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thesis entitled

FOREST DISTRIBUTION AND SITE QUALITY
IN SOUTHERN LOWER MICHIGAN

presented by

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has been accepted towards fulfillment
of the requirements for

M.A. degree in Geography

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Date 5/20/96

FOREST DISTRIBUTION AND SITE QUALITY IN SOUTHERN LOWER MICHIGAN

by

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF ARTS

Department of Geography

1996

ABSTRACT

FOREST DISTRIBUTION AND SITE QUALITY IN SOUTHERN LOWER MICHIGAN

by

Peter Scull

The primary objective of the research was to address the extent to which surviving forest patches represent a sample of the range of habitats present on the pre-settlement landscape. Soils and land cover data for four counties (Ionia, Livingston, Tuscola, and Van Buren) in southern Lower Michigan were collected, stored and analyzed within a geographic information system.

Results suggest that the present-day forest patches may not be a proportionate sample of the primeval forest. Rather, they are concentrated on agriculturally-inferior (coarse-textured, steeply-sloped, or poorly-drained) types of habitat. If true, these results reveal that the existing forest resource in southern Lower Michigan is an inferior (biased) sample of the primeval cover; any public policy aimed at merely preserving these resources would fail to capture the full richness of the original cover.

ACKNOWLEDGMENTS

The author would like to thank the following for their contributions to this work:

Dr. Jay Harman; advisor.

Dr. Randall Schaetzl; committee member.

Dr. David Lusch; committee member.

The Department of Geography for financial support in the form of a Graduate Office Fellowship.

The Natural Resources Conservation Service for providing digital soil survey data (SSURGO).

The Michigan Department of Natural Resources for providing digital landuse/cover data.

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BACKGROUND, LITERATURE REVIEW, AND RESEARCH QUESTIONS

A. Introduction

Many changes in the landscape of southern Lower Michigan have taken place since the area was settled in the mid-nineteenth century by Europeans. These changes are obvious to anyone who has driven through the region and seen the amount of agricultural crops growing on sites that were once forested. However, the total impact of these changes on overall forest richness or bio-diversity is poorly understood. The purpose of this research is to examine this overall issue.

History would suggest that the composition of the present day forest patches may not be representative of the full range of primeval forest if the most productive sites, once cleared for lumber, are agricultural fields today and if forest composition is site-segregated. This paper is an attempt to address this issue. Specifically, I will attempt to identify landscape types that support both a larger and smaller proportion of the total forest area today than they did prior to European settlement to determine how well the present forest patches might represent a proportionate sample of the primeval forest. In addition, I will also analyze the shape of the remaining forest patches to determine whether site quality and forest patch shape are related.

B. Nature and History of Study Area

1. Nature

The purpose of this section is to characterize the nature the study area. Geographically, Ionia, Livingston, Tuscola, and Van Buren are well dispersed across southern Lower Michigan and appear to be typical of the region because they each contain a variety of the areas landscape types (see Figure 1).

Southern Lower Michigan is located within the Eastern Deciduous Forest (Vankat, 1992). Six potential communities exist here: Oak-Hickory, Beech-Sugar Maple, Pine, Northern Hardwood, Deciduous Swamp, and Oak-Savanna (Barnes and Wagner, 1981)(for a listing of species see Table 1). Oak-Hickory communities are found on xeric to dry mesic, well-drained soils and are the most widely distributed community in southern Lower Michigan (Barnes and Wagner, 1981). For example, sandy-textured outwash and dry end moraines within Livingston County support stands of oak-hickory (Albert et al., 1986). Warm climate and long growing seasons lead to common drought and periodic fire, which are "major" habitat factors for the community (Barnes and Wagner, 1981).

Finer-textured, mesic sites are characterized by Beech-Maple communities (Braun, 1964). These forests can be found growing in Ionia County on fine-textured end moraines and till plains (Albert et at., 1986). Beech-Sugar Maple is the second most abundant community in the region (Barnes and

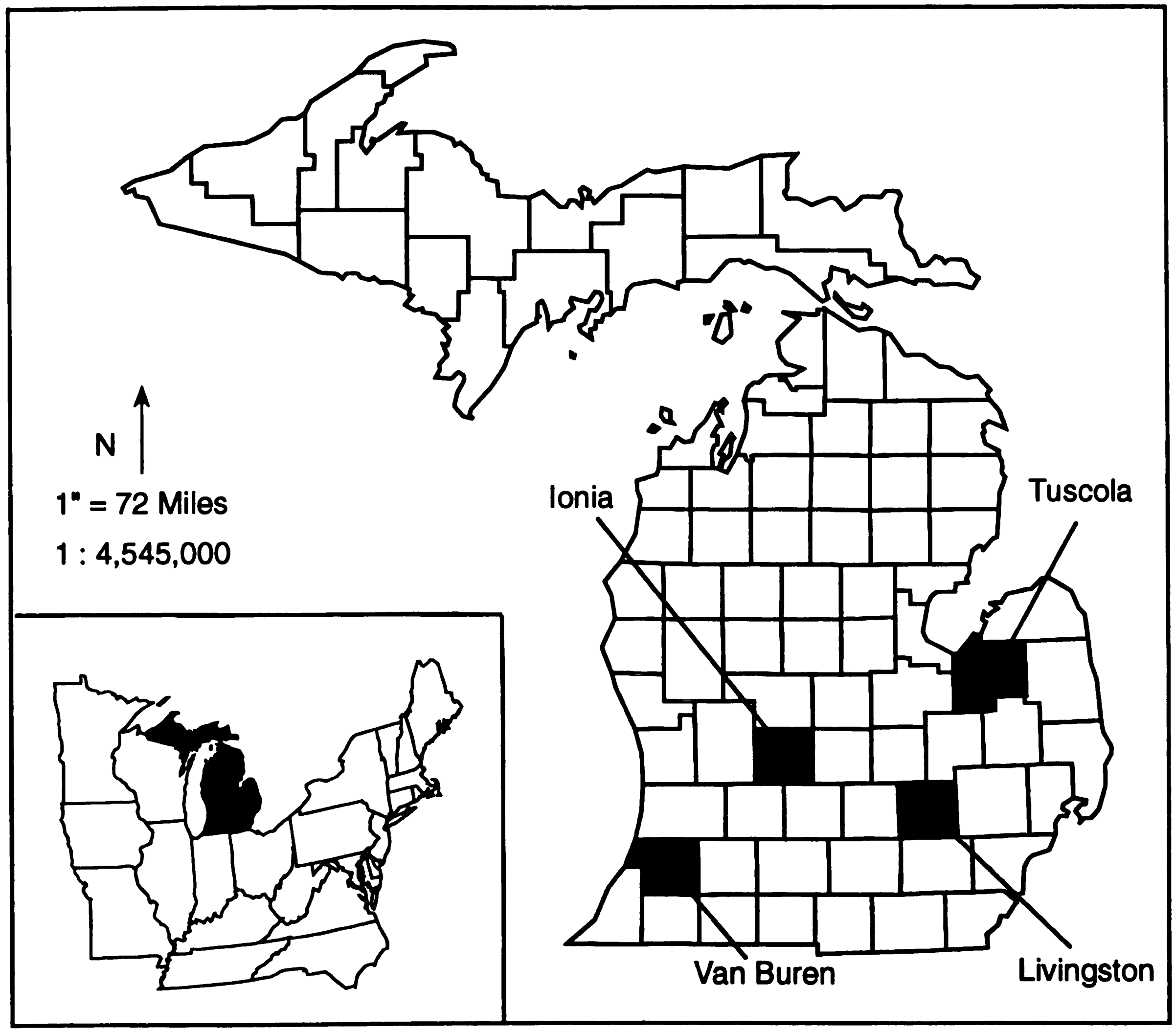


Figure 1 Study Sites

Table 1 Species list

Oak-Savanna Community
Bur oak, *Quercus macrocarpa*
Black oak, *Quercus velutina*
Northern pin oak, *Quercus ellipsoidalis*

Oak-Hickory Community
White oak, *Quercus alba*
Black Oak, *Quercus velutina*
Red oak, *Quercus rubra*
Pignut hickroy, *Carya glabra*
Shagbark hickory, *Carya ovata*
Black cherry, *Prunis serotina*
Hop-hornbeam, *Ostrya virginiana*
White ash, *Fraxinus americana*
Witch-hazel, *Hamamelis virginiana*
Downy serviceberry, *Amelanchier arborea*
Flowering dogwood, *Cornus florida*
Eastern red cedar, *Juniperus virginiana*
Chickapin oak, *Quercus muehlenbergii*
Dwarf chinkapin oak, *Quercus prunoides*
American chestnut, *Castanea dentata*
Dwarf hackberry, *Celtis tenuifolia*

Beech-Sugar Maple Community
Beech, *Fagus grandfolia*
Sugar maple, *Acer saccharum*
Red oak, *Quercus rubra*
Basswood, *Tilia americana*
White ash, *Fraxinus americana*
Black walnut, *Juglans nigra*
Tuliptree, *Liriodendron tulipifera*
Bitternut hickory, *Carya cordiformis*
Shagbark hickory, *Carya ovata*
Slippery elm, *Ulmus rubra*
Rock elm, *Ulmas thomasii*
Alternate-leaf dogwood, *Cornus alterifolia*
Blue ash, *Fraxinus quadrangulata*
Downy serviceberry, *Amelanchier arborea*

Pine Community
Jack pine, *Pinus banksiana*
Red pine, *Pinus resinosa*
Eastern white pine, *Pinus strobus*
White oak, *Quercus alba*
Northern pin oak, *Quercus ellipsoidalis*
Black oak, *Quercus velutina*
Pin cherry, *Prunis pensylvanica*
Scarlet oak, *Quercus coccinea*

Northern Hardwoods Community
Sugar maple, *Acer saccharum*
Beech, *Fagus grandfolia*
Yellow birch, *Betula alleghaniensis*
Eastern Hemlock, *Tsuga canadensis*
Red maple, *Acer rubra*
Basswood, *Tilia americana*
Balsam fir, *Abies balsamea*
Eastern white pine, *Pinus strobus*
Striped maple, *Acer pensylvanicum*

Deciduous Swamp Community
Red maple, *Acer rubrum*
Black ash, *Fraxinus nigra*
Yellow birch, *Betula alleghaniensis*
American elm, *Ulmus americana*
Silver maple, *Acer saccharinum*
Blue-beech, *Carpinus caroliniana*
Alternate-leaf dogwood, *Cornus alternifolia*
Nannyberry, *Viburnum lentago*
Pin oak, *Quercus palustris*
Swamp white oak, *Quercus bicolor*

Note: Species listed in no specific order.
Source: Barnes and Wagner, 1981.

Wagner, 1986). Oak-Hickory and Beech-Sugar Maple communities are often associated together. Regarding the inter-fingering between the two communities, Braun (p. 187, 1964) wrote: "The presence of low morainal ridges, usually sandy or gravelly, on the otherwise gently undulating till plain usually results in alternation of Oak communities (on the ridges) and Beech-Maple (on the till plain)."

In southern Lower Michigan, Pine communities are characteristic of cool, north-facing slopes of ridges that define sandy-textured end moraines, which have droughty, acidic, nutrient-poor soils (Barnes and Wagner, 1981). Similar sites with finer-textured soils support stands of Northern Hardwoods. These communities are similar to Beech-Sugar Maple communities except they lack species such as tulip-tree (*Liriodendron tulipifera*) and bitternut hickory (*Carya cordiformis*), which are less cold tolerant, and include species such as eastern hemlock (*Tsuga canadensis*) and eastern white pine (*Pinus strobus*) (Braun, 1964). Pine and Northern Hardwood communities increase in abundance northward through southern Lower Michigan (Barnes and Wagner, 1981).

Deciduous Swamp communities are most typical of poorly-drained lake plains, where a high water table keeps lacustrine sediments constantly wet. For example, these communities are dominant in lowland areas within Tuscola and southwestern Van Buren County (Albert et al., 1986). Deciduous Swamp communities are also found along floodplains, where elm (Ulmus spp.) and black ash (Fraxinus nigra) species dominate (Sommers, 1984). Tamarack swamps

(Larix laricina) and marshes are most distinctive of lowland, poorly-drained sites within Livingston County and throughout central Lower Michigan (Albert et al., 1986).

Well-drained outwash plains within interior, southwest Lower Michigan are associated with Oak-Savanna communities (Barnes and Wagner, 1981). Since these areas took less effort to clear for agriculture, they were the first to be used for farming, and are extremely rare today (Albert et al., 1986).

The climate of southern Lower Michigan is classified as "Humid Continental," with an average annual temperature of 7.8 to 8.5 degrees Celsius and an average annual precipitation of 700 to 900 mm (Ahrens, 1994; Michigan Department of Agriculture, 1974). This classification is primarily due to the region's interior location (relative to North America) and to the impact of humid air (drawn north from the Atlantic Ocean and the Gulf of Mexico by low pressure cells migrating east with the westerly winds). January and July are the coldest and warmest months of the year, respectively (see Table 2). Ionia, Livingston, Tuscola, and Van Buren Counties have average annual temperatures within one degree of the regional average. Locally, counties in the western part of Michigan receive more winter precipitation (via lake effect snow) than counties further east (Hudgins, 1961). However, across the region, precipitation is reasonable well distributed throughout the year with only a slight warm-season maximum (see Table 2).

The geomorphology of southern Lower Michigan is mostly a result of Pleistocene glaciation (Sommers, 1984). The sedimentary bedrock surface is

Table 2 Climate data

	Mean Temperature				Mean Precipitation Total			
	Ionia[a]	Livingston[b]	Tuscola[c]	Van Buren[d]	Ionia[a]	Livingston[b]	Tuscola[c]	Van Buren[d]
Units	celsius	celsius	celsius	celsius	cm	cm	cm	cm
January	23.0	22.2	22.1	24.3	1.6	2.0	1.4	2.2
February	24.3	23.6	23.3	26.1	1.4	1.9	1.3	1.8
March	33.3	32.4	32.5	34.9	1.9	2.5	1.9	2.9
April	46.9	45.7	45.9	47.9	3.2	3.5	2.4	3.6
May	57.2	56.1	55.9	58.2	3.5	3.4	2.8	3.9
June	67.4	66.6	66.5	68.7	3.6	3.6	3.1	4.2
July	71.0	70.6	70.4	72.1	2.8	3.0	3.1	3.5
August	69.5	69.1	68.6	70.6	3.1	3.4	2.9	2.8
September	62.0	61.7	61.3	63.4	3.0	2.7	2.8	3.0
October	51.7	51.5	51.5	53.0	2.4	2.4	2.5	3.1
November	38.8	37.8	38.7	39.7	2.4	2.4	2.4	2.9
December	27.4	26.5	26.9	28.6	1.9	2.3	1.7	2.4
Year	47.7	47.0	47.0	49.0	30.6	33.3	28.1	36.1

notes:
[a] Collected at Ionia, MI
[b] Collected at Milford, MI
[c] Collected at Caro MI
[d] Collected at Paw Paw MI

Source: Michigan Department of Agriculture, 1971. Average Data collected 1940-1969.

blanketed by a hodgepodge of glacial sediment 60 m thick in local areas (Farrand and Eschmann, 1974). In extreme southern Michigan, deglaciation last occurred around 16,000 B.P. (Farrand and Eschmann, 1974). Because the resulting landscape is geologically young, the rolling topography of southern Lower Michigan lacks an integrated drainage system and, consequently, supports large areas of swamps and small kettle lakes are abundant (Veatch, 1953). Elevations range from 175-390 m above sea level, although most hilltops are below 320 m, and local relief rarely exceeds 30 m (Albert et al., 1986). Landforms include moraines of all types, till plains, outwash plains, and lake plains (Veatch, 1953).

Several physiographic divisions have been recognized within the region (Veatch, 1953; Albert et al., 1986) (see Figure 2). Perhaps the most distinctive region is a lake plain (locally, 50 km wide) bordering lakes Erie and Huron. The terrain within this area is extremely flat and slopes gently toward the east (Albert et al., 1986). Associated soils, which support mostly deciduous swamp communities, are poorly-drained, lacustrine clays. (Mettert, 1986). Northern Tuscola County is located within this landscape.

To the west and south of the lake plain lie wide expanses of till plain. This area extends into central Lower Michigan to the north, west to Kent County, and south to Jackson County. Ionia County is located in the heart of this region. The topography of the till plain consists of gently sloping ground moraine broken by outwash channels and narrow end moraines (Albert et al., 1986). The soils

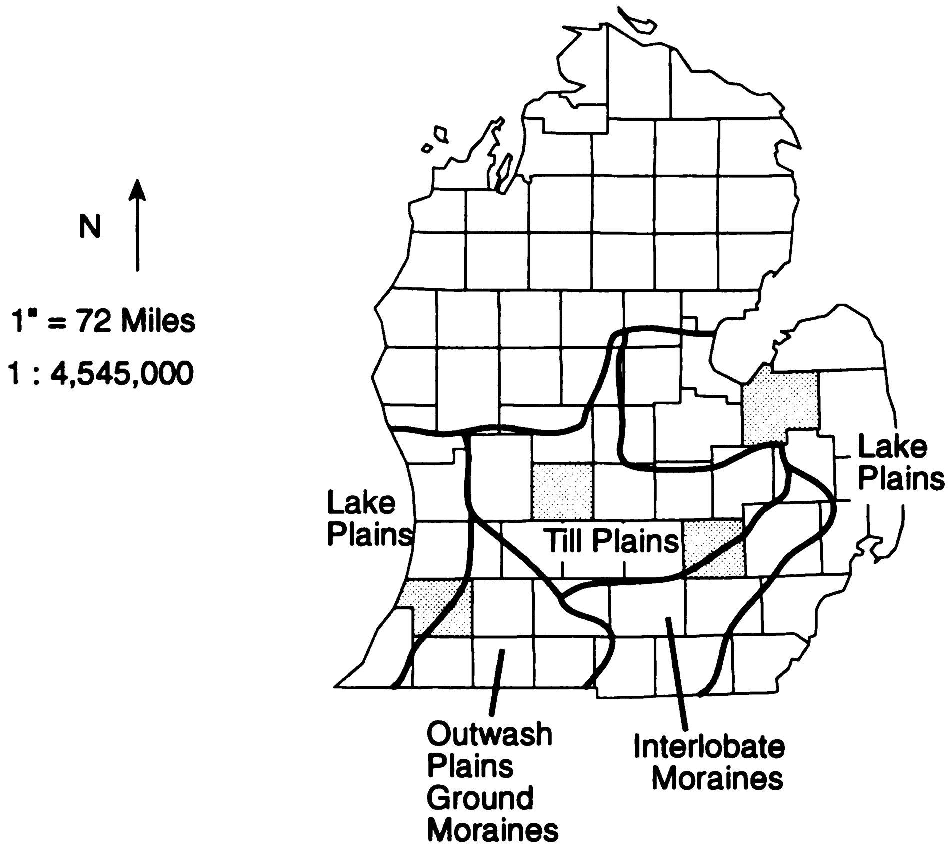


Figure 2 Physiographic Regions of southern Lower Michigan (modified from Albert et al., 1986)

are loamy-textured and support Beech-Maple assemblages (Barnes and Wagner, 1981).

The landscape south and west of the till plain is more hilly and consists of a pair of interlobate areas separated by a flat outwash plain. Geographically, this region borders the lake plain to the east, Indiana to the south, and the southeast corner of Van Buren County to the west. The interlobate areas consist of steeply-sloping kettle and kame topography with coarse-textured soils. Drainage is controlled by topography, where ridge crests and toe slopes are well and poorly-drained, respectively (Albert et al., 1986). Oak-Hickory communities are characteristic of the well-drained, coarse-textured sites which dominate this landscape type (Barnes and Wagner, 1981). Livingston County is located within this region.

Bordering Lake Michigan lies a region that consists of flat lake plain broken in places by steep sand dunes and beach ridges and, farther inland, by steeply-sloping ground and end moraine ridges (Albert et al., 1986). This region extends into northern Lower Michigan, south to the Indiana border, and inland about 35 km. Loamy-textured soils within the region, which includes Van Buren County, support Beech-Maple communities, whereas Oak-Hickory communities are found growing on coarse-textured outwash (Barnes and Wagner, 1986).

2. History

The landscape within southern Lower Michigan was primarily forested before European settlers arrived from New England in the mid-nineteenth century (Bowmen, 1986). Upon arrival, the settlers cleared the forests for timber, and by 1870, Michigan was the leading producer of lumber in the nation (Sommers, 1984). Consequently, the settlers left only a small portion of the primeval forest undisturbed, and the resulting landscape was highly fragmented (Tang, 1991). Around the turn of the century, local economies turned toward agriculture as timber became less available (Sommers, 1984). The resulting farming practices probably maintained at least some of the landscape fragmentation remaining from logging and may even have exacerbated it in those areas not heavily logged. Today, the southern Lower Michigan landscape is still dominated by agriculture; within Ionia, Livingston, Tuscola, and Van Buren Counties the most extensive landuse/landcover category is "Agriculture" (see Table 3).

Table 3 Landuse/cover data

Units	Ionia %	Livingston %	Tuscola %	Van Buren %
urban	4.4	10.7	2.8	5.3
agricultural	68.3	35.6	65.9	51.2
forested	18.7	21.6	20.8	28.9
non-forested	4.7	22.2	9.0	10.3
non-forested wetland	3.0	6.9	1.2	2.7
water	0.9	3.1	0.3	1.7

Source: Michigan Department of Natural Resources, Real Estate Division.

Clearly, decisions made by rural landowners during the past hundred years have had a large though imprecisely understood impact on both the shape and exact location of forest patches surviving in southern Lower Michigan. For example, decisions made by farmers could have been influenced by the perceived site quality of the landscape, with heavier use focused on the better agricultural soils. If so, the landowners may have abandoned mainly the marginal sites, which may then have reforested. Consequently, regenerated woodland may be concentrated on these agriculturally inferior sites and rare on highly productive ones.

The shape of forest patches on the landscape may also have been influenced by land-owner choice. The presence of irregularly shaped, natural features within the landscape (such as floodplains) may have imposed limitations on agricultural use. Accordingly, farmers may have delimited the boundaries separating agricultural lands from areas left to succession or originally uncut based on these limitations. The resulting forests would then be irregularly shaped, similar perhaps to the shape of the limiting feature. However, the boundary of forest patches left by farmers for fuelwood, often located on fertile farmland, may not have been constrained by landscape characteristics and may, therefore, be more regularly shaped.

The exact decisions, made by landowners during the past century, responsible for the current forest/non-forest patterns are unknowable. However, reason suggests that, because "value" played a role in these decisions (which to and not to farm) the possibility arises that our vestigial woodlands do not represent a proportionate sample of the original.

C. Literature Review

The purpose of this literature review is to demonstrate that 1) forest composition and floristic richness vary relative to site character, 2) the Michigan landscape is fragmented, and 3) no past work has been conducted in Michigan to characterize the site quality of the remnant forest patches.

1. Soils and Forest Distribution

A large body of scientific literature has accumulated pertinent to the specific relationship between soil characteristics and forest composition. In this section, I will briefly summarize the literature most relevant to the selected study area and to the site parameters I have chosen (texture, drainage, and slope). Wilde (1933) was one of the first to characterize the relationship between soils and forest composition in the Great Lakes region. Wilde recognized the importance of climate as the predominant variable controlling plant distributions at a small scale. However, concerning soils, he (p. 94, 1933) wrote "soil determines more precisely the composition of the main forest stand, the occurrence of shrubby and herbaceous vegetation, the intensity of growth, the possibility of natural reproduction etc." Further, Wilde described drainage and texture as controlling factors responsible for forest growth and composition across the Great Lakes region. He divided the landscape into three classes based on drainage: very poorly-drained, poorly-drained, and well-drained.

Within the very poorly-drained class, Wilde (1933) recognized four types of organic soils: sphagnum peat, fine woody peat, course woody peat, and muck. Each type of soil was associated with a certain type of vegetation. For example, black spruce (*Picea mariana*) and tamarack (*Larix laricina*) were most distinctive of sphagnum peat; fine woody peat sustained populations of black *ash (Fraxinus nigra*), elm (*Ulmus* spp.), red maple (*Acer rubrum*), yellow *birch (Betula alleghaniensis*), and willow (*Salix* spp.); coarse woody peat supported stands of northern white cedar (*Thuja occidentalis*); alder (*Alnus* spp.) was most typical of muck.

Within the poorly-drained class, Wilde (1933) recognized two general vegetation communities. Sandy textured soils were associated with eastern white pine (*Pinus strobus*), red pine (*Pinus resinosa*), jack *pine (Pinus banksiana*), aspen (*Populus* spp.), and white birch (*Betula papyrifera*). Loamy-textured soils maintained stands of ash (*Fraxinus* spp.), elm, red maple, sugar maple (Acer saccharum), yellow birch, white pine, hemlock (*Tsuga* spp.), spruce (*Picea* spp.), and balsam fir (*Abies balsamea*).

Within the well-drained class, Wilde (1933) recognized several vegetation communities. Sandy soils were generally associated with pines (*Pinus* spp.). Specifically, the following pairs of soil type and species composition were noted: jack pine was most typical of wind-deposited sand, jack and red pine characterized outwash sand, and morainic sand supported stands of red and white pine (sometimes mixed with northern pin oak [*Quercus ellipsoidalis*], and black oak [*Quercus velutina*]). Wilde also noted that aspen, paper birch, red oak (Quercus rubra), and white oak (*Quercus alba*) were occasionally found on the "better" sandy sites.

Wilde (1933) divided loamy soils, within the well-drained class, into two groups. Sugar maple and basswood (*Tilia americana*) were most distinctive of silt loams, whereas clay loams supported populations of maple (*Acer* spp.), elm, yellow birch, and occasionally, hemlock and balsam fir.

Daubenmire (1947) described the manner in which soil texture affects root penetration, infiltration of water, rate of water movement, water holding capacity, fertility, soil structure, soil aeration, and soil temperature. Examples provided by Daubenmire demonstrate how these variables, as controlled by texture, affect the ability of different species to thrive on various sites. Given Daubenmire's emphasis on texture, one can easily see how plant distributions could respond to patterns in soil texture.

In 1953, Elliot compared hardwood composition and soils in central Lower Michigan. He found that species importance changes from one soil series to another. Lindsey (1961) described vegetation composition changes across drainage classes in northern Indiana. Other authors have qualitatively described the relationship between soil texture and species composition within Michigan (Livingston, 1905; Braun, 1950; and Veatch, 1953), the Great Lakes Region

(Curtis, 1959; Crankshaw et al. 1965; Catena, 1967; Whitney, 1982; and Lorimer, 1984), and elsewhere (Howell and Kucera, 1956 and Strahler, 1977)

More recently, Medley and Harman (1988) provided quantitative data to demonstrate that within central Lower Michigan the relationship between soil texture and species composition was statistically significant. For example, they showed that pines were most frequent on sandy soils, and sugar maple was most frequent on fine-textured soils within the transition zone in Michigan.

Barrett et al. (1995) described the relationship between soils and pre-settlement forests in Baraga County, Michigan. They divided the landscape into three broad categories (mesic, hydric, and xeric) based on soil moisture. Different groups of tree species occurred most frequently on each of the categories. For example, mesic sites were associated with sugar maple, yellow birch, red maple, and white pine; hydric sites supported stands of black spruce, northern white cedar, balsam fir, tamarack, and black ash; and xeric sites sustained populations of jack pine, red pine, and white pine. Research by Whitney (1986 and 1987), Host et al. (1987), Nowack et al. (1990), and Leitner et al. (1991) in the past decade has further confirmed and refined these relationships between soils and forest distribution.

2. Landuse/Landcover Change

Recent technological advances (e.g., Geographic Information Systems) have made answering large-scale questions of landscape ecology possible.

Many authors have documented landuse/landcover change over vast areas with the technology (Kloptek et al., 1979; Whitney and Somerlot, 1985; Iverson, 1988; Turner and Ruscher, 1988; and Medley et al., 1995). Most of their work consists of analyzing the spatial impact of human activity upon the environment. For example, Iverson (p. 59, 1988) concluded that most of the landscape in Illinois was highly modified, "with most land patches controlled by human influences and relatively few by topography and hydraulic features." Kloptek et al., (1979) found that the area of elm-ash forest in Michigan, Ohio, and Indiana had been reduced 88% by agriculture and urbanization.

Many other studies have focused on the structure of the remaining forest patches (Forman and Godron, 1981; Krummel et al., 1987; Tang, 1991; and Wickham and Norton, 1994). Pastor and Broschart (1990) analyzed the spatial pattern of the conifer-hardwood landscape in northern Michigan. They concluded that these forest types are segregated by soil types (consistent with other research) and that anthropogenic disturbance favors hardwoods.

Tang (1991) analyzed the spatial characteristics of Lower Michigan's forest patches. Within Ingham county she determined the percentage of the total landscape and the percentage of the total forested land within several categories of farmland. 23% of Ingham county was classified "Prime Farmland with drainage," and 39% was classified "Non-Prime Farmland." However, only 15% of the total forest-land was located on the "Prime Farmland," and 42% was located on the "Non-Prime Farmland." These percentages indicate that forest patches are not evenly distributed among different categories of farmland. Tang's work, therefore, suggests that forest patches in southern Lower Michigan are not evenly distributed across the continuum of site quality.

D. Recapitulation

Although many of the studies described in the literature review have shown that forest composition changes across texture and drainage boundaries and that the landscape is fragmented into a patch-like structure, no known study has directly addressed the extent to which surviving forest patches represent a sample of the range of habitats present on the pre-settlement landscape. Do existing patches, for example, over or under-represent certain types of habitat? Referring to mature hardwood stands in North Carolina, Oosting (p. 89, 1953) commented, "usually they are associated with topographic irregularities and sometimes with inferior site quality." The purpose of this study is to determine whether such an association, in terms of site quality, exists in southern Lower Michigan.

E. Research Questions

1. Do contemporary forest patches represent a proportionate sample of the primeval forest?
2. Do forest patches over or under- represent certain types of habitat?
3. Are forest patches concentrated on sites of inferior agricultural quality?

4. Is forest patch shape related to site quality?

F. Research Objectives

1. Describe and analyze the site quality of the forest land in the four counties chosen for study.
2. Compare expected to observed areal extents of forest on different categories of site quality.
3. Determine the location of some forest patches with high ecological value, based on site quality.
4. Examine the relationship between forest patch shape and site quality.

Chapter 2

DATA AND METHODS

A. Description of Overall Design

In order to accomplish the first three objectives (see Chapter 1), I collected data that allowed me to characterize the range of site quality across the four county study area and the areal extent of each quality category (which then allowed me to calculate the "expected area" of forest patch). I then determined the geographic locations of actual forest patches and classified them according to a measure of their site quality. These steps then allowed me to compare expected and observed areas of forest patches on different categories of site quality (see Figure 3 for an overview of data processing).

In order to accomplish the fourth objective listed above, I analyzed the shape of forest patches, and calculated the mean patch shape for different categories of site quality. From this analysis, I then determined whether different degrees of site quality supported forest patches with characteristic shapes.

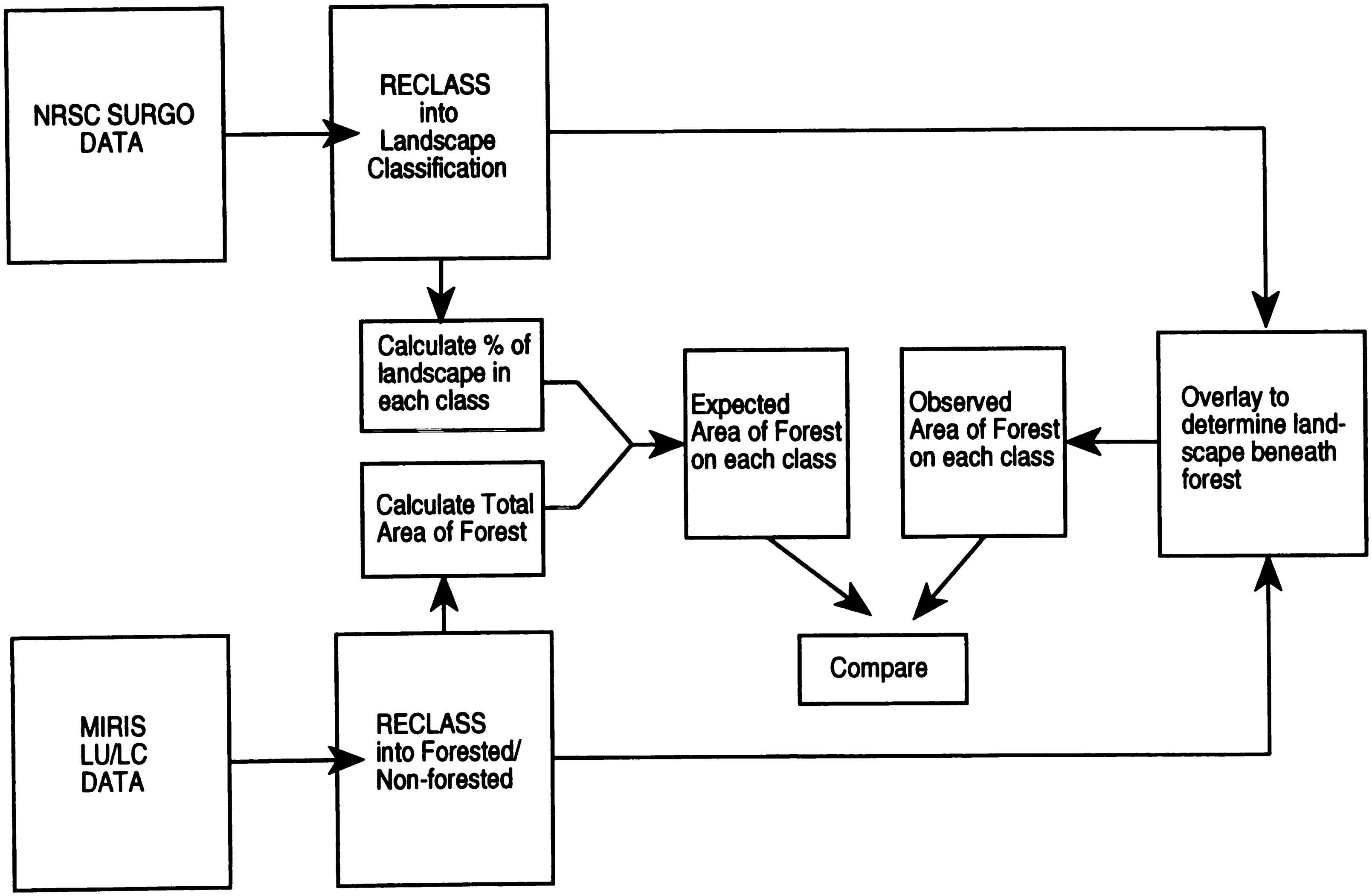


Figure 3 Data processing flow chart

B. Data

1. Site Quality Classification

Drainage, texture, and slope data were extracted from digital soil survey data (SSURGO), provided by the Natural Resources Conservation Service, and used to categorize site quality of patch locations. Most soil series located in southern Lower Michigan have been classified into Soil Management Groups by Mokma (1982). This classification is based upon dominant profile texture, as defined by the textures of the upper 1.5 m of soil, the natural drainage class, and the average percent slope assigned to the series. Mokma suggested six land uses for which the classification can assess degrees of limitation. One of the six is woodland. I used a modification similar to that employed by Medley (1985) to classify the landscape into varying degrees of site quality (see Table 4 and Figure 4). The modification was necessary to maintain an adequate sample within each class, and to try to prevent soil complexes from being classified into different groups. Four, three, and three classes of texture, drainage, and slope, respectively, were possible, yielding thirty-six potential landscape categories (see Figure 4). However, at most, twenty-three classes occurred within the landscape because some potential classes, such as steeply-sloping, very poorly-drained sites, do not exist.

2. Forest Definition

The definition of forest used by the Michigan Department of Natural Resources (MDNR) was adopted for this study, and it states that a parcel of land

Table 4 Site quality classification (modified from Mokma, 1982)

Soil Management Units	Characteristics	Final Class
Texture 1	fine clay, > 60% clay clay, 40-60% clay clay loam & silty clay loam	2
Texture 2.5	loam and silt loam	
Texture 3	sandy loam	
Texture 3/2	sandy loam, 20-40 inches over loam to clay loam	
Texture 3/5	sandy loam 20-40 inches	3
Texture 3.5	between texture 3 & 4	
Texture 4	loamy sand	
Texture 4.5	between texture 4 & 5	
Texture 5	sand with strong subsoil development	
Texture 5.3	sand with medium subsoil development	5
Texture 5.7	sand with weak or no subsoil development	
Texture 4/2	sand to loamy sand 20-40 inches over loam to clay loam	
Texture 4/1	loamy sand, 14-40 inches, over clay	6
Texture 5/2	sand to loamy sand, 40-60 inches over loam to clay loam	
Drainage A	Well and moderately well drained	1
Drainage B	Somewhat poorly drained	2
Drainage C	Poorly and very poorly drained	3 (combined with 2 for shape indexing)
Slope A	Average slope less than 3%	1
Slope B	Average slope greater than or 3% and less than or equal to 5%	2
Slope C Slope D Slope E Slope F	Average slope greater than 5%	3

Figure 4 Site quality classification. The shaded box represents the T2-D1-S3 landscape type, which is fine-textured, well-drained, and steeply-sloping. A total of thirty-six potential types exist (3 * 3 * 4 matrix).

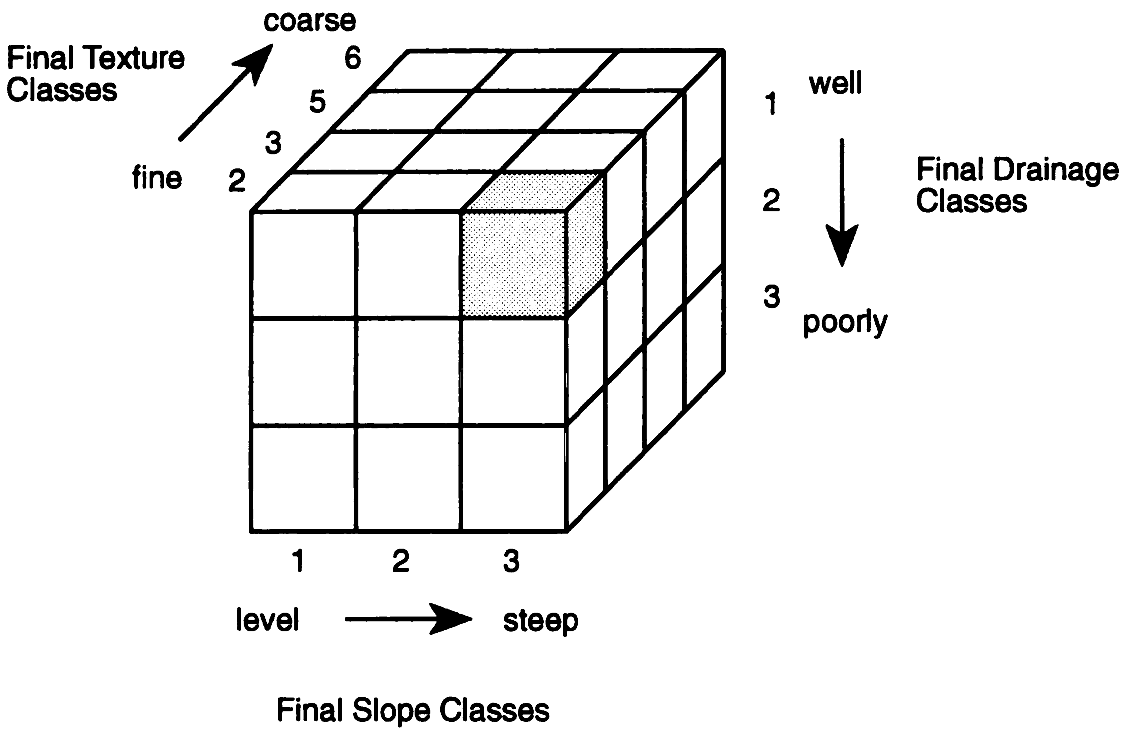


Figure 4 Site quality classification

must be covered by arboreal vegetation having at least 20 percent crown closure to be classified "forested." The data came from MIRIS Land Cover Product Number 200, which is a digitized landuse/landcover coverage provided by the MDNR. The database was digitized from 1:24,000-scale color infrared or black and white aerial photography. Landscape parcels 1 hectare and larger are grouped into categories of urban, agricultural, non-forested, forested, water, wetland, and barren. These landscape classes are defined by the MDNR. I treated all forested and forested wetland categories as "forest patches" (see Table 5).

3. Forest Patch Selection

The four counties selected for study (Ionia, Livingston, Tuscola, and Van Buren) appear to be typical of the southern Lower Michigan landscape, and are described in Chapter 1. Two forest patch selection methods were needed to achieve the objectives of the study. To accomplish the first three objectives (listed in Chapter 1, Part E), the total area of all forest patches (rather than a subset thereof) within the four county region was calculated. Areas of forest that occurred on soil complexes (a mapped soil pedon that consists of a mixture of two soil series) were not included in this calculation, however, if the two series composing the complex fell into two different categories of landscape (as defined in Table 4). In this case, only the area of the forest patch that occurred on the complex was excluded, while the remainder of the patch was included. Accordingly, in this stage of analysis I treated the sample patches not in their

Table 5 Forest classification

Miris Landuse/cover code	Description	Final Class
1	Urban	
2	Agriculture	Non-forested
3	Non-forested	
4	Forested	
41	Deciduous	
411	Northern Hardwood	
412	Central Hardwood	
413	Aspen/ White Birch	Forested
414	Assoc.	
42	Lowland Hardwood	
421	Coniferous	
422	Pine	
423	Other Upland Conifer	
	Lowland Conifer	
5	Water	Non-forested
6	Wetlands	Forested
61	Forested	
611	Wooded	
612	Shrub, scrub	
62	Non-forested	Nonforested
7	Barren	

Source: Michigan Department of Natural Resources, Real Estate Division.

entirety, but, rather, as proportions thereof. (This distinction is worth noting because it is contrary to the selection process described below for selecting patches to accomplish the fourth objective.) For example, the Tappan-Avoca complex in Tuscola County consists of a mixture of the Tappan series (a poorly-drained, loamy-textured soil) and the Avoca series (a somewhat poorly-drained soil composed of coarse-textured sand overlying loamy-textured material)(Mettert, 1986). The landscape type of the portion of a forest patch located on the Tappan-Avoca complex, and similar complexes, is indeterminable, and, therefore, the area of that portion of the patch was not included in the analysis.

To correlate site quality with forest patch shape on the landscape, entire forest patches were either included or not. In other words, and in contrast to the selection process described above, forest patches were treated as entireties, and if an excessive proportion of a forest patch occurred on an indeterminable landscape type, then the entire forest patch was excluded from the analysis. I included all forest patches that had at least ninety percent of their total area within one category of landscape. For example, seventy-five hectares of a one-hundred hectare forest patch might be located on a poorly-drained site, whereas twenty five hectares might be located on a well-drained site. Such patches, with less then ninety percent of their area on one landscape type, could not be classified into a single category of landscape and were, therefore, discarded. This sampling scheme was necessary because a large proportion of forest patches occurred on more than one category of landscape, and the ninety percent threshold was chosen arbitrarily because it initially seemed to include a reasonable proportion of forest patches.

C. Data Processing

1. Objective 1

The first objective of the study was to describe and analyze the site quality of the forested land. All data were analyzed using Arc/Info software. The location of forest patches within the study area had to be determined before the areal extent of forest patches along the site-quality continuum could be described. The MIRIS landuse/landcover data are classified into seven forest types (see Table 5), but I collapsed all seven types of forest into one and determined the total area of forest patch polygons irrespective of type. Furthermore, after each forest patch was geographically located, its site was then classified according to a quality scheme, using the digital soil survey data, in which the landscape is classified into different soil series as a source. The site quality of the landscape was determined by aggregating polygons that represented the geographical extent of different soil series within the study area (see section B 1, Site Quality Classification). For example, two neighboring soil series might be joined if they had similar texture, drainage and slope, which were the three selected site quality variables (see Table 4). This landscape aggregation of soil series reclassified the study area into varying degrees of site quality. Since both the forest patch and the site quality data were georeferenced, which means the geographical extent of the data was known, the two layers of information could be overlaid, and the nature and site quality of the landscape beneath the forest patches could be described.

The total area and proportion of the landscape comprosed of forest patches, irrespective of forest type, within each site quality category (36 possible) were calculated for each county. This information was also calculated for each of the categories of the three site quality variables (texture, drainage, and slope), separately. For example, the area of forest on texture "Final Class 2," regardless of drainage and slope, was calculated, as well as the area of forest on texture "Final Class 2," slope "Final Class 1," and drainage "Final Class 2." This information helped during interpretation.

2. Objective 2.

The second objective of the study was to compare expected to observed forest distributions along the continuum of site quality within each county. The observed distribution of forest refers to the forested area within each category of site quality, which was calculated as stated above. To calculate expected forest distribution in terms of site quality, the total forested area within a county and the proportion of the landscape within each category of site quality were determined (see Figure 3). The total area of forest is the summation of the area of all forest patches within the county. The total study site area and the area within each site quality category were used to calculate the proportion of the landscape in each category of site quality. The expected areal extent of forest within each category of site quality on the landscape was then determined by assuming a random distribution and multiplying the total area of forest land by the proportion of landscape within each category of site quality. This procedure calculated the expected distribution of forest in terms of site quality by dividing the total forest land among the landscape types, relative to how well represented the landscape types were. In other words, categories of site quality that occupy a large proportion of the study area are expected to support a large proportion of the total forest land. The observed and expected distributions were statistically compared as describe below (see Part D "Description and Rationale for Statistical Testing").

3. Objective 3.

The third objective of the study was to determine the location of forest patches in the study area with high ecological value based on the site quality of the landscape beneath the forests. For this study, the value of a forest patch is considered ecologically high if the patch occurs on a landscape type having an under-representation of forest. For example, if the observed area of forest on a certain category of site quality is less than the expected area, then by this procedure the occurring patches are judged to have high ecological value. Rather than define a threshold to determine forest-deficient landscape types, I subtracted the observed area of forest from the expected (for each site quality category), and then normalized the difference (to prevent large classes from appearing more deficient than smaller ones). The forest patches located on the three most deficient landscape types (the ones with the lowest normalized difference) were considered to have highest ecological value relative to the site quality of the landscape.

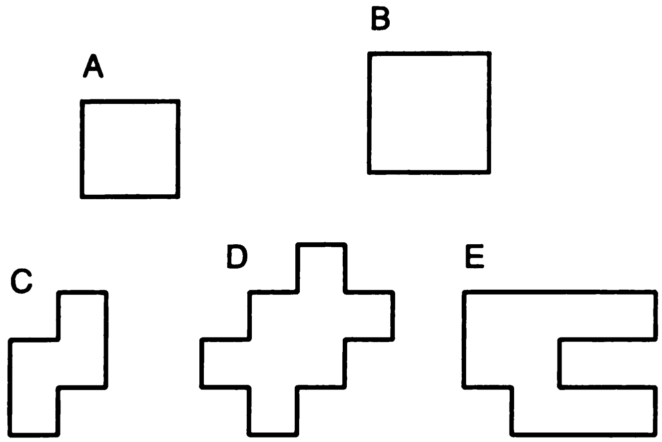
4. Objective 4.

The fourth objective was to examine the relationship, if any, between forest patch shape and site quality. In other words, do forest patches on different categories of site quality have significantly different shapes? In order to accomplish this objective, I calculated two shape indices for all selected forest patches (the selection criteria are discussed below). The first index (Sh1) was calculated as the average of the perimeter-to-area ratio(Iverson, 1988) for all patches within each category of site quality:

$$Sh1 = 1/N_i1 * \Sigma (l_i/a_i)$$

where N_i1 equals the number of patches for a particular category i, l_i the perimeter, and a_i the area of each patch in category i. This index measures the mean patch shape for each site quality category. High values indicate patches with small interiors relative to their area (Hulshoff, 1995)(see Figure 5).

The second shape index (Sh2) is a measure of the deviation of a given patch from an isodiametric patch (circular) with the same area (Forman and



Polygon	Area	Perimeter	Sh1	Sh2
A	4	8	0.0	1.0
B	9	12	1.5	1.0
C	4	10	2.5	1.3
D	8	16	2.0	1.4
E	9	12	2.0	1.7

Figure 5 Hypothetical patches and corresponding shape index values (modified from Holshoff, 1995)

Godron, 1986). The index is calculated as the average deviation of all selected patches:

$$Sh2 = 1/N_i1 * \Sigma (l_i/2 \sqrt{a_i \Pi})$$

where N_i1 equals the number of patches for a particular category i, l_i the perimeter, and a_i the area of each patch in category i. A value of 1.00 for a given site quality category indicates the patches are isodiametric, or circular, whereas greater values indicate increasing isodiametric deviation and, therefore, increasing shape complexity (Hulshoff, 1995)(see Figure 5).

I initially planned to calculate average Sh1 and Sh2 values for all patches that had at least ninety percent of their total area within one of the site quality categories (see Section B 3 Forest Patch Selection). However, because forest patches still had a tendency to occur on more than one category, the classification scheme had to be generalized. I decided to develop a separate classification for each of the three site quality variables (texture, drainage, and slope)(see modification on Table 4), thus allowing the calculation of average Sh1 and Sh2 values for each of three categories of texture, two categories of drainage, and three categories of slope. A T-test or analysis of variance (ANOVA), as appropriate, and, as described below, was then conducted on the categories of each of the variables, separately. For example, I determined whether a mean shape difference existed between patches located on "Final Slope Class 1," "Final Slope Class 2," and "Final Slope Class 3," regardless of texture and drainage.

D. Description and Rationale for Statistical Testing

The relationships between the number of forest patches and landscape types were examined using a contingency table following the method used by Barrett et al. (1995) and Whitney (1986). A 2 by n table was constructed for each county, where n equaled the number of landscape types present. In order to characterize the degree of association between the number of forest patches and a particular landscape type, I calculated Strahler's (1977) signed standardized residuals, following the method of Barrett et al. (1995). The standardized residual was calculated as

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

and measures the strength of association between a landscape type and the number of forest patches. A calculated value of 0.0 for a given type indicates that the difference between observed and expected numbers of patches could have arisen by chance, whereas a high positive residual suggests that forest patches occurred more frequently than would have been expected.

I then used a Chi-square contingency table to determine the association between observed and expected numbers of forest patches across all categories of site quality. The Chi-square test determines whether two sets of frequencies are statistically independent (Earickson, and Harlin, 1994). If the differences between the observed and expected number of patches on different landscape types are small, the conclusion is that the difference could have arisen by chance. The Chi-square (X^2) is computed as

$$X^2 = \sum [(f_o - f_e)/f_e]$$

where f_o equals the observed number of patches for a given landscape type and f_e equals the expected number. To assess the significance of the Chi-square value computed, one compares it to a critical value, pre-determined by the selected level of significance (in this case .01) and degrees of freedom (v), which are computed as v = (r-1)(c-1), where r equals the number of rows from the contingency table (i.e. number of landscape types), and c equals the number of columns (i.e. number of frequencies compared). The Chi-square test cannot be directly used to assess the relative strength of the difference between two frequencies (Earickson and Harlin, 1994). Rather, the computed value tells us only whether the two frequencies are different. Therefore, in order to compare the different counties within this study, I computed the Cramer's V statistic. This statistic measures the strength of the Chi-square value by adjusting for sample size, and allows the comparison of contingency tables with different numbers of rows (landscapes). Cramer's V is computed as

$$V = \sqrt{[(X^2/N)/\min (r-1),(c-1)]}$$

where N equals the sample size (or number of forest patches). Value of V varies from 0 to 1, with increasing values indicating greater strength in the difference between two frequencies.

I used a Student's t-test to compare the mean shape index values for the forest patches occurring on the two classes of drainage. In other words, the mean shape index values for forest patches occurring on poorly-drained sites were compared to the same values for patches occurring on well-drained sites.

The t-test is often used to compare two sample means (Earickson and Harlin, 1994). Since more than two classes of slope and texture exist, the analysis of variance (ANOVA) test was used to compare the mean shape index values for the various variable classes. The ANOVA test is an extension of the difference of means test for sample data that have been partitioned into more than two groups, and it can be used to test the hypothesis that the means of the subsets are equal (Earickson and Harlin, 1994). For example, the ANOVA was used to compare the average shape index values for forest patches occurring on the four categories of texture.

Chapter 3

RESULTS AND DISCUSSION

This chapter is generally organized around the objectives of the study, and organized within each objective by study area. However, the first two objectives are discussed together for the sake of brevity. Within each section, I will report the overall results, highlight those unique to each county, and conclude with a discussion.

Throughout the chapter, I will refer to site quality by using abbreviated codes to reference the different categories. For example, rather then refer to a given category as "Final Texture Class 2," "Final Drainage Class 2," and "Final Slope Class 3," I will simply refer to it as T2-D2-S3. Similarly, T2 will be short for "Final Texture Class 2." The reader is reminded that the texture classification grades from fine (low "Final Texture Class" numbers) to coarse (high "Final Texture Class" numbers). In other words, categories with lower "Final Class" numbers have finer textures. For drainage and slope, "Final Class" number one characterizes well-drained and flat landscapes, respectively, whereas increasing numbers indicate decreasing drainage and increasing average slope (see Table 4).

I will use a system similar to the Land Capability Classification used by the Natural Resource Conservation Service (which groups soils into eight different classes of limitation in order to determine their suitability for most kinds of field crops) to contrast and compare the relative agricultural quality of different types of landscape. A site quality category that imposes limitations on agricultural use, for whatever reason, is considered more inferior than a non-limiting landscape type. For example, very poorly-drained sites are considered inferior relative to somewhat poorly and better drained sites. In terms of slope, steeply-sloping sites are considered more agriculturally limiting than gentle sloping and level landscape. Sandy-textured soils are relatively more limiting than finer-textured soils and loamy-textured soils are considered the least agriculturally limiting.

A. Objectives 1 and 2 results.

Relative to the first two objectives, I will present three different sets of results for each county, which will collectively indicate that a large proportion of contemporary forest patches is located on agriculturally inferior landscape types. The first group of results consists of the site quality categories (of a potential total of 36) that each support greater than ten percent of the total forest area. These results will be given for both the observed (contemporary) and the expected (as defined in Chapter 3) proportions of forest. As will be seen, overall results indicate that the observed categories are generally inferior landscape types and support more forest than expected, whereas the expected categories are, relatively, less inferior landscape types and host less forest than expected. The second group of results consists of the landscape types or site quality categories that are most over-represented and under-represented in terms of their total difference between expected and observed areas of forest. Over-represented categories have more observed area of forest than would be expected by a proportionate sample of the primeval forest assuming that the total area of remaining forest is equally distributed about the categories of site quality relative to their proportions. Under-represented categories host less forest than expected, and are usually the better types of landscape. The third group of results consists of the proportions of the forest on each category for each site quality variable (texture, drainage, and slope), separately. These results further demonstrate the tendency for contemporary forest patches to be located on either end of the three site quality continua. For example, rarely does a large percentage of forest occur on somewhat poorly-drained (D2) or moderately-sloping (S2) landscape.

1. Ionia County

Site quality categories supporting greater than ten percent of observed and expected forest. In Ionia County, two site quality categories (of a total of 23) each support more than ten percent of the total observed forest area. T2-D3-S1, which is a fine-textured, poorly-drained, and relatively flat landscape type, hosts 32 percent of the forest, and T3-D1-S3, upon which 15 percent of the forest grows, is a loamy-textured, well-drained, and steeply-sloping site quality category (see Table 6). Both of these landscape types are either poorly-drained or steeply-sloping and support more forest than expected.

Four site quality categories are each expected to support more than ten percent of the forest, with the T2-D3-S1 and T2-D1-S2 categories each hosting 18 percent of the forest (see Table 6). T3-D1-S2, which is a loamy-textured, well-drained, and moderately-sloping category, is expected to support 13 percent of the forest, and 10 percent of the forest is expected to occur on the T2-D2-S1 category. Three of these four expected categories are not steeply-sloping, poorly-drained, or composed of sandy-textured soil, and they do not individually host more than ten percent of the observed forest. Therefore, of the categories that support greater than ten percent of observed and expected forest in Ionia County, the observed consist of inferior landscape types (poorly-drained or steeply-sloping) and support more forest than expected, whereas the expected are generally better landscape types (level to gently sloping, and well to somewhat poorly-drained) and support less forest than expected.

The difference between observed and expected areas of forest. The analysis of observed versus expected forest areas revealed that the most over-represented site quality category is T2-D3-S1, which was noted earlier for supporting more than thirty percent of the observed forest (see Table 6 and Figure 6). This category, which is poorly-drained, supports 3,615 hectares more

Table 6 Area and proportion of forest within each category of site quality

Classification[a] Texture	Drain	Slope	Observed[b] Area hectare	%	Expected[c] Area hectare	%	dif[d] hectare	norm dif[e]
A. Ionia County								
2	1	2	1786.4	6.9	4667.5	18.0	-2881.1	-0.62
3	1	1	308.0	1.2	800.0	3.1	-492.0	-0.62
2	2	2	544.6	2.1	1202.6	4.6	-658.0	-0.55
2	2	1	1587.3	6.1	2593.5	10.0	-1006.2	-0.39
3	1	2	2179.3	8.4	3376.8	13.0	-1197.5	-0.35
6	1	2	97.7	0.4	134.3	0.5	-36.6	-0.27
3	2	1	532.7	2.1	699.1	2.7	-166.4	-0.24
3	2	2	423.0	1.6	532.1	2.1	-109.0	-0.20
2	1	3	2104.8	8.1	2201.1	8.5	-96.4	-0.04
6	2	2	21.3	0.1	19.6	0.1	1.7	0.09
2	1	1	762.2	2.9	685.7	2.6	76.5	0.11
6	1	1	15.2	0.1	12.3	0.0	2.9	0.24
3	3	1	1505.1	5.8	1077.7	4.2	427.3	0.40
5	1	1	43.4	0.2	28.1	0.1	15.3	0.55
3	1	3	3767.4	14.5	2437.0	9.4	1330.4	0.55
6	2	1	41.5	0.2	25.4	0.1	16.1	0.64
6	1	3	152.5	0.6	88.5	0.3	64.0	0.72
2	3	1	8372.6	32.3	4757.1	18.4	3615.6	0.76
5	1	2	642.9	2.5	263.6	1.0	379.3	1.44
6	3	1	51.4	0.2	20.1	0.1	31.3	1.55
5	2	1	52.1	0.2	18.2	0.1	33.9	1.86
5	1	3	761.7	2.9	230.6	0.9	531.1	2.30
5	3	1	166.6	0.6	48.8	0.2	117.8	2.42
B. Livingston County								
2	2	2	103.4	0.4	272.0	0.9	-168.6	-0.62
6	1	3	26.3	0.1	58.8	0.2	-32.5	-0.55
2	1	2	2025.1	6.9	3889.3	13.3	-1864.2	-0.48
3	1	1	1240.0	4.2	2108.5	7.2	-868.5	-0.41
3	1	2	2176.6	7.4	3259.6	11.1	-1082.9	-0.33
2	1	1	1167.7	4.0	1529.3	5.2	-361.7	-0.24
6	1	1	36.7	0.1	44.6	0.2	-7.9	-0.18
3	2	1	1136.4	3.9	1369.7	4.7	-233.3	-0.17
6	1	2	265.3	0.9	317.4	1.1	-52.1	-0.16
2	2	1	1353.5	4.6	1548.0	5.3	-194.6	-0.13
2	1	3	2084.7	7.1	2349.5	8.0	-264.8	-0.11
3	1	3	5502.7	18.8	4532.4	15.5	970.3	0.21
5	1	2	300.5	1.0	242.7	0.8	57.8	0.24
2	3	1	9979.8	34.0	6556.2	22.4	3423.6	0.52
3	3	1	1915.2	6.5	1235.7	4.2	679.5	0.55

Table 6 (cont'd)

C. Tuscola County

2	1	2	0.2	0.0	2.7	0.0	-2.5	-0.91
2	2	1	499.1	1.2	3811.5	8.9	-3312.4	-0.87
2	2	2	902.0	2.1	2175.5	5.1	-1273.5	-0.59
6	3	1	553.3	1.3	1012.3	2.4	-459.0	-0.45
6	1	2	215.2	0.5	374.9	0.9	-159.7	-0.43
2	1	3	2161.6	5.0	3534.9	8.3	-1373.2	-0.39
3	1	1	595.2	1.4	948.0	2.2	-352.8	-0.37
6	2	1	2113.0	4.9	2769.5	6.5	-656.5	-0.24
2	3	1	8470.5	19.8	10114.2	23.6	-1643.7	-0.16
3	1	2	3645.5	8.5	4230.0	9.9	-584.5	-0.14
3	2	1	2860.6	6.7	3300.5	7.7	-440.0	-0.13
3	1	3	1222.6	2.9	940.6	2.2	282.1	0.30
3	3	1	3724.0	8.7	2563.3	6.0	1160.6	0.45
5	1	3	605.4	1.4	333.1	0.8	272.3	0.82
5	1	2	2771.8	6.5	1308.9	3.1	1462.8	1.12
5	3	1	5354.2	12.5	2371.1	5.5	2983.0	1.26
5	2	1	6910.3	16.1	2954.1	6.9	3956.2	1.34
2	1	1	228.3	0.5	87.6	0.2	140.7	1.61

D. Van Buren County

3	1	2	2706.4	6.7	7146.3	17.8	-4439.8	-0.62
2	1	2	587.8	1.5	1459.8	3.6	-872.0	-0.60
2	2	2	1389.4	3.5	2488.5	6.2	-1099.1	-0.44
2	1	1	309.8	0.8	545.5	1.4	-235.7	-0.43
3	1	1	1005.4	2.5	1705.3	4.2	-699.8	-0.41
2	2	1	484.8	1.2	780.7	1.9	-296.0	-0.38
3	1	3	2036.6	5.1	2439.0	6.1	-402.4	-0.16
6	1	2	741.9	1.8	859.7	2.1	-117.8	-0.14
3	2	1	1545.5	3.8	1639.6	4.1	-94.0	-0.06
5	1	2	3693.0	9.2	3856.9	9.6	-163.9	-0.04
6	2	1	2677.4	6.7	2727.0	6.8	-49.6	-0.02
2	1	3	825.8	2.1	711.8	1.8	114.0	0.16
3	3	1	2272.9	5.7	1775.0	4.4	497.8	0.28
6	3	1	546.4	1.4	383.3	1.0	163.1	0.43
5	2	1	732.1	1.8	504.8	1.3	227.2	0.45
5	1	1	2188.9	5.4	1333.6	3.3	855.3	0.64
2	3	1	13170.0	32.8	7941.1	19.8	5228.9	0.66
5	1	3	3256.7	8.1	1873.0	4.7	1383.7	0.74

Notes:

a- sorted by normalized difference

b- the actual area of forest in hectares

c- total area of forest multiplied by porportion of the landscape in each category

d- difference between observed and expected areas of forest

e- normalized difference

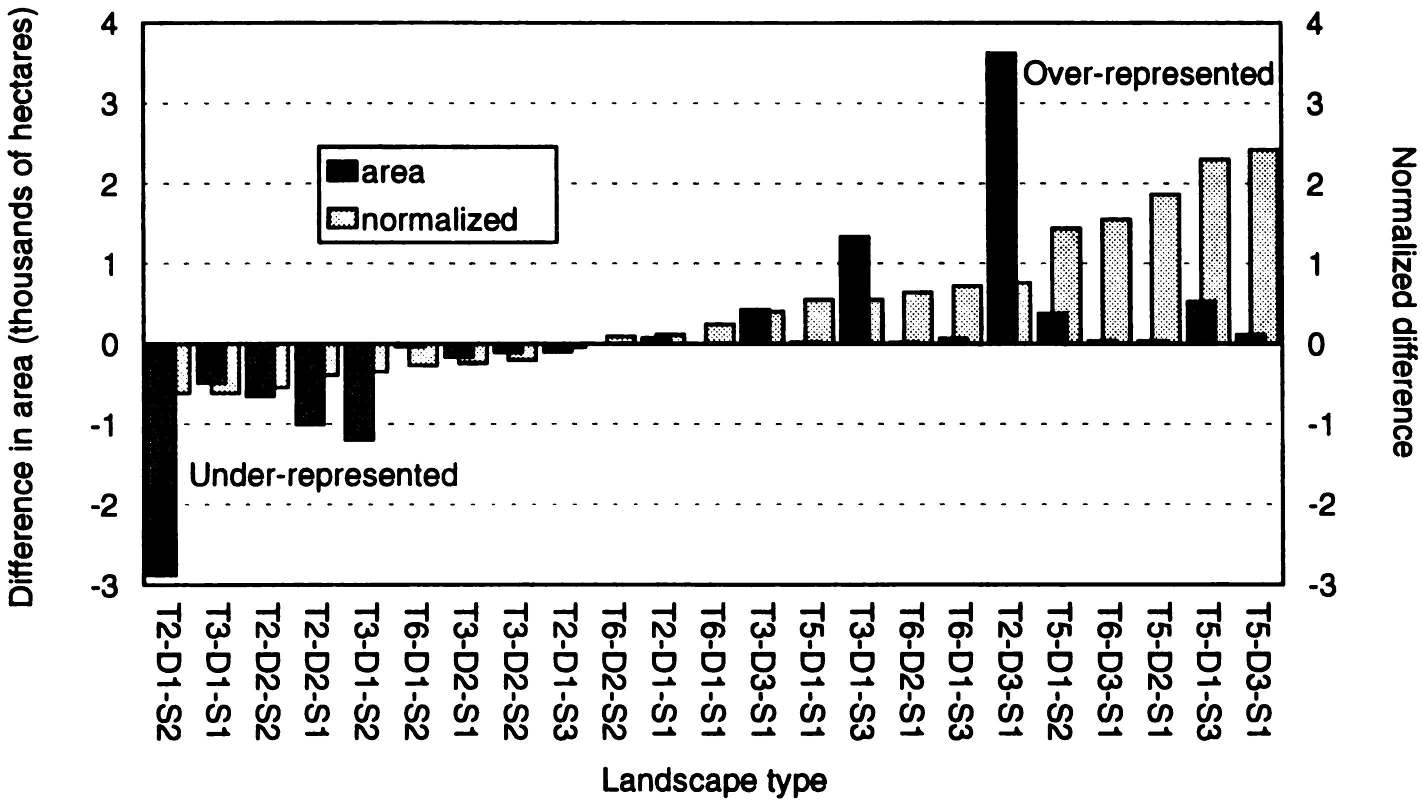


Figure 6 Difference between observed and expected areas of forest, Ionia County

forest than expected. In contrast, T2-D1-S2 supports 2,881 hectares of forest less than would be expected and is the category most under-represented. This category is neither poorly-drained nor steeply-sloping. When the differences are normalized to control for large categories appearing to have greater differences, this latter category is still the most under-represented category, whereas the most over-represented is T5-D3-S1, which is not only poorly-drained, but sandy-textured as well. Therefore, within Ionia County, the most under-represented landscape type appears to be of better site quality (neither poorly-drained, steeply-sloping, or sandy-textured) than the most over-represented type, which is poorly-drained.

Forest area as related to site quality variables. The results of the calculation of the observed proportion of forest on different sites, when broken down by specific variables, indicate that 52 percent of forest land occurs on S1 (the flattest of the three slope classes), whereas only 41 percent is expected, and only 22 percent is observed on S2 (moderately-sloping), but 39 percent is expected (see Table 7 and Figure 7). Similar to the S1 class, the S3 class (steeply-sloping) has less forest than expected (26 versus 19 percent). In terms of drainage, 49 and 39 percent of the forest occur on D1 (well-drained) and D3 (poorly-drained), respectively, whereas 58 and 23 percent are expected, meaning that more forest occurs on poorly-drained sites, and less on well-drained than expected. These results, therefore, indicate that a greater

Table 7 Forest area as related to site quality variables

Units	Ionia Obs. %	Exp. %	Livingston Obs. %	Exp. %	Tuscola Obs. %	Exp. %	Van Buren Obs. %	Exp. %
Texture								
2	58.5	62.1	57.0	55.1	28.6	46.1	41.7	34.7
3	33.6	34.4	40.8	42.7	28.1	28.0	23.8	36.6
4	6.4	2.3	1.0	0.8	36.5	16.3	24.6	18.8
5	1.5	1.2	1.1	1.4	6.7	9.7	9.9	9.9
Slope								
1	51.8	41.5	57.4	49.1	73.1	69.9	62.1	48.1
2	22.0	39.3	16.6	27.2	17.6	18.9	22.7	39.4
3	26.2	19.1	26.0	23.7	9.3	11.2	15.2	12.5
Drainage								
1	48.7	57.6	50.6	62.5	26.7	27.5	43.2	54.6
2	12.4	19.6	8.8	10.9	31.0	35.0	17.0	20.3
3	38.9	22.8	40.6	27.1	42.3	37.5	39.8	25.1

proportion of contemporary forest patches in Ionia County occur on flat, poorly-drained landscape or on steeply-sloping landscape than expected, and a smaller proportion occurs on moderately-sloping, somewhat poorly-drained landscape than expected.

Recap. Observed categories that support greater than ten percent of the forest are either poorly-drained or steeply-sloping, and most expected categories are, relatively, less inferior landscape types (level to gently sloping and well to somewhat poorly-drained). The most over-represented landscape type is poorly-drained, whereas the most under-represented is well-drained and moderately-sloping. For site quality variables considered separately, the

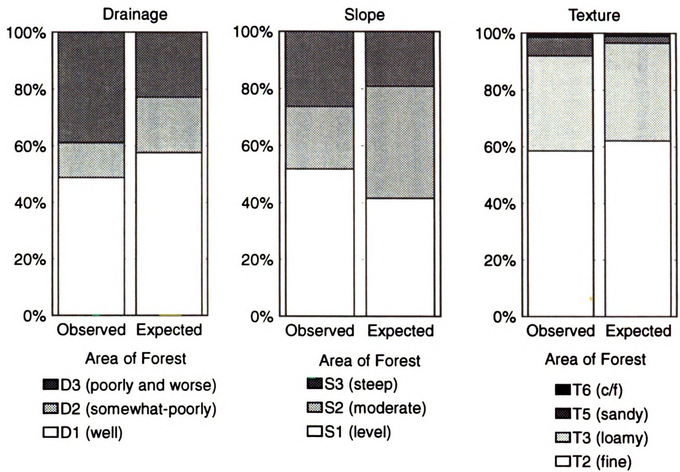


Figure 7 Observed and expected areas of forest relative to site quality variables, Ionia County

individual categories that support the greatest proportion of the forest are located on either end of the particular variable continuum. Therefore, in Ionia County, all three sets of results indicate that a large proportion of the contemporary forest patches is located on inferior landscape types, and the better landscape types appear to be under-represented.

2. Livingston County

Site quality categories supporting greater than ten percent of observed and expected forest. The T2-D3-S1 and the T2-D1-S3 site quality categories support 34 and 19 percent of the observed forest land, respectively, and no other category (15 total) is host to more than 10 percent of the forest land (see Table 6). The T2-D3-S1 landscape type, which was also identified in Ionia County as supporting more than 10 percent of forest, is composed of soils that are fine-textured, poorly-drained, and relatively flat, whereas T2-D1-S3 is characterized by fine-textured, well-drained, and steeply-sloping soils. Similar to Ionia County and important to note, both of the landscape types that each support greater than 10 percent of the observed forest are either poorly-drained or steeply-sloping, and support more forest than expected

The four site quality categories that are expected to support at least 10 percent of the forest land are T2-D1-S2, T3-D1-S2, T2-D3-S1, and T3-D1-S3, the first three of which were recognized in Ionia County, as well (see Table 6). T2-D3-S1 is expected to host 22 percent of the forest, while 16 percent is expected on the T3-D1-S3 category. The first two categories (T2-D1-S2 and T3-D1-S2) are well-drained and moderately-sloping, are expected to support 13 and 11 percent of the forest, respectively, and do not support 10 percent of the observed area of forest. Hence, both are under-represented by contemporary forest patch distribution.

In summary, the two categories that support greater than ten percent of the observed forest are either poorly-drained or steeply-sloping, and, therefore, appear to be agriculturally inferior landscape types. In contrast, two of the categories that are expected to support greater then ten percent of forest appear to be, relatively, less inferior landscape types (neither poorly-drained nor steeply-sloping) and fail to support at least ten percent of the observed forest.

Difference between expected and observed areas of forest. The category T2-D1-S2 has the largest absolute (as compared to normalized) negative difference between expected and observed areas of forest; this fine-textured, well-drained, and moderately-sloping landscape type is expected to support 13 percent of forest area, but only supports seven percent, yielding a difference of 1,864 hectares (see Table 6 and Figure 8). The category with the lowest normalized difference is T2-D2-S2, which is a fine-textured, somewhat poorly-drained, and moderately-sloping landscape. Interestingly, neither of these under-represented categories are poorly-drained, steeply-sloping, nor composed of sandy-textured soil. They are, therefore, landscape types that may not limit

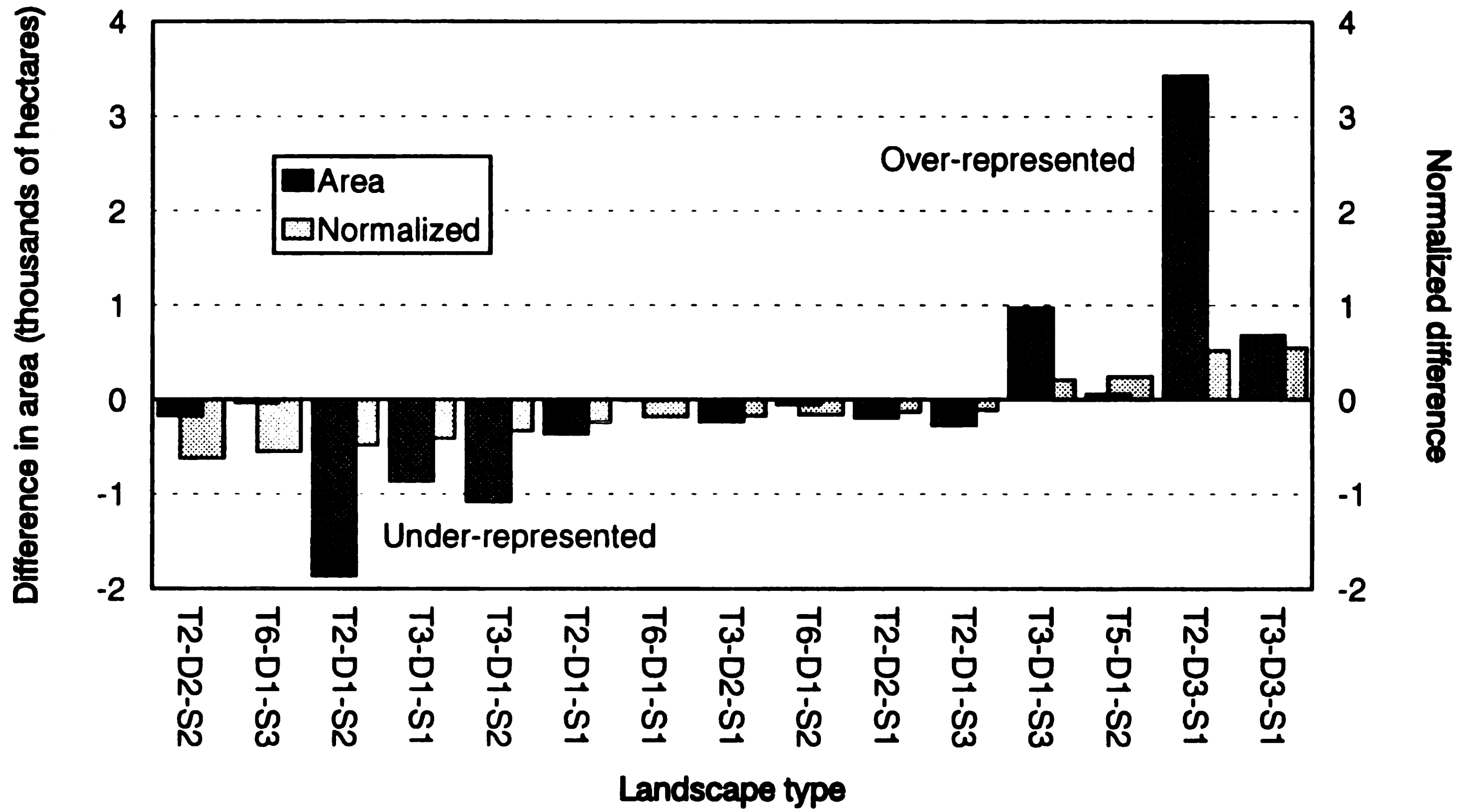


Figure 8 Difference between observed and expected areas of forest, Livingston County

agricultural use. As in Ionia County, the T2-D3-S1 category, which is poorly-drained, is the most over-represented category of site quality with 3,423 more hectares of forest than expected, and also has the second highest normalized difference. Therefore, the most under-represented category appears to be of better site quality than the most over-represented category.

Forest area as related to site quality variables. When the observed area of forest is calculated separately for the various categories of each variable, the following percentages of forest are noted (see Table 7 and Figure 9). In terms of slope, 57 percent of the forest occurs on S1 (level landscape), whereas only 49 percent is expected, and 17 percent is present on S2 (moderately-sloping), but 27 percent is expected, meaning more forest grows on steeply-sloping and level landscape than expected. Meanwhile, the well-drained and poorly-drained landscape types are expected to host 63 and 27 percent of the forest, respectively, whereas 51 and 41 are observed. Consequently, more forest occurs on poorly-drained sites and less on well-drained than expected. Parallel to the situation in Ionia County, less forest than expected grows on moderately-sloping and well-drained sites, while more forest than expected grows on level, poorly-drained soils and steeply-sloping landscape.

Recap. Within the county, both of the categories that support greater than ten percent of the observed forest are agriculturally inferior landscape types

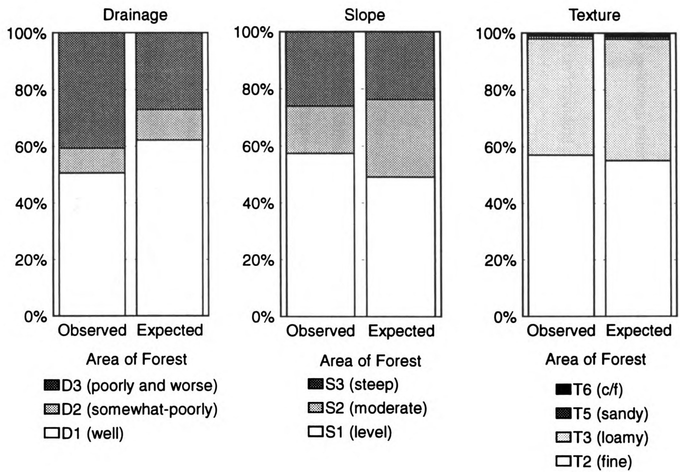


Figure 9 Observed and expected areas of forest relative to site quality variables, Livingston County

(either poorly-drained or steeply-sloping), and some of the expected categories are better landscape types (well-drained and moderately-sloping); the most under-represented landscape type is fine-textured, well-drained, and moderately-sloping, whereas the most over-represented is poorly-drained; and for each site quality variable considered separately, a small proportion of the forest lies on individual categories that occur in the middle of the particular variable continuum. Therefore, as in Ionia County, these results indicate better types of landscape appear to be under-represented, and the contemporary forest patches are located on inferior landscape types.

3. Tuscola County

Site quality variables supporting greater than 10 percent of observed and expected forest. Three site quality categories (of a total of 18) each support greater than 10 percent of the observed area of all forest patches within the county (see Table 6). Twenty percent of the forest is found on the T2-D3-S1 landscape type, which also supported greater than ten percent of forest in Ionia and Livingston counties, and thirteen percent is located on T5-D3-S1. These site quality categories have different soil textures, but are both poorly-drained and level. Sixteen percent of the forest is located on the landscape class T5-D2-S1, which is composed of sandy-textured, somewhat poorly-drained, and level soils. Similar to the situation in the other counties, all three of the categories that each support greater than 10 percent of the observed forest area are either poorly-drained or composed of sandy-textured soil, and support more forest than expected.

Relative to expected forest proportions, two site quality categories are expected to support at least 10 percent of the total forest area (see Table 6). The T2-D3-S1 landscape type, with 24 percent of the expected forest, is fine-textured, poorly-drained, and relatively flat, whereas T3-D1-S2, (10 percent expected) consists of loamy-textured, well-drained, and moderately-sloping soil. Unlike patterns in Ionia and Livingston counties, one of the expected categories (T2-D3-S1), which is a relatively inferior landscape type (poorly-drained), is expected to host more forest than it actually does (24 versus 20 percent). In other words, an inferior landscape type is under-represented. The other category expected to support at least 10 percent of forest (T3-D1-S2), however, is a better landscape type (neither sandy-textured, poorly-drained, nor steeply-sloping) and does not support at least 10 percent of the observed forest, similar to the pattern in the rest of the study area.

Difference between expected and observed areas of forest. As in the other three counties, the site quality category with the largest negative difference (most under-represented) is T2-D2-S1, which is fine-textured, somewhat poorly-drained, and moderately-sloping (see Table 6 and Figure 10). This category supports 3,314 hectares less forest than expected and, disregarding the T2-D1-S2 category (which comprises less than one hundredth of a percent of the

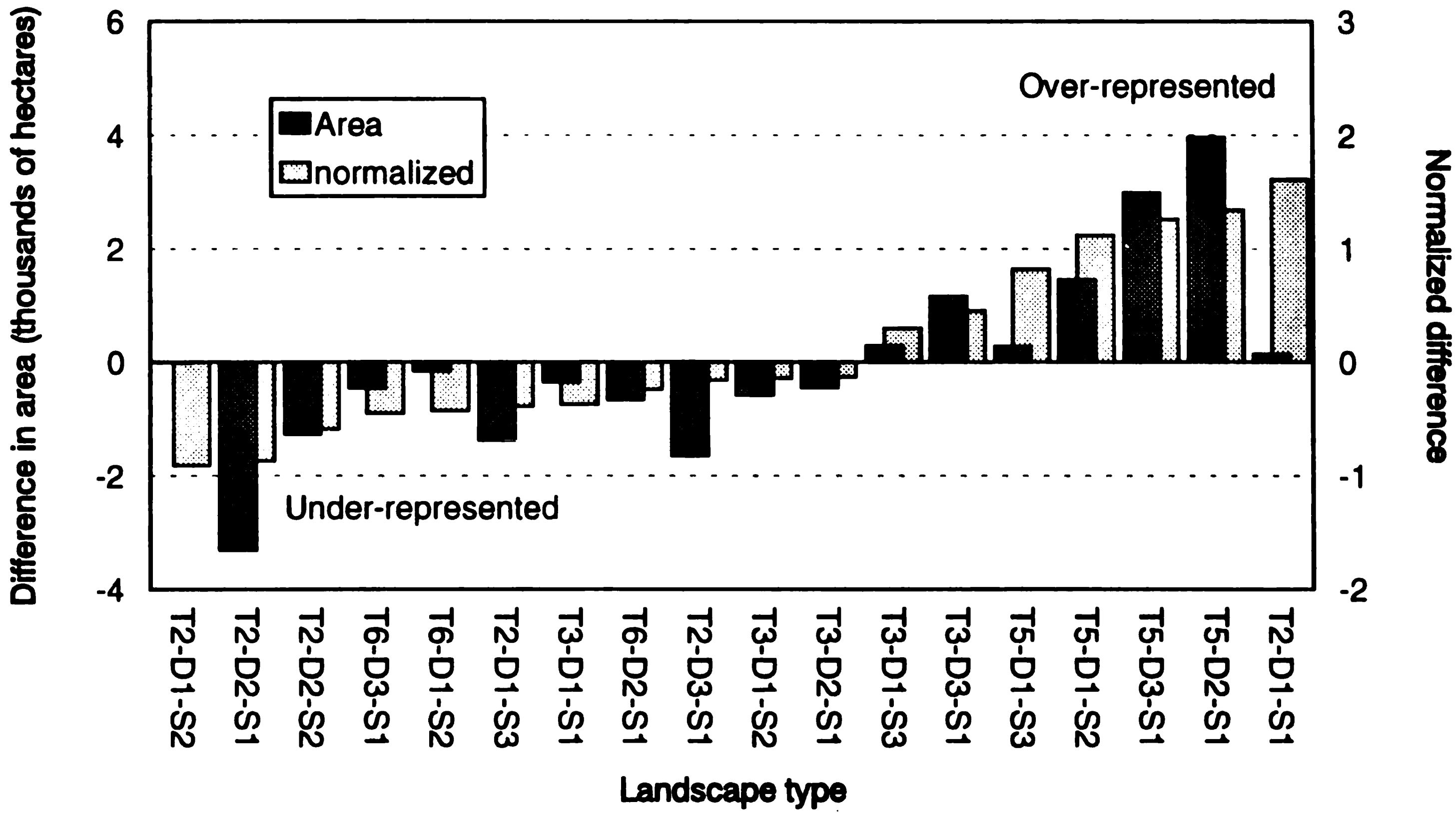


Figure 10 Difference between observed and expected areas of forest, Tuscola County

landscape), T2-D2-S1 is also the category with the largest negative normalized difference. Significantly, this under-represented category is neither a sandy-textured, poorly-drained, nor steeply-sloping landscape type, and, therefore, appears not to be on agriculturally limiting landscape.

In contrast to patterns in the other three counties, the site quality category with the largest positive difference (and second largest normalized difference) between expected and observed area of forest is sandy-textured (T5-D2-S1); it supports 3,956 more hectares of forest than expected. If we disregard the category with the largest negative normalized difference (T2-D1-S1) because of its extremely small percentage (0.2%) of landscape, the most important under-represented category becomes T2-D2-S2, which again appears to be of better site quality (neither a sandy-textured, poorly-drained, nor steeply-sloping) than T5-D2-S1, which is sandy-textured. Unlike the most over-represented category (which is poorly-drained) in Livingston County, and as in Ionia County, T5-D2-S1 is an inferior landscape type with sandy-textured soil.

<u>Forest area as related to site quality variables</u>. In contrast to the proportions in Ionia and Livingston counties, the expected proportions of forest on each of the categories of drainage and slope in Tuscola County are similar to the observed proportions, but are located on either end of the site variable continua. However, and unique to this county, the expected proportion of forest (46 percent) on T2 is much more than the observed (29 percent), meaning less

forest than expected occurs on fine-textured soils; in the previous two counties, more forest than expected occurred on this category (see Table 7 and Figure 11). Furthermore (and in contrast), more observed forest (37 percent) grows on sandy-textured soils (T5) than expected (16 percent). These results emphasize that the over-represented landscape is composed of sandy-textured soils, and, therefore, of inferior site quality.

Recap. Observed categories that support greater than ten percent of the forest are either sandy-textured or poorly-drained, and one of the two expected categories is a relatively better landscape type (loamy-textured, well-drained, and moderately-sloping); the most over-represented category is sandy-textured, whereas the most under-represented is fine-textured, somewhat poorly-drained, and moderately-sloping; and the category that supports the greatest proportion of forest, for each site quality variable considered separately, is located on either end of the variable continua. Therefore, similar to the trend in Ionia and Livingston Counties, all three sets of results indicate that in Tuscola County a large proportion of the contemporary forest patches is located on apparently inferior landscape types, and better types of landscape appear to be under-represented.

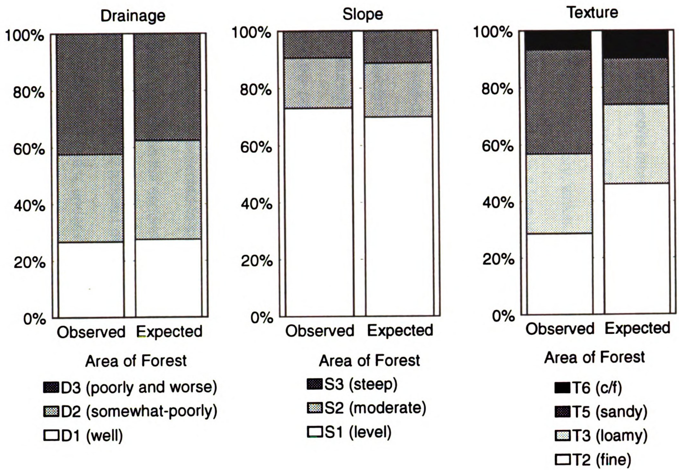


Figure 11 Observed and expected areas of forest relative to site quality variables, Tuscola County

4. Van Buren County

Site quality variables supporting greater than ten percent of observed and expected forest. At 32 percent, T2-D3-S1 is the only category of site quality in the county that supports more than 10 percent of the total observed forest area, although T5-D1-S2 and T5-D1-S3 host nine and eight percent, respectively (see Table 6). This first category, which supports at least 10 percent of observed forest in all four counties, is a fine-textured, poorly-drained, and level landscape type, and supports more forest than expected in the county. The T5-D1-S2 and T5-D1-S3 types differ only in slope; otherwise, both are comprised of sandy-textured and well-drained soils. Accordingly, all the categories that support around ten percent of forest consist of inferior landscape types (poorly-drained or sandy-textured).

As in the other three counties, T3-D1-S1 and T2-D3-S1 are each expected to support greater than ten percent of the total area of forest (see Table 6). The first category, which is loamy-textured, well-drained, and moderately-sloping, is expected to support 18 percent of the forest and only supports seven, whereas the second is fine-textured, poorly-drained, and level, and is expected to host 20 percent of the forest. The first category, therefore, consists of better soils and is under-represented. As in Tuscola County, the second category, which could be considered an inferior landscape type due to its poor drainage, again is expected to host at least ten percent of forest, but since it supports 33 percent it is still over-represented.

Difference between expected and observed areas of forest. Parallel to the situation in Ionia and Livingston counties, the site quality category with the largest positive difference (over-represented) is T2-D3-S1, which was noted above for having twenty percent of the observed forest (see Table 6 and Figure 12). This poorly-drained category supports 5,228 hectares more forest than would be expected, making it the single most over-represented category in the study. The sandy-textured T5-D1-S3 landscape type has the largest normalized difference. Both of these over-represented categories are either poorly-drained or sandy-textured. The T3-D1-S2 type has the largest negative difference and negative normalized difference between observed and expected area (under-estimated) and the category is neither poorly-drained, steeply-sloping, nor sandy-textured. Therefore, the most under-represented category appears to be of better site quality than the most over-represented categories.

Forest area as related to site quality variables. The results of the calculation of the observed proportion of forest on different sites, when broken down by specific variables, indicate that 24 percent of forest land occurs on T3 (loamy-textured), whereas 37 percent is expected, and 25 percent occurs on T5 (sandy-textured) and only 19 percent is expected (see Table 7 and Figure 13). Therefore, relative to soil texture, more forest occurs on sandy-textures and less on loamy-textures than expected. Relative to slope, 62 and 48 percent occur on

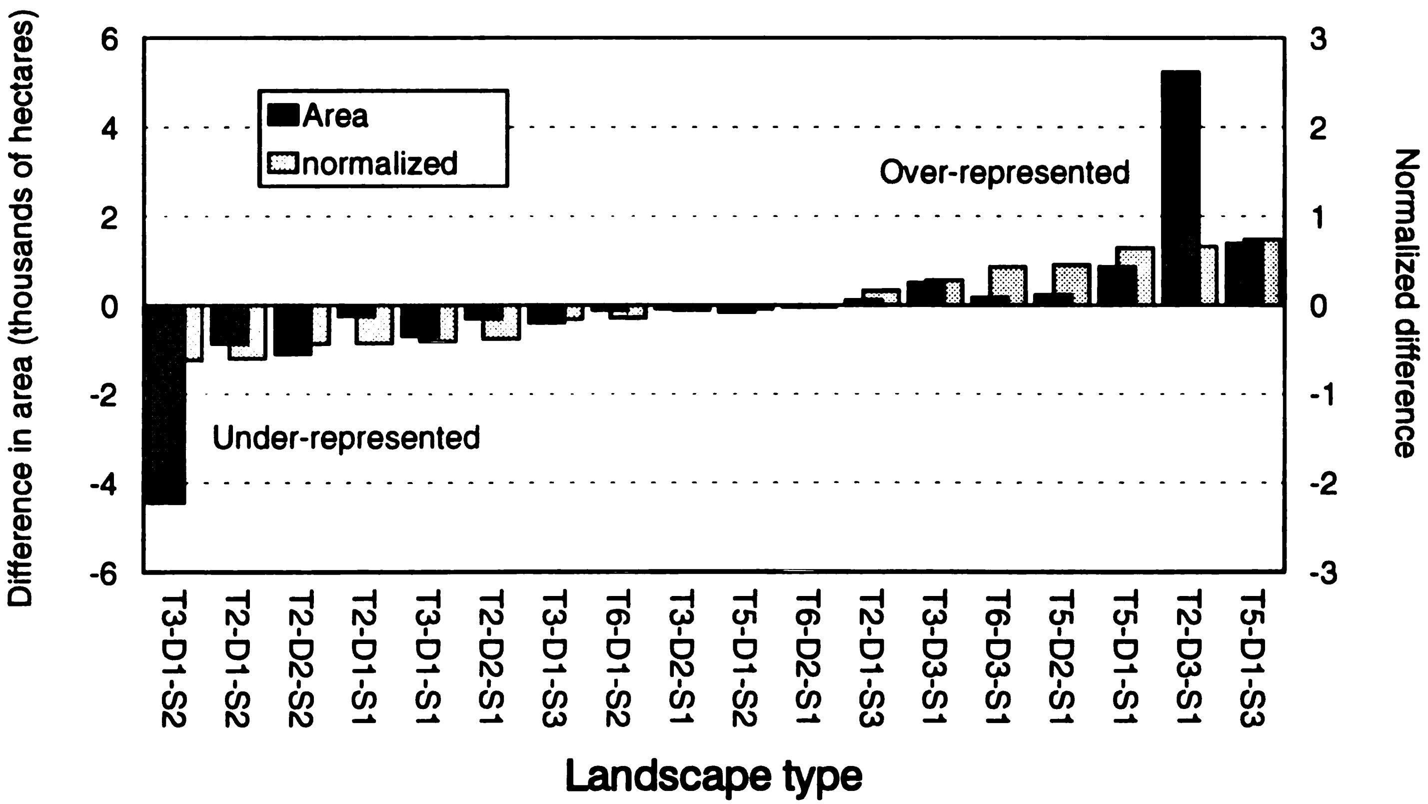


Figure 12 Difference between observed and expected areas of forest, Van Buren County

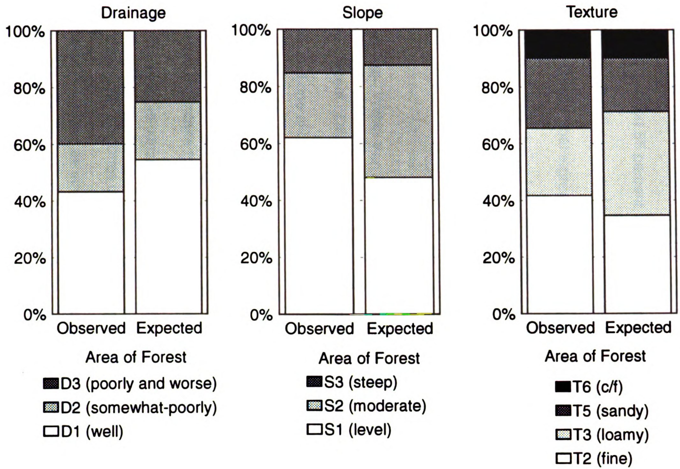


Figure 13 Observed and expected areas of forest relative to site quality variables, Van Buren County

S1 and S2, respectively, whereas 48 and 39 are expected, meaning more forest grows on level landscape, and less on moderately-sloping than expected. Meanwhile, well-drained landscape (D1) hosts 43 percent of forest and is expected to support 55 percent, and poorly-drained landscape (D3) is characterized by 40 percent of forest, but only 25 is expected. These results indicate, therefore, that a greater proportion of contemporary forest patches occur on flat, poorly-drained or sandy textured landscape than expected, and a smaller proportion occurs on moderately-sloping, and somewhat poorly-drained than expected.

Recap. Within Van Buren County, the category that supports greater than ten percent of the observed forest is an inferior landscape type (poorly-drained), and one of the expected categories is a better landscape type (well-drained and moderately-sloping); the most under-represented landscape type is loamy-textured, well-drained, and moderately-sloping, whereas the most over-represented landscape types are poorly-drained or sandy-textured; and for each site quality variable considered separately, only a small proportion of the forest lies on individual categories that occur in the middle of the particular variable continuum. Therefore, as in the other counties, these results indicate better agricultural types of landscape appear to be under-represented, and the contemporary forest patches are located on agriculturally inferior landscape types.

5. Summary of Results for Objectives 1 and 2.

Overall results indicate that categories of site quality that support greater than ten percent of forest are generally inferior landscape types and support more forest than expected (see Table 8, Figure 14, and Figure 15). Meanwhile, categories expected to support greater than ten percent are, relatively, less inferior site quality categories and host less forest than expected. In terms of their total difference between expected and observed areas of forest, the most over and under-represented categories are inferior and, relatively, better types of landscape, respectively. When broken down for each variable separately and within all four counties, the categories that support the greatest proportions of the forest are located on either end of the three site quality continua.

6. Statistical results

A Chi-square probability of $< .01$ within all four counties indicates that a significant difference exists between the observed and expected number of forest patches on different landscape types (see Table 9). Cramer's V values suggest that the strength of the difference is strongest in Tuscola County, followed by Ionia, Van Buren, and Livingston. Strahler's (1977) signed standardized residuals confirm patterns qualitatively described in previous sections. (The statistics used to determine the significance of the described relationships were calculated using numbers of forest patches, not areas.) Therefore, these statistical results confirm that a significant difference exists

Table 8 Summary results for the first two objectives

	Ionia	Livingston	Tuscola	Van Buren
10 % + Observed Forest[a]	T2-D3-S1 (32) T3-D1-S3 (15)	T2-D3-S1 (34) T3-D1-S3 (19)	T2-D3-S1 (20) T5-D3-S1 (13) T5-D2-S1 (16)	T2-D3-S1 (33)
10 % + Expected Forest[b]	T2-D3-S1 (19) T3-D1-S2 (18) T2-D1-S2 (18) T2-D2-S1 (10)	T2-D3-S1 (22) T3-D1-S2 (11) T2-D1-S2 (13) T3-D1-D3 (16)	T2-D3-S1 (24) T3-D1-S2 (10)	T2-D3-S1 (20) T3-D1-S2 (18)
Under-represented[c]				
by area[e]	T2-D1-S2 (-2,281)	T2-D1-S2 (-1,864)	T2-D2-S1 (-3,312)	T3-D1-S2 (-4440)
by norm[f]	T2-D1-S2 (-0.62)	T2-D2-S2 (-0.62)	T2-D1-S2 (-0.91)	T3-D1-S2 (-0.62)
Over-represented[d]				
by area[e]	T2-D3-S1 (3,616)	T2-D3-S1 (3,424)	T5-D2-S1 (3,956)	T5-D2-S1 (5,228)
by norm[f]	T5-D3-S1 (2.42)	T3-D3-S1 (0.55)	T2-D1-S1 (1.61)	T5-D1-S3 (0.74)

Notes:

a- categories that support ten percent of contemporory forest
actual percentages given in parenthesis
b- categories that are expected to support ten percent of forest
c- categories that support less forest than expected
d- categories that support more forest than expected
e- actual difference in hectares between observed and expected areas
f- normalized difference in hectares between observed and expected areas

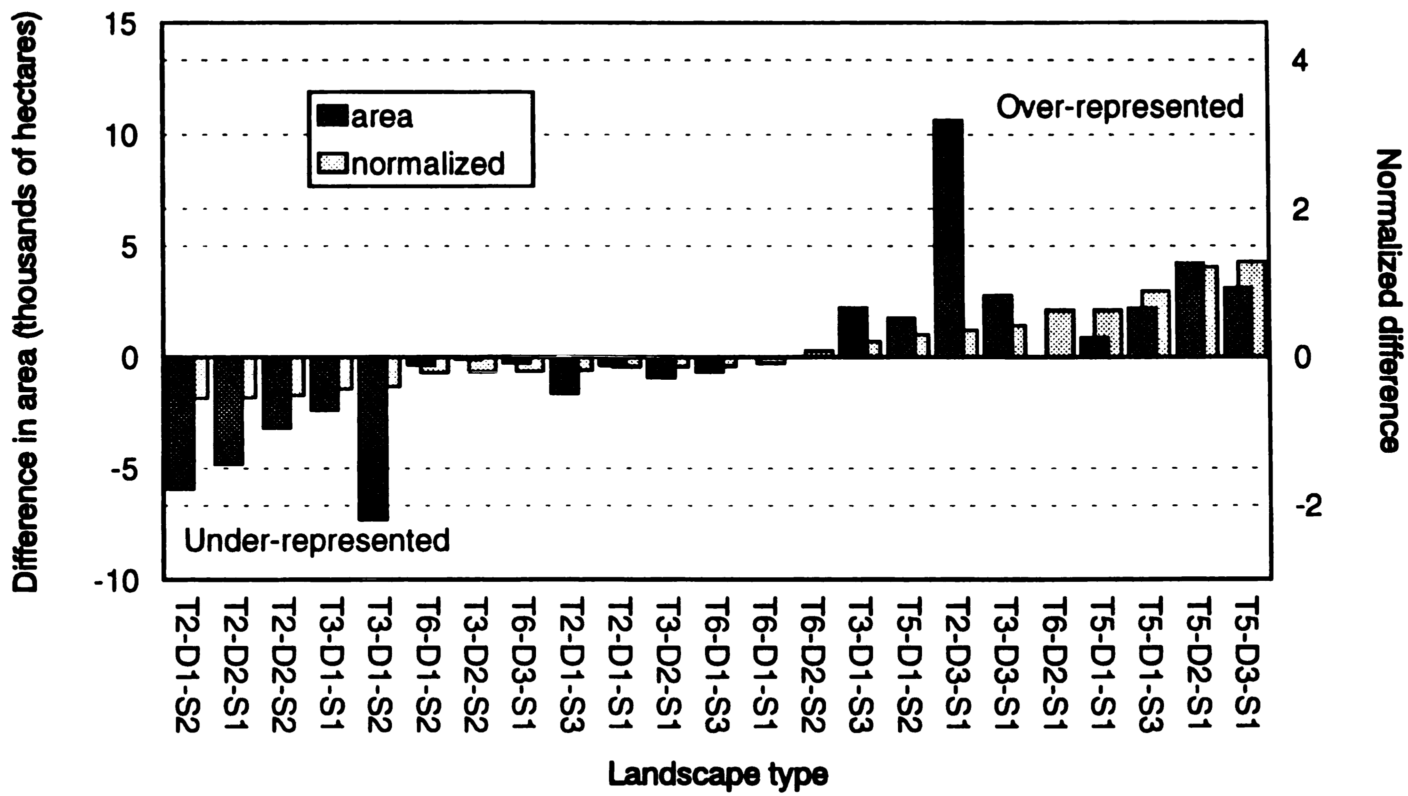


Figure 14 Difference between observed and expected areas of forest (all four counties)

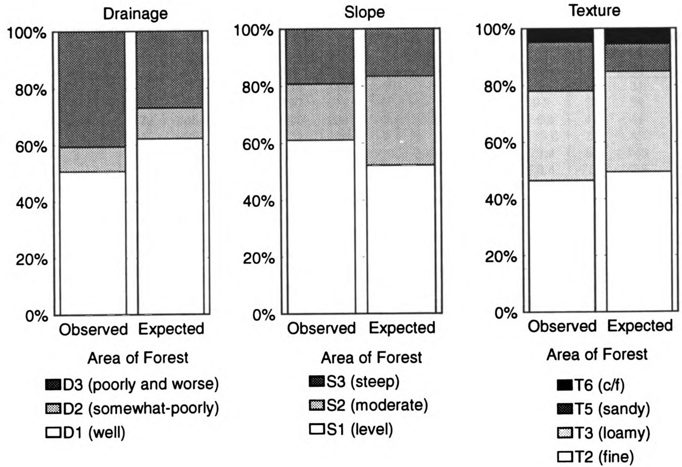


Figure 15 Observed and expected areas of forest relative to site quality variables (all four counties)

Table 9 Statistical Results

Classification			Ionia County Patches			Livingston County Patches			Tuscola County Patches			Van Buren County Patches		
Texture	Drainage	Slope	Obs.	Exp.	Residual	Obs.	Exp.	Residual	Obs.	Exp.	Residual	Obs.	Exp.	Residual
2	1	1	99	89	1.1	113	149	-8.3	24	9	24.1	18	31	-5.9
2	1	2	231	604	-230.0	197	378	-86.8	0	0	-0.2	34	84	-29.9
2	1	3	272	285	-0.5	203	228	-2.9	230	376	-56.8	47	41	1.0
2	2	1	205	335	-50.5	132	150	-2.4	53	406	-306.6	28	45	-6.4
2	2	2	70	156	-46.6	10	26	-10.2	96	232	-79.4	80	143	-27.9
2	3	1	1083	615	355.4	970	637	173.7	902	1077	-28.4	757	456	197.9
3	1	1	40	103	-39.1	121	205	-34.8	63	101	-14.0	58	98	-16.5
3	1	2	282	437	-54.9	212	317	-35.0	388	450	-8.6	156	411	-158.5
3	1	3	487	315	93.9	535	440	20.2	130	100	9.0	117	140	-3.8
3	2	1	69	90	-5.1	110	133	-3.9	305	351	6.2	89	94	-0.3
3	2	2	55	69	-2.9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
3	3	1	195	139	21.9	186	120	36.3	397	273	56.0	131	102	8.0
5	1	1	6	4	1.1	n/a	n/a	n/a	n/a	n/a	n/a	126	77	31.5
5	1	2	83	34	70.6	29	24	1.3	295	139	174.1	212	222	-0.4
5	1	3	99	30	158.2	n/a	n/a	n/a	64	35	23.7	187	108	58.7
5	2	1	7	2	8.2	n/a	n/a	n/a	736	315	564.2	42	29	5.9
5	3	1	22	6	36.8	n/a	n/a	n/a	570	253	399.7	n/a	n/a	n/a
6	1	1	2	2	0.1	4	4	-0.1	n/a	n/a	n/a	n/a	n/a	n/a
6	1	2	13	17	-1.3	26	31	-0.8	23	40	-7.2	43	49	-0.9
6	1	3	20	11	6.0	3	6	-1.7	n/a	n/a	n/a	n/a	n/a	n/a
6	2	1	5	3	1.3	n/a	n/a	n/a	225	295	-16.6	154	157	-0.1
6	2	2	3	3	0.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
6	3	1	7	3	6.3	n/a	n/a	n/a	59	108	-22.2	31	22	4.0
Number of Patches				3349			2849			4562			2309	
Chi-Square Value				1190			418			1797			557.8	
Cramer's V				0.59			0.38			0.62			0.49	

between the observed and expected number of forest patches on different types of landscapes, but they do not directly address differences in area of forest. This discrepancy will be further addressed in the final chapter, within the suggestions for future research section.

B. Objectives 1 and 2 Discussion

Several questions were posed in the Second Chapter. For example, do existing forest patches over or under-represent certain types of habitat? Do they represent a proportionate sample of the original, or are they concentrated on inferior sites and rare on highly productive ones? These questions assume that decisions farmers made (which sites to farm and not farm) may have been influenced by how they perceived the site quality of different types of landscape, and that poorer sites might have been less favored than those with better soils, which would then help determine the distribution of unused (forested) sites relative to site quality. The results described above seem to support these speculations and will be discussed below.

Within all four counties, the T2-D3-S1 landscape type (fine-textured, poorly-drained, and level) supports the greatest proportion of contemporary forest patches and, except in Tuscola County (which will be discussed below), is the most over-represented. It may exemplify the kind of landscape a farmer would choose not to farm due to its poor drainage. Within Ionia, Livingston, and, to a lesser extent, Van Buren Counties, T2-D3-S1 often characterizes small, lowland pockets within the landscape, such as kettles. These areas could have been less agriculturally attractive than better drained sites because they are costly to drain due to surrounding high ground and their small size, and, therefore, they might have been avoided by farmers.

Tuscola County has the greatest expanse of T2-D3-S1, where it is characteristic of a lake plain that gradually slopes toward Saginaw Bay and is interrupted only occasionally by higher ground (beach ridges, and, less frequently, by the Port Huron Moraine). Contrary to the pattern in the other three counties, in Tuscola County this landscape type, which may be considered agriculturally inferior due to its poor drainage, is under-represented (it has less forest than expected). Since drainage is the agriculturally limiting factor, its greater extent here (the average size of an T2-D3-S1 patch in Tuscola County is 21 hectares, whereas in Ionia county it only averages 6.5 hectares) may have facilitated (or justified) artificial drainage more than in the other counties, as it appears to be more developed for agriculture here than elsewhere. Possibly for these reasons, T2-D3-S1 is under-represented in Tuscola County. In other words, in Tuscola County this category appears to be more attractive to farm because it occurs in larger patches, which limits forest (un-farmed) habitat to even more inferior sites (as will be discussed).

Besides T2-D3-S1, other over-represented categories could be considered agriculturally inferior. For example, the T3-D1-S3 landscape type (loamy-textured, well-drained, and steeply-sloping), which is over-represented in

Ionia and Livingston Counties, could be judged agriculturally limiting due to its excessive slope. Landscape with excessive slope is prone to erosion due to increased overland flow, and is difficult terrain to plow. T5-D3-S1 and T5-D2-S1 support more forest than expected in Tuscola County and are both sandy-textured; the first category is poorly-drained, as well. As noted above, the fine-textured, poorly-drained sites in Tuscola County may have been agriculturally developed; however, since T5-D3-S1 supports more forest than expected, apparently the coarse-textured, poorly-drained sites were not. Sandy-textured soils limit agriculture because they have low cation exchange and water holding capacities. Low cation exchange capacities prevent soils from retaining bases and, therefore, lead to leaching and nutrient deficiency, whereas low water holding capacity hinders the soil's ability to provide adequate water for crops and other vegetation. The soils characterized by these over-represented categories are agriculturally limited for the reasons stated above, and, therefore, may have been avoided by farmers for more attractive land.

In contrast to the categories of site quality that support an abundance of forest land, the forest-deficient categories appear to consist of agriculturally favorable soils. T3-D1-S2 (loamy-textured, well-drained, and moderately-sloping) and T2-D1-S2 (fine-textured, well-drained, and moderately-sloping) are under-estimated in all four counties and could be considered agriculturally attractive due to an absence of limiting characteristics. Additionally, most of categories of site quality that support less forest than expected are composed of soils that are neither sandy-textured, poorly-drained, nor steeply-sloping (see Table 8). While I have not categorized the suitability class of all of the soil series within these landscape types, the ones I have were rated favorable for agriculture. The eight categories of site quality that have the greatest negative and normalized negative differences in area between observed and expected areas of forest are also agriculturally favorable because they lack limiting characteristics. If value played a role in the decision making process (which to farm and not farm), as speculated above, then heavier use may have been focused on these attractive sites, which would explain their forest deficiency. The scarcity of forest on the better types of landscape implies that the present day forest patches are not representative of the primeval forest.

C. Objective 3 Results

The third objective of the study was to determine the location of forest patches with high ecological value based on the degree to which the landscape beneath them is forest deficient. For each county, the normalized differences between the expected and observed areas of forest on each category of site quality were calculated (see Table 6). I also determined the three most under-represented landscape types for each county, and the associated number and area of forest patches. These patches are considered to have high ecological value because they are the only patches on extremely forest-deficient landscape types.

1. Ionia County

T2-D1-S2, T3-D1-S1, and T1-D2-S2 are the three most under-represented landscape types. They are not poorly-drained, steeply-sloping, or sandy-textured, and, therefore, appear to consist of agriculturally favorable soils. Roughly 2,600 hectares of high value forest patch are located on these three categories of site quality (see Table 6 and Figure 9), and they are geographically well dispersed within the county.

2. Livingston County

A total of 1,400 hectares of high value forest patch exist within this county qualify. These forests are located on T2-D2-S2 (fine-textured, somewhat poorly-drained, and moderately-sloping), T3-D1-S1 (loamy fine-textured, well-drained, and level) and T2-D1-S2 (fine-textured, well-drained, and moderately-sloping) (see Table 6 and Figure 8). As in Ionia County, they are geographically well dispersed throughout the county.

3. Tuscola County

The T2-D2-S1 (fine-textured, somewhat poorly-drained, and level), T2-D2-S2 (fine-textured, somewhat poorly-drained, and moderately-sloping), and T6-D3-S1 (coarse over fine-textured, poorly-drained, and level) landscape types host 499, 902, and 553 hectares of high value forest patch, respectively (see Table 6 and Figure 10). Contrary to the patterns identified in the other counties, a landscape type that could be considered inferior due to its poor drainage and coarse-textured soils is among the three most under-represented site quality categories.

4. Van Buren County

T3-D1-S2 (loamy-textured, well-drained, and moderately-sloping), T2-D1-S2 (fine-textured, well-drained, and moderately-sloping), and T2-D2-S2 (fine-textured, somewhat poorly-drained, and moderately-sloping) are the three most under-represented categories. They consist of agriculturally favorable soils since they are neither poorly-drained, steeply-sloping, nor composed of sandy-textured soil. Roughly 4,684 hectares of high value forest patch are located on these three categories of site quality (see Table 6), and as in the other three counties, the patches are geographically well dispersed throughout the county.

D. Objective 3 Discussion

The original method used to identify forest patches with high ecological value (see Chapter 2 Part C3) did not include any measure of the relative site quality of the landscape. Rather, forest patches occurring on extremely under-represented landscape types were considered to have highest ecological value by virtue of their relative scarcity. Nevertheless, six of the seven landscape types identified using this method are composed of soils that are also agriculturally attractive (neither poorly-drained, steeply-sloping, nor sandy-textured). Therefore, the degree to which a landscape type is under-represented in forest area appears to reflect overall site quality, as well. My operative definition of high value (based on relative scarcity of extant stands) is clearly over-simplified, however, for the true ecological value of a patch is dependent upon additional variables. Regardless, since the definition used in this study coincidentally identified landscapes with high degrees of agricultural quality, this definition may be useful in determining the potential location of forest patches with true ecological value, without input from more complex variables.

E. Objective 4 results

The fourth objective of the study was to examine the relationship, if any, between forest patch shape and site quality. For each county, I calculated the average Sh1 and Sh2 values for each of three categories of texture, two categories of drainage, and three categories of slope (see Table 10). A t-test or analysis of variance (ANOVA), as appropriate, was then conducted on the categories for each of the variables, separately, to determine whether a mean shape difference existed between patches located on different landscape types.

The two shape indices often were not positively correlated. For example, Sh1 values increase with increasing soil texture in Van Buren County, whereas Sh2 values decrease. These results were surprising because I initially expected the two indices to both indicate the degree of shape complexity. However,

Table 10 Shape indexing results

	A. Ionia			B. Livingston			C. Tuscola			D. Van Buren		
	Number	Mean Sh1	Mean Sh2	Number	Mean Sh1	Mean Sh2	Number	Mean Sh1	Mean Sh2	Number	Mean Sh1	Mean Sh2
Texture												
2	1166	292	1.40	797	262	1.43	756	361	1.47	315	245	1.45
3	543	313	1.37	426	290	1.45	651	366	1.47	287	273	1.36
5	42	327	1.31				604	371	1.51	259	279	1.37
6	7	313	1.33	10	351	1.31	86	338	1.35	50	305	1.35
F-value		7.125	1.898		13.035	1.579		1.417	4.718		10.142	4.514
Prob.		0.000	0.128		0.000	0.207		0.236	0.003		0.000	0.004
Drain												
1	704	315	1.39	640	285	1.42	757	403	1.42	649	278	1.38
3	241	295	1.41	243	271	1.39	486	337	1.45	227	229	1.45
t-test prob.		0.010	0.380		0.101	0.114		0.000	0.143		0.000	0.010
Slope												
1	525	280	1.41	583	264	1.45	1565	355	1.54	605	238	1.47
2	122	312	1.24	71	322	1.26	240	420	1.41	252	278	1.34
3	128	354	1.29	125	301	1.40	140	451	1.40	66	314	1.38
F-value		32.407	19.260		19.430	9.462		59.229	12.697		19.553	7.384
Prob.		0.000	0.000		0.000	0.000		0.000	0.000		0.000	0.000

Hulshoff (1995) also discovered the two indices were not positively correlated. She explained the phenomenon by pointing out that Sh1 is not independent of patch size and may increase with increasing patch size, whereas Sh2 is more closely associated with the complexity of the perimeter and is independent of size. Therefore, Sh2 will be used to determine whether a relationship exists between site quality and forest patch shape. This approach is justified since I initially speculated that the presence of irregularly-shaped, natural features within the landscape (such as floodplain) may have imposed limitations on agricultural use, and this speculation is more closely associated with the complexity of a patch's perimeter than with its size.

1. Ionia and Livingston Counties

The results for these two counties are presented together because similar patterns are observed. Significance tests demonstrate that no apparent relationships exist between the texture and drainage classes and the Sh2 shape index measure. For example, Sh2 means for forest patches located on texture classes 2, 3, 5, and 6 are not significantly different, which indicates that forest patches on different texture classes do not have perimeters with significantly different degrees of complexity.

However, an F-test probability of < 0.001 in both counties suggests that a difference in Sh2 shape index does exist between forest patches located on different slope classes. In Ionia County, patches located on level sites have a mean Sh2 value of 1.41, whereas slope classes 2 (moderately-sloping) and 3 (steeply-sloping) host patches with means of 1.24 and 1.29, respectively. In Livingston County, level sites are characterized by patches with a mean value of 1.45, whereas slope classes 2 and 3 support patches with means of 1.26 and 1.39, respectively. Therefore, patches on flat landscape have more irregular perimeters than patches on more rolling landscapes. However, of the two classes representing rolling landscape, steeply-sloping sites have more complex patches than do moderately-sloping sites.

2. Tuscola County

No significant difference exists between the shape of forest patches (as measured by the Sh2 shape index measure) on different classes of drainage, but I did detect differences among the various texture and slope classes. Forest patches located on T6 (coarse over fine-textured soils) have a mean Sh2 value of 1.35, which is significantly less than the other texture classes (see Table 10); thus, the perimeter of patches located on T6 is less irregular. As in Ionia and Livingston counties, flat sites host forest patches with more complex shapes (mean Sh2 value of 1.54) than moderately-sloping and steeply-sloping sites (means of 1.41 and 1.40, respectively).

3. Van Buren County.

A significant difference exists between the shape of forest patches on different classes of texture, drainage, and slope (see Table 10). As in Tuscola County, forest patch shapes on T6 (coarse over fine-textured soils) are less complex than those on the other texture classes. Unique to this county, T2 (fine-textured soil) hosts forest patches with more complex shapes than does T3 (loamy-textured) and T5 (sandy-textured soils). In other words, poorly-drained landscapes have more irregular patches than do well-drained sites. As in the other three counties, patch complexity on level landscapes is greater (mean Sh2 of 1.47) than on more undulating landscapes (mean Sh2 values of 1.34 and 1.38 for S2 and S3 slope classes, respectively). Additionally, as in Livingston and Ionia Counties, steeply-sloping sites host patches with more complex shapes than do moderately-sloping sites, and both have less complex shapes than does level landscape.

F. Objective 4 Discussion

In the second chapter I posed several questions. For example, do forest patches occurring on different categories of site quality have significantly different shapes? This question assumes that decisions farmers made (which sites to farm and not farm) may have been influenced by how they perceived the site quality of the landscape, and that the presence of irregularly-shaped, natural features within the landscape (such as floodplain) may have imposed limitations on agricultural use. Accordingly, farmers may have delimited agricultural lands from those areas left to succession or originally uncut based on these perceptions. I then speculated that the resulting forests would be irregularly-shaped, in a form similar to the shape of the limiting feature. However, the boundary of patches left by farmers for fuelwood or other domestic uses, often located on fertile farmland, may not have been constrained by landscape character and may be more regularly-shaped. Some of the results described above seem to support my expectations and will be discussed below. In the following paragraphs, I will first discuss the relationship between patch shape and slope, followed by texture and then drainage.

Within all four counties, the mean shape of forest patches is significantly related to the three classes of slope. Forest patches characteristic of S1 have the most irregular perimeters in all four counties, whereas perimeters of patches located on S2 are the least irregular in every county except Tuscola. This pattern appears contrary to the expectation that patches are regularly-shaped on agriculturally attractive sites, since level landscape by itself would have few naturally-imposed boundaries. However, level landscape is also often associated with poorly-drained soils that may be both agriculturally limiting and irregularly-shaped. Therefore, if a large proportion of the patches located on level landscape is indeed poorly-drained, then the observed relationship (more irregular perimeters on the more level land) would still be consistent with the expected outcome, since the poorly-drained land, although level, would nonetheless be agriculturally-limited.

Within three of the four counties, the mean shape of forest patches is not significantly related to the two classes of drainage. In the one county that does have a significant relationship (Van Buren County), patches located on poorly-drained landscape have a more complex shape than do patches on well-drained landscape. However, forest patches often occur on more than one landscape type, obscuring inter-variable relationships. Thus, attributing the irregularity of forest patches on level sites to a particular drainage characteristic is problematic.

Within Tuscola and Van Buren Counties, the shape of forest patches occurring on sandy and fine-textured soils is more complex than those located on loamy-textured soils, consistent with my expectation. That is, forests located on agriculturally favorable, loamy-textured soils may have been left by farmers for other preferred uses once the delimitation of these patches was not constrained by irregularly-shaped, natural features in the landscape. On the other hand, farmers may have delimited the boundary of forest patches located on fine and sandy-textured soils based on landscape limitation. The resulting shape of these patches may be irregular due to the irregular nature of the limiting landscape.

The only county with a significant difference in mean shape of patches occurring on different classes of drainage is Van Buren, where poorly-drained patches are more irregularly-shaped. This expected relationship supports the speculation above. As previously explained, poorly-drained landscape often occurs in irregular patterns on the landscape. For example, a poorly-drained muck soil might occur in a dendritic pattern controlled by the micro-topography of a small stream valley. The perimeter of a forest patch occurring on muck may follow the geographical extent of the muck if the surrounding landscape is composed of agriculturally attractive soils (assuming the farmer delimited the boundary of the field based on the presence of the muck). Therefore, the boundary of the forest patch occurring in muck would be irregular, a possible explanation for the pattern in Van Buren County.

In summary, patches occurring on some types of landscape have more irregular shapes than others (about half of the relationships determined were significant), with the strongest relationships between landscapes occurring on different slope classes. However, a more distinct relationship may exist in the real world, but be undetectable with the methods used in this study. Due to the tendency for forest patches to occur on more than one slope class, a large number of patches could not be included in the analysis and, as previously stated, inter-variable relationships were unknowable. A possible solution to this problem will be discussed in the next chapter.

Chapter 4

SUMMARY AND CONCLUSIONS

The purpose of this chapter is to summarize the significant outcomes of the study and their overall significance, and to make recommendations for future studies. The chapter is organized by these three purposes.

A. Summary

Overall results indicate that categories of site quality that support a large proportion of the present-day forest patches are generally composed of inferior soils and are over-represented with forest. In other words, inferior landscape types support a larger proportion of the total forest area today than they did prior to European settlement. Agriculturally-attractive landscape types are generally under-represented with forest, supporting less than expected. These sites support a smaller proportion of the total forest area today than they did two hundred years ago. The results suggest that the present-day forest patches are not a proportionate sample of the primeval forest. Rather, they are concentrated on inferior types of habitat. These results support speculation that the decisions farmers made (which sites to farm and not farm) were influenced by how they perceived the site quality of the landscape, and that poorer sites were less favored than those with better soils.

The results of patch shape analysis indicate that patches occurring on certain types of landscape have more complex shapes than patches on other sites. Specifically, the one relationship that holds for all four counties is that the perimeter of patches on level landscape is more irregular than the perimeter of patches on moderate and steeply-sloping landscape. However, this pattern can not be directly attributed to the poor site quality of the landscape, because the methods I developed could not determine whether the irregularity of the patches on level landscape was due to the presence of poor drainage (which adversely affects quality). Therefore, these results fail to verify speculation that forest patch shape is more irregular on inferior landscapes. Forest patches often occurred on more than one landscape type, which meant that the classification scheme had to be generalized such that only one variable at a time could be considered. As a result, inter-variable relationships were not determinable, and interpretation was difficult.

B. Implications of study

The general purpose of this paper was to determine the extent of human impact on the landscape in southern Lower Michigan, which was nearly blanketed with forest prior to European settlement. As stated above, results suggest that the present-day forest does not represent a proportionate sample of the primeval forest. Rather, forest land appears to be isolated in patches concentrated on agriculturally inferior sites and rare on highly productive ones. Therefore, obvious changes to the forest landscape have taken place since the region was settled by Europeans.

Prior to European settlement, the geographic extent of a landscape type controlled the amount of forest present on the type, for the landscape was primarily forested. However, the results of this study demonstrate that changes in the relative proportions of forest area on different types of landscape have taken place since the 1850's. These changes through time in forest extent along the site quality continuum could have an impact on overall forest composition, richness, and productivity in the region, since these attributes are related to site character. Moreover, these results suggest that some forest species may have suffered greater impact from land use practices than others. For example, a species that competes best on agriculturally attractive landscapes, which are less available today as forest habitat, might have experienced a decline in overall importance, as those particular sites have been especially heavily worked. In other words, certain species (perhaps, those that compete best on agriculturally favorable sites) are more likely to have experienced a decline in areal importance than others.

Within this study, I attempted to identify forest patches with high ecological value (as a function of their relative scarcity). These patches may play a critical role toward sustaining species richness and bio-diversity in the future. Once a clear definition of ecologic value is established and resulting patches are located, the ownership (public versus private) of these patches could be determined so that public policy can be properly designed to preserve forest areas now in private hands. Otherwise, the species that thrive on these under-represented landscape types may experience a decline in importance in the future.

However, a policy of preserving just existing forest patches would only prevent a further decline in overall regional species richness and bio-diversity. The results of this study further suggest that policy could also be developed to encourage redevelopment of forest habitat on those sites no longer supporting their equal share of forest. In other words, these results can be used not only to characterize the status of the remaining forest, but also to identify landscape types that, if reforested, would help to actually increase bio-diversity and species richness in the future.

Issues of bio-diversity relate to an observation made during the course of this study that, while not directly related to my specific objectives, pertains to the ability of a fragmented forest landscape to sustain species richness in the future. In this study, forest patches were often located within the center of sections defined by the Congressional Land Survey System. This pattern is especially visible within the "thumb" area of Michigan and may be the result of patch isolation relative to roads, which are often located along section lines. This pattern illustrates how the Congressional Land Survey System may have had a negative effect on overall landscape ecology, for the distance between substantial patches in these regions may exceed the dispersal distance of different forest species. If so, along with the site quality of the landscape supporting the forest, the spacing of patches on the landscape may be an important variable to consider when one attempts to forecast future bio-diversity and species richness.

In summary, knowledge of the site quality of the remaining forest patches could be valuable to those making preservation, inventory, and public policy decisions. For example, if forests continue to be confined to landscapes of inferior site quality, overall species richness and biotic diversity may decline. Knowledge of the site quality of the remaining forest patches could improve the quality of future land-use decision if a goal is to preserve desirable eco-system characteristics.

This study also represents a good example of how geographic information science can be for used eco-system management. Once designed, a GIS provides information that can be used to help in decision making processes. For example, a public policy official, who seeks to promote eco-system preservation, may wish to use information generated by a GIS to effectively design public policy. Similarly, resource management people could use information from a GIS to inventory natural resources. For example, a forester could easily assess the future productivity of timber in a region by using a GIS similar to the one in this study. In this example, the GIS could identify the location and type of forest (and its rate of growth, stature etc.), determine the productivity of the soils beneath the forest, and then calculate overall timber productivity, for a given area. In other words, the GIS facilitates the spatial integration of different information across a broad geographic area.

C. Suggestions for future research

I would develop a numeric site quality index if I were to conduct similar work in the future. With methods similar to those employed in this study, a more robust index could be used to better determine the relationship between site quality and forest patch shape. The problem with the site quality classification scheme used in this study is that it did not quantify differences in quality from one landscape type to another or directly identify patches with high ecological value. This deficiency created problems during the shape indexing portion of the study, for patches occurring on two landscape types had to be discarded. A quantitative index could be used to weigh portions of a patch located on different categories of site quality, allowing the calculation of individual patch value (in terms of the landscape upon which it resides). This procedure would also permit the inclusion of all patches in the shape index analysis.

I would also suggest that a study be conducted to identify the tree species that characterize the forest under-represented landscapes identified in this study. These are the species that have experienced the greatest loss in habitat and their future, therefore, may be in most jeopardy. One may want to closely monitor these species so that programs can be developed to help preserve them.

Future study could also determine the ownership of high value patches, and forest-deficient landscape types. This information could be determined very easily by designing a GIS similar to the one used in this study to identify the location of the patches, and then overlaying ownership data. Ownership information would help in the design of public policy developed to both preserve and increase the bio-diversity of the forest in Michigan.

I failed to identify a statistical method useful in directly testing the level of significance between differences of observed and expected areas of forest on different types of landscape. The nominal level of the data and the lack of a true sample were complications. The Chi-square test, although used in this study, cannot directly address differences in area, since the test only deals with frequency data. In other words, the computed Chi-square value would be affected by how the area is expressed (square feet, square miles, etc.). Consequently, I had to convert area of forest into number of forest patches in order to apply the Chi-square test to my data. Therefore, I never truly assessed the statistical significance of the differences identified between observed and expected area of forest, using, rather, the number of forest patches as a surrogate for area. Future study could be conducted to develop a statistical method that would be appropriate for the kinds of data produced within this study.

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