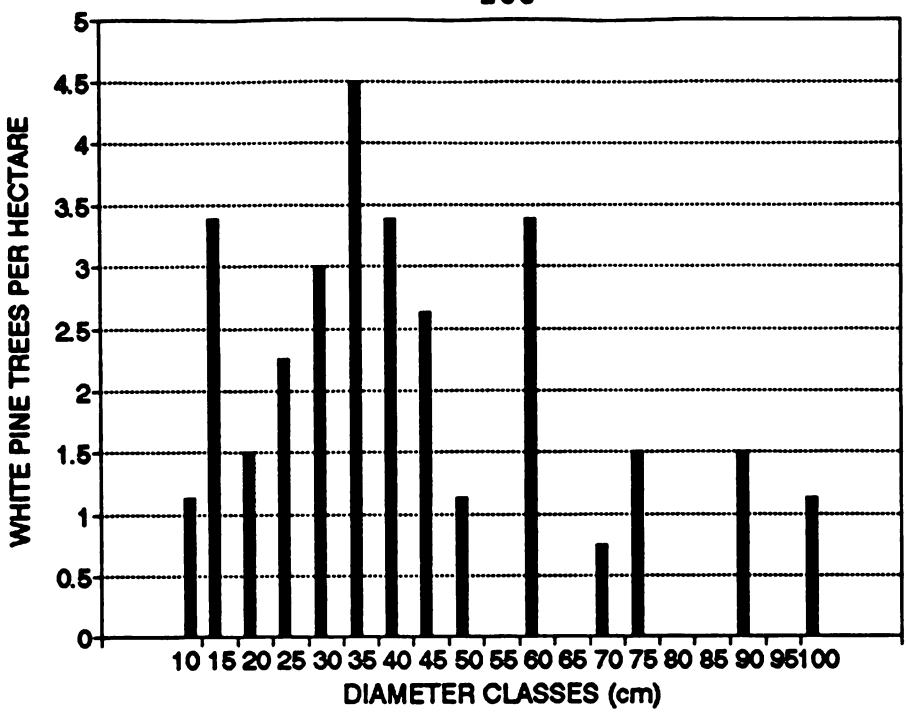

Figure E.12. Diameter distribution of white pine in the mixed conifer/deciduous upland forest type.

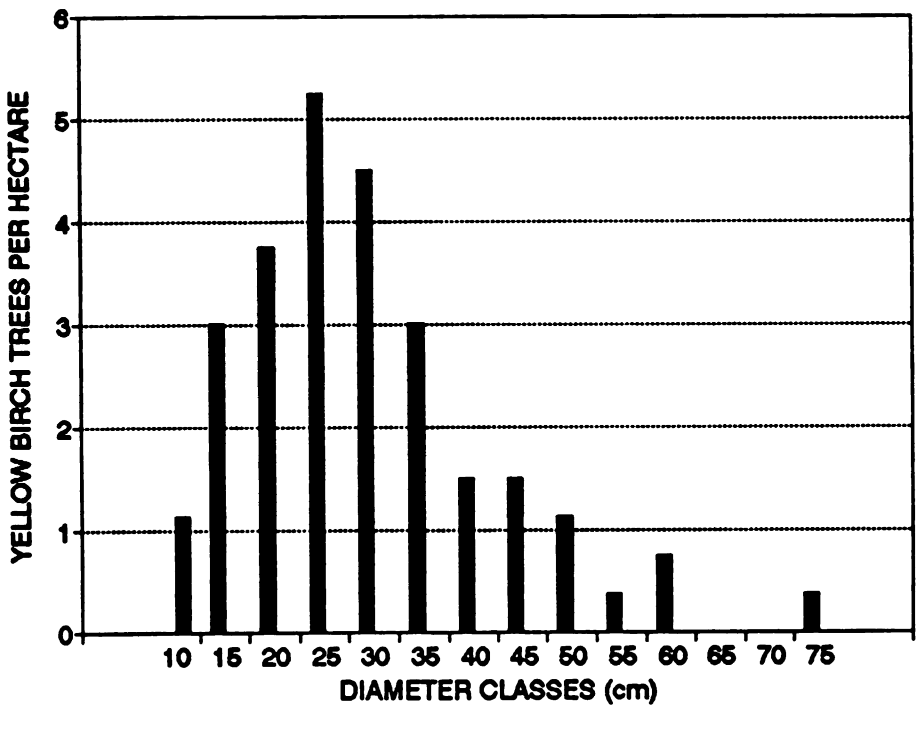

Figure E.13. Diameter distribution of yellow birch in the mixed conifer/deciduous upland forest type.

APPENDIX F

Diameter distribution graphs for significant tree species in the mixed conifer/deciduous lowland forest type.

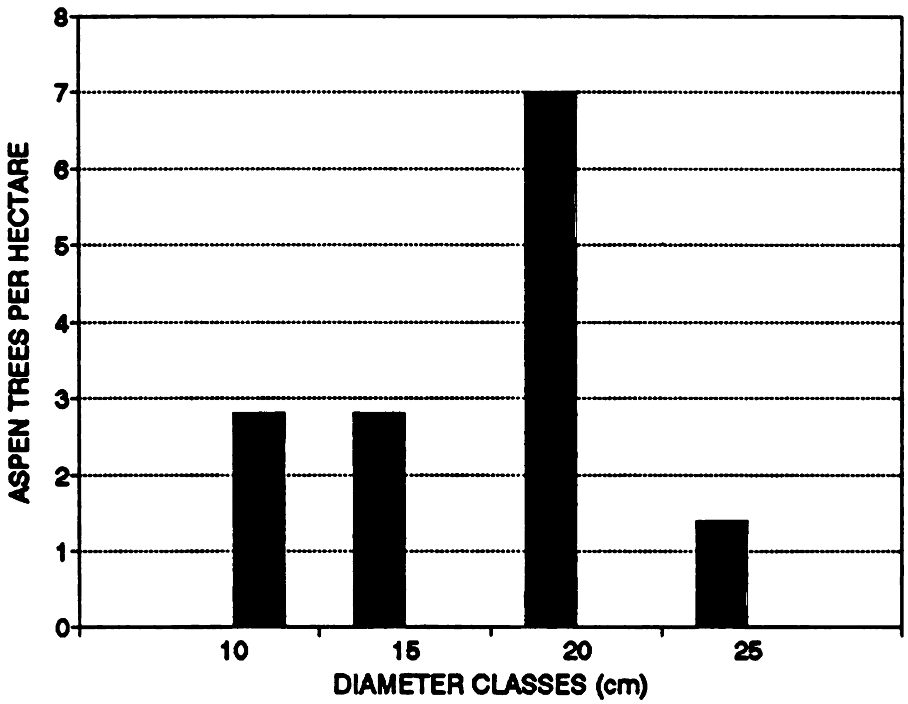

Figure F.1. Diameter distribution of aspen in the mixed conifer/deciduous lowland forest type.

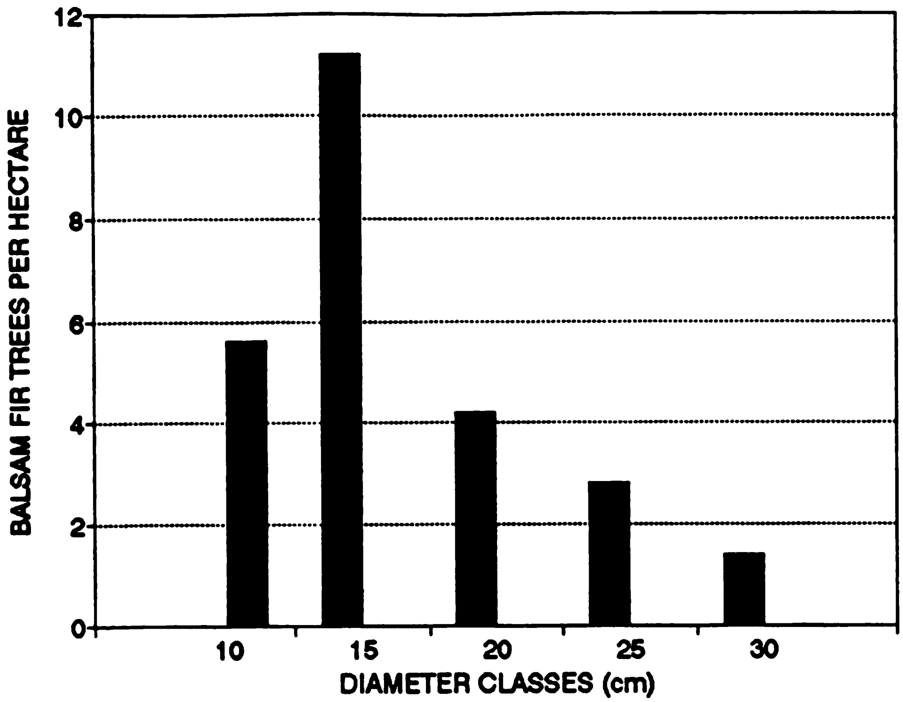

Figure F.2. Diameter distribution of balsam fir in the mixed conifer/deciduous lowland forest type.

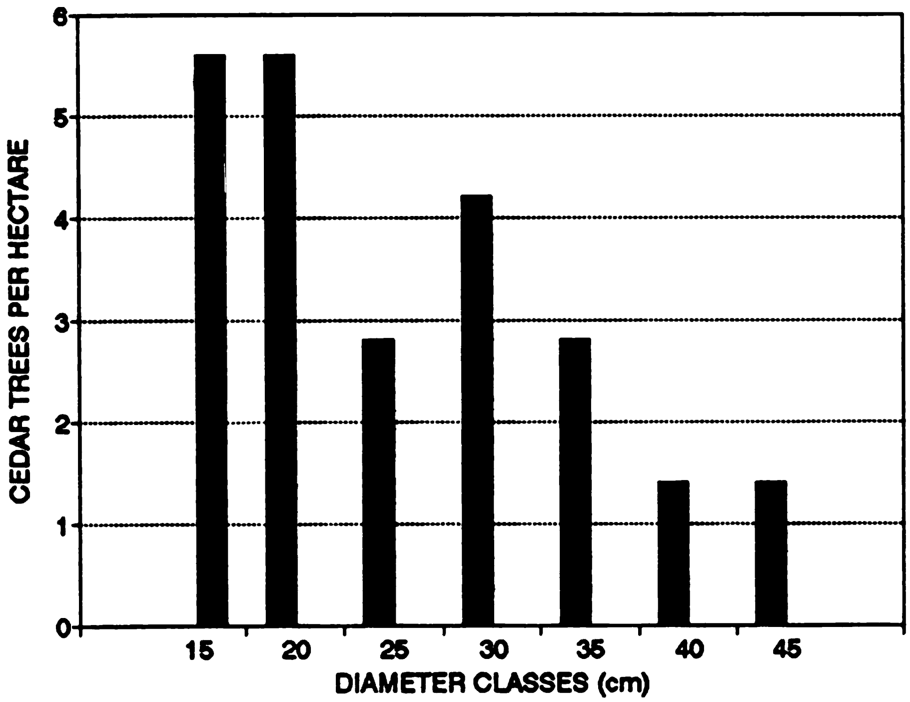

Figure F.3. Diameter distribution of northern white cedar in the mixed conifer/deciduous lowland forest type.

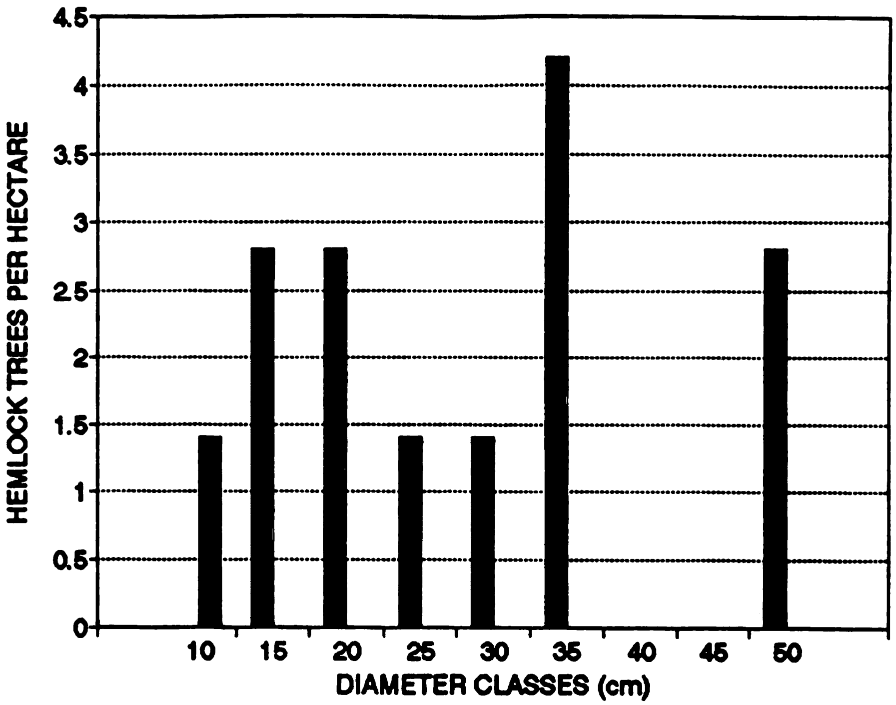

Figure F.4. Diameter distribution of eastern hemlock in the mixed conifer/deciduous lowland forest type.

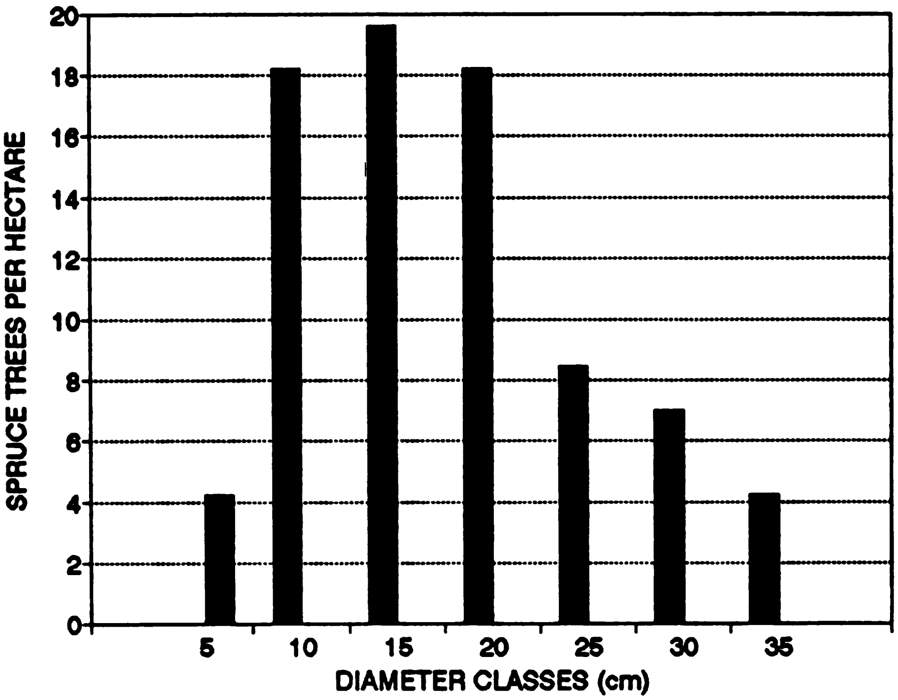

Figure F.5. Diameter distribution of spruce in the mixed conifer/deciduous lowland forest type.

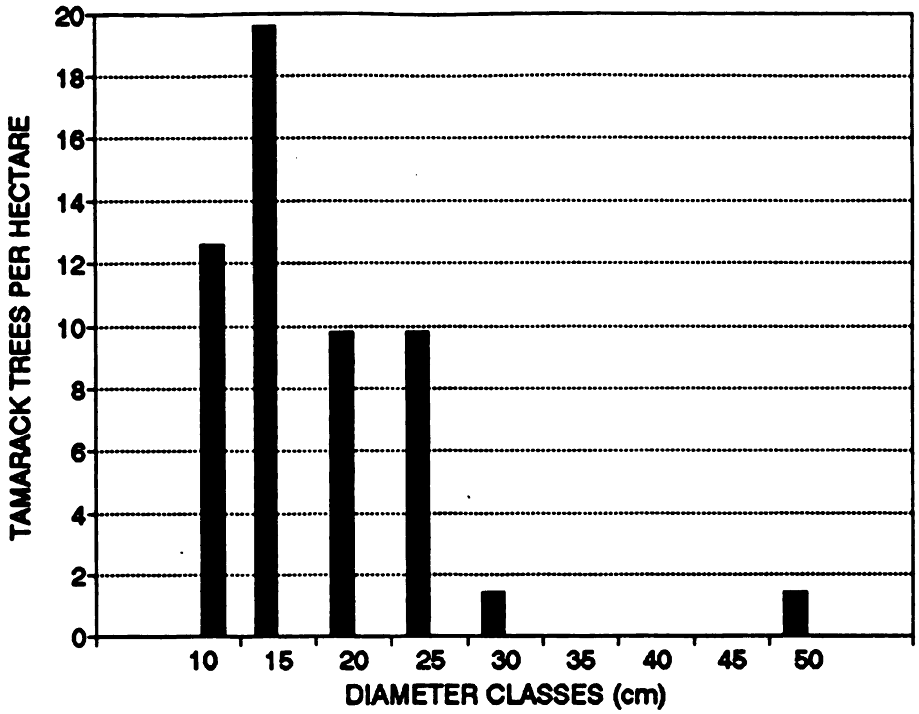

Figure F.6. Diameter distribution of tamarack in the mixed conifer/deciduous lowland forest type.

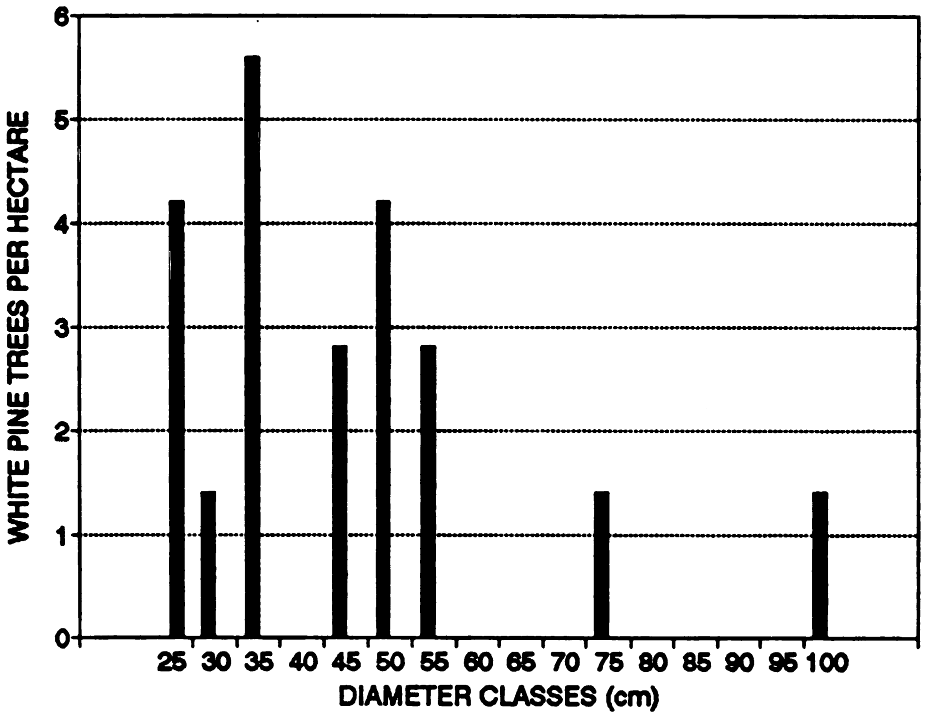

Figure F.7. Diameter distribution of white pine in the mixed conifer/deciduous lowland forest type.

APPENDIX G

Diameter distribution graphs for significant tree species in the mixed conifer swamp forest type.

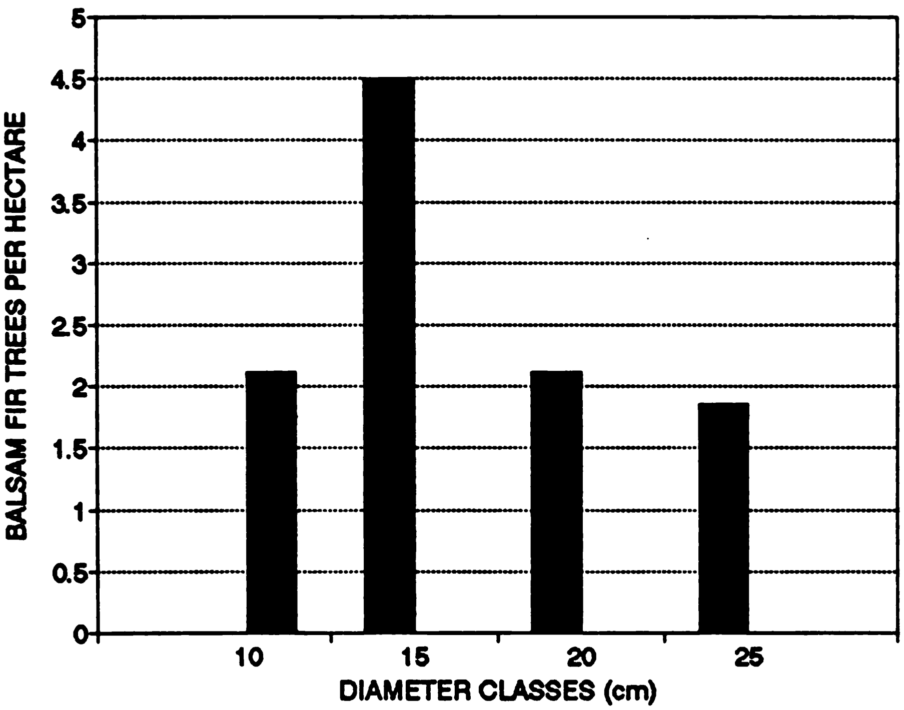

Figure G.1. Diameter distribution of balsam fir in the mixed conifer swamp forest type.

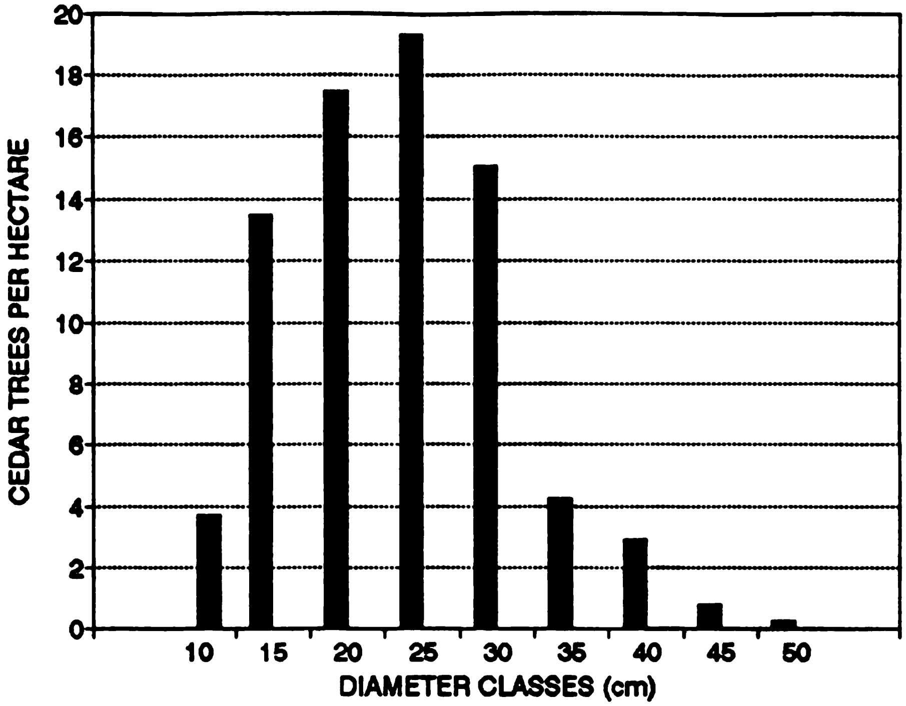

Figure G.2. Diameter distribution of northern white cedar in the mixed conifer swamp forest type.

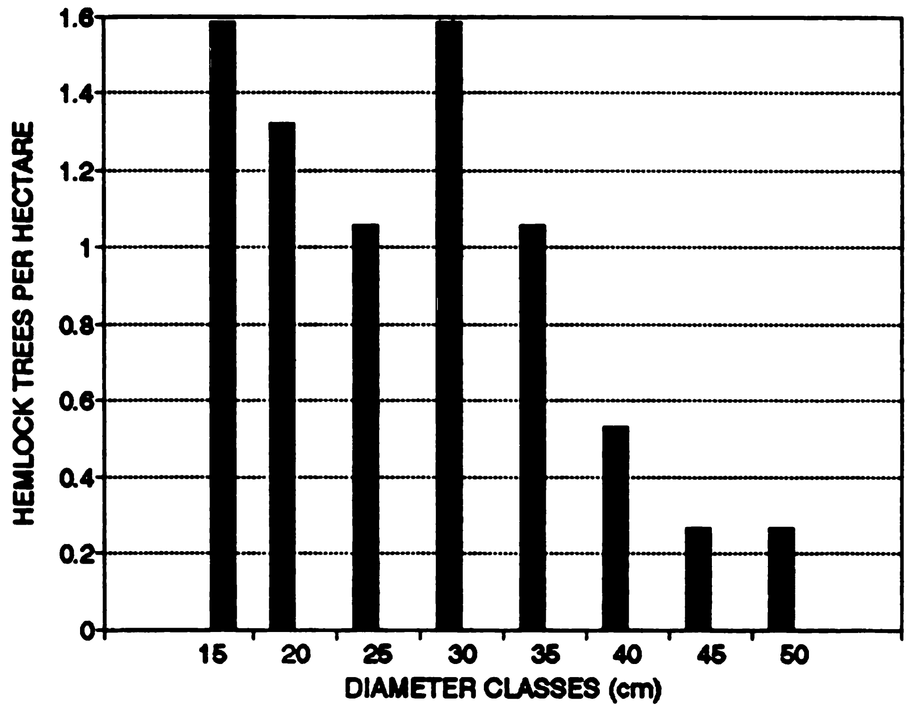

Figure G.3. Diameter distribution of eastern hemlock in the mixed conifer swamp forest type.

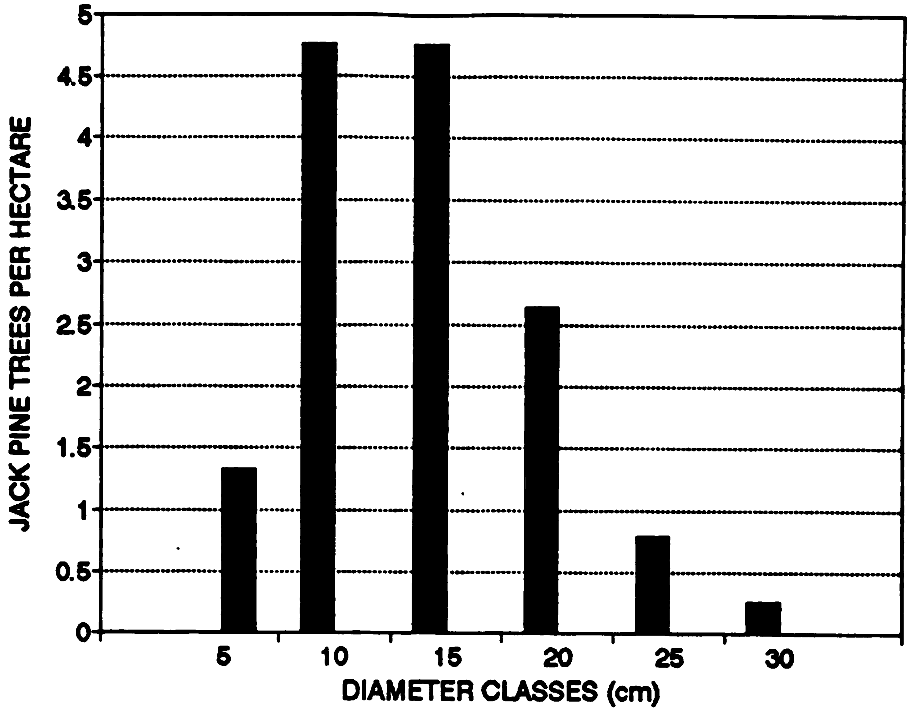

Figure G.4. Diameter distribution of jack pine in the mixed conifer swamp forest type.

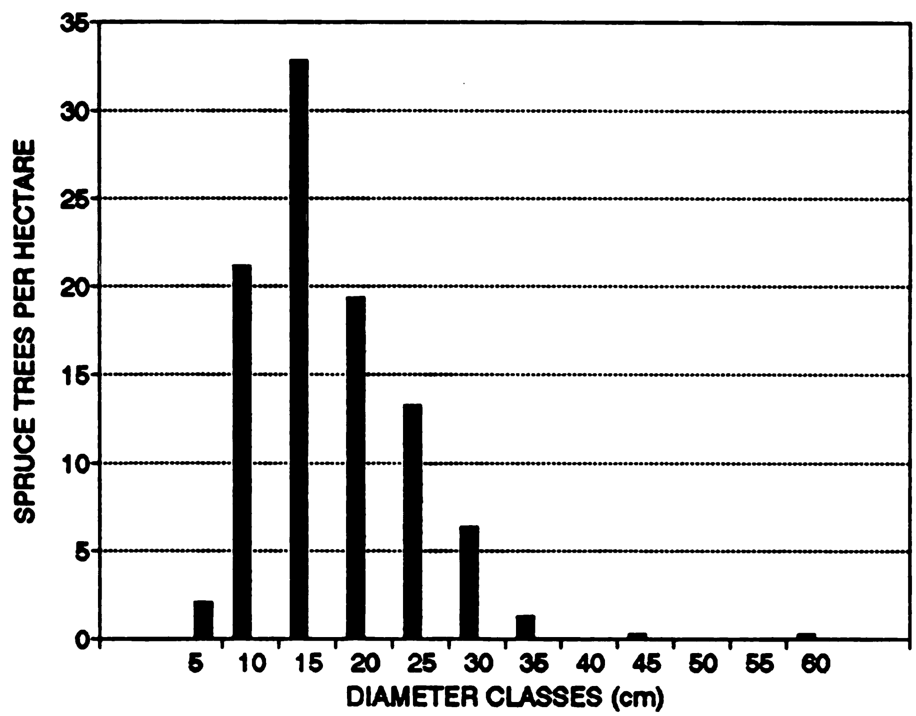

Figure G.5. Diameter distribution of spruce in the mixed conifer swamp forest type.

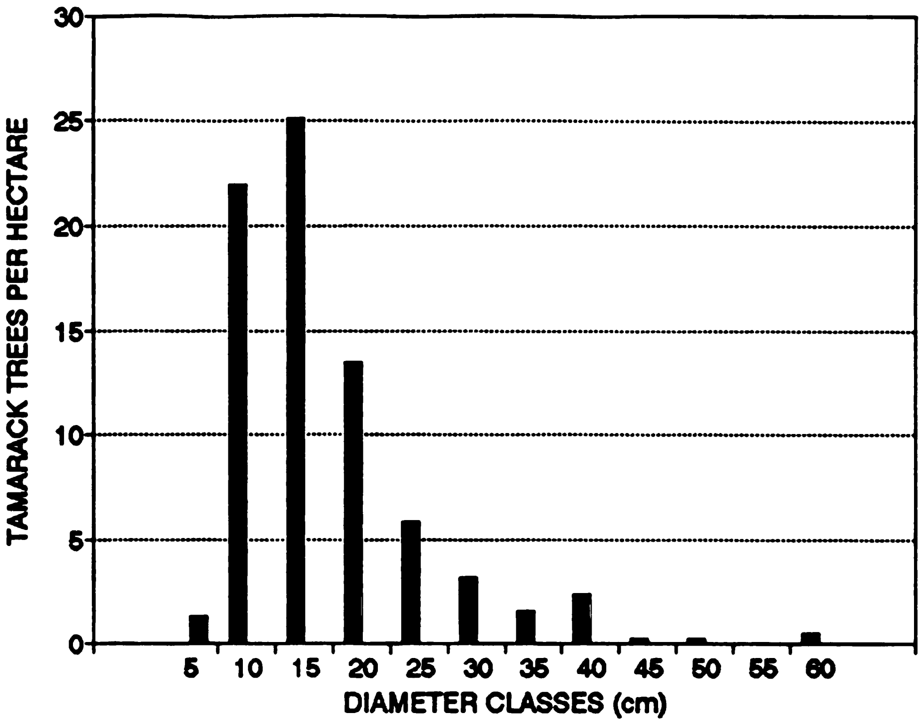

Figure G.6. Diameter distribution of tamarack in the mixed conifer swamp forest type.

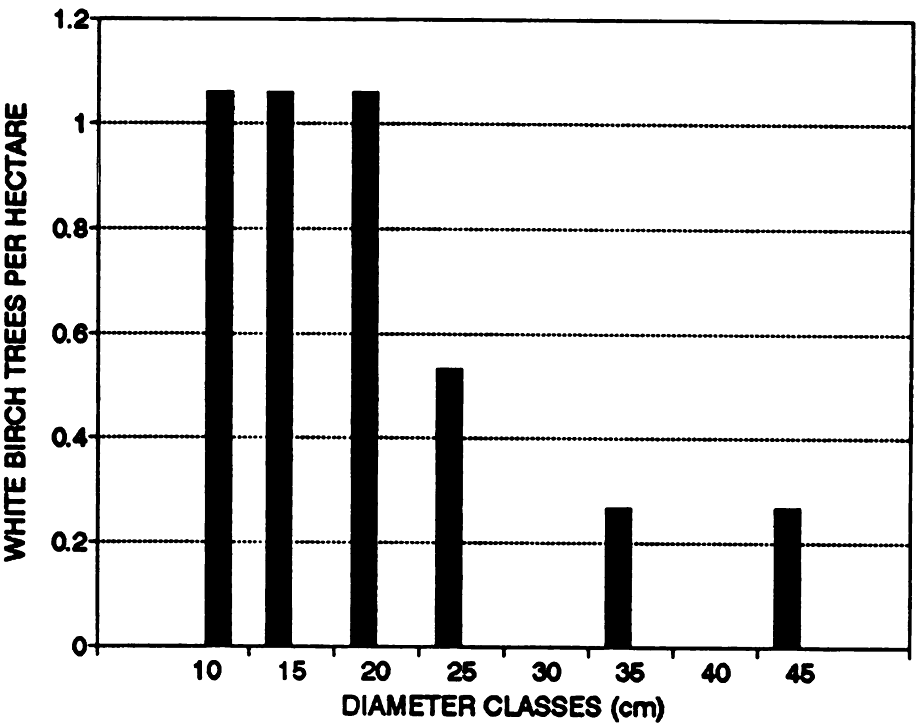

Figure G.7. Diameter distribution of white birch in the mixed conifer swamp forest type.

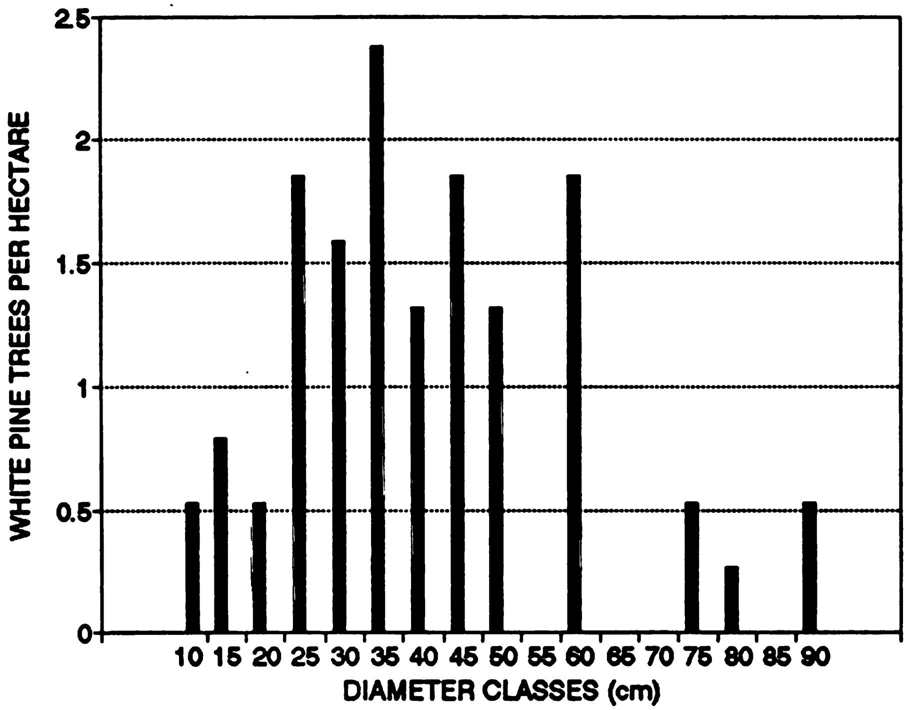

Figure G.8. Diameter distribution of white pine in the mixed conifer swamp forest type.

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