THESIS
2
2001

This is to certify that the

thesis entitled

LAND OWNERSHIP PARCELIZATION AND FOREST FRAGMENTATION IN THREE FORESTED COUNTIES IN NORTHERN LOWER MICHIGAN

presented by

Scott A. Drzyzga

has been accepted towards fulfillment of the requirements for

M.A. degree in Geography

Major professor

Date 9/2/00

O-7639

MSU is an Affirmative Action/Equal Opportunity Institution

**LIBRARY
Michigan State
University**

PLACE IN RETURN BOX to remove this checkout from your record.
TO AVOID FINES return on or before date due.
MAY BE RECALLED with earlier due date if requested.

DATE DUE	DATE DUE	DATE DUE

11/00 c:/CIRC/DateDue.p65-p.14

LAND OWNERSHIP PARCELIZATION AND FOREST FRAGMENTATION IN THREE FORESTED COUNTIES IN NORTHERN LOWER MICHIGAN

By

Scott A. Drzyzga

A THESIS

Submitted to
Michigan State University
In partial fulfillment of the requirements
For the degree of

MASTER OF ARTS

Department of Geography

2000

ABSTRACT

LAND OWNERSHIP PARCELIZATION AND FOREST FRAGMENTATION IN THREE FORESTED COUNTIES IN NORTHERN LOWER MICHIGAN

By

Scott A. Drzyzga

This research assesses historic landscape configurations of private land ownerships and forest habitats in Crawford, Grand Traverse, and Kalkaska Counties, in northern Lower Michigan. This study builds on previous research that has produced quantitative indicators of parcelization (changing average parcel sizes). This study also produces quantitative indicators of regional forest areal extent and fragmentation over a twenty-year period. Spatial and temporal patterns of land parcel subdivision are analyzed using digitized plat map data, while patterns of forest cover and forest cover change are assessed using digital remote sensing data. Changes in land parcel subdivision and forest cover are observed at multiple spatial scales. Examinations of changing spatial structure are used to determine whether or not evidence exists to support a hypothesized link between these phenomena. The purpose of this research is to provide information that may lead to land use planning and forest management strategies that are sensitive to land ownership patterns and their influence on forest structures.

Copyright by

SCOTT A. DRZYZGA

2000

ACKNOWLEDGEMENTS

I would like to thank my committee, Dr. Daniel G. Brown, Dr. Bruce Wm. Pigozzi, and Dr. J. Michael Vasievich for helping me to complete this thesis. Also, I extend a special thank you to Dr. Brown for his role in advising me, editing the many drafts of this text, and showing me how to ask interesting questions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1: Introduction.

We, meaning humans, have converted natural land cover patterns into fragments of natural vegetation within a matrix of human dominated land uses in many places. Fragmentation of natural land cover patterns affects plant and animal habitats, plant and animal biodiversity, and primary productivity (Fox and Macenko, 1985). These changes can limit the natural ability of a landscape to provide resources on a sustained basis and therefore, deteriorate the long-term environmental quality of landscapes (Cawrse, 1994) and resident ecosystems. The State of Michigan and land management agencies within the state are often faced with the task of balancing competing interests that advocate maintaining sustainable forest resources and those that seek to develop forested lands. However, the issue is not simply limited to optimizing the amount of woodland dedicated to each use, but includes many complexities inherent in the spatial patterns and inter-leaved distributions of each land use.

1.2: Background.

In Michigan, land use planning is a local decision process that is directed by local (city, village, or township) legislation. Under the County Rural Zoning Enabling Act (MI PA 183 of 1943) and the Township Zoning Enabling Act (MI PA 184 of

1943) township planning boards are given authority to develop ordinances to provide for regulation of land uses, protection of natural resources, and an ability to limit congestion of human populations. Since basic land-use regulation occurs at the township level, townships are important organizational units for land and ecological planning.

A large portion of idle or abandoned farmland is naturally regenerating into young forests in Michigan's northern Lower Peninsula (NLP). These new forests may become incorporated into proximate forest habitats or may exist as island habitats within a sea of human modified land covers. If these newer forest areas are subjected to development pressures or are overlooked by local forest managers, then monies spent on conservation efforts may not be efficiently applied. Also, development on forested lands may ultimately destroy the natural amenities that make such lands attractive to new property owners. Participation among township entities is necessary if public, private, and protected forest areas are to coalesce into a biologically meaningful ecosystem and a self-sustaining economic base.

Federal and state forest managers have traditionally managed protected areas as independent entities. However, recent research and conservation efforts have recognized habitat sustainability and diversity are also dependent on the character and quality of landscape features adjacent to protected areas (adjacency facilitates the transfer and interaction of nutrients, energy, and organisms between forested areas [Turner and Gardner, 1991]). Hence, tools and models that explicitly accommodate spatial proximity should prove valuable to planning organizations. Geographic information systems (GIS) and remote sensing technology (RS) are tools that can provide local and regional planners the ability to model spatially explicit data, which can represent complex landscape systems.

1.3: Statement of problem.

Forests become fragmented when forested lands are developed for agriculture, logging, or residential settlement purposes. Previously expansive forested landscapes become insular blocks, or fragments, separated by industrial sites, roads, railroads, town sites, and tree harvesting operations (Bell, 1995). Such forest cover changes have been shown to negatively affect timber production (Birch, 1983), wildlife habitat (Hill, 1985), and ecosystem biodiversity (Iida and Nakashizuka, 1995).

Subdivision of large land parcels under a single ownership into smaller parcels under diverse ownerships in various stages of development or use greatly reduces the effectiveness of coordinated management strategies dealing with wildlife habitat, profitable agriculture, and timber production. In Northern Michigan, "public forest managers have recently observed that the influx of new woodlot owners often inhibits their ability to manage State and Federal Forest timber resources" (Potter-Witter, 1995:29) in a manner that satisfies the public policies set forth to utilize and protect said resources. Hence, State and Federal officials are concerned about forested areas in Michigan that are affected by parcel subdivision.

Brown and Vasievich (1996), Bell (1995), Vogelmann (1995), and Saunders *et al.* (1991) have suggested a link exists between increased land ownership subdivision and increased forest fragmentation. Although such a relationship is implicitly understood to exist, as evidenced by Michigan's public forest managers' concerns (Potter-Witter, 1995:29), the literature is lacking definitive explanations of the spatial and temporal relationships between the two phenomena. Understanding how parcel changes manifest as physical changes in terms of forest cover is important because some forest cover changes can negatively affect finite supplies of natural resources.

The Michigan Society of Planning Officials (MSPO) explicitly stated a need for research on "the impact of local, regional, and statewide land fragmentation on natural resources" (Warbach and Norberg, 1995:A-3). This analysis responds to the MSPO's stated need for quantification of the spatial and temporal components of land parcel subdivision and forest cover change within a forested region in Michigan. This thesis is intended to fill the mentioned knowledge gap and to provide information that may lead to better land use planning and forest management strategies.

1.4: Research questions.

I posed four questions in order to determine how the influx of new land owners and subsequent parcel changes have manifested as physical landscape changes, in terms of forest cover:

1. What changes occurred in ownership parcelization within a forested region in Michigan?
2. What changes occurred, if any, in forest cover and forest fragmentation within the same region in Michigan?
3. How were the relative changes in forest fragmentation related to relative changes in land parcelization?
4. At what scale(s), if any, do patterns of change in either phenomenon suggest processes acting on the landscape?

I selected a single, yet representative study area because the time and size requirements necessary to gather detailed data representing parcel ownerships and forest covers for all forested regions within the State of Michigan were too cumbersome.

1.5: Basic definitions.

The terms fragmentation (Brown and Vasievich, 1996; Theobald, *et al.*, 1996) and parcelization (Barlowe, 1978; Erickson, 1995) have been used synonymously in past research to mean the division or subdivision of land ownership in a landscape. However, their meanings are different and must be made specific for use in this study if the results are to be applied to future research or policy decisions. Therefore, I have listed several terms and their definitions below.

1.5.1: Land ownership parcelization or parcelization.

Land ownership parcelization is the division or subdivision of a finite landscape, over time, into smaller, individual ownership parcels. In general, land subdivision is evidenced through history by the surveying of land into states, states into counties, counties into townships, townships into sections, and ultimately sections into individual ownership parcels. Parcelization refers to the subdivision of land under a single ownership into smaller parcels under a diverse ownership. For this study I consider private land ownership changes only in terms of parcel boundaries and areas. The term parcelization includes all divisions, exempt splits, and subdivisions of parcels and tracts as defined by the State of Michigan's Land Division Act (MI PA 87 of 1997).

1.5.2: Forest fragmentation or fragmentation.

The term *forest fragmentation* has been used in the landscape ecology literature to represent static habitat conditions (Hargis et al., 1998). According to Forman (1995), fragmented landscapes can be characterized by having relatively large edge densities and relatively small interior habitat areas. Unfragmented landscapes can thus be characterized by having relatively small edge densities and relatively large interior habitat areas. In this research, is the term forest fragmentation is defined as a static forest condition and it represents the degree to which the amount of interior core area of a forested area differs from its maximum potential habitat area.

1.6: Research objectives.

The objectives of this study are to:

1. Select a forested region in Michigan that has been affected by high population growth rates and is expected to continue to be affected by its population growth trend into the future,
2. describe the character of land ownership parcelization within the region at multiple scales,
3. describe the character and pattern of forest cover change within the region at multiple scales,
4. test specific hypotheses, arising from the research questions, regarding the spatial and temporal relationships between land ownership parcelization and forest cover change,
5. and provide information that may lead to better land use planning and forest management strategies.

CHAPTER 2: STUDY AREA

2.1: Introduction.

The first objective is to select an appropriate region for study. Selection criteria include identifying a sufficiently forested area that has been affected by high population growth rates, and is expected to continue to be affected by population pressures into the future.

2.1.1: Selecting a time frame.

The period from 1970 to 1990 should be useful for studying land ownership parcelization and forest cover changes in Michigan because various stages of population growth, parcel subdivision, and forest cover change may be observed. For example, non-metropolitan Michigan exhibited a positive population growth trend that started during the 1970's (U.S. Department of Commerce, 1960 - 1990) and is expected to continue into the year 2020 (Warbach and Norberg, 1995). Demographic and economic researchers have characterized the observed trend as a "rural renaissance" (Beale, 1977). While this trend is not unique to Michigan[1], the rural renaissance is important because most of Michigan's forested lands are located in these growing rural areas.

---

[1] Johnson (1989) reported the rural renaissance to have been in effect throughout the entire United States.

Recent forest inventories and analyses of the northern Lower Peninsula, which is generally considered to be a rural area, have indicated a six percent increase in total forest land area and an eight percent increase in total timberland area (Leatherberry, 1994) between the years 1980 and 1993. Leatherberry (1994) cautions readers of his report, however, that comparisons between inventories should be kept in general terms because changes have been made in the way forested areas have been sampled and reported from one inventory to another. Yet, even in general terms, such increases are noteworthy because previous inventories have indicated modest declines in forest area within the same region.

The specific twenty-year time frame is also unique to Michigan's landscape evolution because the Subdivision Control Act (SCA) of 1967 (MI PA 288 of 1967) was in effect and enforced during this period[2]. The significance of the SCA and its effect on parcelization has been well documented by Norgaard (1984) and Wyckoff and Reed (1995). In brief, the SCA provided for an expensive platting process to be imposed on landowners that subdivided land into parcels 10 acres in size or smaller. According to Norgaard (1984), the statewide response to the SCA has been a proliferation of parcels just larger than 10 acres in size. Negative by-products of the proliferation of newly created 10+ acre parcels are higher infrastructure-per-capita costs and land cover fragmentation (Grand Traverse County Planning Commission, 1997).

---

[2] The Land Division Act (MI PA 87 of 1997) has since repealed and replaced significant portions of the SCA and has begun a new era of state zoning legislation.

The period from 1970 to 1990 is a time frame that is appropriate for this study. During this time, the northern Lower Peninsula (NLP) experienced a significant rural population growth trend, underwent forest fragmentation due in part by landowners responding to a particular piece of state zoning legislation (Wyckoff, 1995), and yet, exhibited signs of forest regrowth and succession (Leatherberry, 1994). These trends are counter-intuitive and worth research.

2.1.2: Selecting an area frame.

The MSPO asserts that urbanization will catch up with the current trend of forest recovery (Warbach and Norberg, 1995). The critical junction is expected to occur first in the northern portion of Michigan's Lower Peninsula. The MSPO assertion is seemingly based on the assumption that developing human settlements and self-sustaining forests are mutually exclusive phenomena. Given the above mentioned population growth trend and the concern of local planners, attention should be focused on a forested region within the northern Lower Peninsula (NLP).

Grand Traverse, Kalkaska, and Crawford Counties (see Figure 2.1) have been selected as suitable areas for study for several reasons. First, the three counties are representative of an extreme case in northern Lower Michigan as each has experienced substantial population increases over the last twenty years, although not concurrently. The three counties are also expected to incur

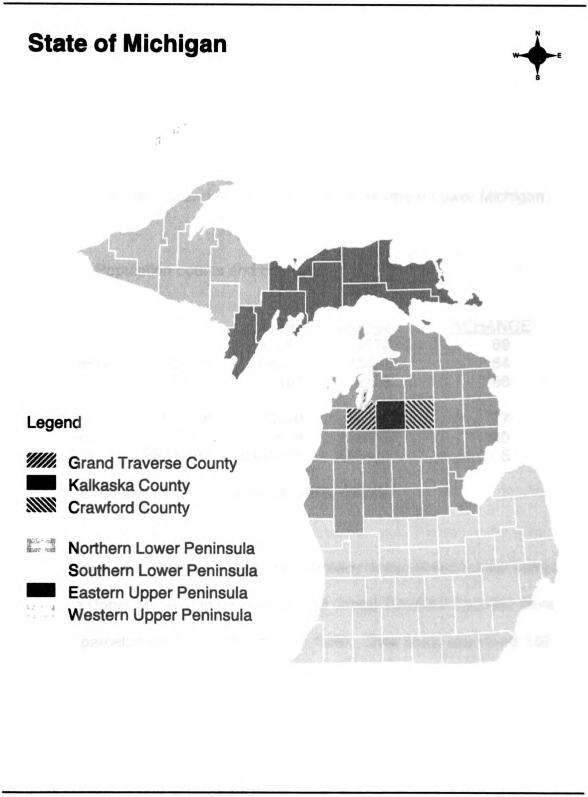


Figure 2.1: Selected counties.

continued population growth through the next twenty years (Grand Traverse County Planning Commission, 1997; Warbach and Norberg, 1995). Table 2.1 highlights the population growth trends for the three-county region, the NLP, and the State. The %CHANGE figures in Table 2.1 demonstrate that population growth has occurred more rapidly in the NLP than in the state. In turn, the three selected counties have grown more rapidly than all northern Lower Michigan.

Table 2.1: Population counts and changes.

County	1970	1990	Change	%CHANGE
Crawford	6482	12260	5778	89
Grand Traverse	39175	64273	25098	64
Kalkaska	5272	13497	8225	156
Region	50929	90030	39101	77
NL Michigan	383965	538534	154569	40
State	8881826	9295287	413461	5

Source: U.S. Department of Commerce: 1972, 1992a.

Second, Brown and Vasievich (1996) have already documented in their sample study of the Upper Midwest that Crawford and Grand Traverse Counties have undergone parcelization from 1960 through 1990. Their study examined 136 sample sites across seventeen counties. Each county, including Crawford and Grand Traverse, was characterized by decreasing average parcel sizes. Lastly, Crawford, Grand Traverse, and Kalkaska counties were selected because the counties constitute one contiguous region, and land cover change phenomena may be studied at scales both larger and smaller than the county scale.

2.2: Description.

In order for the reader to become better acquainted with the study area, several general descriptions are provided in this section.

2.2.1: General geomorphology.

Michigan's land characteristics, along with the number of lakes that speckle the landscape, are residuals of glacial processes that occurred during the Pleistocene epoch (Sommers *et al.* 1984). Areas of higher elevation tend to be moraines that were formed by the Wisconsin age ice advance. The inland areas of lower elevations and flatter slopes tend to be sandy outwash plains created by glacial runoff and deposition. Most coastal areas (e.g. the Old Mission Peninsula of Grand Traverse County) are fringed by lacustrine plains that surfaced after glacial lakes (e.g., Glacial Lake Algonquin) receded. The remaining shorelines now outline the modern Great Lakes. All of these features are represented in the study area (see Figure 2.2) and they exist along an elevation gradient that tends to increase from west to east. Morainic features dominate portions of Crawford and Kalkaska Counties while much of Grand Traverse County can be characterized as plains. However, local topography and landforms are varied throughout the region.

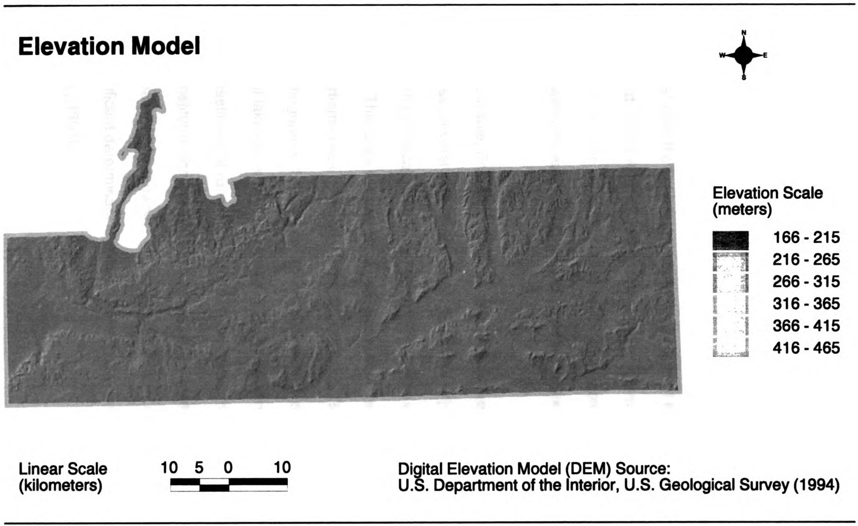


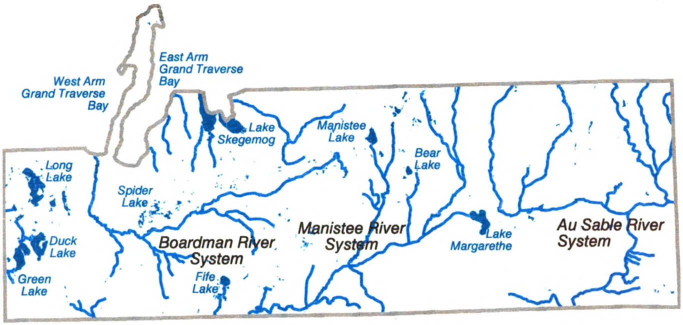
Figure 2.2: Elevation model.

2.2.2: General hydrography.

Three main rivers provide natural drainage for the region: (1) the Boardman River receives runoff from the west-central portion of Kalkaska County and the central and southern portions of Grand Traverse County, (2) the Manistee River collects water from the central and southern portions of Kalkaska and Crawford Counties, and (3) the Au Sable River drains the northern and central portions of Crawford County. The remaining areas within the region are drained by subsurface water flows toward Lake Michigan (Sommers *et al.* 1977).

While the Au Sable, Boardman, and Manistee Rivers are important ecological infrastructures, several large inland lakes, along with adjacent Lake Michigan, prove to be the physically dominant hydrologic features within the region (see Figure 2.3). The lakes not only store vast amounts of fresh water but also have many recreational uses (Sommers *et al.* 1984). Lakes Bear, Duck, Green, Long, Manistee, Margerethe, Spider and others provide the area with over 100 kilometers of lakefront shoreline, mostly in Grand Traverse County. The Lake Michigan coastline that runs along Grand Traverse County and neighboring counties constitutes another 100+ kilometers of freshwater access. In a recent survey of seasonal homeowners, proximity to such water features was identified to be a significant determinant in seasonal home development (Stewart, 1994; Stynes *et al.*, 1997).

Local Hydrography



Linear Scale (kilometers) 10 5 0 10

Source:
U.S. Department of the Interior, U.S. Geological Survey (1993)

Figure 2.3: General hydrography.

2.2.3: Forest cover characteristics.

Michigan forests have undergone several dramatic changes within the last 175 years. Almost every forest stand has been disturbed by tree harvesting activities of the late nineteenth century. Due to subsequent erosion of northern Lower Michigan's sandy soils, second growth forest compositions and structures do not reflect the composition and structure of forests that existed before the logging boom (Sommers *et al.* 1984).

During Michigan's first years of statehood (late 1830's), public lands had to be surveyed before they could be offered for private purchase. Hence, a general land survey was conducted. The purpose of the general land survey was to locate and divide the land into Jeffersonian townships and sections, and to record detailed information about lakes, streams, and trees (Stearns, 1997). Since then, the written recordings of witness trees, those trees located nearest to surveyed section corners, have been studied in order to quantitatively recreate the spatial pattern of pre-settlement vegetation (Brown 1998a, Brown 1998b, and Comer *et al.*, 1995). These recreated patterns are often used as a baseline with which past and present changes are compared (Stearns, 1997).

The US Forest Service (1997a), in their Great Lakes Assessment Project, have classified both the digital map of interpreted nineteenth century survey notes (Comer *et al.*, 1995) and recent remotely sensed imagery in order to quantitatively identify changes in vegetation type distributions in the Upper Midwest, over the last 175 years. Using their publicly available data, which was stored in a geographic information system file format, I was able to subset each data set by "clipping" the data by my study area boundary (see Figure 2.4). I was then able to quantify and compare temporal similarities and differences in regional vegetation cover types. Table 2.2 highlights the proportional conditions of vegetation types and changes between the early settlement and post-settlement classifications for my study region.

Early settlement vegetation (circa 1830) can be characterized as dominated by the maple, beech, birch, and aspen forest type. The white, red, and jack pine type was abundant while the spruce and fir type was present in lesser proportions. Post-settlement vegetation (circa 1991) can also be characterized by a maple, beech, birch, and aspen forest type majority but, it exists as a lesser proportion of the total. Pine types and non-forested areas cover similar extents.

Table 2.2: Vegetation changes within the study area.

Type	%Early-settlement*	%Post-settlement**	Change
Elm, ash, and cottonwood	0.2	0.0	-0.2
Maple, beech, birch, and aspen	45.3	36.7	-8.6
Oak and hickory	0.0	12.3	12.3
Spruce and fir	10.2	0.0	-10.2
White, red, and jack pine	34.7	28.4	-6.3
Non-forested	9.5	22.6	13.1

Sources: U.S. Forest Service, Department of Agriculture: 1997a*, 1993**.

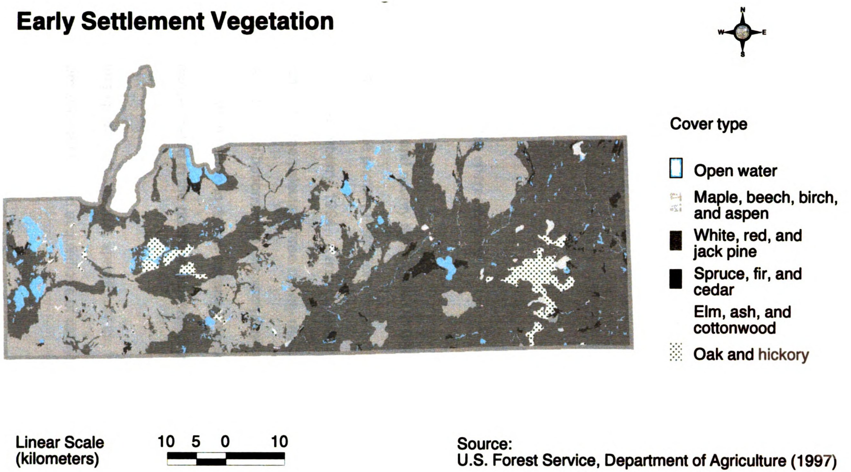


Figure 2.4: Early settlement vegetation.

The largest differences between the historic and modern forest covers is the measured loss of the maple, beech, birch, and aspen type, the loss of several coniferous types, and the large increase in non-forested areas. Although changes induced by growth, mortality, and fire disturbances can and do occur naturally, the large increase in non-forested areas, when taken together with the aforementioned regional population increases, lends support to Harman's (in Sommers *et al.* 1984) assertion that human settlements have expedited forest alterations to degrees and extents far greater than would have occurred naturally.

2.2.4: Forest ownership characteristics.

Federal agency, state and county agency, forest products industry, and non-industrial private are the primary institutions that own and manage regional forested lands (Leatherberry, 1994). Table 2.3 highlights the distribution of forest ownerships for the selected three county region, northern Lower Michigan, and the State. The distributions of public and private forests vary disproportionally from region to region because the distribution of public land in Michigan is concentrated in the northern portions of the State.

Federal ownership within the region, specifically the Huron National Forest, originated from state authorized acquisitions of abandoned agricultural land for the creation of national forests (Weeks Law of 1911 [36 Stat. 961]). Federal forests are currently managed for multiple uses and sustainable ecosystems.

Table 2.3: Forest ownership by class.

County	Federal	State/County	Industry	Private
Crawford	13.1	52.4	0.0	34.5
Grand Traverse	0.0	43.9	0.0	56.1
Kalkaska	0.0	53.9	0.0	46.1
Region	5.2	50.9	0.0	43.8
NL Michigan	12.6	27.9	0.1	59.4
State*	13.8	21.8	10.9	53.4

Sources: Leatherberry, 1993:26 and *MacKay and Ellefson, 1997:79.

Typical forest outputs include timber products, recreation, and preserved natural habitats. Within the range of outputs, National Forests in Michigan tend away from commodity outputs and toward recreation and natural habitat conditions (Webster, 1997). Perhaps this tendency is the result of a voting public's perception that recreational uses benefit a greater number of people than do timber harvests.

State ownership, specifically the Pere Marquette and Au Sable State Forests and Hartwick Pines State Park, is the dominant ownership class within the study area. State forests originated from abandoned agricultural lands and other lands that reverted back to state ownership via property tax forfeitures. State forests, like federal forests, are also managed for multiple uses and multiple outputs.

Such outputs include timber goods, recreation, and natural habitat sustainability. Since state ownership is more localized than federal ownership, these lands tend to play a more dominant role in regional economic development (Webster, 1997). For example, the State Forest Products Industry Development Council (MI PA 451 of 1994, formerly MI PA 150 of 1984) was initiated in order to develop forest product industries so that Michigan's economy would become more diversified and less dependent upon the automobile industry (Webster, 1997). Michigan State Forest resources have also become tied to tourism based economic development. According to Chappelle (1997, p. 228), "efforts to attract additional visitors, and to provide improved facilities" to forested areas are "the core of resource based economic development efforts" within the region. Because recreation and forest product economies are often viewed as competing economies (as one requires forest accessibility and the other requires forest cutting, respectively), forests in these areas require management practices that synchronize the needs of each economy in order to optimize the outputs of both. Should parcelization occur within these areas, efforts to synchronize developments of multiple economies, which will include multiple new landowners, would become increasingly difficult.

Private forest owners are the smallest ownership class individually and the second largest in aggregate (see Table 2.3). Parcel sizes range from less than one hectare to thousands of hectares with the majority of parcel sizes skewed toward the low end of the range. According to Webster (1997), private forests tend to be more productive than publicly owned and managed forests for a "simple historic reason" (p. 256); most public lands came into existence by being poor farmland with poor soil qualities. Subsequently, these poor farmlands reverted into state ownership and prime lands with good soil qualities remained in private ownership. The forest resources on private lands also serve many different purposes. As private lands undergo parcelization and are further developed, Michigan's most productive forest land could be replaced by more human dominated land covers and uses.

2.3: Summary.

The area selected for study has been shown to exhibit characteristics both similar to and different from other forested areas in Michigan. Grand Traverse, Kalkaska, and Crawford Counties contain common topographic, geologic, and hydrologic features found in the NLP. Also, the region contains forested lands that are owned by each of the dominant ownership institutions found in Michigan. However, what sets the selected study area apart from the NLP and the rest of Michigan has been its strong population growth trend, parcel subdivision trend, and the expectation that this region will be the first region in Michigan to experience a reversal of the current forest recovery trend.

CHAPTER 3: LITERATURE REVIEW

3.1: Introduction.

The Michigan Territory was granted statehood and admitted into the Union in 1837. In order for the new state to generate funds for operation and self-improvement, government officials offered public lands for private purchase (Warbach and Norberg, 1995). As described in Chapter 2, all such lands were surveyed and reported according to the Jeffersonian-style public land survey system. New landowners immediately recognized the market value of large timber stands that existed on their properties and, as a result, began harvesting timber to generate funds for their own benefit and improvement.

Timber harvesting in Michigan was a boom economy by 1840. The state became the nation's leading timber producer in 1870 and held that claim through 1890 (Sommers *et al.* 1984). For almost eighty years, timber was harvested in a wave that enabled Michigan's economy to flourish and yet, left a cleared and impoverished landscape in its wake. Unfortunately, Michigan's forest resources were severely over-estimated and by the early 1900's, the state was left with almost no remaining timber (Warbach and Norberg, 1995). In addition to losses attributed to logging, approximately 2 million acres of forest were destroyed by fire (Warbach and Norberg, 1995).

During the 1920's, State of Michigan officials began to recognize certain natural resources, including forests, to be of some benefit to the public good. Poor and marginal agricultural lands were bought or reclaimed by the state and were appropriated for either State or National Forest designation. During the 1930's, the Civilian Conservation Corps replanted and reforested many of these lands (Warbach and Norberg, 1995).

Subsequent to the Great Depression, the State of Michigan reclaimed an additional 2.2 million acres of land via tax forfeitures and purchase programs and was ultimately in charge of approximately 4.5 million acres by the early 1940's (Warbach and Norberg, 1995). While some of the reclaimed lands were later sold back into private ownership, many were put into either the state or federal forest systems and left to naturally regenerate into young forest conditions.

The United States Congress signed into law the Multiple Use Sustained Yield Act in 1960 (74 Stat. 215; 16 U.S.C. 528 et. seq.) and the Forest and Rangeland Renewable Resources Planning Act of 1974 (88 Stat. 476; 16 U.S.C. 1600 et. seq.). The federal legislation mandated the creation of compartments or zones within public areas for the sake of developing natural resources and for the preparation of multiple-use plans. The legislation also improved the existing standard by mandating additional local involvement and management. The Michigan Forestry Planning and Development Committee was later created so the renewed forest inventory could be efficiently managed in order to "use

Michigan's forest resources for enhanced economic development plus diversification to enhance recreational opportunities and protect natural values" (Warbach and Norberg, 1995:2-7). Hence, Michigan's young forests today serve a variety of vaguely stated interests. Such interests include: some development, managed timber production for wood and wood pulp, recreation and tourism, and protection of several plant and animal species (e.g., the Kirtland's Warbler).

According to the United States Department of Agriculture Forest Service (Leatherberry, 1994), twenty-one percent (3.8 million acres) of Michigan forested lands are owned by state agencies and another fourteen percent (2.6 million acres) are owned by the Federal Government. Since the State of Michigan holds such a large amount of forested land, it has earned its claim to having the largest state forest system in the continental United States. Yet, despite the state's sizable forest assets, private owners control property rights to the majority of Michigan's forest resources. Over fifty-three percent, approximately 9.8 million acres, of all forested lands are held by thousands of private individuals while another eleven percent are owned by private industry (Potter-Witter, 1995).

3.2: Population studies.

As mentioned above in Section 2.1.1, demographic and economic studies in Michigan have characterized a "rural renaissance" (Beale, 1977) that was in effect during the 1970's. For nearly the first time in Michigan's history the population growth rate in non-metropolitan areas exceeded the growth rate in metropolitan areas. Throughout the 1980's and 1990's, Michigan's non-metropolitan populations have continued to grow (U.S. Department of Commerce, 1970; 1980; 1990). Public forest managers have become concerned that development associated with continued population growth has caused observed increases in forest fragmentation. Such concerns have given rise to the MSPO's stated need for research on the characterization and quantification of such landscape changes.

In order to characterize landscape changes, historical land use and land cover change analyses have often been grounded in Malthusian philosophy (McPherson, 1982). Population growth was attributed the singular responsibility for causing landscape change within any observed area (Leibenstein, 1957; Vanderpol, 1963; Scheer, 1963; Wolf, 1966; Holmberg and Dobyns, 1969; Grigg, 1974 and Todaro, 1981). The logic behind these population growth studies seemed intuitive: the greater the number of people moving into and settling on a finite area, the greater the demand for natural resources and, hence, the greater the subsequent landscape fragmentation and change. For example, Leibenstein (1957), in his global summary of agricultural areas asserted that land "holdings are continually subdivided as the population on the land increases" (p. 41). Scheer (1963) argued in his study of Netherlands' agriculture that "a very serious consequence of the population pressure" is "the splitting up of a great number of farms into scattered parcels of small and impractical size" (p. 519).

In 1963, Papageorgiou published his article on Greece's agricultural problems and succinctly described the "conditions which greatly facilitate progressive fragmentation" to be "the growing population and the existence of the right of landowners to transfer and alienate his right in the land freely and, in particular, the right to subdivide or add to existing holdings" (p. 546). By recognizing the rights of individuals to transfer property rights, other researchers expanded landscape change analysis to include examinations of inheritance systems (Wolf, 1966; Grigg, 1974). However, such analyses were just simple extensions of the population growth and limited carrying capacity arguments.

Many other landscape and land cover analyses were conducted with an overwhelming majority focused on the effects of farmland subdivision on primary productivity. In a series of working papers for the Harvard Institute for International Development, McPherson (1982; 1983) reviewed over 120 different studies on agricultural land fragmentation and most were cited to conclude that either population growth, local inheritance structures, or a combination of the two were the primary drivers of landscape change.

Vesterby and Hiemlich (1991) examined landscape change as a result of several interacting socio-economic factors and high levels of population growth. A minimum rate of population growth, coupled with a minimum number of persons, was used to select a set of developing areas within the United States. Urbanization was then characterized by land conversion to urban uses and increasing population densities. The most notable portion of the authors' analysis indicated that changes in land use were most dramatic during the earlier stages of urbanization rather than during the later. The authors specified the building of infrastructure and critical services at the onset of development as reasons for the trend they observed. Vesterby's and Hiemlich's (1991) findings also serve to suggest the importance of understanding initial landscape conditions at the onset of landscape change research. Without an understanding of initial landscape conditions, researchers may find interpreting subsequent landscape analyses difficult because relationships determined to exist at one stage of development may not exist at another.

Vogelmann (1995) commented on his surprise at finding a strong relationship between forest fragmentation and increasing population densities within a forested region in New England. The author statistically compared the spatial concurrence of mapped population data with mapped forest cover fragmentation. Township population data were gathered from published US Census reports and forest cover and forest fragmentation data were measured from classified remotely sensed imagery. Both data sets were georeferenced and analyzed using a GIS. In his discussion of results, the author tried to recognize "government policy and fiscal incentives" as "significant determinants of land-cover change" (Vogelmann, 1995:445). However, his regression results highlighted only increasing population density as the dominant factor contributing to forest fragmentation. Vogelmann (1995) also indicated that the strength of the relationship he observed diminished above and beyond a particular population density threshold. This population density threshold supports, in part, Vesterby's and Hiemlich's findings. Both studies suggest that processes identified to affect landscape change may be dependent upon the set of initial conditions specified at the beginning of analysis. Therefore, in landscape change research, the set of initial conditions cannot be chosen arbitrarily without an effort to understand *a priori* the limitations they may impose on subsequent research findings.

As evidenced so far, many researchers have studied the effects of growing human populations and the landscapes on which they settle and develop. McPherson's (1982,1983) work emphasizes just how many have contributed to such research. In all of the agricultural analyses discussed above, research findings seem to have reaffirmed the notion that landscape changes are linked to increases in resident populations. However, the last two studies (Vesterby and Hiemlich, 1991; Vogelmann, 1995) show that the relationship between population growth and land cover change is neither perfect nor direct.

I have already illustrated recent population growth trends in both the NLP and the study area (Table 2.1). Because the study area is considered to be rural and has exhibited a strong resident population growth trend, it might seem logical to some to apply a test of population growth theory to the region. However, I do not believe that such an application can be easily accomplished given the traditional source of United States population data - U.S. Census Bureau reports.

Stewart (1994) has reported the significant impacts of seasonal homes and seasonal populations on local industries and regional economies. In related research Stynes *et al.* (1997) wrote the population of a Great Lakes county, like any one in the study region, can be six or seven times the official resident population because official census counts do not include seasonal homes or seasonal home owners in their population totals. Also, because the proportions of seasonal homes (see Figure 3.1) and seasonal populations vary across the region, it is reasonable to assume that the impacts of resident populations, relative to total populations, also vary across the landscape. Therefore, given the extensive nature of seasonal home development within the region, the non-uniform distribution of seasonal homes throughout the region, and inconsistent temporal reporting of seasonal home data in US Census publications, a simple analysis of residential population growth and landscape change is not appropriate for this region.

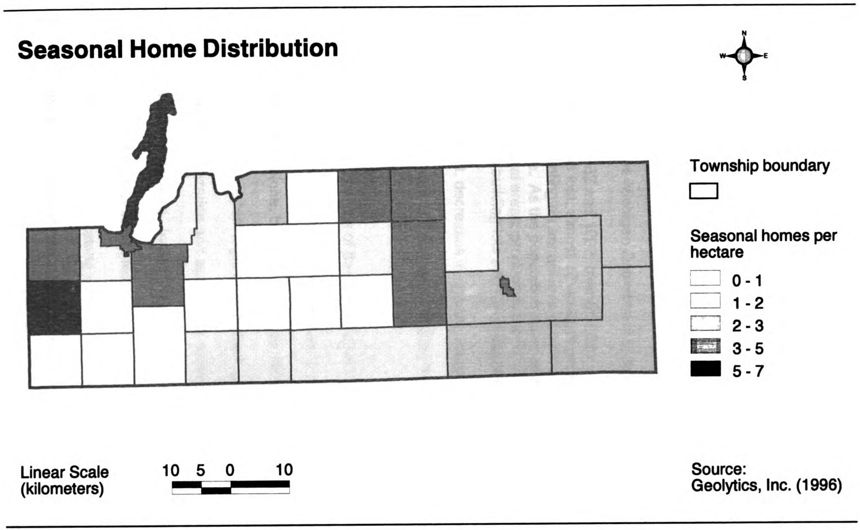


Figure 3.1: Seasonal homes.

3.3: Agricultural land use changes.

Since the 1970's, Michigan has been in a period of agricultural decline. Many Michigan counties have experienced either small farm aggregation into fewer and larger farms or losses in both the number of farms and total acreage farmed (U.S. Department of Commerce, 1992b). According to a press release issued on October 23, 1996 by the Michigan Department of Agriculture:

> "Between 1982 and 1992, over 854,000 acres of Michigan farmland was lost, almost 10 acres of every hour of every day, representing an annual loss of over $100 million in local farm revenue. As the population spreads out from the cities into more rural areas, productive farmland is often carved up into large building lots and taken out of production."

To a lesser areal extent, decreases in agricultural production have also been reported (U.S. Department of Commerce, 1992b) for the selected study area.

Erickson (1995), in her analysis of the River Raisin Watershed of Southeast Michigan, used a GIS and regression techniques to demonstrate urbanization and population growth alone, between the years 1968 and 1988, do not serve to predict forest cover change "as might be expected" (p. 230). Her original hypothesis stated urbanization and agricultural decline simultaneously effected a net decrease in forested area. Instead, agricultural decline was shown to have a significant positive relationship with forest cover change. The authors concluded that agricultural land decisions, along with agricultural mechanization and economics, were also useful for explaining forest cover changes. Such a conclusion demonstrates that processes other than population growth can be used to explain land cover change. However, the authors maintained that their quantitative description captured only a snapshot of the iterative relationship between human decision making processes and physical landscape conditions.

3.4: Parcelization pressures.

Increased accessibility, recreation and tourism development, and urban spillover were general reasons cited by Hart (1984a) for the population turnaround, or rural renaissance, in rural areas of the Upper Midwest. Hart (1984b) also suggested that regions attract development for many reasons including accessibility to a variety of natural features. Rural areas in northern Michigan have attracted recreational development because of access gained from new highway construction, the presence of extensive forests, and accessibility to many lake front areas (Stewart, 1994). Since northern Michigan's tourist economy has expanded to meet the demands of such recreational and tourism development, in the form of additional service-oriented businesses and accelerated seasonal home construction, pressures have become even greater on proximate forested lands. In other words, forested areas have become the focus of development pressures because of their aesthetic qualities.

Land use patterns on developing private lands affect forest resources located on both private lands and adjacent public lands. In a series of working papers published by the Michigan Society of Planning Officials Trend Future Project, the

MSPO has clearly stated their concern about the impacts of land use practices on forested lands:

> "Land use patterns on private land continue to affect the quality and sustainability of the forest base. Private forests are the focus of development pressures and public forests are the focus of pressures for more varied uses. As a result of changes in the composition of forests, there are changes in wildlife populations and the visual character of the forest. With the fragmentation of the forest into smaller blocks, edge species of plants and animals have proliferated, and deep forest species have declined" (Warbach and Norberg, 1995:iv).

In their conclusion, the MSPO went on to argue that if current land use trends continue they...

> "...can result in significantly less land in a cohesive natural condition thereby reducing wildlife habitat and a biologically diverse range of species" (Warbach and Norberg, 1995:4-6).

Negative attention has fallen on land ownership parcelization and its current and future impacts on a young and vulnerable forest base. While parcelization certainly results in the fragmentation of land ownership, parcelization may also partition the land into different land uses. Should new adjacent landowners decide to utilize their lands in many different ways, the resulting landscape could ultimately assume the appearance and durability of a poorly woven quilt. Continued parcelization and development of lands adjacent to forested lands can; limit the abilities of forest managers to manage forests, limit the abilities of forest production efforts to meet an increasing demand for timber products, alter a delicate mix of plant and animal species, and cause a loss of wildlife from existing ecosystems to occur.

Brown and Vasievich (1996) examined land ownership parcelization in Michigan, Minnesota, and Wisconsin. Attention was focused on socio-economic and locational factors that contributed to parcel sizes and parcel changes. Multi-scaled analyses were conducted for three time periods; the 1960's, 1970's, and 1980's. Brown and Vasievich (1996) reviewed relevant work on regional ecological factors (Stewart, 1994), economic factors (Fuguitt *et al.* 1989), social and demographic factors (Hart, 1984a), and institutional factors (Kufuor, 1981 and Norgaard, 1994). The authors gathered sampled parcel information from published parcel plat maps in order to measure parcelization for the region as a whole, between counties, and within counties. Also, variables were selected to represent each of the examined factors with a generalized linear model. The authors tried to determine whether or not the spatial pattern of parcelization could be predicted by the spatial pattern of complex and interacting factors. Brown and Vasievich (1996) stated that their generalized linear model results provided "explanation of spatial variation in parcel fragmentation" (p. 1207). In their conclusion, the authors discussed the moderate predictive ability of their model ($R^2 = 0.30$, $\rho F = 0.000$) but were satisfied with its statistical significance. The authors also discussed the possible effects of ownership parcelization on plant and animal habitats, plant and animal biodiversity, and primary productivity and wondered about the ability of ecosystems to sustain themselves in the future given the current trend of land subdivision.

In continued research, Brown (unpublished manuscript) documented statistical and spatial analyses of his parcel data and found that parcelization "tended to peak or lag slightly behind" county population growth rates when they "reached their highest levels" (p. 25). After reviewing spatial autocorrelation and other statistical test results, Brown concluded that the relationship between population growth and parcelization "on a coarse scale, supports a link between the movement of people and impacts on the landscape" (p. 25). Given the results of his previous work, coupled with this latest evidence, Brown suggested a link between parcelization and its implications on land cover types and patterns. To suggest such a link seems reasonable since parcelization has been shown to be associated with a complex set of landscape pressures (population, social, institutional, and ecological), each of which has been identified independently as a possible driver of physical landscape change. Therefore, parcelization should be useful for representing a set of many driving factors in landscape change research. Also, the opportunity exists to expand this research to include and test continuous data representing the complete landscape because Brown and Vasievich (1996) and Brown (unpublished manuscript) used only sampled data to represent counties within the study area.

Even though the research reviewed above has shown promise, not everyone is in favor of associating parcel patterns with complex landcover change processes. Theobald, *et al.* (1996), in their research on rangeland fragmentation in the Colorado Mountains, cautioned that "unlike roading and building, which result in physical fragmentation, parcel subdivision necessarily results in ownership fragmentation, which may or may not entail physical landscape change" (p. 413). However, while their advice may hold true at the time of deed transfer and shortly thereafter, only a few land cover changes are necessary to effect changes in the character of an entire landscape. For example, in the same article, Theobald *et al.* (1996) mitigated their own cautions by reporting the concern among residents within the study area about the loss of open spaces even though less than a quarter of all subdivided parcels observed contained a building. The authors' recognition of such resident concerns reinforces, in part, Vesterby's and Hiemlich's (1991) conclusion that the most dramatic land cover changes occur during the earlier stages of development. Perhaps, even more dramatic than the land use changes already observed within the Colorado Mountain study area is the real potential for much greater landscape fragmentation and loss of open spaces as the results of future development on all remaining parcels.

The study of land ownership parcelization, while uncommon, is not new. Roche reported his analysis of parcelization trends in nineteenth century France in 1963. Using historical land survey documents, Roche measured a 25 million parcel increase over a twenty-five year period. He also reported that parcelization varied across the country as did the agricultural inefficiencies he associated with it. Roche concluded that parcelization was detrimental to agriculture because "the average size of a parcel" in some regions did "not allow efficient mechanical farming." The conclusion reached by Roche is, in effect, the same argument being put forth by forest managers in Michigan today; breaking large forested parcels into many smaller ones is ecologically inefficient. According to Potter-Witter, small forested parcels are ecologically inefficient because wildlife "rely on contiguous ecosystems of certain minimum size for travel corridors and territorial requirements" (Potter-Witter, 1995:18).

3.5: Land consumption theory.

The Consumption Theory of Land Rent (CTLR) (Thrall, 1987) provides a model of land consumption around a central market or central business district (CBD). The CTLR is based upon the idealized relationship between the maximum "magnitude of happiness" (Thrall, 1987:11) or welfare a household can attain and its distance from the CBD. Many assumptions are needed to operationalize the CTLR. The list of assumptions includes, but is not limited to: (a) a perfectly malleable and isotropic landscape surrounding the CBD; (b) socioeconomic homogeneity of all households within the landscape; (c) perfect information on market conditions available to and used by all households; (d) the existence of urban and non-urban land uses (a concept developed by Von Thűnen [1842] in his original work on agricultural land location); and (e) the attainment of equal welfare by all households having the same income (Thrall, 1987).

The CTLR can be operationalized by evaluating the rent per unit of land with respect to the equilibrium of household welfare in space as constrained by the household budget. Since income and the composite price of goods are considered exogenous variables, and thus are held constant, the price per unit of land is allowed to vary with distance from the CBD. According to Thrall (1987), the results of the CTLR can be stated as several principles. Several of those principles I have deemed relevant to this research are:

> "*Principle 2.2* Land rent adjusts thereby compensating households from locating in places that have relatively inferior access to central locations. In general, rent per unit of land decreases with a reduction in access to the central location, all other things being equal.
>
> *Principle 2.3* The consumption of land is inversely related to the households' access to the central location.
>
> *Principle 2.7* The spatial equilibrium quantity of land consumed increases at an increasing rate, and hence population density decreases at an increasing rate with increasing distance from the city center." (Thrall, 1987:23-25).

Thrall (1987) summarized his review of the CTLR by stipulating that, in order for remote households to compensate for the cost of transportation to and from the CBD, "land rents are less and consequently households can consume more land" (Thrall, 1987:26).

The CTLR has relevance to this research because of the rural nature of the study area and the presence of Traverse City, which is located in the northwest portion of the region at the base of the peninsula, had the highest population density of any minor civil division within the area during the 1970's and 1980's, and can be considered a CBD despite observed population decreases over time (see Table 4.1). Also, the several townships adjacent to Traverse City had relatively high population densities while many of those located in Crawford County had much lower densities. Such a spatial gradient of population density is similar to the gradient suggested to exist by the CTLR. Although this particular landscape does not meet most of the requisite assumptions of the CTLR (including the lack of "roadways or rivers... ...or features built by nature and humankind" (Thrall, 1987:10)), the opportunity exists to compare the study region to an idealized one. By substituting the term parcel size for the term consumption of land, one might expect parcel sizes to increase with increasing distance from Traverse City if one makes the same assumptions.

3.6: Other concerns.

Some of the issues discussed in this chapter have also been reviewed in the MSPO Trend Future Project reports and were used to support their stated need for research on "the impact of local, regional, and statewide fragmentation on natural resources" (Warbach and Norberg, 1995:A-3). The logical next step is to conduct a landscape change study of land ownership and forest cover in order to characterize the proposed relationship between parcelization and fragmentation. However, landscape studies are often fraught with difficult quantitative problems. Issues of spatial and temporal scales are common in the literatures provided by landscape ecologists and conservation biologists and are expected during this analysis. Allen and Starr (1982) developed hierarchy theory to help analyze how processes and determinants shift in relative importance across multiple scales. Meentemeyer (1989) and Turner (1990) have continued to developed hierarchy theory, but within the vernacular of landscape ecology. Regardless of discipline, each author has suggested the need for landscape research to be conducted at multiple scales so that the effects of space and time can lead to a better understanding of observed landscape processes.

Landscape ecology acknowledges many interrelationships between humans and nature. According to landscape ecologists, landscapes are characterized in terms of matrices, patches, and corridors, and are often done so with respect to a specific species of interest (neo-tropical songbirds are typical in the literature). Patches are considered the basic landscape unit (Forman, 1995) and are further characterized by descriptions of size, shape, quantity, interior core areas, and connectivity. The strength of landscape ecology lies in its fundamental use of spatial concepts to measure the structural abilities of landscape patches to distribute energy, materials, and species throughout a given area (Forman and Godron, 1986). Since landscape ecology emphasizes both an understanding of complex systems and the use of spatial principles, I have reason to believe some of the tools used in landscape ecology research will be appropriate for use in this study of land parcelization and forest fragmentation.

Perhaps the reason for the lack of large scale parcelization research, Brown and Vasievich (1996), Kleiman and Erickson (1996), and Roche (1963) not withstanding, has historically been the daunting task of observing thousands of parcels and thousands of forest patches over a period of time. The requirements for gathering, storing, and analyzing such data were, until recently, virtually impossible. However, GIS and RS technologies have systematically mitigated each of the above data requirements and offer researchers and planners effective tools for recording and analyzing landscape data. Parcel maps can be digitized and analyzed, and remote sensing technology allows us the ability to gather detailed data about land covers from space.

3.7: Summary.

Reviewing the above research has helped me to gain additional perspectives on both the potential strengths and weakness of my proposed study. The foremost challenge that exists for this research is to deal with the degree of complexity that exists within the study area. I have reviewed historic and current variations in regional geology, hydrology, and vegetation type patterns - variations that can influence forest distributions independently and co-dependently. Also, I have reviewed variations in regional population growth trends, land ownership institutions, ecological determinants, and a few planning ordinances - variations that can influence parcel subdivision independently and co-dependently. While all the intricacies of landscape change cannot be accounted for in a single study of parcelization and forest fragmentation, perhaps enough will be accounted for so that I may achieve a better understanding of the way forests and humans relate to each other.

This literature review has also prompted me to be aware of the fact that any relationship(s) I might find to be significant may have existed only during the period from 1970 to 1990. Since relevant processes and determinants can shift in relative importance through time (Allen and Starr, 1982; Vesterby and Hiemlich, 1991) my results may also be dependent upon the set of initial conditions that existed before the year 1970. However, instead of viewing such questions as potential limitations, I believe they provide me an opportunity to question and identify the effects space and time on the proposed relationship between land ownership parcelization and forest cover fragmentation. By organizing my investigation into multiple spatial and temporal scales, I will not only be able to test whether the proposed relationship exists, but, if it does, I will also be able to characterize how it has changed.

CHAPTER 4: METHODS

4.1: Introduction.

The general approach I adopted to quantify land ownership parcelization included; converting published parcel plat maps into a digital GIS polygon format, classifying each parcel by ownership type, and using a GIS to aide in the calculation of average parcel sizes at several levels of spatial aggregation. Spatial distributions of average parcel size and annual rates of parcelization were examined with basic and spatial statistical techniques.

Forested landscape patterns were measured using classified remotely sensed imagery. Each sample image, a Landsat Multi-spectral Scanner (MSS) scene, was classified using a consistent process of unsupervised classification techniques. Three resulting maps, each representing a historical land-cover landscape, were tested for accuracy with several common assessment techniques, including the use of historical aerial photographs as ground truth references. Quantitative measures of historic forest cover and forest fragmentation were calculated for several levels of aggregation. Spatial patterns of forest fragmentation and annual rates of change were also examined with basic and spatial statistical techniques.

Ultimately, both static and dynamic patterns of parcelization and forest cover fragmentation were compared at each spatial and temporal scale.

4.2: Scales of analysis.

Measures of average parcel size, parcelization, percent forest cover, and forest fragmentation were quantified and described at five spatial scales. Figure 4.1 illustrates the different scales used to sample each landscape data set. I selected region, county, and township (minor civil division) as three of the five levels of analysis because policy decisions in Michigan are made and implemented at each respective level. Figure 4.2 has been included so that the location of individual minor civil divisions can be identified by name. A fourth scale, which I call the sample site, was used to measure landscape variation at frequencies and with a spatial regularity greater than the township analysis could provide. Sample sites are defined as nine square mile blocks consisting of nine survey sections, each site with three sections to a side. Brown and Vasievich (1996) used three-by-three section units in their study of parcelization and such a sample unit was proven adequate for parcel area and statistical analyses. Slight adjustments to several sample site boundaries were made in order to accommodate a dominant presence of open water in some areas. For example, the land portion of Tier 28, Range 10, Section 13 was appended to sample site #281026 because 90 percent of the original sample site to which the section belonged existed underwater as part of the East Bay.

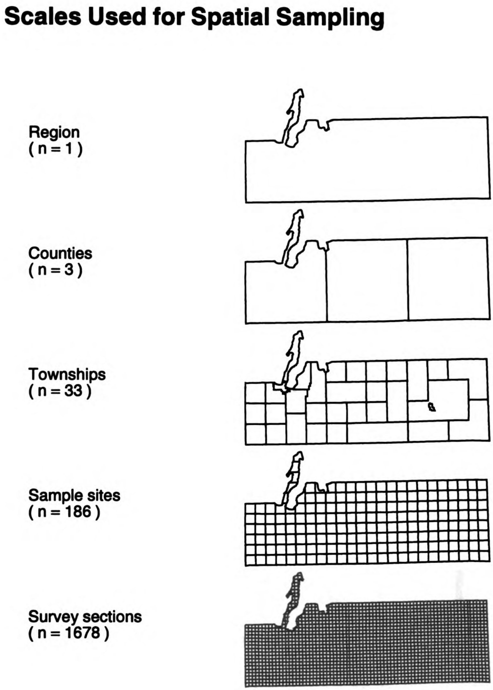


Figure 4.1: Spatial scales of analysis.

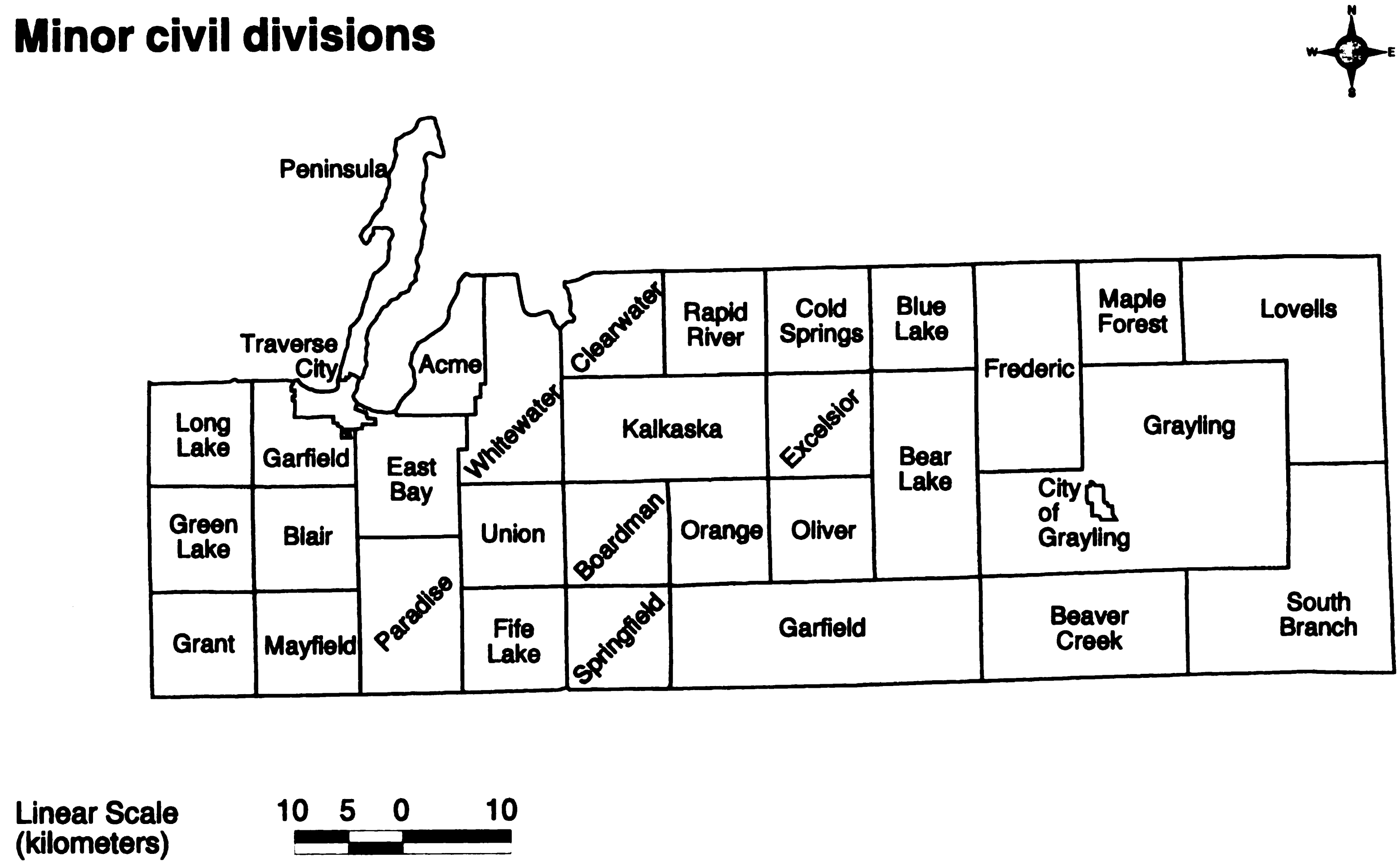


Figure 4.2: Minor civil divisions.

The fifth level of analysis was conducted using public land survey sections as sample units and it provides the most detailed look at the regional landscape. Each survey section is approximately 259 hectares (one $mile^2$) in size. This smallest sampling unit uncovers the greatest variation in the distributions of average parcel size and forest fragmentation.

4.3: Parcel data.

In Section 3.4, I summarized reasons for conducting an investigation of land ownership parcelization, rather than of population pressure, and its potential effects on the regional forest base. Since so little work has been done regarding the collection of parcel data and quantifying land parcel changes on a large scale, I had few examples to follow. However, Brown and Vasievich (1996) have provided the most detailed, concise, and reasonable approach to doing such research. Therefore, my methods are similar to theirs in many respects.

4.3.1: Collection.

I collected plat map books (Rockford Map Publishers Inc. 1969-1991) for each of the selected counties for the approximate years 1970, 1980, and 1990. When plat map books were unavailable for the exact dates, the closest available date was used as a surrogate. Appendix A includes metadata descriptions of the plat map books used and the final digital data sets. County plat map books contain detailed maps that show the various parcels in townships as they are located geographically. Each parcel is labeled with the name of the parcel owner and, in some cases, the approximate size of the parcel. Roads, schools, cemeteries, and civil division boundaries are also illustrated. Patterns of land ownership and parcel boundary changes were developed by digitizing each parcel plat map into a GIS database using Arc/Info (ESRI Inc., Redlands, CA) software. Each digitized parcel map was registered and georeferenced to the UTM coordinate system given ground control coordinate information obtained for survey section corners (MIRIS, 1978).

4.3.2: Classification.

After digitization, I classified all polygons in the parcel data into one of five categories. The categories included privately owned large parcels, privately owned small tracts, public lands, open water, and other. Descriptions of each parcel category are listed below:

1. Privately owned large parcels.

    Such parcels are individually mapped in the plat map books. Private ownerships were maintained by either individuals, groups of individuals, or corporations. Ownerships maintained by schools, government entities, incorporated cities, or villages were not classified as private. The size of each parcel was determined to be equal to its area.

2. Privately owned small tracts.

Small tracts are collections of small parcels of private land that share a common mapped boundary. These small parcels were not mapped individually, but rather, were mapped as a single block. Small tracts are usually subdivisions, blocks of cottages, and/or seasonal residences. Parcel ownerships are maintained by individuals, groups of individuals, or corporations, but specific ownerships within a small tract polygon are unknown and usually include many different individuals, groups, and/or corporations. Because the distribution of parcel areas within blocks of small tracts could not be discerned from the plat maps, an assumed average parcel size within these areas was used. Average parcel sizes within each block of small tracts were assumed to be equal to 0.20 hectares (0.5 acres). According to Kufour (1984) the average size of parcels within such small tract areas tended between 0.12 and 0.20 hectares (0.3 and 0.5 acres) in size between the years 1970 and 1980. Kufour (1984) also noted that such small tract areas tended to be larger, (0.41 hectares (1.0 acres)) during the 1950's and 1960's. Because several of these older small tract areas remain throughout the landscape, I thought it appropriate to use the larger, average estimate. If actual average parcel sizes within small tract areas were less than or greater than 0.2 ha, then measures of parcelization will be underestimated or overestimated, respectively. This assumption was necessary because, as mentioned above, actual parcel sizes within these areas were not discernable from the plat map books and no better estimate was available.

3. Public lands.

   These parcel types included ownerships maintained by public schools and government entities. Public lands also included all county, state, and national parks, lakeshores, forests, and wildlife reserves.

4. Open water.

   Open water areas were permanent inland water features, such as lakes, reservoirs, and ponds. In Michigan, open water areas that are legally determined to be navigable (Article IV, Northwest Ordinance of 1787) are held in the public trust. Because it is not possible to divide fairly the surface area of a lake or stream among adjacent owners in proportion to their land ownership, or by the projection of their property boundaries that reach the water at varying angles, the courts have held that all riparian owners share an equal right to a reasonable use of the entire surface area of the lake or stream. Therefore, open water areas were classified independently of private land ownerships.

5. Other.

Any parcel that did not fit directly into any above stated ownership group was classed into the "other" category. These parcels included mostly ownerships maintained by incorporated cities, villages, utility companies, and all military lands. These ownership entities can and do exert unique pressures on a physical landscape (i.e., powerline construction and heavy artillery maneuvers) and therefore, were classified separately so as not to be included in this particular analysis and earmarked for future study.

The three parcel data sets are relatively large and difficult to illustrate within the confines of this document. Therefore, a single township, Whitewater Township, has been arbitrarily selected to graphically represent the data. Figure 4.3 illustrates the classified distribution of 1970 parcel data for Whitewater Township.

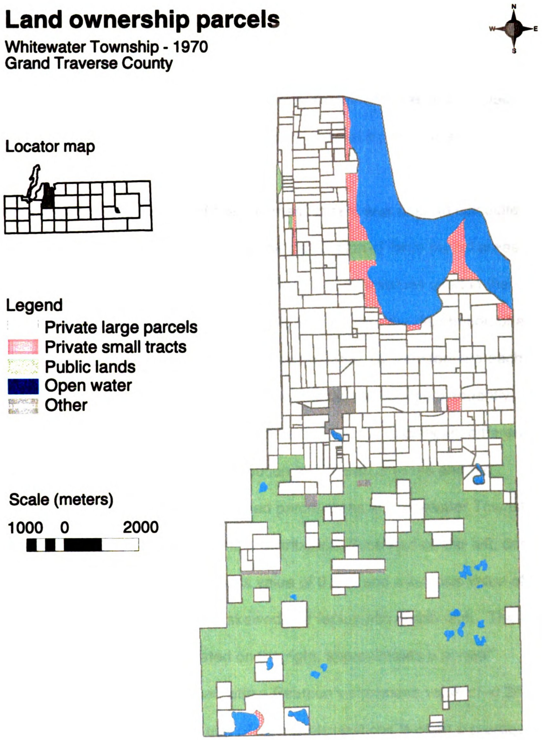


Figure 4.3: Illustrated example of the parcel classification scheme.

4.3.3: Temporal analysis.

Average parcel sizes were calculated for each sampled area using an average parcel size index (APS) similar to that used by Brown and Vasievich (1996). The APS index is a measure of average parcel size within a given area.

The geometric mean, instead of the arithmetic mean, was used to calculate the average of large parcel areas because the distribution of large parcel areas was positively skewed. A natural log transformation of area values used in the calculation of the geometric mean attempts to normalize the distribution of areal data for further use in common statistical techniques. By transforming each sample distribution of parcel sizes into a normal distribution, subsequently calculated means can be compared and easily tested for significant differences. Figure 4.4 shows the frequency distribution of 278 parcel areas and the frequency distribution of log transformed parcel areas in Whitewater Township for the year 1970. The untransformed distribution, illustrated on the left, can be described with a Pearson's skewness value of 0.844 and a kurtosis value of 12.349, which implies a positively skewed and leptokurtic distribution. The transformed distribution, illustrated on the right, approximates a normal distribution and can be described with a Pearson's skewness value of -0.262 and a kurtosis value of 0.920. The use of normal distributions is often a prerequisite of common statistical techniques so, log transformed parcel areas were deemed more suitable for analysis than untransformed areas.

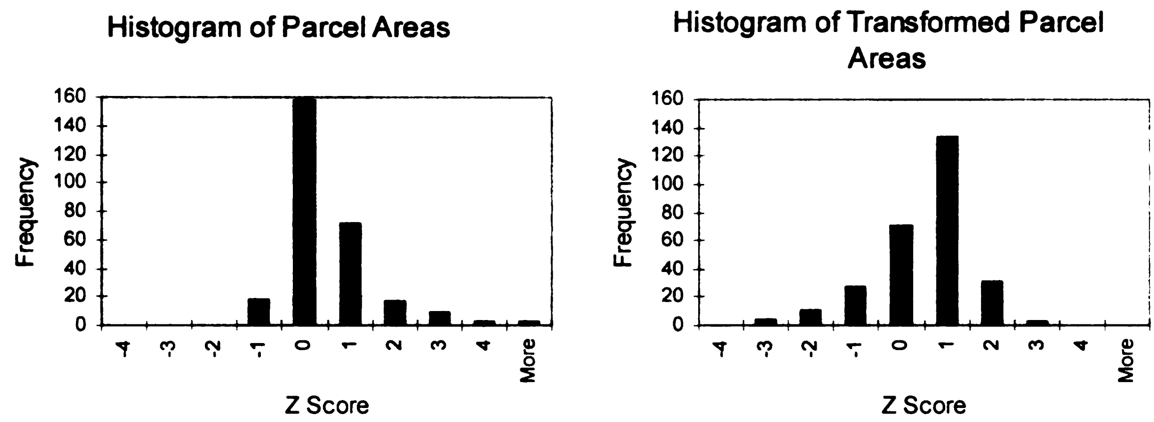


Figure 4.4: Frequency distributions of parcel areas.

The APS index is derived using the following equation:

$$APS \quad = \quad \left(e^{\left(\left(\rho_{large} \frac{\Sigma \ln A}{n_{large}} \right) + \left(\rho_{small} \cdot \ln 2000 \right) \right)} \right) / \, 10000$$

where:

ρ_{large} = the proportion of private land area classified as large parcels
ρ_{small} = the proportion of private land area classified as small tracts
$\frac{\Sigma \ln A}{n_{large}}$ = the mean of natural log transformed large parcel areas (m^2)
2000 = the assumed size (m^2) of all parcels in small tracts
10000 = a constant used to convert meter^2 to hectares

The calculated geometric mean of large parcels, and the assumed geometric mean of small parcels within small tracts, are weighted according to the proportion of private land area each class covered within a sample unit and then summed into a single measure. Large values of APS are associated with larger average parcel sizes and, conversely, small values are associated with smaller averages.

Land ownership data were summarized with summary statistics for each approximate date (1970, 1980, and 1990) and annual rates of parcelization were calculated for both ten-year intervals and the entire twenty-year period. Average parcel sizes were compared in order to answer the question: Have average parcel sizes changed over time and if so, how?

Three results are possible for each scale of analysis:

a. average parcel sizes have decreased over time.
b. average parcel sizes have not changed over time.
c. average parcel sizes have increased over time.

Brown and Vasievich (1996) reported estimates of average parcel sizes that decreased over time in their study of the Upper Midwest. Because their study area included Crawford and Grand Traverse Counties, detecting increased average parcel sizes during this analysis seemed unlikely. However, Brown and Vasievich (1996) sampled only portions of each county whereas I analyzed each completely. Thus, the possibility of uncovering a parcel aggregation trend still remained provided Brown and Vasievich (1996) did not sample appropriately. However, I hypothesized similar decreases in parcel size over time in my study area based on their results. My first formal hypothesis was stated as follows:

Hypothesis I

H_1: average parcel sizes have decreased over time

H_0: average parcel sizes have not decreased over time

This hypothesis was tested between decades and at all spatial scales. Matched pairs *t* tests were used to test for significant mean difference between values of

APS. Should significant test results indicate the null hypothesis be rejected, the trend of declining average parcel sizes would serve to support Michigan public forest managers' concerns (Potter-Witter, 1995).

Table 4.1 lists population growth figures for the region, three counties, and 33 townships. For almost every case, greater population growth rates were calculated for the 1970's than for the 1980's. The two notable exceptions were the City of Grayling and Traverse City. Both urban areas exhibited higher rates of declining total population during the 1970's than during the 1980's. The observed decline in urban populations during this time period follows the rural renaissance trend described by Beale (1977). According to Brown and Vasievich (1996), the majority of counties observed in their study had peak parcelization rates in a decade that corresponded to the decade of peak population growth. Given Brown's and Vasievich's (1996) results, taken together with the peak population increases outlined in Table 4.1, I hypothesized higher parcelization rates existed during the 1970's than did during the 1980's.

My second hypothesis was:

Hypothesis II

H_1: the rate of parcelization during the 1970's was significantly greater than the rate of parcelization during the 1980's

H_0: the rate of parcelization during the 1970's was not significantly greater than the rate of parcelization during the 1980's

Table 4.1: Population growth rates - 1970-1990.

County / Township	Population 1970	Population 1980	Population 1990	Mean annual growth rate 1970 - 1980	Mean annual growth rate 1980 - 1990
Region totals	50929	75316	90030	4.8	2.0
Crawford	6482	9465	12260	4.6	3.0
BeaverCreek	523	745	1175	4.2	5.8
Frederic	697	1142	1287	6.4	1.3
City of Grayling	2143	1792	1944	-1.6	0.8
Grayling	2252	4019	5647	7.8	4.1
Lovells	117	316	420	17.0	3.3
Maple Forest	217	355	407	6.4	1.5
SouthBranch	533	1096	1380	10.6	2.6
Grand Traverse	39175	54899	64273	4.0	1.7
Acme	1662	2909	3447	7.5	1.8
Blair	1677	4613	5249	17.5	1.4
East Bay	3356	6212	8307	8.5	3.4
Fife Lake	638	1056	1344	6.6	2.7
Garfield	4917	8747	10516	7.8	2.0
Grant	507	676	745	3.3	1.0
Green Lake	1206	2997	3677	14.9	2.3
Long Lake	1584	3823	5977	14.1	5.6
Mayfield	651	806	967	2.4	2.0
Paradise	1434	2117	2508	4.8	1.8
Peninsula	2642	3833	4340	4.5	1.3
Traverse City	18048	15516	15116	-1.4	-0.3
Union	57	185	255	22.5	3.8
Whitewater	796	1409	1825	7.7	3.0
Kalkaska	5272	10952	13497	10.8	2.3
Bear Lake	186	433	639	13.3	4.8
Blue Lake	238	300	378	2.6	2.6
Boardman	310	903	1076	19.1	1.9
Clearwater	884	1531	1959	7.3	2.8
Cold Springs	321	942	1073	19.3	1.4
Excelsior	232	580	714	15.0	2.3
Garfield	214	366	596	7.1	6.3
Kalkaska	1964	3544	4269	8.0	2.0
Oliver	136	241	291	7.7	2.1
Orange	258	792	885	20.7	1.2
Rapid River	249	581	746	13.3	2.8
Springfield	280	739	871	16.4	1.8

This hypothesis was tested between decades and at all spatial scales. One-tailed matched pairs *t* tests were used to test for a significant mean decrease between values of annual rate of change in APS. If the average rate of parcelization was significantly greater during one decade than the other, then it should be interesting to see if changes in forest cover followed the same trend.

4.3.4: Location analysis.

Determining the urban extent of a city is useful because it can provide insight into how a parcel of land may be used given its location with respect to the city. For example, a parcel of land located within the urban extent of a city (e.g., near to the city center) will tend to be used for urban purposes (i.e., commercial). Conversely, a parcel of land located beyond the urban extent of a city (e.g., farther away) will tend to be used for non-urban purposes (i.e., forest land). Lands used for urban purposes are usually more developed than non-urban lands and are often associated with higher population and road densities, and thus are more accessible to goods and services. Such higher densities are, in turn, associated with land covers that replace or displace natural cover types. Therefore, areas that become urbanized over time may exhibit decreases in natural land covers and increases in human dominated land covers. According to Thrall (1987), the urban extent of a city can be characterized by a useful rule-of-thumb, such as a specific population density. Those areas above a specific population density threshold can be considered urban areas while those below can be considered either non-urban or transitional. A rough estimation of the urban/non-urban interface can also be made by substituting parcel size for population density, which in this case assumes (1) one household exists per parcel, and (2) areas with smaller average parcel sizes are associated with higher population densities. For example, areas with average parcel sizes above a specified threshold can be considered non-urban while those areas with averages below the same threshold can be considered urban.

In order to characterize land consumption around Traverse City, I divided each parcel landscape into several distance bands of equal width and calculated an APS index value for each. Each band radiated from the geometric center of Traverse City. The spatial pattern of land consumption radiating from Traverse City can be visualized by plotting calculated index values against the middle distance value of each band and interpolating index values between points.

In order to estimate changes in the extent of urban land uses around Traverse City, I compared each APS value to a threshold value of 4.047ha (10 acres). I arbitrarily chose a parcel size threshold value of 4.047ha because this value has been used by Michigan lawmakers to distinguish lands available for development from lands unavailable (MI Plat Act of 1929 and MI PA 288 of 1967). Starting from the center of the city and moving outward, the urban extent is marked at the first distance at which average parcel size values exceed the threshold value.

Movement of the urban extent can be tracked over time by plotting this relationship for several successive dates and observing changes in the calculated intersection.

Should results indicate the urban extent of Traverse City increased over time, those areas that came under urban pressures may have experienced decreases in forest cover and increases in forest fragmentation. Conversely, should the urban extent of Traverse City have decreased over time, those areas relinquished from urban pressures may have experienced increases in forest cover and decreases in forest fragmentation. Population figures reported for Traverse City from 1970 to 1990 (see Figure 4.1) indicate a negative population growth trend. So, given this trend and the decreasing population densities associated with it, I suspect the urban extent of Traverse City decreased over time and subsequently, fragmentation decreased in the relinquished areas.

As stated in Section 3.5, the study area does not meet all of the assumptions required by the CTLR. Therefore, graphs that describe the radial distribution of average parcel sizes and the urban extent of Traverse City are used only to characterize change on the landscape. No formal hypothesis was made during this portion of analysis because no effort was made to control the effects that unsatisfied assumptions would have on subsequent results.

4.3.5: Spatial analysis.

According to Brown (unpublished manuscript), the spatial patterns of average parcel sizes and parcelization rates across the region can reveal...

> "...(a) spatial organization in the relative degree of parcelization on a regional scale; and / or (b) the influence that space has on the process of parcel subdivision. Such information can be used to form spatially explicit hypotheses about the causes of regional-scale patterns of parcelization and changes in parcelization"

Brown's (unpublished manuscript) observations are relevant to my research because I have also been interested in determining the influence that space has on both land ownership parcelization and forest cover fragmentation. Should estimates of parcelization and forest fragmentation exhibit similar spatial structures such a spatial coincidence might serve to further support a link between the two phenomena. Also, if the coincidence of spatial structures is examined at multiple scales, strong correlations between structures observed at one scale, relative to others, may indicate at which scale(s) landscape processes were operating.

The spatial structure of parcelization was examined using spatial autocorrelation techniques. Spatial autocorrelation is a measure of the similarity of objects or phenomena that are separated by a specified distance. An object or phenomenon can have a least two types of descriptive elements; aspatial and spatial attributes. For this study, spatial autocorrelation measures the relationship between the values of the aspatial attributes (average parcel size and annual rate of parcelization) of townships, sample sites, and sections at specified distances between townships, sample sites, and sections, respectively. Spatial autocorrelation indices are useful in this analysis because a single value is used to describe spatial distributions of parcel sizes and parcelization rates. The Moran statistic (Moran, 1948), also known as Moran's I, was used to measure spatial autocorrelation within the data. Moran's I represents spatial autocorrelation along a continuum from -1 to 1. Values approaching 1 indicate positive correlation meaning places near to each other are more similar than places far from each other. Values approaching -1 indicate negative correlation meaning places near to each other are more dissimilar than places far from each other. Values of zero or near zero indicate that the aspatial variable is not spatially distributed in a manner significantly different from random. The strength of the Moran statistic can be tested for statistical significance by comparing the calculated value to the mean and variance of a critical sampling distribution.

Brown (unpublished manuscript), in his spatial analysis of parcel size changes, suggested that spatial autocorrelation...

> "...might be expected in the pattern of parcelization at short distances, because the same characteristics that make one site more favorable for parcel subdivision might be expected to hold for a nearby site. Furthermore, the favorability of a site might have more spillover effects on nearby sites. For example, if a site has a large lake in it that attracts parcel subdivision, then a nearby site might also experience increased parcel subdivision because it is near, but not on, that lake. Decreased autocorrelation might be expected to accompany increasing distance separation, or lag, between sites as such spillover effects are diminished. Aside from this simple relationship between spatial autocorrelation and distance, the actual form of the correlogram can yield useful

> information about the scale of the process (i.e., at what distances does autocorrelation become insignificant?) and the underlying cause of the pattern."

The same observations hold true for the data in this study as well as the landscapes they represent.

A correlogram can be calculated by partitioning the range of distances separating sampled units into distance bands. By plotting the calculated values of Moran's I for each distance band against the values of the midpoint of each band, the spatial structure of parcelization can be visualized. In this technique, the Moran statistic is not necessarily indicative of similarities between values near or far but, rather, between values separated by a specific range of distances.

Brown (1997) constructed correlograms in his analysis of sampled parcel data. He reported specific autocorrelation values that described the spatial distribution of average parcel size for sample sites separated by distances up to 600 kilometers apart. Although Brown (1997) was able to identify a regional spatial structure that included an initial diameter of 60 kilometers, he was unable to observe structures at finer scales due to his sampling strategy. My research design allows for spatial structures of parcelization to be examined of scales finer than Brown's (1997), and equal to and finer than the basic political units charged with land use planning, zoning, and development responsibilities.

Spatial correlograms were calculated in order to describe the influence of distance, without respect to direction, on the similarity of sampled units in terms of average parcel sizes and annual rates of parcelization. By utilizing a multi-scaled approach, I had hoped to identify at which scale, perhaps, at which political scale, the pattern of parcelization was most evident. Rather than formally testing the existence of a specific spatial lag, I constucted correlograms in order to explore and summarize the overall existence of pattern in my attribute data. I wanted to answer three basic questions regarding each parcel dataset and the temporal changes between them. The three questions were:

a. At what distance did spatial autocorrelation become insignificant?
b. Did estimates of average parcel size and parcelization exhibit any periodic structure or particular spatial lags?
c. If a periodic structure did exist, at what scale(s) was it most evident?

If I could identify at what distance and at what scale changes in parcelization formed patterns on the landscape, I might then be able to use such clues to infer what landscape process(es) operated during that time.

Spatial autocorrelation techniques are subject to many rules governing statistical appropriateness. Due to the lack of appropriate sample sizes necessary for variance-based statistical analysis ($n \geq 30$) (McGrew Jr. and Monroe, 1993) at the region (n=1) and county (n=3) levels, spatial autocorrelation indices were calculated only for the township (n=33), sample site (n=186), and section (n=1678) level analyses

4.4: Forest data.

Satellite data are commonly used for forest classification and mapping. By superimposing satellite images taken at different dates, land cover change can be detected and rates of change calculated (Iverson, *et al.* 1989). When such satellite images are also incorporated into a GIS, lengths, areas, spatial coincidences, and proximities of natural features can be derived (Johnson, 1990). Using a GIS to manipulate satellite data allows users the ability to efficiently sample landscapes at multiple scales in order to gain insight into landscape processes.

4.4.1: Collection.

I collected three pairs of available satellite imagery that cover the study area for the approximate years 1973, 1985, and 1991. Each satellite image has been registered, georeferenced, and distributed as part of the North American Landscape Characterization (NALC) data set at a spatial resolution of 60 meters (Lunetta, *et al.*, 1998). Slight registration errors were detected and corrected using PCI ImageWorks (PCI, Richmond Hill, Ontario) workstation software and known UTM coordinate system information obtained for regional road networks stored in vector GIS format (MIRIS, 1978). Appendix B includes a metadata description of the satellite images used for this analysis.

4.4.2: Image processing.

Two options are generally available for classification of areas larger than or more than one satellite image. In one method, each scene is classified individually and resulting class maps can then be mosaiced. This method can produce abrupt boundaries between mapped classes as an artifact of the seam joining the two original images. Such abrupt boundaries can be problematic during calculation of common landscape indices. (Landscape indices and metrics are discussed later in this chapter.) Boundaries between land cover types are thought of as important ecological features in the landscape ecology literature (Forman and Godron, 1986). Therefore, false edges in landscape data can bias subsequent ecological analysis. The second method, and the one chosen for this experiment, results in a seamless class map by mosaicing raw image pairs prior to classification.

The histogram matching method of mosaicing adjacent images compares a 'slave' image to an adjacent 'master' image (Jensen, 1996). This method has been used in recent research (Homer *et al.*, 1997; Vogelmann *et al.*, 1998) and its ease of use and reasonable results makes histogram matching an efficient option. In the process of histogram matching, regions of spatial overlap are selected and the distribution of brightness values in the slave image is normalized to match the distribution of brightness values in the master image. This normalization, or matching, is carried out for each spectral band.

Before each pair of scenes could be matched and mosaiced, however, all clouds and cloud shadows needed to be removed. Clouds and cloud shadows often produce extreme brightness values in visible light bandwidths. Such extreme values are statistical outliers and can perturb the histogram normalization process by exaggerating the observed distribution of brightness values within each visible light image band. Clouds were identified and removed through on-screen polygon digitizing according to their popcorn shapes and corresponding displaced shadows. The cloud and cloud-shadow polygons were then used to "mask" the images, thus removing pixel values associated with these features. In an effort to further reduce the amount of non-essential variation between corresponding histograms, each individual scene was clipped by the areal extent of the study area plus a one-mile buffer zone. This clipping discarded unwanted variations in brightness values representing waves in Great Lakes Huron and Michigan, as well as those variations induced by real landscape changes outside of the area of interest.

After each pair of masked and clipped images were histogram matched and mosaiced, a composite cloud mask, which was generated by aggregating all clouded areas within all six images, was used to mask the three resultant image mosaics. This masking was done in order to maintain a consistent area of analysis throughout the experiment.

4.4.3: Image classification.

My primary remote sensing task was to identify and distinguish all forested areas from non-forested areas. I used Vogelmann's (1995) research, which made use of Landsat MSS data to identify forested areas in New England, to guide my own classification scheme. My target classification scheme included five classes: forested areas, not forested areas, open water, clouds, and background.

The ISODATA clustering algorithm (Tou and Gonzalez, 1977) was used to identify statistically homogenous areas within each landscape mosaic. Like other unsupervised image classification techniques, this numerical operation was used to search for "natural groupings of the spectral properties of pixels" (Jensen, 1996:231) that I could ultimately label into land cover classes of interest. The ISODATA algorithm is an iterative technique that partitions *n*-dimensional image space into homogenous groups, or clusters, along calculated mean vectors by averaging digital numbers in each cluster across several spectral channels. For all iterations past the initial seeding, each mean vector is statistically adjusted by reassigning each pixel to the nearest cluster mean in n-dimensional space. Several pre-specified parameters, like cluster size and separability, control the pixel assignment and iteration processes. Then, each cluster is recalculated. The process continues until changes within the cluster set fall below a set of pre-determined tolerances. At that point, the algorithm converges upon a final cluster solution. In this experiment, four image bands, plus a fifth Normalized Difference Vegetation Index (NDVI) band, were used as inputs for each image. The NDVI, a mathematical combination of MSS bands 2 and 4 (Jensen, 1996:181) has been found to be a sensitive indicator of the presence of green vegetation (Lillesand and Kiefer, 1994:506). Vegetated areas, like trees and forest canopies, will generally yield higher NDVI values than bare soils, urban surfaces, water, and clouds. The parameter values used to control the ISODATA algorithm are outlined in Appendix C. Each process converged on a solution set of 72 clusters.

Subsequent to cluster analysis, I used three sets of sixteen aerial photograph mosaics (each set was obtained for the approximate dates 1970, 1980, and 1990) to aide me in cluster identification and accuracy assessment. The photos had already been scanned into digital form, georeferencd, and mosaiced into three-mile by three-mile images corresponding to the sample areas in Crawford and Grand Traverse Counties used by Brown and Vasievich (1996). I divided each temporal set of photographs into two subsets of eight by maximizing the geographic extents covered by each. The first subset for each date was used to identify and classify clusters and assign them to historic land cover types. The second subset was set aside for use in testing the quality of my final classification maps. By digitally 'linking' each photograph to its corresponding ISODATA output image, I could be confident about the positional accuracy of land covers identified in the photographs and the image clusters that were spatially associated with them. Appendix D includes a metadata description of the three sets of sixteen aerial photograph mosaics used. Also, Appendix E has been included to provide the reader with a review of common accuracy assessment techniques and quantitative descriptions of my classified images. A water mask was created using published 1:100,000 Digital Line Graph hydrography data (U.S. Department of the Interior, 1993) in order to remove pixels associated with water from each classified image. I concede that, in reality, open water boundaries are rarely static in nature - even over geologically short ten and twenty year periods. However, I assumed constancy of the presence and extent of open water within my study area in order to isolate changes only in forested and non-forested land covers.

4.4.4: Temporal analysis.

Forest cover data were necessarily partitioned into private and non-private land cover categories because the APS index is a measure of parcel subdivision on private lands *only* and one of my objectives was to compare relative changes in parcelization to relative changes in forest fragmentation. For this experiment, all references to changes in forest cover and forest fragmentation are limited to changes observed on only privately owned lands. Classified imagery was converted from PCI image (raster) to Arc/Info polygon (vector) format. Percent forest cover estimates were calculated from each classified coverage for sample units at all spatial scales. Percentage forest cover is defined as the sum of privately owned forest polygon areas divided by the sum of all non-water and non-cloud, private areas. Changes in percent forest cover were calculated for each decade and the entire eighteen-year period. I note here that the amount of land as private remained very stable over the entire time frame. Therefore, calculated changes in percent forest cover can be attributed to changes in forested area (the numerator) and not to changes in the amount of land as private (the denominator). Percentages and rates of change were examined in an effort to answer the question: Has privately owned forest cover changed over time and if so, how?

Three possible results for each scale of analysis are:

a. the extent of privately owned forest land has decreased over time
b. the extent of privately owned forest land has not changed over time
c. the extent of privately owned forest land has increased over time

As stated in Section 2.1, a recent forest inventory analysis reported a six percent increase in total forest land area between the years 1980 and 1993 for the NLP (Leatherberry, 1994). Conversely, as reported in Section 3.3, Michigan planning officials have expressed concern about observed occurrences of forest fragmentation (Wyckoff, 1995). I tested the data to uncover what had really happened because each of these sources has advocated seemingly different views of recent forest changes. My third and fourth hypotheses were:

Hypothesis III

H_1: the average percentage of private lands as forested changed over time

H_0: the average percentage of private lands as forested did not change over time

Hypothesis IV

H_1: the annual rate of change in percent forest cover has changed over time

H_0: the annual rate of change in percent forest cover has remained the same over time

These hypotheses were tested between decades and at all spatial scales. Two-tailed matched pairs *t* tests were used to test for significant difference between mean values of percent forest cover at each time and for significant difference between the mean values of annual rate of change in percent forest cover ever each time step.

4.4.5: Landscape patterns and metrics.

The use of landscape metrics or landscape indices is common for quantifying landscape patterns. Landscape ecology is based upon the premise that landscape patterns are indicative of ecological processes (Forman and Godron, 1986; Turner, 1989; Gustafson, 1998) and quantitative metrics allow measurable links to ecological processes to be determined (Frohn, 1998).

In the landscape ecology literature, spatially distinct contiguous areas within a landscape class are referred to as patches. Patches can be quantitatively described in terms of size, shape, interior core area, and complexity. Much research has been done that has utilized several or many such landscape metrics (McGarigal and Marks, 1995; Ritters *et al.*, 1995; Li and Reynolds, 1993;

Baker and Cai, 1992; Milne, 1991; Turner and Gardner, 1991; and Forman and Godron, 1986).

Studies of forest fragmentation often use metrics to describe interior core areas and edge effects (Fahrig and Merriam, 1994: Merriam and Wegner, 1992: Villard, 1992). Interior core areas, sometimes referred to as interior habitat areas, are internal patch areas where some natural species and ecosystems can function independently and better sustain themselves. These interior areas contain requisite energy, nutrients, materials, and gene pools necessary for self-perpetuation. Edges are portions of an ecosystem (forest patch) near the perimeter where influences of surrounding areas prevent natural interior environmental conditions (Forman, 1995) and can be considered habitat by other species. Those forest areas influenced by the effects of non-forest edges are often called disturbed forest areas. Thus, patch size and shape can influence population dynamics and survival as two patches of the same area but with different amounts of edge may effect core areas of differing quality and species composition (Saunders *et al.*, 1985; Saunders *et al.*, 1991).

Gustafson (1998), however, is critical of the current set of landscape metrics often used in the landscape ecology literature and of the lack of any means to interpret them consistently. He stated, "[t]here is seldom a one-to-one relationship between index values and pattern (that is, several configurations may produce the same index value)" (p.150). In the same paper he argued...

> "[v]ery few pattern indices produce values that are useful by themselves. Their most instructive use is in comparing alternative landscape configurations, either the same landscape at different times or under alternative scenarios, or different landscapes represented by using the same mapping scheme and at the same scale" (p.152).

So, I have found it necessary to construct a landscape index of my own that could be (1) useful by itself, (2) useful for describing conditions of forest fragmentation, and (3) have a direct relationship with degrees of fragmentation. The core fragmentation (CF) index can be derived with the following equation, which is expressed here in condensed terms:

$$CF = \frac{CORE_{max} - CORE_{obs}}{CORE_{max}}$$

The CF index can be interpreted as the proportion of the potential core area ($CORE_{max}$) of a patch that is not core area ($CORE_{max}$ - $CORE_{obs}$) because of shape induced edge effects. The index is constrained between zero and one, has a direct relationship with core area fragmentation, and is useable on its own. Calculated CF values approaching a value of one indicate a highly fragmented landscape with all forest areas being influenced by edge effects. Urban forests, with few core areas would generally fit into this category. Calculated CF values approaching zero indicate an unfragmented forest area subjected minimal edge effects. Such areas would include the interior areas of very large forest stands. Appendix F contains a detailed description of the heuristic used to calculate the CF index.

As mentioned above, Michigan planning officials have hypothesized increases in forest fragmentation. In order to test the validity of these observations, on a regional scale, I posed my fifth and sixth hypotheses:

Hypothesis V

H_1: Forest fragmentation has increased over time.

H_o: Forest fragmentation has not increased over time.

Hypothesis VI

H_1: The annual rate of change in forest fragmentation has increased over time.

H_0: The annual rate of change in forest fragmentation has not increased over time.

These hypotheses were tested between decades and at all spatial scales. One-tailed matched pairs *t* tests were used to test for significant mean difference between estimates of forest fragmentation and between estimates of annual rate of change in fragmentation.

4.4.6: Location analysis.

In order to describe the distribution of forest cover and forest fragmentation with respect to distance from Traverse City, I calculated percent forest cover and the CF index for each of the distance bands radiating from Traverse City as specified in Section 4.3.4. By plotting the calculated values of percent forest cover and the CF index for each distance band against the value of the midpoint of each band, the spatial structure of forest cover and forest cover change around

Traverse City can be visualized. The results of this exploratory experiment were then compared to the results calculated for Section 4.3.4 in order to observe and characterize any coincidence or dissimilarity.

As stated above, should results indicate that the hypothetical radial extent of Traverse City increased over time, those areas that have become urban might reasonably be expected to have exhibited decreases in forest cover and increases in forest fragmentation as human dominated land covers replaced more natural land covers. Conversely, should the radial extent of Traverse City have decreased over time, those areas relinquished from urban pressures might be expected to have exhibited increases in forest cover and decreases in forest fragmentation as trees were allowed to regenerate.

4.4.7: Spatial analysis.

The spatial structure of calculated CF indexes and annual rates of fragmentation were also examined using spatial autocorrelation techniques in the same manner described in Section 4.3.5. Spatial correlograms were calculated and graphed in order to describe the influences of distance on the similarity of sampled units in terms of CF values and annual rates of change in CF values. I wanted to answer three basic questions regarding each forest cover data set and the temporal changes between them.

The three questions were:

a. At what distance did spatial autocorrelation become insignificant?
b. Did estimates of forest fragmentation exhibit any periodic structure or particular spatial lags?
c. If a periodic structure did exist, at what scale(s) was it most evident?

Again, by utilizing a multi-scaled approach, I had hoped to identify at which scale(s) the pattern of forest fragmentation is most evident. Since I had found no theoretical or practical basis for the existence of a particular spatial lag, this portion of my analysis was also exploratory in nature. Examining the spatial structure of fragmentation is of interest because such an analysis has the potential to reveal spatial patterns that may have been similar to those exhibited by average parcel sizes and parcelization. Should the two phenomena be similarly distributed across space with respect to time, such results would provide additional evidence supporting the link between land ownership subdivision and forest cover changes.

4.5: Summary.

I have outlined a detailed approach to quantifying land ownership parcelization and forest cover fragmentation using basic and spatial statistical techniques. Attention was paid to the collection and preparation of accurate and valid data with respect to: (1) successful theories and methods found in the literatures of geography, remote sensing, and landscape ecology, (2) meeting the assumptions of statistical appropriateness, (3) a basis in logic and common sense, and (4) answering my five basic research questions. Geographic information tools were used to capture and store the necessary data and to provide an effective interface for querying and analyzing landscape states and patterns of change. Quantitative methods were used to allow measurable links to ecological processes to be determined (Frohn, 1998).

CHAPTER 5: RESULTS

5.1: Introduction.

This chapter presents results of basic and spatial statistical treatments of digitized land parcel data and remotely sensed forest cover data for Crawford, Kalkaska, and Grand Traverse Counties in Northern Lower Michigan. Quantitative measures of land ownership parcelization and forest cover fragmentation were calculated for three dates and analyzed at multiple scales. Spatial patterns of parcelization and fragmentation were examined. Also, images in this thesis are presented in color. However, most images should withstand black-and-white duplication without loss of content.

5.2: Scales of analysis.

Five spatial scales were used to analyze landscape data. The five scales were region, county, township, sample site, and survey section (see Section 4.2). Each sampling unit at the region, county, and township scales contained large areas of privately owned land and forested land covers. However, at the smallest scales (i.e., sample sites and survey sections) some observation units had to be removed from analysis because each lacked privately owned land area. Further, other sampled units contained only a very small number of parcels that, in aggregate, covered only a very small portion of the land area. In order to prevent changes in any one small parcel from leveraging an observation unit, I arbitrarily set a minimum threshold of 16.2 hectares (40 acres) of private land. Any sample site or survey section containing less than 16.2 hectares of privately owned land for any of the three dates was omitted from further study. The effects of the threshold altered the sample size of sample sites from 186 to 168 and reduced the survey section sample size from 1678 to 1176. Sample units that did not meet the minimum threshold criterion were generally located within interior regions of large public land areas.

Matched pairs *t* tests were used to test for significant mean differences between values measured for each set of sampling units for two dates. Changes measured at the region scale were accepted as significant changes during all hypothesis testing, therefore no *t* values were calculated for region level analyses. However, significance testing of landscape data sampled at smaller scales was done in order to ensure results and conclusions obtained from areal analysis were commensurate with region scale results and not characteristic of the units used to sample the landscape (Openshaw, 1984). A 95 percent confidence interval was used to assess the significance of all statistical tests. The significance of this interval meant that only a 5 percent chance existed to falsely reject a null hypothesis due to random sampling error.

5.3: Parcel data - hypothesis I

I hypothesized that APS values had decreased over time based on results published by Brown and Vasievich (1996). The APS index (see Section 4.3.3) was used to estimate the average size of parcels for each sampled unit. Table 5.1 outlines APS index values calculated for each sample unit in the region, county, and township level analyses. In all but one case, the City of Grayling, APS values decreased over time. Review of the original plat map data revealed that almost all small tract areas mapped within the City of Grayling city limits in 1970 had been cartographically reclassified by the publisher into polygons associated with the incorporated city (the exceptions being public land areas, water bodies, and utility corridors) by 1980. Subsequently, no small tract areas were used in the calculation of the 1980 APS index and the resultant value did not measure their influence. No APS values were calculated for the City of Grayling and Traverse City for 1990 because all private parcels had been reclassified into city-owned parcels by 1990. Hence, each respective value was replaced with a 'NO DATA' entry in Table 5.1.

Because the number of cases in both the sample site and section level analyses are too numerous to outline here, Table 5.2 is provided to summarize changes in APS over time. As the numbers indicate in Table 5.2, many more areas experienced parcel subdivision (decreases) than experienced parcel aggregation (increases).

Table 5.1: Average parcel size estimates for political sampling units (ha).

County Township	1970	APS 1980	1990
Region totals	9.64	4.92	4.11
Crawford	5.65	3.30	3.03
Beaver Creek	7.77	3.95	3.15
Frederic	6.20	3.37	2.88
City of Grayling	3.38	7.03	NO DATA
Grayling	3.38	2.40	2.25
Lovells	6.81	4.33	3.89
Maple Forest	10.53	5.11	4.29
South Branch	5.57	3.02	3.26
Grand Traverse	12.18	5.77	4.27
Acme	10.79	6.29	4.32
Blair	11.75	4.98	3.68
East Bay	7.14	3.62	2.79
Fife Lake	16.88	5.62	5.38
Garfield	6.83	3.28	2.25
Grant	17.92	9.53	7.60
Green Lake	10.92	4.81	3.68
Long Lake	8.16	3.83	2.45
Mayfield	23.10	10.33	8.12
Paradise	22.53	7.82	6.47
Peninsula	6.86	4.90	3.04
Traverse City	0.71	0.36	NO DATA
Union	15.95	8.56	6.73
Whitewater	11.74	5.57	4.48
Kalkaska	10.71	5.40	4.77
Bear Lake	7.29	3.82	3.02
Blue Lake	5.36	3.99	3.03
Boardman	11.57	6.91	5.78
Clearwater	11.59	5.94	4.58
Cold Springs	6.53	3.17	2.90
Excelsior	12.37	6.34	5.31
Garfield	9.50	5.11	5.27
Kalkaska	9.87	5.12	4.52
Oliver	11.27	5.70	5.68
Orange	17.47	6.13	6.00
Rapid River	8.98	4.42	4.18
Springfield	13.03	6.50	5.69

Table 5.2: Summary of parcel size changes for small sampling units.

Scale	n	% Increase	% Decrease	% No Change
Sample sites				
1970 to 1980	168	6	94	0
1980 to 1990	168	15	85	0
Survey sections				
1970 to 1980	1176	19	77	4
1980 to 1990	1176	32	64	4

One-tailed matched pairs *t* tests were used to test for a significant decrease between sets of APS values measured at different times. This test was applied between dates and at all spatial scales. Table 5.4 highlights the test results.

Table 5.3: Average parcel sizes changes for all scales (ha).

	1970 to 1980			1980 to 1990		
Scale	1970	1980	%Change	1980	1990	%Change
Region	9.64	4.92	-49	4.92	4.11	-16
County	9.51	4.82	-49 *	4.82	4.02	-17
Township	10.29	5.20	-49 *	5.20	4.14	-20 *
Sample	13.79	6.91	-50 *	6.91	5.78	-16 *
Section	18.05	10.85	-40 *	10.85	8.07	-26 *

* Denotes statistical significance with 95% confidence.

For all tests but one, mean estimates of average parcel size were significantly less than those observed on the previous date. The regional average changed from 9.64 ha in 1970 to 4.92 ha in 1980 - a 49 percent reduction over the ten-year period. Average parcel sizes decreased again during the next ten years, but exhibited only a 16 percent reduction. Township, sample site, and survey section test results provided evidence to reject null hypothesis I for each of these scales. In the single test that I was unable to reject null hypothesis I (county level, 1980 to 1990) the calculated mean parcel size for 1990 (4.02ha) is less than that calculated for 1980 (4.82ha) but, not at the 95 percent confidence level. So, even though the county result could not meet the requirements for statistical significance, I found no reason to mitigate the results obtained from the other scales. Therefore, null hypothesis I was rejected. It can be stated that average parcel sizes decreased over time within the study area.

I should indicate here that the set of mean APS values presented in Table 5.3 reveals a large range of average parcel sizes calculated for each date across the different scales. For example, the 1970 section analysis produced a mean APS equal to 18.05 ha, a value almost twice the value calculated for the county average. Mean APS values appear inversely related to the size of individual landscape sampling units, therefore indicating a scale effect exists.

5.4: Parcel data - hypothesis II.

I hypothesized higher parcelization rates existed during the 1970s than during the 1980s because regional population growth rates peaked during the 1970s (see Table 4.1); Brown's ([unpublished manuscript] see Section 3.4) results suggest higher parcelization rates occurred during the 1970's; and Stewart (1994) indicated a strong seasonal home development trend existed during the

1970's. Average annual rates of change in APS were calculated between dates and for all spatial scales. Linear rates of change between dates were assumed. One-tailed matched pairs *t* tests were used to test for a mean decrease in average annual parcelization rates over time.

Table 5.4 lists average annual parcelization rates for each sample unit in the region, county, and township level analyses. Also listed in Table 5.4 are rankings associated with each township. High ranks (i.e. 1,2,3...) indicate relatively high parcelization rates. Conversely, low ranks (i.e. 30,31,32...) indicate relatively low parcelization rates. In every case but one, rates of change were greater during the 1970s than during the 1980s. Peninsula Township, Grand Traverse County proved the exception as the parcelization rate of this township increased slightly over time.

Individual cases used in both the sample site and section level analyses are too numerous to itemize so, Table 5.5 is provided to summarize, using percentages, how many sample sites and survey sections experienced the highest average annual parcelization rate for each decade. More areas experienced higher rates of parcel subdivision during the 1970s than during the 1980s. For example, two average annual parcelization rates were calculated for each sample site; one for the 1970's and one for the 1980's. Of 168 sample sites sampled, 90 percent had the highest average annual parcelization rate occur during the 1970's.

Table 5.4: Average annual parcelization rates for political units (ha/yr).

County	1970 to 1980		1980 to 1990	
Township	Rate	Rank	Rate	Rank
Region totals	-0.471		-0.074	
Crawford	-0.261		-0.023	
Beaver Creek	-0.425	16	-0.067	20
Frederic	-0.315	24	-0.041	22
City of Grayling	0.406	33	NO DATA	
Grayling	-0.108	31	-0.013	27
Lovells	-0.276	28	-0.036	23
Maple Forest	-0.602	8	-0.069	19
South Branch	-0.284	27	0.020	31
Grand Traverse	-0.583		-0.150	
Acme	-0.409	19	-0.197	2
Blair	-0.615	7	-0.130	8
East Bay	-0.320	23	-0.083	16
Fife Lake	-1.024	4	-0.024	25
Garfield	-0.323	22	-0.103	12
Grant	-0.763	5	-0.193	3
Green Lake	-0.555	11	-0.114	10
Long Lake	-0.393	21	-0.138	6
Mayfield	-1.161	2	-0.221	1
Paradise	-1.337	1	-0.136	7
Peninsula	-0.178	29	-0.186	4
Traverse City	-0.031	32	NO DATA	
Union	-0.671	6	-0.183	5
Whitewater	-0.561	10	-0.108	11
Kalkaska	-0.483		-0.057	
Bear Lake	-0.315	24	-0.073	18
Blue Lake	-0.124	30	-0.088	15
Boardman	-0.424	17	-0.102	13
Clearwater	-0.514	13	-0.123	9
Cold Springs	-0.306	26	-0.025	24
Excelsior	-0.548	12	-0.093	14
Garfield	-0.399	20	0.014	30
Kalkaska	-0.432	15	-0.054	21
Oliver	-0.507	14	-0.001	29
Orange	-1.031	3	-0.012	28
Rapid River	-0.415	18	-0.021	26
Springfield	-0.594	9	-0.074	17

Table 5.5: Decadal summary of parcelization rates for small sampling units.

		% Having highest rate of change (ha/yr) in decade		
Scale	n	1970's	1980's	No Change
Sample sites	168	90	10	0
Survey sections	1176	70	27	3

Table 5.6 highlights the results of the one-tailed matched pairs *t* tests. For all tests, mean parcelization rates were significantly greater during the 1970s than during the 1980s. Therefore, I rejected null hypothesis II for all scales and could state that the study area exhibited higher parcelization rates during the 1970s than during the 1980s.

Table 5.6 Parcelization rates and changes for all scales (ha/yr).

Scale	1970 to 1980	1980 to 1990	% Change
Region	-0.471	-0.074	-84
County	-0.442	-0.077	-83 *
Township	-0.471	-0.100	-79 *
Sample	-0.673	-0.104	-85 *
Section	-0.684	-0.251	-63 *

* Denotes a statistically significant change with 95% confidence.

I note here that the set of average annual parcelization rates presented in Table 5.6 reveals a large range of values for each date and across scales. For example, the 1970 to 1980 section-level analysis produced a rate equal to -0.684 ha/yr, a value much larger than the value calculated for the region (-0.471 ha/yr). Average annual parcelization rates appear to be inversely related to the size of individual landscape sampling units, therefore indicating a scale effect exists. This scale effect is similar to the scale effect observed in Section 5.3.

5.5: Parcelization - location analysis.

According to Thrall (1987)[1] and his CTLR, each additional increment in distance from a city center should result in an increase (at a decreasing rate) in the quantity of land consumed per household. Therefore, by assuming each household exists on one and only one parcel on land, the radial pattern of land consumption around a city can be represented by the theoretical function graphed in Figure 5.1 (after Thrall, 1987). The shape of the theoretical function can serve as a general baseline with which actual consumption functions can be compared.

Actual land consumption functions were graphed for Traverse City by calculating APS index values for a set of concentric bands radiating from the geometric center of the City. The radial pattern of land consumption can be visualized by plotting calculated APS index values against distance band midpoints and interpolating index values between points (see Figure 5.2).

---

[1] Thrall (1987) is the latest in a series of researchers that have examined this spatial relationship between land consumption and household economic conditions (Alonso, 1964; Barlowe, 1978; Casetti, 1971; Muth, 1969; and Von Thünen, 1842).

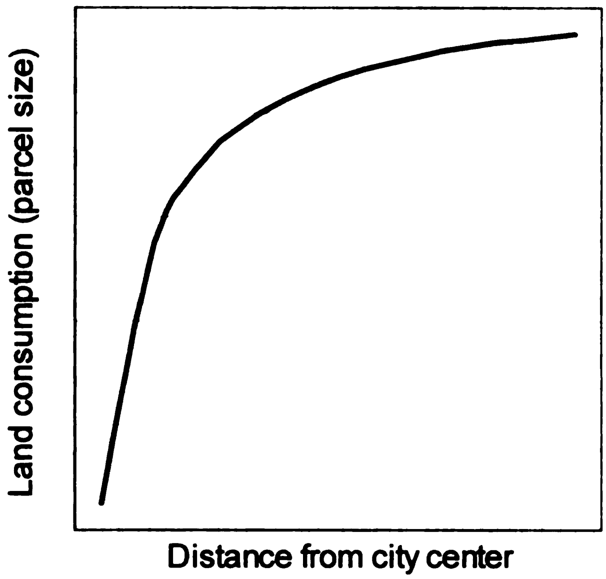


Figure 5.1: Theoretical land consumption function.

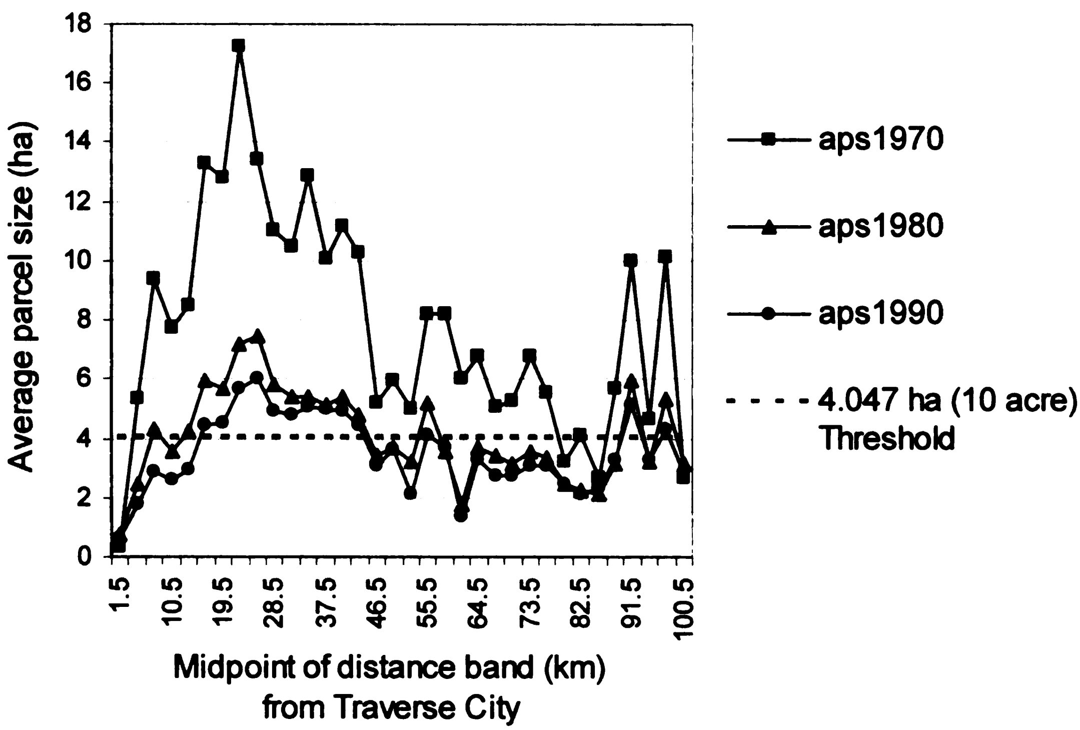


Figure 5.2: Actual land consumption functions for Traverse City.

For this exercise I assumed 4.047 ha (10 acres) to be the largest parcel size associated with the urban extent of Traverse City (see Section 4.3.4). By comparing APS values calculated for all 1970, 1980, and 1990 distance bands to the threshold value, I could determine the urban extent for each date. Table 5.7 lists APS index values for each band. Starting from the center of the city (distance = 0) and moving outward, Figure 5.2 clearly shows that the first distance at which average parcel size values exceeded the threshold value increased over time. In 1970, the first intersection occurred between the first and second bands. In 1980, the first intersection occurred between the second and third bands. In 1990, the intersection occurred between the fifth and sixth bands. Movement of this intersection away from the city suggests the urban extent of Traverse City increased over time. This extent increased even though Traverse City resident population decreased during the same period.

Also important are observable changes in slope of the land consumption function over time. The general decrease in slope indicates that the parcel density gradient around Traverse City became less steep and areas located farther away from the city became more densely subdivided over time. This trend suggests that places farther from Traverse City may have gained better access to the city and its amenities, or that proximity to the city became less important to new land owners over time. These reasons may explain why adjacent townships like Acme, East Bay, and Garfield experienced increases in resident populations during the same period that Traverse City experienced losses.

Table 5.7: Average parcel sizes for concentric bands around Traverse City (ha).

Band (km)	1970	1980	1990
0 to 3	0.339	0.727	0.633
3 to 6	5.363	2.476	1.762
6 to 9	9.347	4.319	2.897
9 to 12	7.707	3.567	2.623
12 to 15	8.487	4.226	2.925
15 to 18	13.287	5.960	4.453
18 to 21	12.821	5.649	4.486
21 to 24	17.274	7.218	5.649
24 to 27	13.433	7.438	6.022
27 to 30	11.002	5.795	4.913
30 to 33	10.484	5.417	4.825
33 to 36	12.890	5.373	5.064
36 to 39	10.064	5.149	5.001
39 to 42	11.152	5.373	4.936
42 to 45	10.295	4.796	4.454
45 to 48	5.225	3.388	3.106
48 to 51	5.925	3.691	3.649
51 to 54	4.974	3.203	2.128
54 to 57	8.224	5.191	4.128
57 to 60	8.216	3.555	3.712
60 to 63	6.033	1.793	1.374
63 to 66	6.750	3.720	3.272
66 to 69	5.086	3.419	2.734
69 to 72	5.295	3.153	2.711
72 to 75	6.748	3.588	3.092
75 to 78	5.510	3.373	3.070
78 to 81	3.244	2.446	2.439
81 to 84	4.079	2.239	2.129
84 to 87	2.684	2.112	2.358
87 to 90	5.665	3.163	3.271
90 to 93	9.962	5.921	5.125
93 to 96	4.662	3.212	3.255
96 to 99	10.159	5.306	4.284
99 to 102	2.692	3.131	2.776

Inspection of the APS-distance relationships in Figure 5.2 reveals two additional and important trends. First, APS values tended to decrease with increasing distance from the CBD beyond the 24 to 27 kilometer band. The basic CTLR discussed by Thrall (1987) does not account for such decreases as the model assumes (a) the existence of only one urban center within an isotropic landscape and (b) land consumption per household increases infinitely from that one center. Because average parcel sizes (a surrogate for land consumption) do not increase infinitely from Traverse City, and because the study area does contain other population centers (e.g., Village of Kalkaska and City of Grayling), the trends observed beyond the 27 kilometer distance band could have been produced by other central places operating on the landscape. And second, several points along each graph consistently fall below the threshold value through time, hence indicating lands used for urban purposes existed beyond the urban extent of Traverse City. Review of the original plat map data revealed several places that probably also serve as central places on this landscape. Most obvious is the City of Grayling in Crawford County. The location of City of Grayling, and the large military reserve surrounding it, explains the dip in average parcel sizes observed between 57 and 76 kilometers. The Town of Frederic is also located within this region - a town that nearly doubled in population from 1970 to 1980. However, most interesting are the potential central places that explain the dips between 45 and 54 kilometers, and 72 and 102 kilometers. Manistee Lake, a large inland lake, is located within the 45 to 54 kilometer region. Many small-tract areas surround this lake (and others near to it) and have grown in number and extent over time, thereby explaining the dip between 45 and 54 kilometers. Parcelization along the Au Sable River of Crawford County may explain the dip between 76 and 102 kilometers. The distance bands in this region contain many public land areas due north and south of the river. Therefore, it is easy to attribute parcelization along the Au Sable River to the observed dip in average parcel sizes because these areas were the only areas able to exhibit significant changes in land subdivision.

These additional findings are important because they suggest the important role natural features, like water bodies, play in attracting new landowners to an area. This role of attraction has been traditionally attributed to urban places and the human produced goods and services associated with them.

5.6 Parcelization - spatial analysis

Spatial autocorrelation statistics can be calculated to measure relations among locations separated by different distances, or lags. A spatial correlogram can be calculated as a series of autocorrelation statistics and "shows spatial autocorrelation as a function of spatial lags and allows autocorrelation at different spatial lags to be analyzed and compared" (Odland, 1988:p. 64).

Spatial correlograms illustrating the spatial patterns of average parcel size distributions and the distributions of land ownership parcelization rates were calculated. The correlograms describe the influence of distance, without respect to direction, on the similarity of values at various spatial lags. Correlograms were calculated for the township, sample site, and section level analyses. Individual values of Moran's I (a measure of spatial autocorrelation that is theoretically constrained between +/- 1), which define points along each autocorrelation function, were tested for statistical significance. Mean and variance estimates were calculated for each sampling distribution (see Griffith, 1987 and Odland, 1988 for complete descriptions of mean and variance estimate calculations for use in significance testing of the Moran statistic) and the calculated Moran coefficients were compared to critical values associated with the 95 percent confidence interval. Also, because "autocorrelation is a direct extension of classical correlation" (Griffith and Armhein, 1991:134) qualitative descriptions of autocorrelation values are similar to descriptions of classical correlation values. When individual Moran coefficients exceed +/- 0.7, then the relationship between values can be described as strong. When Moran coefficients tend between –0.3 and 0.3, the relationship between values can be described as weak with values near zero indicating no relationship. All other coefficients describe moderate relationships.

Observed peaks and patterns in graphed autocorrelation functions were used to describe the effects of distance on pattern at each time. Also, distances at which spatial patterns were statistically indiscernible from random patterns were used to infer the scale at which parcelization processes operated.

5.6.1 Townships

An interdistance matrix was calculated for all pairs of townships using the geometric center of each township as both a point of origin and destination. Uniform distance bands of 12,000 meters were used in this particular analysis in order to assure ample numbers of paired comparisons within each spatial lag. The interdistance matrix was reclassified into a binary weight matrix for each distance band. For example, all inter-township distances that fell between 0 and 12,000 meters were reclassified as 1's (signifying contiguity) while all others were reclassified as 0's (signifying no contiguity). The resultant binary weight matrix was then used as the contiguity matrix during the calculation of Moran's I for connected townships in the 0 to 12,000 meter distance band. Next, all inter-township distances that fell between 12,000 and 24,000 meters were reclassified as 1's (signifying contiguity) while all others were reclassified as 0's (signifying no contiguity). The new binary weight matrix was then used as the new contiguity matrix during the calculation of Moran's I for connected townships in the 12,000 to 24,000 meter distance band. This procedure was iterated for all other distance bands.

Table 5.8 lists calculated values of Moran's I for each distance band for the distribution of APS values. Figure 5.3 illustrates the results. Brown (unpublished manuscript) suggests positive spatial autocorrelation might be expected at shorter distances (see Section 4.3.5). The patterns depicted by functions graphed in Figure 5.3 are consistent with this expectation. With respect to the distribution of APS values, townships nearer to one another exhibited significantly greater similarities in average parcel sizes than townships located farther apart.

Table 5.8: Spatial autocorrelation results: township values of APS.

		Confidence Interval		Moran Statistic		
n	Midpoint	Upper	Lower	1970	1980	1990
30	6000	0.043	-0.112	0.547	0.404	0.517
33	18000	0.011	-0.073	0.037	-0.030	-0.008
33	30000	0.009	-0.071	-0.032	-0.051	-0.162
33	42000	0.017	-0.079	-0.113	-0.032	-0.153
33	54000	0.026	-0.089	-0.091	-0.073	-0.043
30	66000	0.042	-0.111	-0.373	-0.246	-0.161
22	78000	0.042	-0.137	-0.154	-0.115	-0.007
13	90000	0.092	-0.259	-0.125	-0.098	-0.022

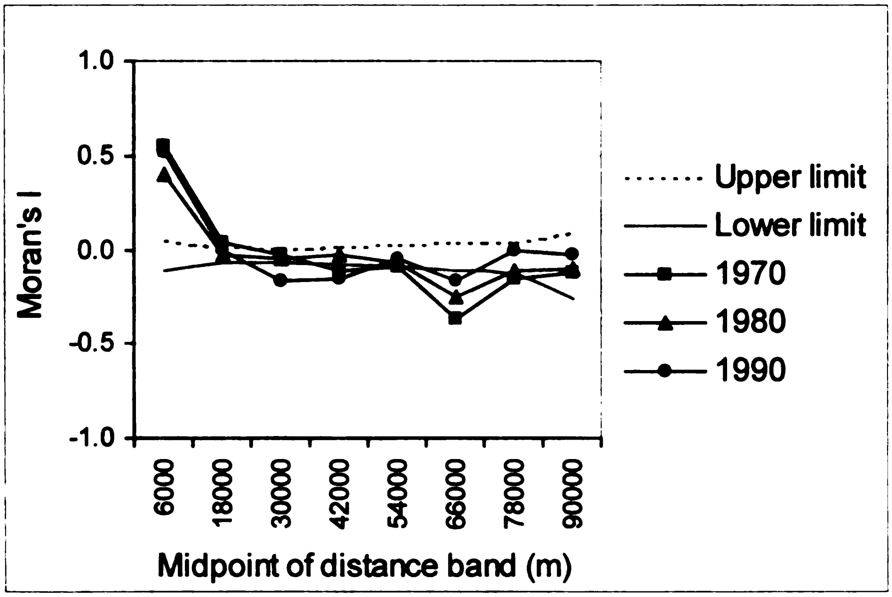


Figure 5.3: Spatial correlograms: township values of APS.

However, such similarity disappeared in the second spatial lag and an erratic and near-random spatial pattern persisted into the last lag. The overall pattern suggests that similarities between townships existed over only short distances. These results suggest some sort of simple adjacency or spillover effect existed. Also, negative autocorrelation that had existed within the 60 to 72 km distance band in the 1970s steadily became less distinguishable from random over time. As the lag within the 60 to 72 km band weakened, a new significant lag emerged within the 24 to 36 km distance band. Because negative spatial autocorrelation is associated with a spatial dissimilarity of values, one could infer dissimilar township characteristics became separated by shorter distances over time.

With respect to average annual parcelization rates, results indicate (see Table 5.9 and Figure 5.4) that positive autocorrelation existed at short distances for both time periods. The distance over which parcelization rates were positively autocorrelated extended from the second lag (12 to 24 km) during the 1970s into the third lag (24 to 36 km) during the 1980s. Also, negative spatial autocorrelation increased over time at greater distances as the spatial pattern of dissimilar rates of parcelization increased from a single lag (60 to 72 km) to all distances beyond 60 kilometers. However, when comparing values associated with spatial lags greater than 60 kilometers, the reader should be aware that such values increasingly reflect differences between Grand Traverse and Crawford Counties rather than differences across the entire landscape.

Table 5.9: Spatial autocorrelation results: township parcelization rates.

		Confidence Interval		Moran Statistic	
n	Distance	Upper limit	Lower limit	1970s	1980s
30	6000	0.043	-0.112	0.496	0.306
33	18000	0.011	-0.073	0.029	0.252
33	30000	0.009	-0.071	-0.050	0.167
33	42000	0.017	-0.079	-0.134	-0.011
33	54000	0.026	-0.089	-0.080	-0.317
30	66000	0.042	-0.111	-0.331	-0.290
22	78000	0.042	-0.137	-0.086	-0.383
13	90000	0.092	-0.259	-0.096	-0.612

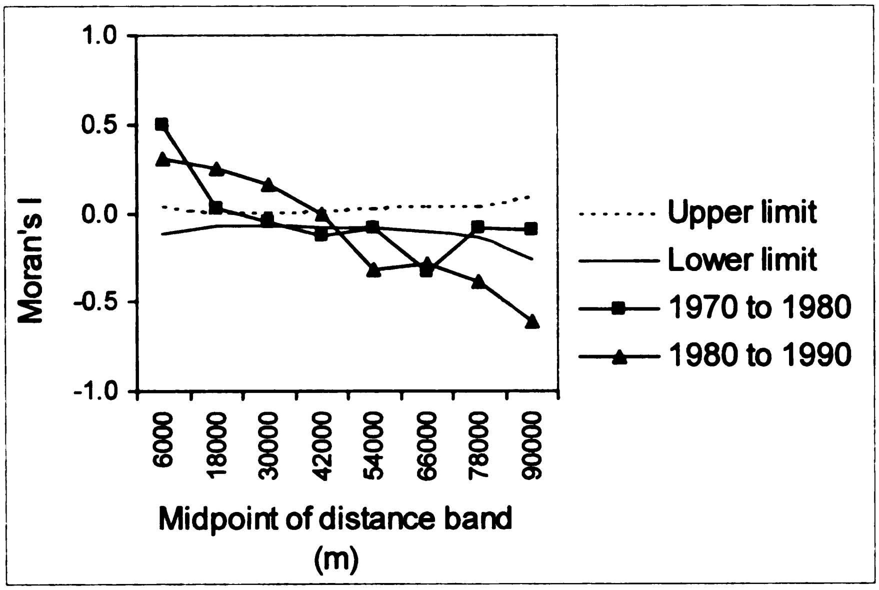


Figure 5.4: Spatial correlograms: township parcelization rates.

Such a polar comparison exists because interior townships, those townships located within Kalkaska County and geometrically centered within the study area, were systematically removed from Moran coefficient calculations as spatial lags were increased beyond 60 kilometers. Yet, these results are still useful as they do suggest that townships associated with Grand Traverse and Crawford County, respectively, became increasingly dissimilar over the twenty-year period. They also indicate a regional east/west trend had existed in the parcelization process. Visual inspection of the parcelization rate distribution revealed higher rates tended to occur in Grand Traverse County and lower rates tended to occur in Crawford County in both decades. These observations indicate a parcelization rate gradient existed with higher values occurring in the west and lower rates occurring in the east.

5.6.2: Sample sites.

An interdistance matrix was calculated for all selected sample sites (n=168) using the geometric center of each site as both a point of origin and destination. Binary contiguity weight matrices were constructed using the reclassification procedure discussed above (see Section 5.6.1). However, because each sample site was smaller than any township, I was able to partition the range of distances separating sample sites into uniform distance bands of 6000 meters. The use of shorter spatial lags provided for more detailed examinations of the spatial patterns of APS values and annual parcelization rates.

Table 5.10 highlights values of Moran's I calculated for each spatial lag. Figure 5.5 graphically illustrates the spatial correlograms calculated for each temporal distribution of APS values. For 1970 and 1980 dates, adjacent sample sites exhibited a significant similarity in average parcel sizes. Yet, such similarity disappeared in the second spatial lag and erratic and near-random patterns were observed into the last distance band. By 1990, the spatial pattern of average parcel sizes became nearly indistinguishable from random for all spatial lags - including the first lag where significant values were expected to have occurred. The lack of any significant and moderate measure of negative autocorrelation along the correlogram suggests no regional trend or periodicity in the parcel size distribution was detectable, at least not with this scale of analysis.

Table 5.10: Spatial autocorrelation results: sample site values of APS.

		Confidence Interval		Moran Statistic		
n	Midpoint	Upper limit	Lower limit	1970	1980	1990
167	3000	0.007	-0.019	0.212	0.325	0.025
168	9000	0.001	-0.013	0.028	-0.015	-0.009
168	15000	0.000	-0.012	-0.014	-0.015	-0.009
168	21000	0.000	-0.012	-0.032	-0.011	0.001
168	27000	-0.001	-0.011	-0.009	-0.004	-0.008
168	33000	-0.001	-0.011	-0.014	-0.009	-0.009
168	39000	0.000	-0.012	-0.035	0.014	-0.007
168	45000	0.000	-0.012	-0.029	-0.001	0.001
168	51000	0.000	-0.012	0.012	-0.006	-0.001
168	57000	0.002	-0.014	-0.041	-0.008	0.000
165	63000	0.002	-0.014	-0.026	-0.016	-0.003
148	69000	0.002	-0.016	0.008	-0.004	-0.003
128	75000	0.002	-0.017	0.030	0.013	0.005
112	81000	0.003	-0.021	0.024	0.000	-0.004
92	87000	0.004	-0.027	-0.013	-0.008	-0.008
72	93000	0.004	-0.032	-0.020	-0.012	-0.020
56	99000	0.006	-0.042	-0.032	-0.024	-0.031

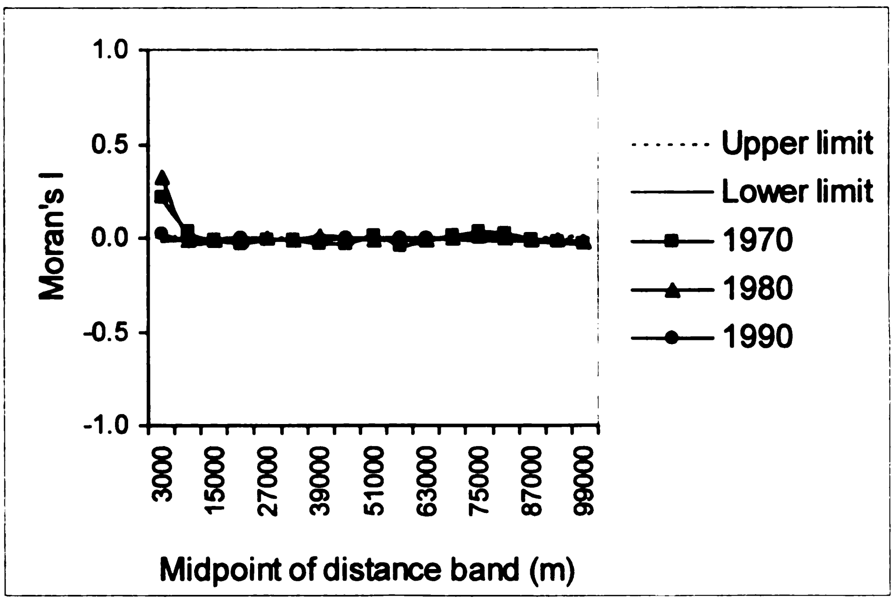


Figure 5.5: Spatial correlograms: sample site values of APS.

The distribution of parcelization rates exhibited no spatial pattern for either time period. Table 5.11 outlines the results and Figure 5.6 illustrates both correlograms. Even though a very weak positive autocorrelation coefficient did emerge within the first lag during the 1980s, the strength of the relationship was so weak that its presence provides little power to explain the pattern. I note here that both temporal functions contain many significant coefficients. However, because almost all coefficient values exist within a range between –0.05 and 0.05, each function can only be described as very weak. I believe these correlograms collectively betray no interpretable spatial patterns or relationships.

Table 5.11: Spatial autocorrelation results: sample site parcelization rates.

		Confidence Interval		Moran Statistic	
n	Midpoint	Upper limit	Lower limit	1970s	1980s
167	3000	0.007	-0.019	0.007	0.045
168	9000	0.001	-0.013	-0.019	0.006
168	15000	0.000	-0.012	-0.006	-0.003
168	21000	0.000	-0.012	-0.022	-0.002
168	27000	-0.001	-0.011	-0.007	-0.016
168	33000	-0.001	-0.011	-0.006	-0.025
168	39000	0.000	-0.012	0.026	-0.023
168	45000	0.000	-0.012	-0.035	0.001
168	51000	0.000	-0.012	0.012	0.032
168	57000	0.002	-0.014	-0.046	0.048
165	63000	0.002	-0.014	0.012	-0.001
148	69000	0.002	-0.016	0.029	0.010
128	75000	0.002	-0.017	0.003	-0.061
112	81000	0.003	-0.021	0.004	0.010
92	87000	0.004	-0.027	-0.054	-0.034
72	93000	0.004	-0.032	0.017	-0.066
56	99000	0.006	-0.042	-0.010	-0.072

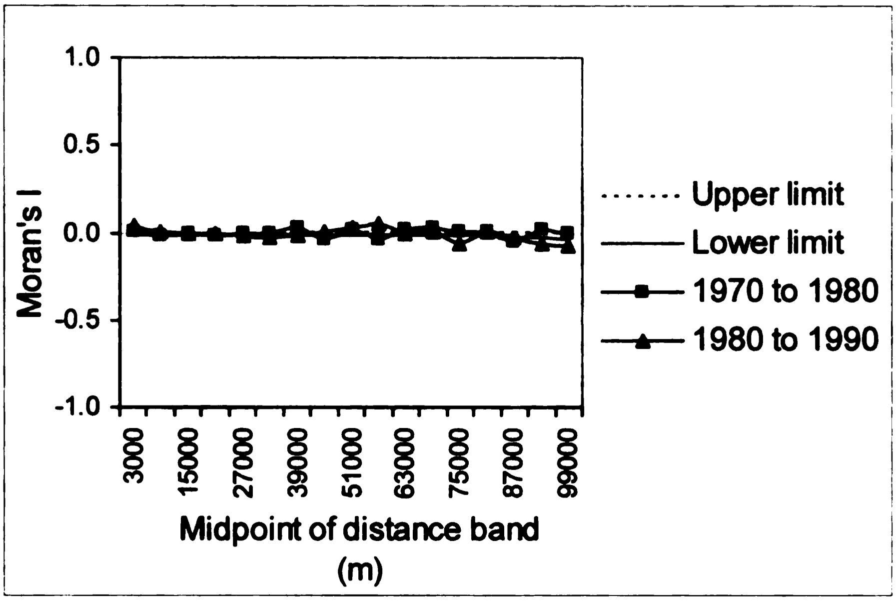


Figure 5.6: Spatial correlograms: sample site parcelization rates.

5.6.3: Survey sections.

An interdistance matrix was calculated for all selected sections using the geometric center of each section as both a point of origin and destination. Uniform distance bands of 3000 meters were used to reclassify the interdistance matrix into the appropriate set of binary contiguity weight matrices. Tables 5.12 and 5.13 highlight the autocorrelation results for APS values and parcelization rates, respectively. Also, Figures 5.7 and 5.8 illustrate each set of correlograms, respectively.

Table 5.12: Spatial autocorrelation results: survey section values of APS.

		Confidence Interval		Moran Statistic		
n	Midpoint	Upper limit	Lower limit	1970	1980	1990
1172	1500	0.001	-0.003	0.245	0.189	0.214
1172	4500	0.000	-0.002	0.098	0.095	0.122
1169	7500	0.000	-0.002	0.087	0.077	0.110
1169	10500	0.000	-0.001	0.058	0.059	0.082
1168	13500	0.000	-0.001	0.038	0.038	0.054
1166	16500	0.000	-0.001	0.029	0.019	0.036
1164	19500	0.000	-0.001	0.013	0.005	0.014
1162	22500	0.000	-0.001	-0.006	-0.015	-0.016
1160	25500	0.000	-0.001	-0.013	-0.016	-0.025
1159	28500	0.000	-0.001	-0.015	-0.011	-0.032
1157	31500	0.000	-0.002	-0.018	-0.020	-0.040
1155	34500	0.000	-0.002	-0.031	-0.022	-0.039
1153	37500	0.000	-0.002	-0.027	-0.023	-0.044
1151	40500	0.000	-0.002	-0.024	-0.022	-0.047
1149	43500	0.000	-0.002	-0.010	-0.010	-0.030
1147	46500	0.000	-0.002	-0.035	-0.029	-0.037
1146	49500	0.000	-0.002	-0.042	-0.033	-0.038
1144	52500	0.000	-0.002	-0.031	-0.025	-0.030
1142	55500	0.000	-0.002	-0.029	-0.035	-0.033
1140	58500	0.000	-0.002	-0.014	-0.013	-0.004
1106	61500	0.000	-0.002	-0.024	-0.014	0.009
1050	64500	0.000	-0.002	-0.019	-0.018	0.010
989	67500	0.000	-0.002	-0.028	-0.010	0.003
927	70500	0.000	-0.002	0.000	-0.019	-0.018
864	73500	0.000	-0.002	0.008	0.008	0.027
803	76500	0.000	-0.002	0.009	0.002	0.033
740	79500	0.000	-0.003	0.016	0.024	0.035
676	82500	0.000	-0.003	0.001	0.008	0.010
611	85500	0.000	-0.003	-0.001	-0.008	-0.014
552	88500	0.000	-0.004	0.016	0.014	0.015
491	91500	0.000	-0.004	0.013	0.017	0.019
436	94500	0.000	-0.005	-0.013	0.022	0.020
376	97500	0.000	-0.005	0.006	0.031	0.017
319	100500	0.000	-0.006	0.003	0.018	0.004
259	103500	0.000	-0.008	-0.024	-0.028	-0.046
199	106500	0.000	-0.010	0.030	0.000	-0.019
137	109500	0.000	-0.015	-0.010	0.013	0.029
76	112500	0.000	-0.027	-0.025	-0.014	0.002

Table 5.13: Spatial autocorrelation results: survey section parcelization rates.

		Confidence Interval		Moran Statistic	
n	Midpoint	Upper limit	Lower limit	1970s	1980s
1172	1500	0.001	-0.003	0.016	0.063
1172	4500	0.000	-0.002	-0.003	0.025
1169	7500	0.000	-0.002	0.006	0.001
1169	10500	0.000	-0.001	-0.001	-0.003
1168	13500	0.000	-0.001	-0.007	-0.004
1166	16500	0.000	-0.001	0.005	-0.005
1164	19500	0.000	-0.001	0.000	-0.004
1162	22500	0.000	-0.001	-0.001	-0.008
1160	25500	0.000	-0.001	0.007	-0.002
1159	28500	0.000	-0.001	-0.007	0.006
1157	31500	0.000	-0.002	-0.004	-0.002
1155	34500	0.000	-0.002	-0.005	0.000
1153	37500	0.000	-0.002	0.007	0.003
1151	40500	0.000	-0.002	-0.010	-0.003
1149	43500	0.000	-0.002	0.006	-0.001
1147	46500	0.000	-0.002	-0.009	-0.010
1146	49500	0.000	-0.002	-0.014	-0.006
1144	52500	0.000	-0.002	0.013	-0.002
1142	55500	0.000	-0.002	-0.012	0.001
1140	58500	0.000	-0.002	0.006	0.005
1106	61500	0.000	-0.002	-0.006	0.005
1050	64500	0.000	-0.002	-0.011	0.006
989	67500	0.000	-0.002	0.007	0.006
927	70500	0.000	-0.002	0.008	0.007
864	73500	0.000	-0.002	0.003	-0.013
803	76500	0.000	-0.002	0.004	-0.009
740	79500	0.000	-0.003	0.000	-0.001
676	82500	0.000	-0.003	0.001	-0.007
611	85500	0.000	-0.003	0.003	-0.017
552	88500	0.000	-0.004	0.002	0.006
491	91500	0.000	-0.004	-0.002	-0.012
436	94500	0.000	-0.005	0.001	0.007
376	97500	0.000	-0.005	-0.007	0.001
319	100500	0.000	-0.006	0.003	-0.003
259	103500	0.000	-0.008	0.005	-0.008
199	106500	0.000	-0.010	0.002	0.007
137	109500	0.000	-0.015	-0.009	0.008
76	112500	0.000	-0.027	-0.016	-0.015

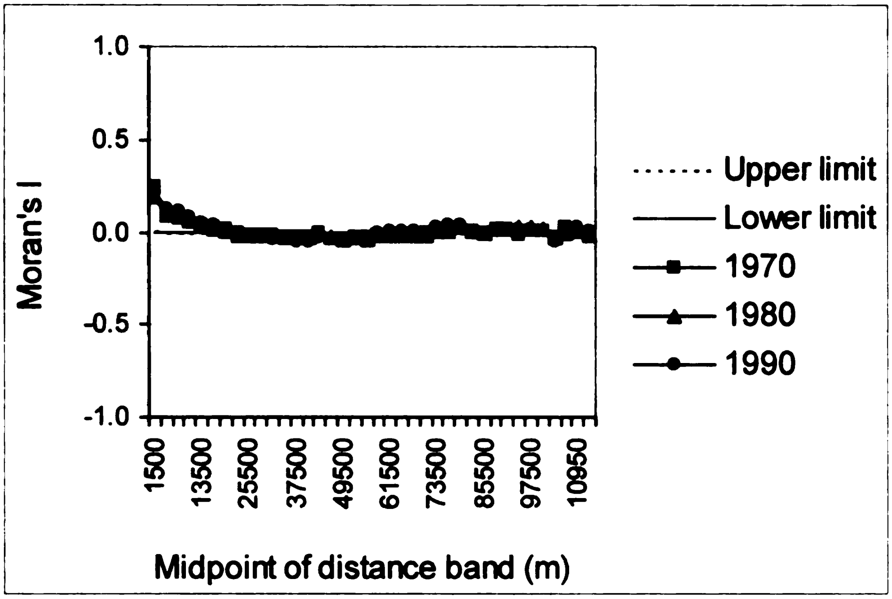


Figure 5.7: Spatial correlograms: survey section values of APS.

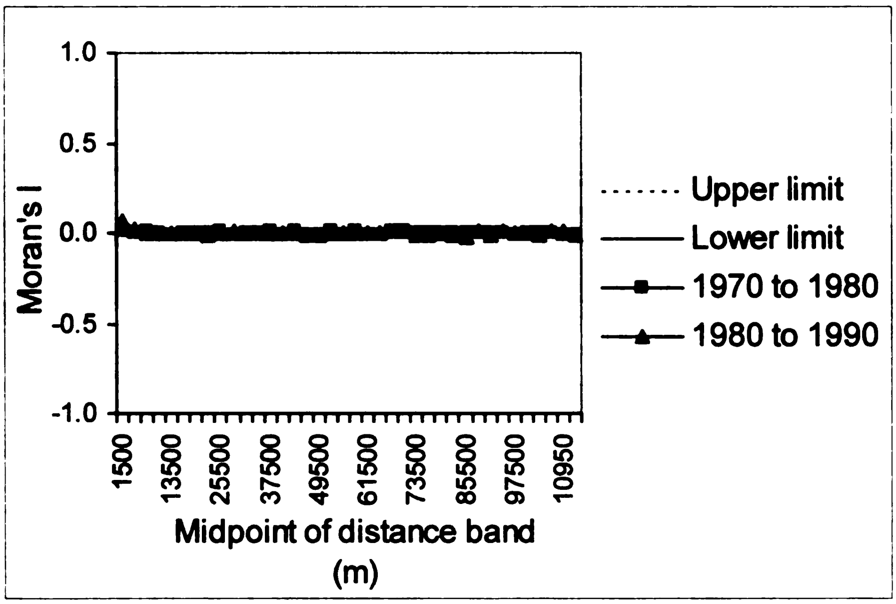


Figure 5.8: Spatial correlograms: survey section parcelization rates.

With respect to parcel sizes, positive spatial autocorrelation appears to have existed at shorter distances for all three dates. Although first lag statistics indicate only weak positive relationships, such patterns persisted into the seventh spatial lag. Beyond the seventh spatial lag, the pattern becomes nearly indistinguishable from random. No spatial pattern is observable within any distance band beyond 21 kilometers for any date. As a whole, the correlograms provide a slight indication of landscape periodicity but, Moran values associated with lags beyond the first lag are so weak they command little attention.

With respect to annual rates of parcelization, a spatial pattern of positive autocorrelation seems to have appeared during the 1980s within the first spatial lag - a lag where no such pattern had been evident during the previous decade. However, a coefficient value of 0.063 is very weak and does not imply a strong pattern existed. Yet, the emergence of positive spatial autocorrelation within the first lag can serve to suggest that sections near to one another exhibited slightly stronger similarities between average rates of change than had existed before.

5.7: Forest cover.

The spatial extent of the study area is approximately 420 kha. Basic image statistics have been extracted and examined to provide a foundation for this analysis of forested land covers (see Table 5.14).

Table 5.14: Landscape metrics describing forest patch and core distributions.

Forest	1973	1985	1991	Core Area	1973	1985	1991
Landscape area (kha)	420	420	420	Landscape area (kha)	420	420	420
Forest area (kha)	282	298	302	Core area (kha)	111	168	160
%Landscape as Forest	67	71	72	%Landscape as Core	26	40	38
% Forest as Private	40	39	40	% Core as Private	34	33	35
% Forest as Public	45	46	47	% Core as Public	51	52	53
% Forest as other	15	15	13	% Core as other	15	15	12
Number of patch areas	5899	4607	4890	Number of core areas	3117	2314	2571
Mean patch area (ha)	19	25	25	Mean core area (ha)	12	24	22
Patch area std. dev. (ha)	163	205	221	Core area std. dev. (ha)	60	105	89
Coefficient of variation	8.5	8.1	8.9	Coefficient of variation	4.9	4.4	4.1

Mapped image classes (e.g. forested, non-forested, open water, clouds, and background) and the distribution of their areas indicate each temporal landscape was moderately heterogeneous. Descriptive statistics show forests were the dominant land cover type and occupied no less than two-thirds of the landscape.

Private forest owners controlled approximately forty-percent of all forested areas and public agencies, in aggregate controlled approximately forty-five percent. The balance of forested lands was held by other ownership institutions.

Forest patches ranged in size from 0.36 ha (one satellite image pixel) to 54.9 kha, a maximum size observed on the 1985 landscape. Although mean patch sizes tended near 25 ha, most patch areas (at least 63 percent) were less than 3 ha. These descriptions indicate the majority of forest patches were very small while a majority of forested area existed as large contiguous blocks, hence describing highly and positively skewed distributions of forest patch areas. Patch area variation statistics (see Table 5.14) suggest variation among patch sizes increased over the eighteen-year period.

Descriptive analysis of forest core areas indicate no more than 26 kha of interior forest area (i.e., core area) existed after a 100 meter edge was removed from all patches. No more than 56 percent of the all forest in the study area could have been considered interior forest because nearly one-half of all forested areas were disturbed by edge effects. Mean core area and coefficient of variation statistics indicate the average size of core areas increased over time (albeit a small decrease was observed from 1985 to 1991) while variation in core areas decreased, respectively. These descriptions suggest the distribution of interior forest areas, with respect to size and without respect to geography, tended towards homogeneity over time. In summary, the numbers do not illustrate a clear picture of forest area trends as variation in patch areas increased while variation in core areas decreased during the same period. Also, both increases and decreases were observed in patch and core areas even though forest growth trends were observed between all three dates. These trends suggest forest structure is not directly tied to the amount of forest present.

5.8: Forest cover - hypothesis III.

I tested for change in the amount of private lands as forest because Leatherberry (1994) and Wyckoff (1995) presented conflicting views of forest cover. I used a two-tailed matched pairs t test instead of a one-tailed test to test the hypothesis that average percentages of private land as forested had changed over time because I had no basis on which to build a directional argument. Hypothesis III was tested between dates and at all spatial scales. Table 5.15 lists statistical test results.

Table 5.15: Average percent private land as forest and changes for all scales.

	1973 to 1985			1985 to 1991		
Scale	1973	1985	Change	1985	1991	Change
Region	54.0	55.7	1.7	55.7	58.7	3.0
County	57.2	59.6	2.3	59.6	61.9	2.3
Township	52.2	55.1	2.9 *	55.1	57.6	2.5 *
Sample	59.1	62.1	3.0 *	62.1	64.1	2.0 *
Section	57.4	59.3	1.9 *	59.3	61.5	2.2 *

* Denotes a statistically significant change with 95 percent confidence.

The county level results, although indicating a trend of increasing forest cover, failed to meet the requirements of statistical significance for each date. Therefore, I failed to reject null hypothesis III at this scale. However, as each forested landscape was examined with smaller sampling units and at greater frequencies, matched pairs *t* test results indicate a significant mean difference exists between mean percent forest values. These results were significant at the 95 percent confidence level and null hypothesis III was rejected for each of these scales. Forest growth trends can be inferred by comparing mean values of percent forest cover over time at the township, sample site, and section scales,.

Table 5.16 summarizes the results of the sample site and section level analyses. Both scales produced results that indicate more areas experienced forest growth than forest loss, and no more than 35 percent of areas sampled showed signs of forest decline. Contrary to Wyckoff's (1995) assertion that a trend of forest decline is beginning, the number of areas in decline decreased over time.

Table 5.16: Percent forest summary for small sampling units.

Scale	n	%Increase	%Decrease	%No Change
Sample sites				
1973 to 1985	168	68	32	0
1985 to 1991	168	71	29	0
1973 to 1991	168	74	26	0
Survey sections				
1973 to 1985	1176	65	35	0
1985 to 1991	1176	68	31	1
1973 to 1991	1176	69	31	0

Table 5.17 outlines temporal percent private land as forest cover values for each observation unit in the region, county, and township level analyses. In most cases, trends of forest growth were observed over time. Townships such as Bear Lake, Blue Lake, Union, and Fife Lake exhibited eighteen-year growth trends. Only Grayling Township exhibited an eighteen-year trend of forest loss.

However, Grayling Township is the largest township in Crawford County and it contains many large public land areas. I was surprised to see such a large degree of forest loss in a township that contained so many managed areas. Additional research revealed several large forest fires occurred in areas in or around Grayling Township between 1985 and 1995 (USDA Forest Service, 1997b). Specifically, the Stephan Bridge Road fire of 1990 burned 2450 ha (6000 acres) of private and public forest in Crawford County (Winter and Fried, 1997). Most forest loss associated with the Stephan Bridge Road fire occurred in Grayling Township (see Figure 5.9) and thus, contributed to the loss trend observed between the 1985 and 1991 satellite images. However, without more spatially explicit information about other fire disturbances that occurred between 1973 and 1991, the possible extent of forest loss in Grayling Township (or any other township) due to fire is unknown.

Table 5.17: Summary of percent private land as forest for political units.

County / Township	1973	Percent 1985	1991
Region totals	53.95	55.69	58.69
Crawford	74.08	77.56	75.56
Beaver Creek	69.49	75.25	70.19
Frederic	72.97	77.49	77.52
City of Grayling	28.34	36.42	23.71
Grayling	78.05	75.29	71.93
Lovells	80.69	83.66	81.70
Maple Forest	57.57	63.67	64.38
South Branch	74.33	84.17	83.00
Grand Traverse	43.75	40.24	44.18
Acme	31.64	26.03	34.05
Blair	41.01	36.64	39.58
East Bay	46.88	44.16	49.33
Fife Lake	48.94	55.59	58.24
Garfield	27.71	21.42	25.01
Grant	56.66	44.57	48.99
Green Lake	59.85	59.14	61.92
Long Lake	42.74	40.73	44.61
Mayfield	41.52	27.43	31.13
Paradise	46.24	48.21	49.82
Peninsula	29.22	25.05	27.45
Traverse City	16.35	27.49	24.55
Union	63.01	72.59	75.43
Whitewater	42.69	42.01	49.00
Kalkaska	53.83	60.89	65.89
Bear Lake	76.59	85.54	87.18
Blue Lake	72.56	76.06	79.91
Boardman	41.05	48.99	54.53
Clearwater	53.00	61.90	66.50
Cold Springs	78.20	81.60	83.80
Excelsior	49.07	57.98	64.33
Garfield	54.70	60.45	64.41
Kalkaska	47.59	51.98	59.64
Oliver	60.94	66.10	72.00
Orange	47.07	55.83	60.90
Rapid River	43.06	52.31	56.38
Springfield	43.94	52.06	59.22

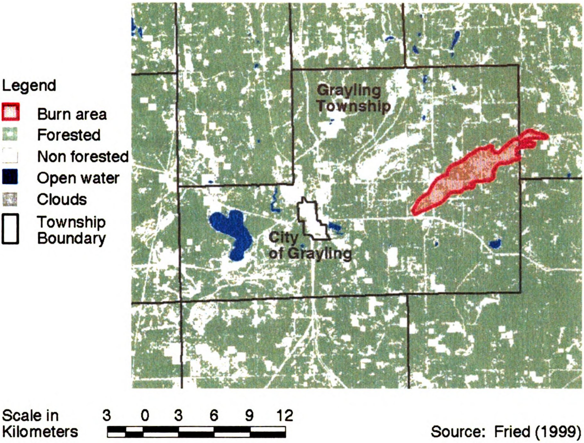


Figure 5.9: Map of the Stephan Bridge Road Fire.

All townships other than Grayling demonstrated some sort of fluctuation with either gains or losses occurring during the first period followed by a reverse trend during the second period. The region as a whole however, exhibited a statistically significant forest growth trend over the entire eighteen-year period.

5.9: Forest cover - hypothesis IV.

I hypothesized the annual rate of change in forest cover had changed over time within the study area. All two-tailed matched pairs *t* test results (see Table 5.18) indicate modest forest growth trends occurred between 1973 and 1991. However, only the section level results for the period between 1985 and 1991, derived using a very large sample (n=1176), met the requirements for statistical significance. Notwithstanding, each calculated mean value was a positive value and increased over time. Therefore, one can infer forest *growth* occurred at a faster rate during the 1980s than during the 1970s.

Table 5.18: Average annual forest change rates for all scales.

Scale	1973 to 1985	1985 to 1991	Change
Region	0.174	0.500	0.326
County	0.234	0.385	0.151
Township	0.287	0.417	0.130
Sample	0.297	0.329	0.032
Section	0.189	0.458	0.269 *

* Denotes a statistically significant change with 95 percent confidence.

Tables outlining the region, county, and township results or summarizing sample site and section level results are not included in this section because hypothesis IV was tested with a two-tailed test of differences, rather than a directional one-tailed test of differences. The posting of individual values would not contribute to an explanation of these test results.

5.10: Forest fragmentation - hypothesis V.

According to the Michigan Society of Planning Officials Future Trend Project (Wyckoff, 1995), forest fragmentation has increased in Michigan. I tested this hypothesis within the study area by using a one-tailed matched pairs *t* test to test for a significant mean increase between calculated CF values. Recall that CF values are estimates of forest fragmentation and have values that range between zero and one. Values near one indicate highly fragmented forest areas and values near zero indicate unfragmented forest areas (see Appendix F for a complete description). Hypothesis V was tested between dates and at all spatial scales. Table 5.19 highlights the results.

Table 5.19: Forest fragmentation changes for all scales (CF units).

	1973 to 1985			1985 to 1991		
Scale	1973	1985	Change	1985	1991	Change
Region	0.66	0.52	-0.14	0.52	0.54	0.02
County	0.66	0.52	-0.137 *	0.52	0.54	0.02
Township	0.68	0.56	-0.12 *	0.56	0.58	0.02 *
Sample	0.65	0.50	-0.15 *	0.50	0.52	0.02 *
Section	0.65	0.52	-0.13 *	0.52	0.53	0.01 *

*Denotes statistically significant change with 95 percent confidence.

For all tests between sets of CF values calculated for 1973 and 1985 landscape data, mean estimates of core area fragmentation were determined to significantly decrease over time. These results were opposite of what was hypothesized, therefore, I failed to reject null hypothesis V for all scales.

For tests between sets of values calculated for 1985 and 1991 landscape data, mean estimates of core area fragmentation were determined to significantly increase over time for all scales but county. Interestingly enough, this period was the period during which the region experienced less rapid growth. I failed to reject the null in the county example because calculated average CF values were statistically determined not to be different. However, in the township, sample site, and section level analyses, null hypothesis V was rejected.

Table 5.20 summarizes the results of both section and sample site level analyses. According to the sample site results, the region experienced an eighteen-year trend of decreasing forest fragmentation as evidenced by more defragmented sites (80 percent) than fragmented sites (20 percent). However, upon review of the results presented for each shorter time period, one can see that between 1985 and 1991, more sample sites experienced forest fragmentation (57 percent) than did forest defragmentation (43 percent).

Table 5.20: Summary of forest fragmentation for small sampling units (%).

Scale	n	%Increase	%Decrease	%No Change
Sample sites				
1973 to 1985	168	16	84	0
1985 to 1991	168	57	43	0
1973 to 1991	168	20	80	0
Survey sections				
1973 to 1985	1176	25	73	2
1985 to 1991	1176	48	49	3
1973 to 1991	1176	26	72	2

The section level analysis also reveals an eighteen-year trend of decreasing forest fragmentation. A review of both shorter trends, however, indicates two defragmentation trends, unlike the results posted for the sample sites. Yet, one should note the large increase in the number of survey sections that underwent forest fragmentation during the second period (48 percent) compared to the number that fragmented during the first period (25 percent).

Table 5.21 outlines CF values calculated for each observation unit in the region, county, and township scale analyses. As the numbers indicate, no dominant trend of fragmentation or defragmentation existed over the entire eighteen-year period. Crawford and Grand Traverse Counties exhibited trends of defragmentation from 1973 to 1985 and trends of fragmentation from 1985 to 1991. Most townships within these two counties, with exceptions like Blair, Long Lake, and Union Townships, exhibited similar trends. On the other hand, Kalkaska County demonstrated an eighteen-year defragmentation trend even though townships like Clearwater, Excelsior, and Garfield exhibited increases in forest fragmentation between 1985 and 1991.

In general, forest fragmentation appears to have decreased throughout the landscape between 1973 and 1991. The general pattern however, is insensitive to the shift from a period of defragmentation that existed between 1973 and 1985 to a period of forest fragmentation that existed between 1985 and 1991.

Table 5.21: Summary of forest fragmentation indices for political units.

County Township	CF Index 1973	1985	1991
Region totals	0.662	0.524	0.543
Crawford	0.597	0.405	0.461
Beaver Creek	0.620	0.439	0.534
Frederic	0.555	0.376	0.421
City of Grayling	0.710	0.600	0.715
Grayling	0.543	0.441	0.509
Lovells	0.636	0.368	0.435
Maple Forest	0.607	0.497	0.544
South Branch	0.631	0.310	0.339
Grand Traverse	0.728	0.662	0.669
Acme	0.792	0.699	0.752
Blair	0.723	0.670	0.654
East Bay	0.724	0.684	0.691
Fife Lake	0.713	0.549	0.563
Garfield	0.862	0.870	0.867
Grant	0.611	0.601	0.607
Green Lake	0.605	0.541	0.552
Long Lake	0.762	0.730	0.715
Mayfield	0.779	0.770	0.784
Paradise	0.710	0.627	0.618
Peninsula	0.848	0.855	0.870
Traverse City	0.957	0.992	0.978
Union	0.691	0.508	0.506
Whitewater	0.694	0.576	0.607
Kalkaska	0.647	0.501	0.492
Bear Lake	0.601	0.313	0.295
Blue Lake	0.525	0.538	0.506
Boardman	0.805	0.614	0.606
Clearwater	0.591	0.487	0.491
Cold Springs	0.454	0.399	0.367
Excelsior	0.682	0.419	0.439
Garfield	0.690	0.530	0.535
Kalkaska	0.729	0.608	0.578
Oliver	0.567	0.365	0.364
Orange	0.706	0.501	0.502
Rapid River	0.609	0.521	0.512
Springfield	0.713	0.576	0.550

5.11: Forest fragmentation - hypothesis VI.

I hypothesized the annual rate of forest fragmentation had increased over the selected eighteen-year period. As one-tailed matched pairs *t* test results indicate in Table 5.22, the average rate of forest fragmentation increased over time for all spatial scales. Table 5.23 is provided to list region, county, and township trends in forest fragmentation rates as well as relative rankings over time. However, as indicated above in Section 5.10, static measures of forest fragmentation indicate a trend of decreasing forest fragmentation during the late 1970s and a trend of increasing forest fragmentation during the late 1980s. By comparing a previous period of forest defragmentation to a later period of forest fragmentation, the rate of forest fragmentation will, by mathematical definition, increase over time. So, the test of hypothesis VI was most useful in determining the statistical significance of the mean differences between fragmentation rates over time rather than identifying a particular direction of change. In any case, the rate of forest fragmentation had increased from 1973 to 1991.

Table 5.22: Forest fragmentation rate and changes for all scales (CF/yr).

Scale	1973 to 1985	1985 to 1991	Change
Region	-0.012	0.003	0.015
County	-0.014	0.003	0.017 *
Township	-0.012	0.002	0.014 *
Sample	-0.014	0.003	0.017 *
Section	-0.013	0.001	0.014 *

* Denotes a statistically significant change with 95 percent confidence.

Table 5.23: Summary of forest fragmentation rates for political units (CF/yr).

County	Township	1973 to 1985 Change	Rank	1985 to 1991 Change	Rank
Region totals		-0.012		0.003	
Crawford		-0.016		0.009	
	Beaver Creek	-0.015	24	0.016	2
	Frederic	-0.015	24	0.008	6
	City of Grayling	-0.009	15	0.019	1
	Grayling	-0.009	15	0.011	3
	Lovells	-0.022	30	0.011	3
	Maple Forest	-0.009	15	0.008	6
	South Branch	-0.027	33	0.005	8
Grand Traverse		-0.006		0.001	
	Acme	-0.008	14	0.009	5
	Blair	-0.004	9	-0.003	27
	East Bay	-0.003	7	0.001	15
	Fife Lake	-0.014	23	0.002	12
	Garfield	0.001	2	-0.001	22
	Grant	-0.001	5	0.001	15
	Green Lake	-0.005	10	0.002	12
	Long Lake	-0.003	7	-0.003	27
	Mayfield	-0.001	5	0.002	12
	Paradise	-0.007	12	-0.002	24
	Peninsula	0.001	2	0.003	10
	Traverse City	0.003	1	-0.002	24
	Union	-0.015	24	0.000	19
	Whitewater	-0.010	19	0.005	8
Kalkaska		-0.012		-0.002	
	Bear Lake	-0.024	32	-0.003	27
	Blue Lake	0.001	2	-0.005	31
	Boardman	-0.016	27	-0.001	22
	Clearwater	-0.009	15	0.001	15
	Cold Springs	-0.005	10	-0.005	31
	Excelsior	-0.022	30	0.003	10
	Garfield	-0.013	22	0.001	17
	Kalkaska	-0.010	19	-0.005	31
	Oliver	-0.017	28	0.000	19
	Orange	-0.017	28	0.000	19
	Rapid River	-0.007	12	-0.002	24
	Springfield	-0.011	21	-0.004	30

5.12: Forest fragmentation – location analysis.

Numerical results of the location analysis are listed in Table 5.24. The spatial structure of forest fragmentation, with respect to distance from Traverse City, can be visualized in Figure 5.10. Negative sloping trends observed at shorter distances indicate a spatial gradient of forest fragmentation existed around Traverse City. Areas closer to the city tended to be more fragmented than those areas located farther from the city. This fragmentation gradient existed within a 48 kilometer radius and had become steeper over time. Erratic patterns of increases and decreases in fragmented forest conditions were observed at distances greater than 48 kilometers for all three dates.

Within the 48 kilometer radius, observed increases in negative slope indicate decreases in forest fragmentation over time. Also, the effect of distance on fragmentation conditions appears to have increased over time, meaning the magnitudes of defragmentation increased with increased distance from Traverse City. It is significant to note here that most of the change observed in the fragmentation gradient occurred between 1973 and 1985. Little change was observed in the gradient between 1985 and 1991.

Table 5.24: Fragmentation indices for concentric bands around Traverse City.

Band (km)			CF METRIC 1970	1980	1990
0	to	3	0.959	0.996	0.991
3	to	6	0.781	0.794	0.785
6	to	9	0.794	0.786	0.796
9	to	12	0.805	0.756	0.757
12	to	15	0.691	0.608	0.629
15	to	18	0.671	0.612	0.606
18	to	21	0.740	0.674	0.688
21	to	24	0.724	0.647	0.641
24	to	27	0.665	0.559	0.564
27	to	30	0.725	0.594	0.576
30	to	33	0.674	0.565	0.548
33	to	36	0.777	0.633	0.620
36	to	39	0.704	0.593	0.585
39	to	42	0.666	0.472	0.481
42	to	45	0.559	0.463	0.474
45	to	48	0.537	0.328	0.316
48	to	51	0.552	0.401	0.360
51	to	54	0.657	0.413	0.379
54	to	57	0.469	0.335	0.336
57	to	60	0.646	0.484	0.444
60	to	63	0.744	0.535	0.552
63	to	66	0.457	0.353	0.427
66	to	69	0.627	0.393	0.431
69	to	72	0.553	0.381	0.464
72	to	75	0.652	0.518	0.570
75	to	78	0.615	0.434	0.503
78	to	81	0.467	0.457	0.499
81	to	84	0.442	0.421	0.524
84	to	87	0.533	0.389	0.429
87	to	90	0.688	0.354	0.460
90	to	93	0.601	0.334	0.360
93	to	96	0.664	0.277	0.315
96	to	99	0.750	0.304	0.329
99	to	102	0.322	0.145	0.124

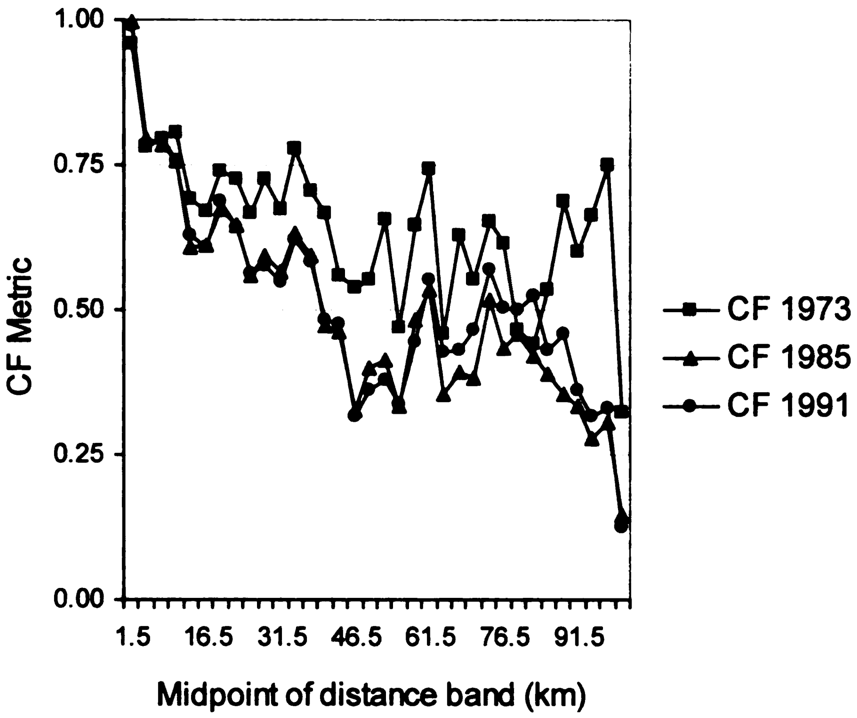


Figure 5.10: Forest fragmentation functions for Traverse City.

As reported in Section 5.5, the parcel size distance functions observed for Traverse City indicated the urban extent increased over time from the third distance band in 1973 to include the entire study area by 1985. The area within this large region was reasonably expected to exhibit signs of increased forest fragmentation as urban pressures had come to influence forested lands. However, as the distance functions in Figure 5.10 and Table 5.24 indicate, forest fragmentation conditions decreased over the eighteen-year period, even though small increases were observed between 1985 and 1991. This result does not suggest forest fragmentation was directly related to urbanization or urban sprawl but, perhaps, that the opposite is true.

5.13: Forest fragmentation - spatial analysis.

Spatial patterns of static forest fragmentation conditions and average annual rates of forest fragmentation were measured using spatial autocorrelation analysis. Spatial correlograms were calculated for the township, sample site, and section level forest data analyses. Observed peaks and depressions in graphed autocorrelation functions were used to describe the effects of distance on pattern at each time. Also, distances at which spatial patterns were statistically indiscernible from random patterns were used to infer the scale of forest fragmentation. The same sets of binary contiguity weight matrices used during parcel data analyses were used during forest data analysis with respect to appropriate distance bands and sampling schemes.

5.13.1: Townships.

Uniform distance bands of 12000 meters were used to sample township level forest data. Moran coefficients calculated for each distance band are listed in Table 5.25. Moran coefficient values were plotted against distance band midpoints and are presented in Figure 5.11. Moderate peaks of positive spatial autocorrelation observed at shorter distances imply a simple adjacency effect existed as nearby townships tended to exhibit more similar forest conditions than did distant townships.

Table 5.25: Spatial autocorrelation results: township CF indices.

n	Midpoint	Confidence Interval Upper limit	Confidence Interval Lower limit	Moran Statistic 1973	Moran Statistic 1985	Moran Statistic 1991
30	6000	0.043	-0.112	0.515	0.659	0.686
33	18000	0.011	-0.073	0.323	0.442	0.441
33	30000	0.009	-0.071	0.133	0.194	0.108
33	42000	0.017	-0.079	-0.250	-0.133	-0.211
33	54000	0.026	-0.089	-0.482	-0.504	-0.577
30	66000	0.042	-0.111	-0.318	-0.399	-0.279
22	78000	0.042	-0.137	-0.474	-0.498	-0.328
13	90000	0.092	-0.259	-0.048	-0.569	-0.510

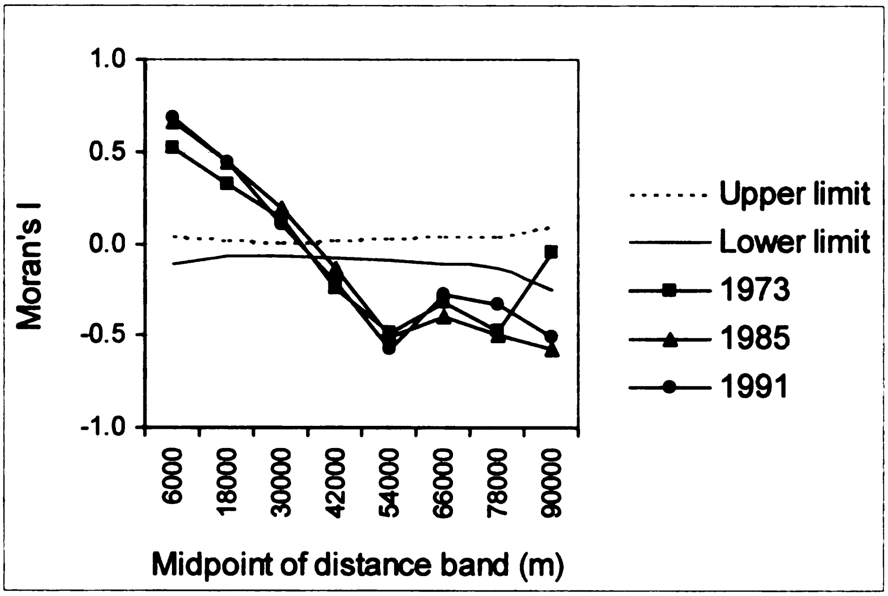


Figure 5.11: Spatial correlograms: township CF indices.

For all three dates, coefficient values declined as lag distances were increased to 60 kilometers. Because zero autocorrelation can be inferred from Figure 5.11 at approximately 36 kilometers, the scale of static fragmentation conditions can be considered to have been 36 kilometers. The consistent indirect relationship between autocorrelation and distance suggests a stable spatial and temporal landscape gradient existed between townships separated by distances less than 60 kilometers. Moran coefficients associated with distances greater than 60 kilometers suggest the spatial structure of fragmentation fluctuated over time at greater distances. However, as higher order spatial lags were tested, fewer and fewer townships representing Kalkaska landscape patterns were included during analysis. As a result, observed fluctuations in Moran coefficient values measured at distances greater than 60 kilometers cannot be discriminated between those fluctuations induced by changes in sample size and those by real differences in forest structure (see Table 5.25).

Analysis of average annual fragmentation rates revealed interesting distance relationships. Table 5.26 outlines values of Moran's I calculated for each spatial lag and Figure 5.12 graphically illustrates the results.

Table 5.26: Spatial autocorrelation results: township fragmentation rates.

		Confidence Interval		Moran Statistic	
n	Midpoint	Upper limit	Lower limit	1970s	1980s
30	6000	0.043	-0.112	0.611	0.104
33	18000	0.011	-0.073	0.240	0.168
33	30000	0.009	-0.071	-0.001	0.051
33	42000	0.017	-0.079	-0.021	-0.294
33	54000	0.026	-0.089	-0.283	0.014
30	66000	0.042	-0.111	-0.074	0.011
22	78000	0.042	-0.137	-0.054	-0.641
13	90000	0.092	-0.259	-0.897	-0.761

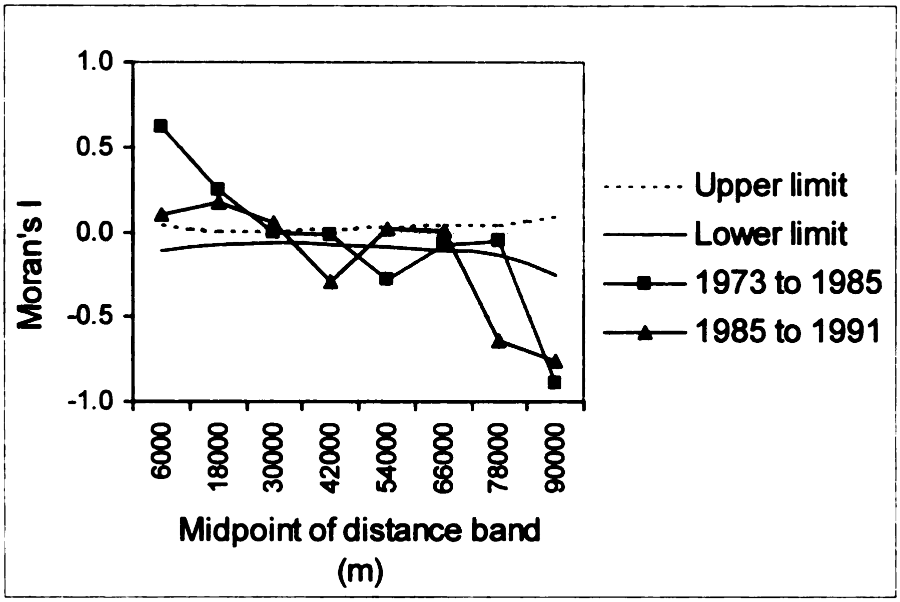


Figure 5.12: Spatial correlograms: township fragmentation rates.

In general, both functions yielded steep autocorrelation functions that signified steep fragmentation rate gradients existed on the landscape over time. Positive coefficients were measured at short distances and negative coefficients were measured at greater distances. However, a peak in autocorrelation existed in the earlier function between the 66 and 78 kilometer bands. This peak is important because is represents a deviation from the general landscape trend. The later function nearly mirrors the earlier function but, with two notable exceptions. First, the level of spatial dependency associated with nearby townships decreased sharply. The values of Moran's I in the first spatial lag dropped from a moderate 0.611 to a weak 0.104. This sharp drop implies rates of fragmentation showed a weaker adjacency effect over short distances than they did before. Second, the peak in autocorrelation shifted from the 66 and 78 kilometer lags to the 54 and 66 kilometer lags. This shift implies the deviation in the landscape gradient could be observed over shorter distances and with greater frequency. This deviation in pattern, is similarly located, with respect to distance to the change in spatial pattern observed during township level parcel analysis.

5.13.2: Sample sites.

Uniform distance bands of 6000 meters were used to sample forest data during sample site autocorrelation analysis. Table 5.27 lists Moran coefficient values calculated for each spatial lag. Values of Moran's I were plotted against distance band midpoints and are illustrated in Figure 5.13. For all three dates, each correlogram indicates a negative sloping trend from moderate and positive coefficients at short distances to moderate and negative coefficients at long distances. Because these correlograms remained relatively stable over both space and time, they provide further evidence to support the fragmentation gradient identified in Section 5.13.1. Fluctuations in the spatial structure of CF indices at distances greater than 51 kilometers are also consistent with those observed at the township scale. From 1973 to 1985, forest conditions became more dissimilar between dates, then rebounded towards randomness by 1991. This fluctuation was most evident in the 60 to 72 kilometer lag.

Table 5.27: Spatial autocorrelation results: sample site CF indices.

		Confidence Interval		Moran Statistic		
n	Midpoint	Upper limit	Lower limit	1973	1985	1991
167	3000	0.007	-0.019	0.384	0.595	0.585
168	9000	0.001	-0.013	0.177	0.454	0.385
168	15000	0.000	-0.012	0.101	0.361	0.246
168	21000	0.000	-0.012	0.138	0.300	0.187
168	27000	-0.001	-0.011	0.139	0.270	0.158
168	33000	-0.001	-0.011	0.092	0.207	0.122
168	39000	0.000	-0.012	0.021	0.112	0.038
168	45000	0.000	-0.012	-0.059	0.004	-0.033
168	51000	0.000	-0.012	-0.185	-0.224	-0.235
168	57000	0.002	-0.014	-0.170	-0.330	-0.320
165	63000	0.002	-0.014	-0.181	-0.315	-0.198
148	69000	0.002	-0.016	-0.214	-0.291	-0.088
128	75000	0.002	-0.017	-0.284	-0.442	-0.192
112	81000	0.003	-0.021	-0.298	-0.573	-0.338
92	87000	0.004	-0.027	-0.236	-0.714	-0.553
72	93000	0.004	-0.032	-0.022	-0.782	-0.655
56	99000	0.006	-0.042	0.034	-0.547	-0.428

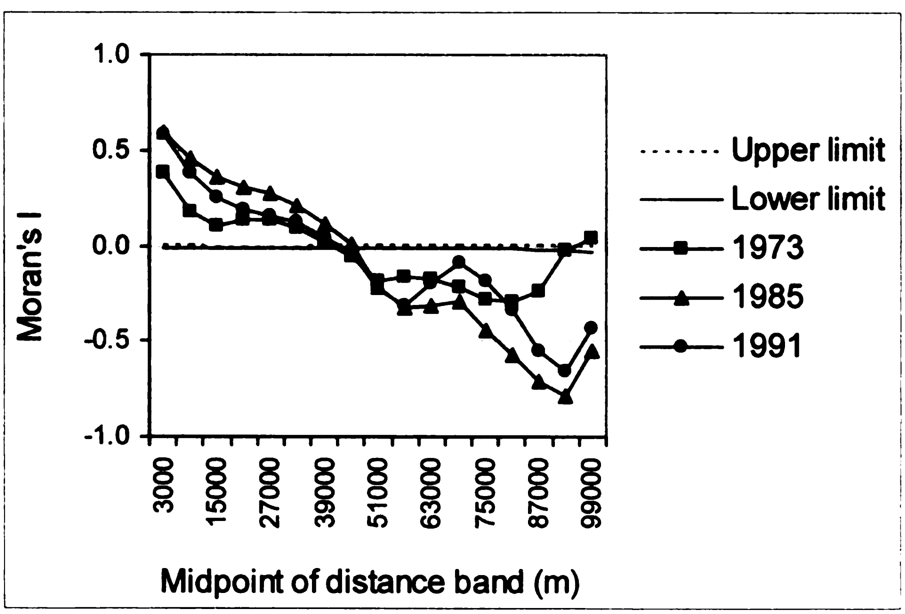


Figure 5.13: Spatial correlograms: sample site CF indices.

Sample site autocorrelation analysis of forest fragmentation rates also revealed a general landscape trend existed over time. Table 5.28 outlines the calculated set of Moran statistics and Figure 5.14 illustrates the correlograms. Again, positive and significant coefficients were measured at short distances and negative coefficients were measured at greater distances. However, finer resolution distance bands had revealed peculiar changes in an otherwise stable spatiotemporal gradient. The earlier function exhibited small peaks in autocorrelation at the 45 and 75 kilometer lags, which signify two irregularities, or deviations from the general landscape trend. Although these deviations were not as large as those observed during township analysis, the general location along the distance axis had remained about the same. The peaks in the pattern also suggest a sort of 'leap-frog' effect as places characterized by higher (lower) fragmentation rates existed between places characterized by lower (higher) fragmentation rates. Yet, these deviations disappeared in the later correlogram. In general, the changes observed over time imply a trend with distinct local variations was transformed into a more general landscape trend. The later pattern appears smoother and indicative of a broader spatial gradient of fragmentation rates.

Table 5.28: Spatial autocorrelation results: sample site fragmentation rates.

		Confidence Interval		Moran Statistic	
n	Midpoint	Upper limit	Lower limit	1970s	1980s
167	3000	0.007	-0.019	0.531	0.308
168	9000	0.001	-0.013	0.288	0.198
168	15000	0.000	-0.012	0.106	0.188
168	21000	0.000	-0.012	0.093	0.110
168	27000	-0.001	-0.011	0.068	0.076
168	33000	-0.001	-0.011	0.028	0.012
168	39000	0.000	-0.012	0.017	-0.040
168	45000	0.000	-0.012	0.073	-0.105
168	51000	0.000	-0.012	-0.058	-0.144
168	57000	0.002	-0.014	-0.155	-0.153
165	63000	0.002	-0.014	-0.106	-0.121
148	69000	0.002	-0.016	-0.024	-0.111
128	75000	0.002	-0.017	0.006	-0.145
112	81000	0.003	-0.021	-0.154	-0.185
92	87000	0.004	-0.027	-0.411	-0.202
72	93000	0.004	-0.032	-0.600	-0.179
56	99000	0.006	-0.042	-0.634	-0.122

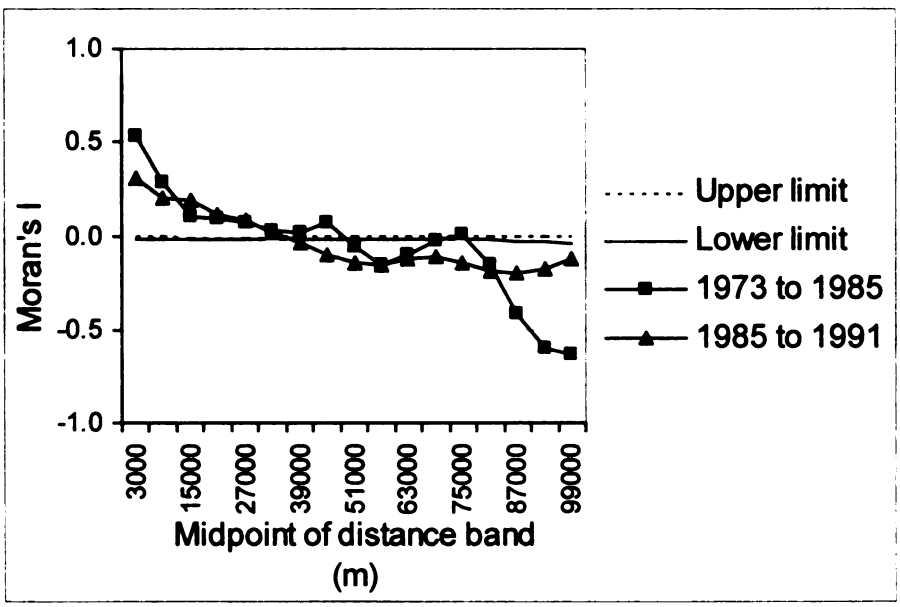


Figure 5.14: Spatial correlograms: sample site fragmentation rates.

5.13.3: Survey sections.

Survey section forest data were sampled using uniform distance bands 3000 meters wide. Correlograms calculated at this scale provided the most detailed look at the structure of spatially distributed CF indices. Graphed correlograms are illustrated in Figure 5.15 and spatial autocorrelation test results are outlined in Table 5.29. The inverse relationship between spatial autocorrelation and distance characterized in the township and sample site analyses was also evident in the section scale correlograms.

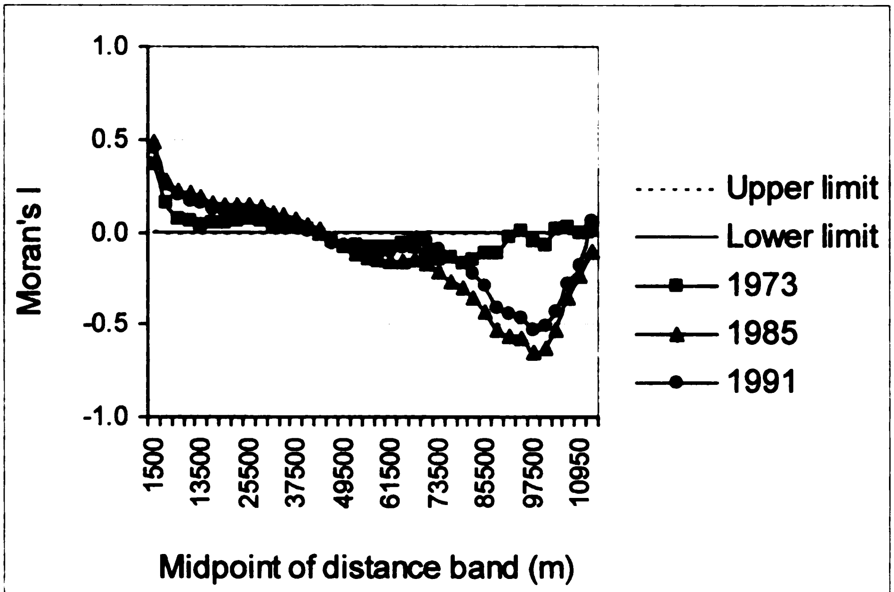


Figure 5.15: Spatial autocorrelation results: survey section CF indices.

Table 5.29: Spatial autocorrelation results: survey section CF indices.

n	Midpoint	Confidence Interval Upper limit	Lower limit	Moran Statistic 1973	1985	1991
1172	1500	0.001	-0.003	0.370	0.484	0.453
1172	4500	0.000	-0.002	0.161	0.276	0.253
1169	7500	0.000	-0.002	0.076	0.222	0.200
1169	10500	0.000	-0.001	0.060	0.209	0.174
1168	13500	0.000	-0.001	0.041	0.191	0.155
1166	16500	0.000	-0.001	0.048	0.160	0.125
1164	19500	0.000	-0.001	0.052	0.143	0.110
1162	22500	0.000	-0.001	0.058	0.152	0.108
1160	25500	0.000	-0.001	0.073	0.145	0.094
1159	28500	0.000	-0.001	0.064	0.132	0.081
1157	31500	0.000	-0.002	0.042	0.106	0.060
1155	34500	0.000	-0.002	0.037	0.093	0.047
1153	37500	0.000	-0.002	0.035	0.068	0.029
1151	40500	0.000	-0.002	0.013	0.042	0.011
1149	43500	0.000	-0.002	-0.017	0.011	-0.016
1147	46500	0.000	-0.002	-0.051	-0.036	-0.058
1146	49500	0.000	-0.002	-0.080	-0.067	-0.074
1144	52500	0.000	-0.002	-0.071	-0.111	-0.114
1142	55500	0.000	-0.002	-0.079	-0.138	-0.134
1140	58500	0.000	-0.002	-0.078	-0.142	-0.121
1106	61500	0.000	-0.002	-0.087	-0.162	-0.107
1050	64500	0.000	-0.002	-0.061	-0.157	-0.085
989	67500	0.000	-0.002	-0.079	-0.143	-0.043
927	70500	0.000	-0.002	-0.131	-0.168	-0.054
864	73500	0.000	-0.002	-0.146	-0.212	-0.089
803	76500	0.000	-0.002	-0.141	-0.265	-0.136
740	79500	0.000	-0.003	-0.166	-0.306	-0.170
676	82500	0.000	-0.003	-0.144	-0.356	-0.229
611	85500	0.000	-0.003	-0.118	-0.428	-0.293
552	88500	0.000	-0.004	-0.117	-0.533	-0.407
491	91500	0.000	-0.004	-0.022	-0.564	-0.447
436	94500	0.000	-0.005	0.007	-0.579	-0.467
376	97500	0.000	-0.005	-0.050	-0.652	-0.527
319	100500	0.000	-0.006	-0.070	-0.624	-0.509
259	103500	0.000	-0.008	0.013	-0.535	-0.430
199	106500	0.000	-0.010	0.029	-0.357	-0.274
137	109500	0.000	-0.015	-0.004	-0.231	-0.176
76	112500	0.000	-0.027	0.004	-0.108	0.060

Again, the spatial structure of the fragmentation gradient appeared relatively stable over both space and time as the functions coincide at many distances. However, the spatial patterns exhibited by the 1985 and 1991 CF distributions are visibly different from the 1973 distribution in two important ways. First, stronger positive autocorrelation coefficients and lesser instantaneous slopes within the first twelve spatial lags suggest distance played a weaker role in the fragmentation process over time. Given the forest growth trend that occurred during this time period, coalescence between neighboring forest patches could have reduced the amount of abruptness that existed, and subsequently relaxed the distance decay effect. And second, much stronger negative Moran coefficients were recorded for lags greater than 75 kilometers, which indicate a steeper fragmentation gradient appeared at greater distances. Because those sections separated by at least 75 kilometers represent sections located within Crawford and Grand Traverse Counties, one could infer forest fragmentation conditions within these counties changed over time and the two counties became increasingly dissimilar.

Spatial autocorrelation analysis of average annual fragmentation rates revealed spatial patterns similar to those revealed during township and sample site analyses. Table 5.30 outlines values of Moran's I calculated for each spatial lag and Figure 5.16 graphically illustrates the results.

Table 5.30: Spatial autocorrelation results: survey section fragmentation rates.

		Confidence Interval		Moran Statistic	
n	Midpoint	Upper limit	Lower limit	1970s	1980s
1172	1500	0.001	-0.003	0.325	0.143
1172	4500	0.000	-0.002	0.221	0.084
1169	7500	0.000	-0.002	0.156	0.062
1169	10500	0.000	-0.001	0.100	0.059
1168	13500	0.000	-0.001	0.072	0.050
1166	16500	0.000	-0.001	0.060	0.062
1164	19500	0.000	-0.001	0.051	0.052
1162	22500	0.000	-0.001	0.050	0.040
1160	25500	0.000	-0.001	0.028	0.038
1159	28500	0.000	-0.001	0.030	0.029
1157	31500	0.000	-0.002	0.009	0.011
1155	34500	0.000	-0.002	-0.008	-0.002
1153	37500	0.000	-0.002	-0.008	-0.017
1151	40500	0.000	-0.002	-0.018	-0.020
1149	43500	0.000	-0.002	-0.014	-0.034
1147	46500	0.000	-0.002	-0.023	-0.031
1146	49500	0.000	-0.002	-0.013	-0.036
1144	52500	0.000	-0.002	-0.044	-0.038
1142	55500	0.000	-0.002	-0.035	-0.032
1140	58500	0.000	-0.002	-0.042	-0.057
1106	61500	0.000	-0.002	-0.024	-0.051
1050	64500	0.000	-0.002	-0.016	-0.030
989	67500	0.000	-0.002	0.007	-0.048
927	70500	0.000	-0.002	0.024	-0.045
864	73500	0.000	-0.002	0.044	-0.040
803	76500	0.000	-0.002	0.032	-0.043
740	79500	0.000	-0.003	-0.007	-0.061
676	82500	0.000	-0.003	-0.044	-0.047
611	85500	0.000	-0.003	-0.124	-0.053
552	88500	0.000	-0.004	-0.189	-0.094
491	91500	0.000	-0.004	-0.256	-0.043
436	94500	0.000	-0.005	-0.380	-0.063
376	97500	0.000	-0.005	-0.478	-0.112
319	100500	0.000	-0.006	-0.571	-0.059
259	103500	0.000	-0.008	-0.644	-0.124
199	106500	0.000	-0.010	-0.619	-0.056
137	109500	0.000	-0.015	-0.456	-0.065
76	112500	0.000	-0.027	-0.183	-0.088

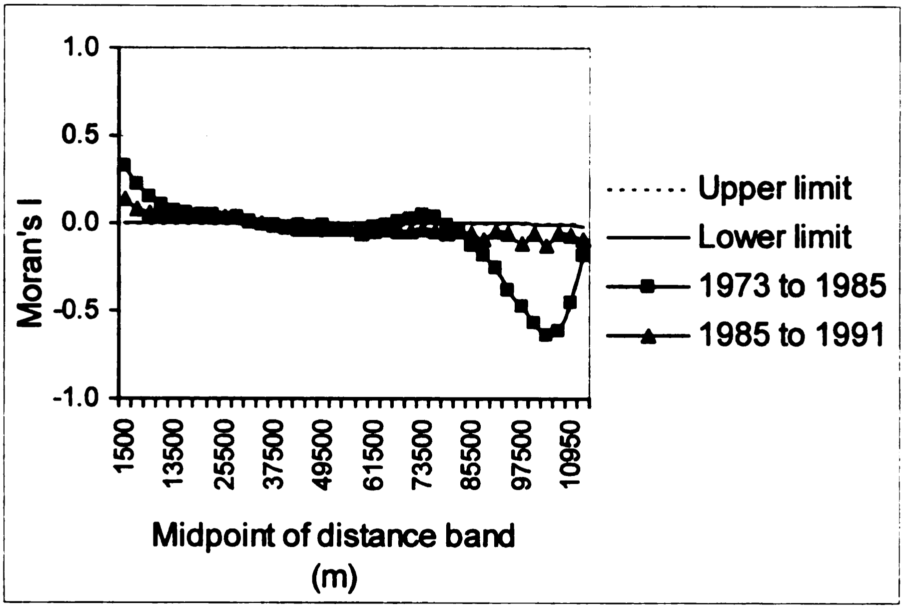


Figure 5.16: Spatial correlograms: survey section fragmentation rates.

Section level autocorrelation analysis results support the existence of a general landscape trend, or gradient, of forest fragmentation rates. Again, positive coefficients were associated with shorter distances and negative coefficients were associated with greater distances. The earlier function indicates a disturbance in the gradient existed between the 67.5 and 76.5 kilometer bands. Also, moderate negative values associated with the greatest distances indicate one side of the region had fragmented at a much different rate than the other side. Both the small peak and the large depression suggest a lot of localized fragmentation activity had taken place between 1973 and 1985. However, by 1991 the landscape gradient appeared to have 'calmed down' as the peak and the depression had both disappeared. All that remained was a gentle sloping landscape gradient.

5.14: Summary.

Basic statistical analyses on digitized land parcel data and remotely sensed forest cover data for Crawford, Kalkaska, and Grand Traverse Counties provide evidence to support four basic trends; (a) average parcel sizes decreased over time, (b) land ownership parcelization occurred at a faster rate during the 1970s than during the 1980s, (c) forest cover increased by nearly 5 percent between 1973 and 1991, and (d) forest fragmentation decreased from 1973 to 1991, although a small trend of increased forest fragmentation did appear after 1985.

Spatial autocorrelation analysis of temporal parcel data revealed spatial relationships that existed over only short distances and imply a simple adjacency or spill-over effect. For example, a piece of land undergoing parcelization may have induced further parcelization in a nearby or adjacent area, but would have had little to no effect on a more distant piece of land. Only the township level analysis yielded evidence of a broader landscape trend. Review of the data indicated land in Grand Traverse County parcelized faster than in Kalkaska County, which in turn parcelized faster than in Crawford County. The landscape trend identified at the township scale was an important finding because most land use decisions are made at the township level. Therefore, this trend suggests that land use and zoning policies may also exhibit a spatial gradient.

Spatial autocorrelation analysis of temporal forest data revealed spatial gradients of both fragmentation indices and fragmentation rates that transcended all scales. For example, Grand Traverse County was characterized by having the least amount of forest cover, the most fragmented forests, and the lowest rate of change over the eighteen-year period. Crawford County had the most amount of forest cover, the least fragmented forests and the highest rate of forest change. Kalkaska County was geographically and characteristically located somewhere in the middle. Autocorrelation results also indicated irregularities in the forest gradient occurred between 1973 and 1985. Although these irregularities were marked by statistically insignificant Moran coefficients, they occurred in the same general location along the distance axis as did the periodic trend observed in the township level parcel trend, hence indicating a relationship exists between the phenomena. However, the relationship between forest fragmentation and land ownership parcelization should be posited as speculation only. I discuss my reasons later in this document.

CHAPTER 6: DISCUSSION

6.1: Introduction.

This discussion is intended to provide information that may lead to land use planning and forest management strategies that are sensitive to ownership patterns and their influence on forest structures.

6.2: Influences of scale on results and their implications.

Spatiotemporal land ownership and forest cover landscape data were partitioned and analyzed five times, each time with more numerous and smaller-sized sampling units. I calculated average parcel size (APS) and forest fragmentation (CF) indices for each sampling unit. Values representing sample unit characteristics were arithmetically combined into mean values to summarize each landscape. Some test results suggest differences in spatial scale influenced mean value calculations. For example, forest fragmentation results do not to vary much with scale, but parcel size results do. Results that do not vary with scale suggest that the methods used during analysis were not sensitive to changes in scale. Alternatively, results that vary with scale suggest that the methods used during analysis were sensitive to scale changes.

A review of mean CF values (see Table 5.19) reveals small ranges across spatial scales thus suggesting spatial scale independence. For example, the 1973 section analysis produced a mean CF value of 0.65, a value similar to the 1973 regional average (0.66). Sample site, township, and county analyses also produced similar mean magnitudes for the same year. These results show that static levels of forest fragmentation were observable using all five spatial scales and the method used to summarize fragmentation values was not sensitive to the partitions used to sample the landscape. Fragmentation rate results (see Table 5.22) can be characterized in the same way. Therefore, I am confident that CF values represent landscape conditions and not statistical influences associated with scale changes.

Parcel size and parcelization rate results show strong evidence for scaling effects. A review of mean APS values (see Tables 5.3 and 5.6) reveals large ranges across spatial scales. For example, the 1970 section analysis produced a mean APS of 18.05 ha, a value almost two times the regional average (9.64 ha) for the same year. As smaller sampling units were used, calculated mean values increasingly exceeded the regional value. Stated another way, mean APS values appear inversely related to sample unit sizes, thereby indicating the method used to calculate APS indices was sensitive to changes in scale. Also, although all parcelization results indicate the same direction of change (average parcel sizes decreased over time with higher average annual rates of change occurring during the 1970s), calculated values are not similar across scales (see

Table 5.6). These differences suggest that mean values calculated for finer scales may not solely represent landscape conditions, but also statistical influences associated with scale changes.

I attribute the scale effect on APS calculations to the method used to sample large private parcels at different scales. Such parcels contributed greater leverage over sample unit calculations as smaller sampling units were used. Large parcel areas influenced measures of central tendency in two ways: first, fewer parcels were included in each smaller unit calculation, which means each large parcel had a relatively greater influence over mean values; and second, large and extreme values biased the mean upwards. In some cases (section analysis only), single large parcel areas contributed the only area value to sample unit calculations. Therefore, when sample unit values were combined into a single mean value, some large parcels assumed an entire degree of freedom. I did not foresee this problem at the outset of analysis hence I did not design a sampling scheme to mitigate it. Therefore, APS values associated with smaller sampling units should be used only for relative comparisons and little confidence placed on actual values. Values associated with larger sampling units (i.e. counties and townships) can be used to summarize parcel sizes with relatively greater confidence.

6.3: Changes in ownership parcelization.

Land ownership parcelization is a phenomenon that causes many planners concern. Parcelization, especially when left unchecked, reduces viable agricultural land, disrupts scenic landscapes, and can limit access to mineral or water deposits (Wyckoff, 1995). Legislation, like the Subdivision Control Act of 1967 (SCA), has been used to preserve open spaces, agricultural land, and scenic landscapes. However, such legislation has also contributed toward high infrastructure per-capita costs, a high price for open spaces. Forest managers are also concerned about parcelization because it retards their ability to manage forested areas that extend over multiple parcel ownership boundaries.

A useful way to visualize land ownership parcelization is to compare published plat maps for the same area for different dates. To find evidence of land subdivision or ownership change, one can often identify blocks of small parcels under diverse ownerships that were previously bounded under a single ownership. Other observable possibilities include aggregated parcels as well as parcels that did not undergo a change in either ownership or extent.

I analyzed digital representations of published plat maps using a geographic information system in order to quantify the parcelization phenomenon in Grand Traverse, Kalkaska, and Crawford Counties. A regional APS index value was calculated for each date. APS values decreased over time from 9.64 ha (23.8

acres) in 1970, to 4.92 ha (12.2 acres) in 1980, and to 4.11 ha (10.2 acres) in 1990. Differences between values show the region experienced higher average parcelization rates during the 1970s than during the 1980s. These trends coincide temporally with residential population growth trends. This temporal coincidence might lead some people to believe the two phenomena are directly related and infer changes in one phenomenon cause changes in the other to occur. However, I believe this coincidence should not be interpreted in this manner. Out of curiosity, I measured the relationship between township growth rates (average number of persons per year) and parcelization rates (average change in parcel size per year) with Spearman's rank-order correlation coefficients.[1] Resultant coefficients (see Table 6.1) indicate township parcelization rates were statistically unrelated to residential growth rates. Furthermore, correlation results of lagged township rates (1970s population growth and 1980s parcelization) suggest changes in land subdivision were not statistically related to earlier residential growth rates. Therefore, the two phenomena, statistically speaking, were not directly related across time and space. However, I speculate that weak coefficients presented in Table 6.1 do not necessarily discount the role new resident populations played in the land subdivision process, but imply other factors must have played a larger role.

[1] Only 31 of 33 townships were used in calculating correlations between 1980 and 1990 township data because City of Grayling and Traverse City parcelization rates are undefined (see Table 5.5). All correlation results are statistically insignificant using a two-tailed, 95 percent confidence interval.

Table 6.1: Correlations between township growth and parcelization rates.

	Parcelization Rate	
Growth Rate	1970 to 1980	1980 to 1990
1970 to 1980	0.086	0.230
1980 to 1990	-	0.185

Recall that seasonal populations are not accounted for in census counts, and hence, were not accounted for in this simple test for correlation. Stewart (1994) and Stynes *et al.* (1997) have shown how seasonal home development and seasonal populations have contributed substantially to rural landscape development in the Great Lakes region.

It is likely that seasonal homeowners who made new claims on the landscape influenced the subdivision process. Local planners and planning organizations should take interest in the results presented in Table 6.1 because they suggest that a measured change in residential population alone may not serve as an adequate indicator of land ownership change for this region. Again, Stynes *et al.* (1997) demonstrated that the population of a Great Lakes county, like any one of the three counties in the study area, can be six or seven times the official resident population because official census counts do not include seasonal homes or seasonal home owners in population totals. Yet, official census counts are often used to describe landscape conditions and inform planning decisions, probably because such data are readily available and often distributed free of charge. For example, Wyckoff and Reed (1995) used census data to describe past and project future demographic changes in Michigan. The authors then used their projections to speculate about what landscape changes might occur should current population trends continue. However, they paid little attention to seasonal population trends or the impacts associated with them. Thereby, Wyckoff and Reed (1995) probably underestimated the impacts that future population changes will have on the landscape.

Given the importance of seasonal home populations to this region, I think an effort spent to record, map, and monitor the spatial and aspatial characteristics of seasonal homes, in addition to residential homes, would produce new and valuable information. This information can be used to better inform our ideas about land ownership and potential landscape change in this region.

Another useful way to visualize land ownership parcelization is to compare parcel size frequency distributions for different dates. Changes between measured frequencies and percentages can be used to infer changes on the landscape. For example, Figures 6.1 and 6.2 illustrate temporal frequency and percentage distributions of parcel areas for the region, respectively. At first glance, one can see each distribution is positively skewed, is multi-modal, and has peaks occurring in the 4, 8, 16, 32, and 65 hectare bins.

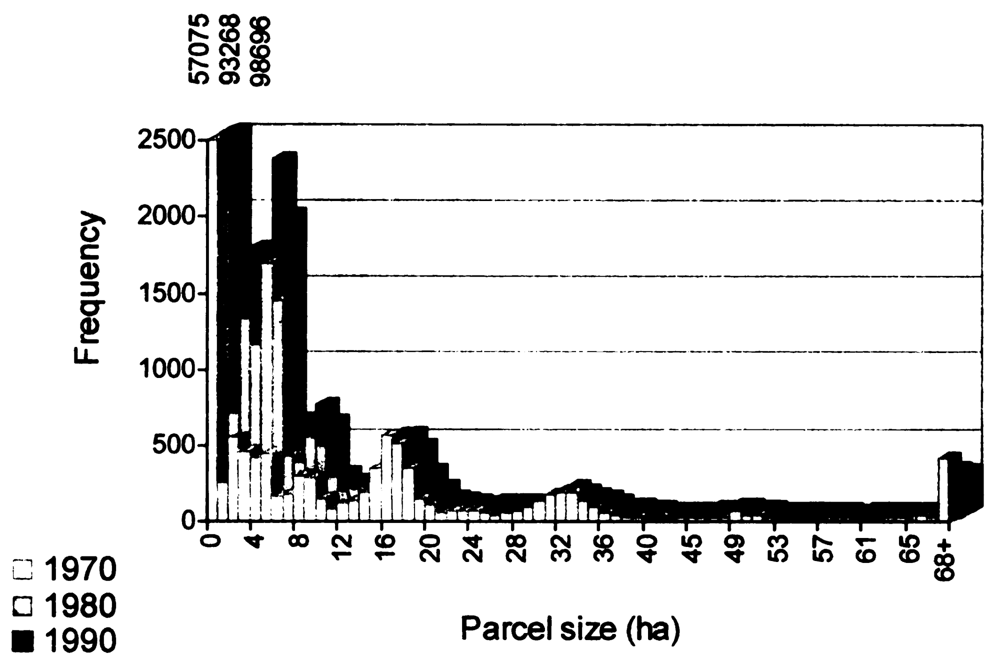


Figure 6.1: Temporal frequency distribution of private parcels.

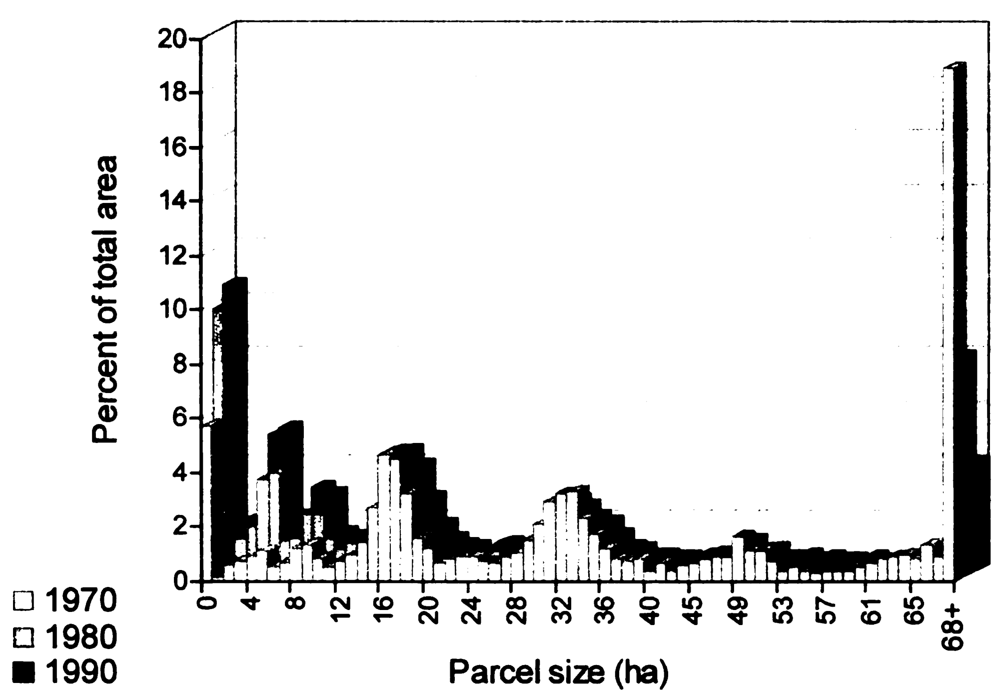


Figure 6.2: Temporal percentage distribution of private parcels.

I believe these peaks betray the effects of recursive halving and/or quartering of Jeffersonian-style survey sections - a pattern typical of the post-colonial American landscape.[2]

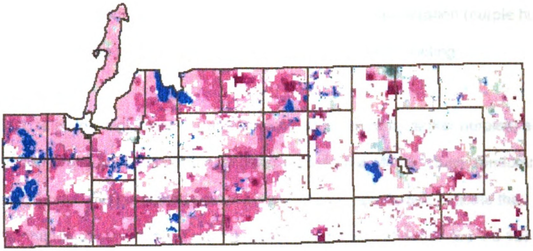
Figures 6.1 and 6.2 reveal large increases in the number and aggregate extent of small parcels and coincident decreases in the number and aggregate extent of large parcels over time. Numbers of small parcels were calculated by dividing the total area classified as small tracts by 0.2 ha, the assumed average size of parcels in small tract areas (see Section 4.3.2). In 1970, parcels smaller than 1 ha, in aggregate, consumed 11415 ha (6%) of private land, while parcels larger than 65 ha consumed more than 43710 ha (19%). By 1990, parcels larger than 65 ha covered only 10620 ha in aggregate (4%), while parcels smaller than 1 ha consumed 19740 ha (10%). Obviously, newly created parcels were carved out of larger parcels given the finite amount of land. On this landscape however, many newly created parcels seem to have been carved out of the largest large parcels.

[2] Public land survey section are approximately 259 ha (640 acres) in size. Typical section subdivisions produce parcel areas approximately equal to 65ha (160 acres), 32ha (80 acres), 16ha (40 acres), 8ha (20 acres), 4ha (10 acres), etc.

This finding will probably strike a nerve in local planners, forest managers, and especially those interested in agriculture because I believe it represents, to some extent, agricultural losses for this region. As stated in Section 3.3, Michigan experienced trends of agricultural decline between 1970 and 1990. Grand Traverse, Kalkaska, and Crawford Counties were not exceptions to these trends (U.S. Department of Commerce, 1992b). Because agricultural land uses are land-consumptive uses, it is likely that the measured loss of very large parcels reported above represents agricultural losses. If these very large parcels do represent past agricultural lands, then this study will provide evidence to support claims made by the Michigan Society of Planning Officials that suggest urban sprawl has occurred in this region (Wyckoff, 1995).

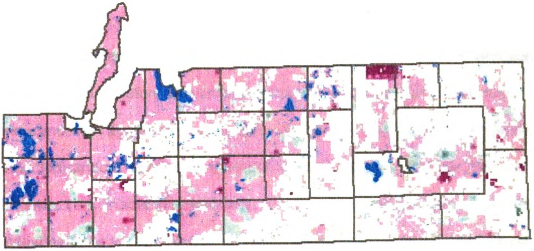
Figures 6.1 and 6.2 also reveal large increases in the number and aggregate extent of parcels 4 to 5 hectares (10 to 12.5 acres) in size. These increases likely reflect the influence the Subdivision Control Act (SCA) of 1967 (MI PA 288 of 1967) had on the parcelization process during this time. As described in Section 2.1.1, the SCA was a piece of legislation that provided for an expensive platting process to be imposed on landowners who subdivided land into parcels smaller than 10 acres. According to Norgaard (1984), the observed statewide response to the SCA was a proliferation of parcels just larger than 10 acres in size. Increases in 10+ acre parcels represented in Figure 6.1 provide additional evidence to support Norgaard's claim. Local and regional planners should pay particular attention to these parcels for three reasons. First, so many parcels of this size now exist; second, they accounted for a relatively large area in aggregate (5%) in 1990; and third, I suspect that many land cover changes have occurred on these parcels. For example, the possibility exists that large parcels, perhaps once held in agriculture, were subdivided into these many 10+ acre parcels. If this is true, then the likelihood exists that subsequent residential development was concentrated on only a small portion of each 10 acre parcel, thereby leaving the balance of each to regenerate from an open field condition into a young forest condition. This scenario might serve as one possible explanation for the forest growth trend reported in Section 5.7. Secondarily, this scenario also attributes to the SCA of 1967 a positive by-product.

Summary values like the ones presented above are easy to calculate and useful for describing general land ownership trends, however such values do not reveal extant spatial variations in the data. Spatial variations in land ownership data can be revealed by mapping land ownership characteristics and using small sampling units. Mapping parcel size changes using survey section data is useful for identifying relative "hot spots" on the landscape. Differences between maps representing two dates or periods indicate changes in hot spot locations over time. Figures 6.3 and 6.4 illustrate relative parcelization rate surfaces interpolated from 1970s and 1980s section level results, respectively. Interior areas not mapped with either purple or green hues represent non-private lands. Areas mapped with a blue hue represent inland lakes.



Legend: Parcel Aggregation Parcelization

Figure 6.3: Map of parcelization rates for the period between 1970 and 1980.



Legend: Parcel Aggregation Parcelization

Figure 6.4: Map of parcelization rates for the period between 1980 and 1990.

Although a majority of private land areas underwent parcelization (purple hues) during both time periods, interesting differences are worth noting.

First, relatively high rates of parcelization (represented by darker purples) appear randomly distributed about the landscape during the 1970s. Such randomness is supported by fine-scaled spatial autocorrelation results that indicate the distribution of parcelization rates exhibited no spatial pattern during the 1970s (see Tables 5.11 and 5.13). In contrast, relatively high rates of change occurred in scattered clumps during the 1980s. Slight clumping during the 1980s is suggested by slight increases in spatial autocorrelation values at short separating distances (see Tables 5.12 and 5.14). Obvious changes in spatial pattern are evident in Kalkaska County and the southern portions of Grand Traverse County.

Many possible reasons exist to explain these changes, such as: a) land supply tightened and therefore was limited to fewer locations, b) new landowner preferences, in aggregate, became focused on a few areas, c) local townships restricted random development with new zoning plans, or d) other reasons. At this time, I am unable to specify with any certainty what actually caused these spatial patterns to change, but perhaps a better understanding could be obtained with additional research.

Second, although the focus of this paper is on parcelization, some areas did experience parcel aggregation. A place of particular interest is located in the northeast corner of Frederic Township, Crawford County (represented by the dark green cluster on Figure 6.3). At some time between 1970 and 1980, several parcels were merged to form a few very large parcels. However, by 1990, these very large parcels were platted as subdivisions and subsequently chopped into small tracts. This particular location is adjacent to several creeks and surrounded by the Au Sable State Forest (due west), the Hartwick Pines State Park (due southeast), and several large inland lakes (due north and just across the county line). It seems likely that proximity and centrality to these recreational features were factors that influenced the parcelization process in this location. Interestingly, 1990 aerial photographs of this location clearly show the land was roaded in order to accommodate scores of new homes. However, only a few homes were actually built. Perhaps the developer experienced difficulties during early stages of the project and was unable to complete it.

6.4: Urban sprawl.

According to the MSPO, urban sprawl is becoming the dominant land use pattern in the Northern Lower Peninsula (Wyckoff, 1995). The MSPO characterizes urban sprawl as a process that produces low-density home developments, population densities lower than urban centers but greater than will permit profitable agriculture, large infrastructure per capita ratios, and a diminished rural character (Wyckoff, 1995). These negative by-products often provide grist for articles and editorials in local newspapers.

The Encyclopedia of Community Planning and Environmental Management offers a similar description of urban sprawl:

> "[Urban sprawl is] an unattractive use of land and resources, causing infrastructure costs related to extending utilities to remote areas. It has also been accused of eliminating environmentally important open space while leapfrogging developable parcels" (Schulz and Kasen, 1984).

These descriptions explicitly identify a link between parcelization and urban sprawl, and they suggest both phenomena are spatial phenomena because they occur with respect to existing locations of open spaces and developable parcels. It seems likely that urban sprawl is preceded by subdivisions of large parcels into small parcels. Therefore, the concept of urban sprawl can be a useful way of thinking about the consequences of parcelization.

Township level spatial autocorrelation analysis results support the idea that the parcelization process is a spatial process, and indicate its extent is larger than any one township. These results suggest that township level parcel patterns do not occur independently of, but are influenced by, surrounding townships. For example, significant Moran's I values in Figure 5.3 show APS values were positively autocorrelated in space at short distances, and negatively autocorrelated at distances greater than 66 kilometers. Also important, the separating distance associated with negatively autocorrelated results decreased from 66 km to 33 km from 1970 to 1990, thus indicating dissimilar 1990 parcel characteristics were separated by half the 1970 separating distance. This decrease in separating distance over time suggests that new landowners leapfrogged developed areas as they bought and divided parcels of land. These results, when considered together with the regional decreases in APS reported above and Shulz and Kasen's (1984) description of urban sprawl, are evidence of new landowners tending to locate not in closed urban spaces, but in open rural spaces. Given this evidence, decision makers for each township may want to consider coordinating planning efforts with other township planners -- and not just those that share a common border. These results indicate township planners should plan at the scale of the process, and not just at the scale of the township, if they want to be proactive and mitigate consequences associated with urban sprawl.

Figure 6.5 represents the parcel size gradient within the 1990 urban extent of Traverse City - a portion of the results presented in Section 5.5. Changes in parcel size indicate average parcel sizes decreased in areas surrounding the city and the urban extent increased over time. Also, the general slope of the trend away from Traverse City (represented by the lines connecting point data in Figure 6.5) decreased over time. This change in slope over time suggests that the landscape, which at one time changed rapidly as one traveled away from the city, became more homogeneous.

A person can visualize increasing population densities (decreasing parcel sizes) that spread into areas surrounding the city by considering changes in the average parcel size gradient in terms of population density. One can also visualize these new densities, although high enough to be considered urban in this example, to be low relative to the urban core. So, location analysis results from this research can be used to support the claim that urban sprawl has occurred in areas surrounding Traverse City.

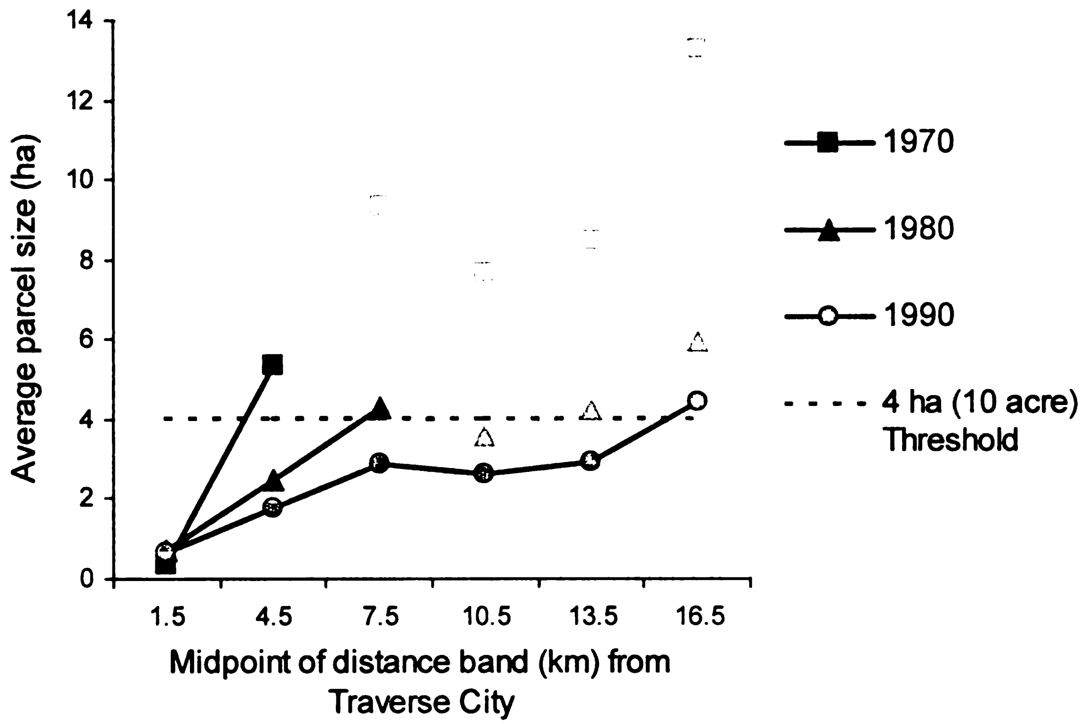


Figure 6.5: Temporal APS values in the Traverse City area.

Recall, however, that forest fragmentation results from Section 5.12 indicate forest defragmentation occurred in these same areas (Figure 6.6 represents the portion of the results presented in Figure 5.10 that fall within the 1990 urban threshold). The areas around Traverse City were expected to show signs of increased forest fragmentation if urban pressures had increased. They did not.

Thus, these results do not indicate a direct relationship exists between parcelization and forest fragmentation.

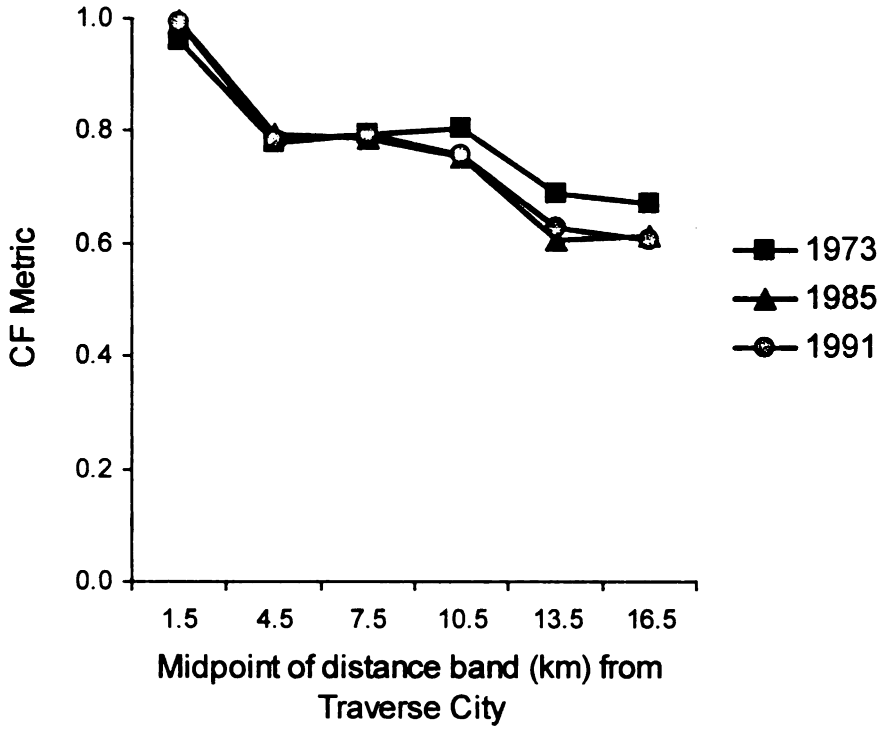


Figure 6.6: Temporal CF values in the Traverse City area.

Location analysis results seem counter-intuitive unless I assume parcelization and subsequent development occurred on non-forested lands, but not on forested lands. If low-density development occurred on non-forested lands, then the possibility exists that areas not maintained as buildings or lawns succeeded from open field conditions to young forest conditions. Such non-forested lands may have been agricultural lands and were taken out of production, parcelized, and subsequently developed for either residential or seasonal home purposes.

Such speculation seems quite reasonable, especially when one considers the agricultural loss, resident population growth, seasonal home development, and tourism development trends that distinguish this region.

6.5: Forest cover change.

Regional forest covers increased by almost five percent from 1973 to 1991, although particular areas of forest growth and loss varied across space and time. This increase seems reasonable because it is similar to the proportion published by the United States Forest Service; Leatherberry (1994) reported a six percent increase for the same region between 1980 and 1993 after a recent forest inventory analysis. Differences between inventory dates and methods may account for the measured difference between forest growth percentages.

In real numbers, forested area increased by 3072 ha from 1973 to 1985, and by another 5602 ha from 1985 to 1991 (see Table 5.15). These numbers do not confirm the idea that a reduction in forest cover occurs as population, urbanization, and parcelization pressures increase. This finding may come as a surprise to many local residents and planners, although probably not to area forest managers.

6.5.1: Forest parcelization.

The Michigan Society of Planning Officials (MSPO) has raised concern about land use practices on forested lands (Wyckoff, 1995). They describe forest fragmentation as the result of forests being cut into configurations where "edge species of plants and animals have proliferated" and deep forest habitats and resident species have declined (Warbach and Norberg, 1995:iv). This definition explicitly links physical landscape changes to human activities. However, the MSPO also describes forest fragmentation as a process of subdividing large forested parcels into many smaller parcels under a diverse ownership. The effect of this process does not necessarily involve a loss of habitat or scenic area, but an impediment to forest management strategies. Forest management strategies are difficult to construct and implement when many, rather than few, landowner viewpoints must be considered. The second MSPO definition, unlike the first, does not imply physical landscape change, but a political consequence. The two definitions are not synonymous.

Additional confusion surrounds the term fragmentation because landscape ecologists have used it to describe different kinds of structural habitat change.[3] For example, Bell (1995) defined fragmentation as the "process of detaching or

---

[3] In the English language the suffix *-ion* has three meanings associated with it when attached to either a noun or a verb. It can be used to identify: a) an action or a process, b) a result of an action or process, and c) a state or condition. Accordingly, the term forest fragmentation has been attributed these three meanings.

separating expansive tracts of forest into spatially segmented tracts." Saunders *et al.* (1991) defined it as the results of a process that "produces a series of remnant vegetation patches surrounded by a matrix of different vegetation and/or land use." And third, Hargis *et al.* (1998) used the term to denote static habitat conditions.

I used a single definition for forest fragmentation consistently throughout this analysis in order to avoid any such confusion. For this research, forest fragmentation means a static forest condition and it represents the degree to which the amount of interior core area of a forest patch or class differs from its maximum potential core area. This definition is concerned with physical landscape change, not political consequences. However, I recognize that the political connotation of the term fragmentation is very important to some planners and planning agencies so, I have included a brief discussion of the phenomenon I think should be called *forest parcelization*.

A useful way to visualize private forest parcelization is to compare forested parcel size frequency distributions for different dates. I used a GIS to query parcel and forest data in order to create histograms of forested parcel areas. For this discussion, private parcels were considered forested if they contained at least 0.4 ha (1 acre) of forest area. Figure 6.7 illustrates a temporal frequency distribution of forested parcel areas for the region.

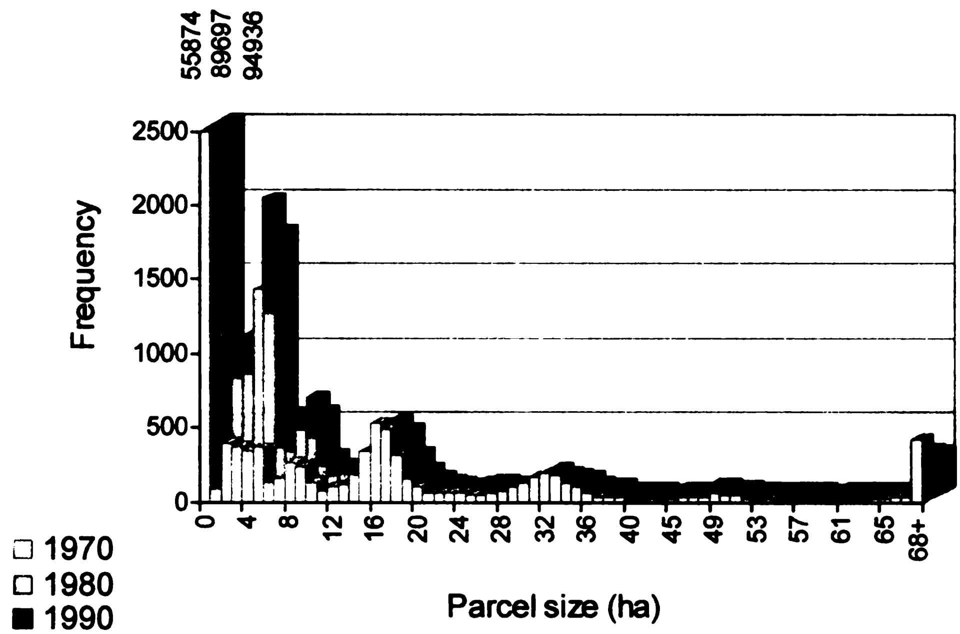


Figure 6.7: Forested parcel size frequency distributions.

Each distribution displayed in Figure 6.7 is positively skewed, is multi-modal, and has peaks occurring in the 4, 8, 16, 32, and 65 hectare bins, just like each total private parcel distribution. In fact, forested parcel distributions (see Figure 6.7) are similar to total parcel distributions (see Figures 6.1) because relatively few parcels existed without some forest cover.

Changes between measured parcel-size frequencies can be used to infer changes on the landscape. For example, Figure 6.7 reveals large increases in the number and aggregate extent of small, forested parcels and coincident decreases in the number and aggregate extent of large forested parcels over time. In 1970, forested parcels smaller than 4 ha (n=57070) contained 8270 ha (7%) of privately owned forest, while forested parcels larger than 65 ha (n=492) contained more than 34970 ha (31%). By 1990, forested parcels larger than 65 ha (n=303) contained only 24330 ha (20%), while forested parcels smaller than 4 ha (n=99400) consumed 19430 ha (16%). Obviously, forests in this region underwent parcelization as thousands of new landowners gained control over private forests. It is no wonder that forest managers are concerned about how to best implement new management strategies, especially when so many different forest owner viewpoints must be recognized and considered.

6.5.2: Forest fragmentation.

Changes in forest structure can disrupt or create new pathways for plant and animal species, nutrients, and energy to disperse in forested landscapes. A change in forest structure is implied by the term *forest fragmentation*. Increases in forest fragmentation can increase the amount of edge-dependent species while simultaneously stranding and extinguishing local populations of interior-dependant species (Fahrig and Merriam, 1994). If enough local populations are extinguished in one region, then a regional population may become extinct. Iida and Nakashizuka (1995) have shown how measured decreases in landscape biodiversity, and subsequently forest health, are associated with increases in forest fragmentation. These associations explain why forest fragmentation is another concern for planners and resource managers in the region. The health of regional tourism- and timber-based economies are linked to the health of regional forest ecosystems.

Unfortunately, the results of this analysis do not help to paint a clear picture of forest fragmentation trends in this region. In brief, forest fragmentation decreased from 1973 to 1985 during a period of average forest growth, but then increased between 1985 and 1991 during another forest growth trend. In general, forest fragmentation trends are usually associated with forest loss trends, and defragmentation trends are associated with growth trends. However, these associations were not consistently evident between 1985 to 1991. Complicating matters further, forest fires occured in the region between 1973 and 1991. Although the extent of the Stephen Bridge Road Fire (see Section 5.8) has been well documented (Winter and Fried, 1997), the extent of other fires have not been explicitly recognized or accounted for in this study. Thus, it is impossible for me to ascertain the influence that forest fires had on my results. Therefore, I cannot posit a single scenario that conveniently summarizes all changes that occured on this landscape.

Yet, I can imagine a likely scenario that may explain forest trends between 1973 and 1985, assuming that data and methods used in this research are accuracte and appropriate. I speculate that as farmland was abandoned, many forest patches naturally extended beyond linear boundaries and into open spaces, thereby allowing patches to grow and coallesse into fewer and larger patches. Aforementioned agricultural trends and patch number, patch area, and core areas statistics in Table 5.14 can be used to support this scenario. At the same time, the possibility exists that some small and highly fragmented forest patches were removed from the landscape in order to accomodate large construction equipment, new home sites, and new roads. Therefore, it may be possible that policies or economic conditions that contributed to agricultural land abandonment and higher intensity development may have also resulted in forest growth and defragmentation trends. According to Iida and Nakashizuka (1995), such forest structure changes are associated with increased biodiversity levels.

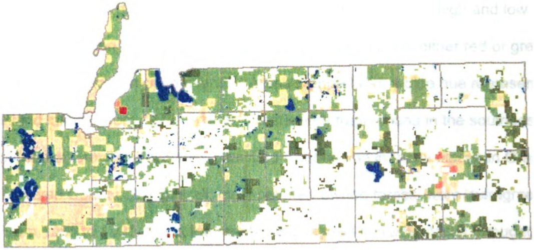
I can imagine two scenarios that can be used to explain the forest growth and fragmentation trends that occured between 1985 and 1991. First, I speculate a possibility exists that during the 1970s, open land was heavily parcelized and small portions of these parcels were developed. Further, undeveloped portions were either landscaped or abandoned to natural succession processes. After several years, many new small patches emerged in these undeveloped portions, and exhibited many forest edges and few core areas. Second, and also possible, several large forest patches may have been bisected by efforts to build new roads, or perforated by new mineral well, logging, or home construction efforts. These processes could have slowed the previous forest growth trend and also resulted in increased fragmentation conditions. Patch number, patch area, and core area statistics in Table 5.14 can be used to support these two scenarios. According to Iida and Nakashizuka (1995), such forest structure changes are associated with decreased biodiversity levels.

Obviously, the above scenarios, although possible, are highly speculative and were not tested. They cannot be confirmed by the data, methods, or results described in this study. However, I included them because they are reasonable and may provoke planners and forest managers to ask additional questions about the relationship between humans and forest environments in this region.

Unlike the results of parcel analysis, spatial analysis of forest fragmentation indices produced results that transcended all observed scales and consistently indicated the existence of general trends. For each date and for each scale, positive spatial autocorrelation decreased with an increase in distance. Such a pattern indicates sampling units near to one another exhibited similarities in static fragmentation conditions while units far from one another exhibited strong differences. Sommers *et al.*, (1984) and Stearns (1997) have described the physical environments that support regional forest covers in terms of spatially varying phenomena (i.e. elevation, hydrology, and soils) so, naturally, one would expect forest conditions in this region to also vary along these spatial gradients.

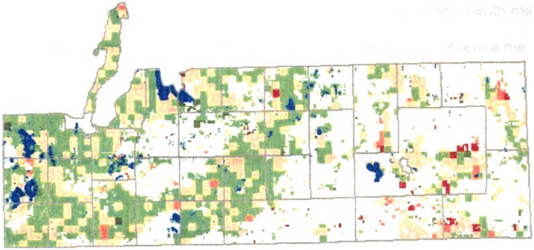
When fragmentation results are interpreted with the original data, these general trends can be better defined. For example, regional amounts of forest cover tended to increase from west to east, and regional fragmentation rates tended to increase from west to east. The forest cover trend represents common knowledge about the area, Grand Traverse County is more populated and contains fewer forested areas than Kalkaska County, which in turn is more populated and contains fewer forested areas than Crawford County. However, the second trend is interesting because it suggests that higher fragementation rates occured in the county with lower populations and higher forest concentrations. Perhaps this trend was unduly influenced by forest fires that occurred in Crawford townships. These results may also suggest the same conclusions made by Vesterby and Hiemlich (1991), Vogelmann (1995), and Theobald, *et al.* (1996); landscape changes tend to be more dramatic during earlier stages of development than during later stages. By comparison, Crawford County was much less developed and urbanized than Grand Traverse County. Therefore, more dramatic changes in forest cover were more likely to be observed in Crawford County than in Grand Traverse County because Crawford County was in an earlier stage of development. This finding has policy implications. Forest managers in Crawford County may have a better opportunity to apply new forest management strategies than those in Grand Traverse County because fewer landowner viewpoints must be organized and considered during decision making processes. Subsequently, forest managers in Crawford County may have a better opportunity to mitigate dramatic forest changes than do forest managers in Grand Traverse County.

Spatial variation in forest fragmentation data can be revealed by mapping average annual fragmentation rates with small sampling units. Figures 6.8 and 6.9 illustrate relative fragmentation rate surfaces that were mapped from section level results.



Legend: Defragmentation Fragmentation

Figure 6.8: Map of fragmentation changes between 1973 and 1985.



Legend: Defragmentation Fragmentation

Figure 6.9: Map of fragmentation changes between 1985 and 1991.

Figures 6.8 and 6.9 are useful for visualizing where relatively high and low rates of fragmentation occurred. Interior areas not mapped with either red or green hues represent non-private lands. Areas mapped with a blue hue represent inland lakes. From 1973 to 1985, forests were fragmenting in the southeast portion of Grayling Township, Crawford County, and in many places in Grand Traverse County. Yet overall, most privately owned forests were defragmenting. From 1985 to 1991, forest fragmentation occurred in many places throughout the landscape. Relatively high rates are noticeable in every county. Note the many sections in Crawford County that exhibited relatively high fragmentation rates. The cluster located in the east-central portion in Grayling Township surely represents structural damage caused by the Stephen Bridge Road Fire (see Figure 5.9). Also note that many sections with high fragmentation rates were located adjacent to inland lakes. This association is observable in both maps and suggests that activities that occur near inland lakes may influence the fragmentation process.

6.6: The link between parcelization and fragmentation.

Spatial distributions of average parcel size and forest fragmentation indices appear to exist along spatial gradients that trend from Grand Traverse County to Crawford County. In general, smaller parcel sizes are associated with higher fragmentation indices. This spatial coincidence is reasonable because one would expect small parcel and small tract areas to be dominated by dense anthropogenic land covers. Location analysis results clearly realize this expectation as forest fragmentation indices tended to decrease with an increase in distance from Traverse City. Also, one would expect areas with many large parcels to contain lower densities of anthropogenic land covers and open spaces available for natural forest covers. Therefore, the spatial concurrence of the average parcel size gradient with the static forest fragmentation gradient seems to support the proposed link between parcelization and fragmentation (Brown and Vasievich, 1996; Bell, 1995; Freedman *et al.*, 1994; and Saunders *et al.*, 1991).

However, I found little evidence to continue to support the proposed link after I visually examined spatially coincident distributions of parcel and forest changes. In general, areas that exhibited high parcelization rates tended not to have high fragmentation rates -- although some specific locations did. In general, areas that exhibited low parcelization rates tended not to have low fragmentation rates -- although a few specific locations did. A simple interpretation would suggest that forest defragmentation was associated with land subdivision, at least within this particular study area.

These findings are very important because they suggest that parcelization and fragmentation processes in this region were not associated in the same manner as coincident patterns of static landscape conditions. This means that we cannot use the relationship between static landscape patterns in this region as a proxy for an understanding the relationship between landscape processes. Furthermore, these findings demonstrate that a complexity exists between these two phenomena that cannot be explained by a simple cause-and-effect relationship. Therefore, these patterns and processes require continued investigation.

6.7: Conclusions.

This research has assessed landscape configurations of private land ownerships and forest habitats in Grand Traverse, Kalkaska, and Crawford Counties. Quantitative analysis of landscape parcel data revealed average parcel sizes decreased over time and land ownership parcelization occurred at a faster rate during the 1970s than during the 1980s. Analysis of forest cover data revealed forest covers increased by nearly 5 percent from 1973 to 1991, forest fragmentation decreased from 1973 to 1985, and increased from 1985 to 1991.

Final interpretations of results suggest six basic conclusions. First, locations with recreational amenities (e.g. inland lakes) seem to influence parcelization and fragmentation patterns as do locations with urban amenities. Second, local planners and forest managers have legitimate concerns about the impacts that urban sprawl can have on the landscape and their abilities to manage forested areas. Third, the Subdivision Control Act of 1967 had an impact on the way land was subdivided, and perhaps, also facilitated some forest growth. Fourth, a need exists for a better accounting of seasonal populations and impacts associated with them. Fifth, parcelization and fragmentation patterns exist with spatial extents larger than any one township in this region. This finding is very important because land use planning in Michigan is a local decision process that is directed by legislation at the township scale, but landscape patterns indicate processes are operating at larger scales. And sixth, we cannot use an association between static landscape patterns in this region as a proxy for understanding a dynamic relationship between landscape processes. In summary, the relationship between land ownership parcelization and forest cover fragmentation is very complex. A need still exists for research results that will help us better understand the ways human decisions and landscape processes interact.

APPENDICES

APPENDIX A: PARCEL DATABASE

I collected plat map books (Rockford Map Publishers, Inc., 1969-1991) that contain cadastral maps representing the Crawford, Grand Traverse, and Kalkaska County ownership patterns for the approximate years 1970, 1980, and 1990. When plat map books were unavailable for the exact target dates, the closest available date was used as a surrogate. In any such case, the difference between obtained date and target date was not greater than one year. Table A1 lists the dates for the set of plat map books used. All parcel maps were published at an approximate scale of 1:51,000 with a consequent positional error in parcel boundaries of about +/- 25.5 meters.

Table A1: Parcel plat map book dates.

	Target Date		
County	1970	1980	1990
Crawford	1970	1979	1991
Grand Traverse	1969	1980	1990
Kalkaska	1969	1980	1991

Parcel maps were digitized, registered, and georeferenced using Arc/Info software (ESRI Inc., 1997) using known section corner locations (MIRIS, 1978) stored in UTM zone 16 coordinates as positional control. All parcel maps were oriented to the section corners with a positional root mean squared error (RMSE) no greater than 12 meters. Individual map coverages were appended to create region coverages for each target date. Region coverages were then edited to remove unwanted sliver polygons, unattributed polygons, and non-existent parcel boundaries. Each regional parcel coverage was topologically correct and attributed consistently and completely with respect to the published source data.

APPENDIX B: SATTELITE IMAGE DATABASE

I collected three pairs of Landsat Multi-Spectral Scanner (MSS) scene data that covered the study area for the approximate years 1973, 1985, and 1991. As mentioned in Chapter 4, each image had been registered, geo-referenced, and distributed as part of the North American Landscape Characterization (NALC) Data set (Lunetta *et al.*, 1998) at a spatial resolution of 60 meters (0.36 hectares / 0.88 acres). Table B1 lists the path/row locations, acquisition date, reported geopositional RMSE, and sun/sensor geometries for the set of images used. Figure B1 illustrates the geographic coverage of the selected NALC data used and the clipped area selected for study.

Table B1: NALC Imagery metadata.

	Target date					
	1970		1980		1990	
Attributes	West	East	West	East	West	East
Path	22	21	22	21	22	21
Row	29	29	29	29	29	29
Acquisition date	6/9/73	8/1/75	6/28/85	8/8/85	7/15/91	8/9/91
RMSE	0.56	0.49	0.85	0.72	0.33	0.31
Sun elevation angle	60	53	59	53	56	52
Sun azimuth angle	128	127	124	131	133	129

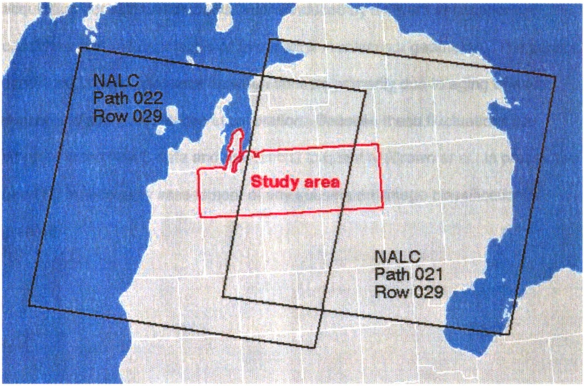


Figure B1: Geographic coverage of NALC imagery.

According to the Yuan *et al.*, (Yuan *et al.*, 1994) the NALC triplicate data sets "constitute a unique data base with which to investigate multidisciplinary issues related to land use/land cover issues, human interactions with the environment, carbon cycling dynamics, and numerous land process studies" (p. 130). Because the data are coregistered and were processed consistently using standardized methods, the NALC data set provides a valuable temporal baseline for regional analyses. However, the NALC data do contain imperfections that pose limitations on some analyses. Major sources of problem are acquisition conditions, changes in phenology, and sensor conditions (as two different satellite sensors were used to gather the data used during this analysis). The acquisition conditions include variations induced by different atmospheric conditions and different levels of illumination (sun/sensor geometry). The sensor conditions include variations between sensors primarily due to aging of each sensor and slight differences in calibration. Because these fluctuations are inherent in the NALC data and are difficult to quantify (Brown *et al.*, in press), the need for an accuracy assessment of any subsequent image classification is greater.

APPENDIX C: ISODATA CLUSTERING ALGORITHM PARAMETERS

Table C1 lists the parameter settings used to instruct the ISODATA clustering iterations in the PCI (PCI, 1997b) XPACE software module.

Table C1: ISODATA clustering algorithm parameters.

Option	Description of input
Database input channels	Bands 1 thru 4 (DNs) + NDVI band ((band4 - band2)/(band4 + band2))
Clustering result output channel	Channel 6
Area mask	Study area less cloud mask
Number of clusters desired	30
Maximum number of clusters	255
Minimum number of clusters	10
Seedfile	blank (uses computers internal clock)
Maximum number of iterations	500
Movement threshold	0.01
Generate signatures file (yes/no)	no
Minimum sample threshold	32
Standard deviation	2
Lumping parameter	1
Maximum number of lumping pairs	5
Background grey-level value	0
Number of image pixels used in sample	100,000

APPENDIX D: HISTORICAL AERIAL PHOTOGRAPH DATABASE

Table D1 lists the attributes used to describe each mosaic. Tables D2, D3, and D4 contain metadata information for photos mosaics used to represent land cover conditions for the years 1970, 1980, and 1990, resepctively.

Table D1: Aerial photograph metadata legend.

Site#:	1 thru 8	Within county identifier for airphoto mosaic
Classification:	C	Photo used for image classification
Accuracy:	A	Photo used for accuracy assessment
Tier/Range/Section:		PLSS identifier of upper left corner of mosaic
Status:	Done	Photo mosaic completely covers site
	Partial	Photo mosaic partially covers site
	Missing	No photo exists for site for date
Date:		Photo acquisition date
Type:	B&W	Black and white
	CIR	Color infrared
	COLOR	Color
Scale:		Linear cartographic scale of original photo
Agency:	ASCS	Agricultural Stabilization & Conservation Service
	BDR	
	MDSH	Michigan Department of State Highways and Transportation
	NHAP	National High Altitude Photography
	USGS	United States Geological Survey

Table D2: Aerial photograph metadata: 1970.

Crawford County, 1970

Site #	C	A	Tier	Range	Section	Status	Date	Type	Scale	Agency
1	x		26	4	3	Done	7/7/73	CIR	1:36,000	MDSH
2	x		28	4	3	Done	7/7/73	CIR	1:36,000	MDSH
3		x	26	3	6	Done	7/7/73	CIR	1:36,000	MDSH
							1963	B&W	1:20,000	ASCS
4		x	25	2	22	Missing				
5	x		28	1	19	Done	1963	B&W	1:20,000	ASCS
6	x		26	2	5	Done	1963	B&W	1:20,000	ASCS
7		x	25	3	19	Done	7/7/73	CIR	1:36,000	MDSH
							1963	B&W	1:20,000	ASCS
8		x	27	1	22	Done	1963	B&W	1:20,000	ASCS

Grand Traverse County, 1970

Site #	C	A	Tier	Range	Section	Status	Date	Type	Scale	
1		x	27	10	18	Done	8/3/73	CIR	1:36,000	MDSH
2		x	25	12	15	Done	7/29/73	CIR	1:36,000	MDSH
							7/7/73	B&W	1:40,000	ASCS
3		x	25	10	18	Done	8/3/73	CIR	1:36,000	MDSH
4	x		25	12	7	Done	7/29/73	CIR	1:36,000	MDSH
5	x		25	11	10	Done	8/3/73	CIR	1:36,000	MDSH
6	x		27	11	15	Done	8/3/73	CIR	1:36,000	MDSH
7		x	26	12	3	Done	7/29/73	CIR	1:36,000	MDSH
							7/7/73	B&W	1:40,000	ASCS
8	x		27	12	6	Done	7/29/73	CIR	1:36,000	MDSH

Table D3: Aerial photograph metadata: 1980.

Crawford County, 1980

Site #	C	A	Tier	Range	Section	Status	Date	Type	Scale	Agency
1	x		26	4	3	Done	Nov-81	BCIR	1:58,000	NHAP
2	x		28	4	3	Done	10/27/81	B&W	1:18,000	USGS
						Partial	Nov-81	BCIR	1:58,000	NHAP
3		x	26	3	6	Done	Nov-81	BCIR	1:58,000	NHAP
4		x	25	2	22	Done	Apr-81	BCIR	1:58,000	NHAP
5	x		28	1	19	Done	Apr-81	BCIR	1:58,000	NHAP
6	x		26	2	5	Done	Apr-81	BCIR	1:58,000	NHAP
7		x	25	3	19	Done	Nov-81	BCIR	1:58,000	NHAP
8		x	27	1	22	Done	Apr-81	BCIR	1:58,000	NHAP

Grand Traverse County, 1980

Site #	C	A	Tier	Range	Section	Status	Date	Type	Scale	Agency
1		x	27	10	18	Done	11/1/81	BCIR	1:58,000	NHAP
2		x	25	12	15	Done	11/1/81	BCIR	1:58,000	NHAP
3		x	25	10	18	Done	11/1/81	BCIR	1:58,000	NHAP
4	x		25	12	7	Done	4/30/77	B&W	1:18,000	USGS
5	x		25	11	10	Done	11/1/81	BCIR	1:58,000	NHAP
6	x		27	11	15	Done	11/1/81	BCIR	1:58,000	NHAP
7		x	26	12	3	Done	11/1/81	BCIR	1:58,000	NHAP
8	x		27	12	6	Done	5/1/81	BCIR	1:58,000	NHAP

Table D4: Aerial photograph metadata: 1990.

Crawford County, 1990

Site #	C	A	Tier	Range	Section	Status	Date	Type	Scale	Agency
1	x		26	4	3	Done	Aug-91	COLOR	1:98,000	ASCS
2	x		28	4	3	Done	8/1/91	COLOR	1:98,000	ASCS
3		x	26	3	6	Partial	Aug-91	COLOR	1:98,000	ASCS
4		x	25	2	22	Done	Aug-91	COLOR	1:98,000	ASCS
5	x		28	1	19	Partial	Aug-91	COLOR	1:98,000	ASCS
6	x		26	2	5	Partial	Aug-91	COLOR	1:98,000	ASCS
7		x	25	3	19	Done	Aug-91	COLOR	1:98,000	ASCS
8		x	27	1	22	Done	Aug-91	COLOR	1:98,000	ASCS

Grand Traverse County, 1990

Site #	C	A	Tier	Range	Section	Status	Date	Type	Scale	Agency
1		x	27	10	18	Done	8/1/92	COLOR	1:98,000	ASCS
2		x	25	12	15	Done	8/1/92	COLOR	1:98,000	ASCS
3		x	25	10	18	Done	8/1/92	COLOR	1:98,000	ASCS
4	x		25	12	7	Done	8/1/92	COLOR	1:98,000	ASCS
5	x		25	11	10	Done	8/1/92	COLOR	1:98,000	ASCS
6	x		27	11	15	Done	8/1/92	COLOR	1:98,000	ASCS
7		x	26	12	3	Done	8/1/92	COLOR	1:98,000	ASCS
8	x		27	12	6	Done	8/1/92	COLOR	1:98,000	ASCS

APPENDIX E: CLASSIFICATION ACCURACY ASSESSMENT

The accuracy of photo-interpreted satellite imagery is often accepted as correct and without qualification. Congalton (1991; p.35) argues, however, "given the complexity of digital classification, there is more of a need to assess the reliability of the results." Meyer and Werth (1990) have addressed problems and issues associated with digital classifications and were critical of decisions made based on invalid and undocumented classification maps. The authors suggested that a quantitative method of accuracy assessment would be most useful for qualifying the usefulness of a particular classification map. According to Jensen (1996), in order to perform classification accuracy assessment, two sources of information must be compared: (a) the derived classification map and (b) accepted ground truth information. Jensen (1996) adds that the relationship between these two sets of information can be summarized and quantified in an error matrix.

An error matrix represents overall and categorical map accuracy together with errors of commission and omission between derived and referenced classes. *Producer's accuracy* is a commonly used measure of omission error whereas *user's accuracy* is a term used to describe errors of commission. Producer's accuracy indicates the probability of a reference pixel being correctly classified on the image and is calculated by dividing the "number of correctly classified pixels in each category by the number of reference pixels in that category" (Lillesand and Kieffer, 1994; p. 613). User's accuracy indicates the probability that "a pixel classified on the map/image actually represents that category on the ground" (Congalton, 1991:37) and is calculated by "dividing the number of correctly classified pixels in each category by the total number of pixels that were classified in that category" (Lillesand and Kieffer, 1994; p. 613).

The K_{hat} statistic is another measure of agreement or accuracy that is often used to test whether of not the results presented in an error matrix are significantly better than results obtained by random chance (Jensen, 1996). The K_{hat} statistic is an estimate of KAPPA used in discrete multivariate analysis. Jensen (1996) maintains that where overall accuracy figures incorporate only proportions of categories classified correctly, the K_{hat} statistic is more robust as it also incorporates commission and omission errors.

For this analysis I utilized error matrices and the K_{hat} statistic in order to evaluate the accuracy of the three classification maps. Historical aerial photographs were collected and used as ground truth references. Figure E1 illustrates the study region with the geographic distribution of aerial photograph mosaics used for image classification and accuracy assessment. Although this approach is favored by Congalton (1991), the best method of comparing derived and referenced data sets probably has yet to be determined. So, rather than pick one method arbitrarily, I have chosen to assess the classified image mosaics according to three common methods outlined by Lillesand and Kiefer (1994).

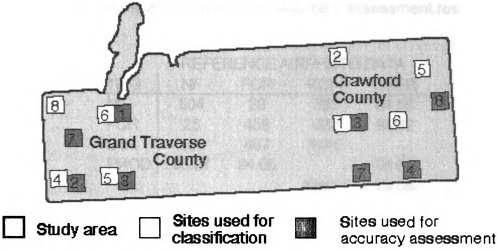


Figure E1: Location of reference aerial photograph mosaics.

The post-classification training sets method utilizes manually selected homogenous areas representing derived land cover categories. Areas representing forested and non-forested cover type are on-screen digitized from each subset of aerial photographs, rasterized, and compared to the classified images. Table E1 presents the post-classification training sets method results obtained during this analysis.

Table E1: Post classification training sets accuracy assessment results.

	REFERENCE AIRPHOTO DATA			
1973	NF	FOR	ROW	USER
NF	504	29	533	94.56
FOR	25	458	483	94.82
COL	529	487	1016	
PROD	95.27	94.05		94.69
			Khat =	89.35

1985	NF	FOR	ROW	USER
NF	476	9	485	98.14
FOR	53	504	557	90.48
COL	529	513	1042	
PROD	89.98	98.25		94.05
			Khat =	88.11

1991	NF	FOR	ROW	USER
NF	511	9	520	98.27
FOR	13	521	534	97.57
COL	524	530	1054	
PROD	97.52	98.30		97.91
			Khat =	95.83

For	=	Forested
NF	=	Not Forested
USER	=	Users Accuracy
PROD	=	Producers Accuracy
Khat	=	Kappa Statistic

The accuracy results presented in Table E1 suggest the cluster classification process was quite successful for classifying all three image mosaics. The 1985 image mosaic produced the lowest relative scores with an overall accuracy of 94.05% and a K_{hat} statistic equal to 88.11%. These numbers indicate 94 percent of the pixels in the image were classified correctly and suggest I could be 88 percent confident that these results were better than a random classification.

However, Lillesand and Kiefer (1994) caution that results obtained from assessments using homogenous training areas are often overly optimistic because bounday pixels tend to be undersampled.

The stratified random sampling method is a process of randomly selecting pixel locations within derived land cover areas that are also represented by historical aerial photographs. This process is stratified so small but potentially important areas within each area are not undersampled (Lillesand and Kieffer, 1994). Next, all selected pixel locations are attributed with both image classes and reference classes. Finally, an error matrix is used to compare the two sets of classes for all locations. This method is often preferred to the post classification training set method because the random method allows selection of pixels that represent borders between adjacent land cover categories. In a study of forest fragmentation, such borders between forested and non-forested land cover categories are important ecological features and should be considered in any accuracy assessment. The post classification training sets method tends to avoid such boundaries as homogeneous areas are preferred. Table E2 highlights the results of the stratified random sampling method obtained during this analysis.

Table E2: Stratified random sampling accuracy assessment results.

	REFERENCE AIRPHOTO DATA			
1973	NF	FOR	ROW	USER
NF	284	59	343	82.80
FOR	81	440	521	84.45
COL	365	499	864	
PROD	77.81	88.18		83.80
			Khat =	66.52

1985	NF	FOR	ROW	USER
NF	275	29	304	90.46
FOR	56	499	555	89.91
COL	331	528	859	
PROD	83.08	94.51		90.10
			Khat =	78.79

1991	NF	FOR	ROW	USER
NF	231	28	259	89.19
FOR	20	529	549	96.36
COL	251	557	808	
PROD	92.03	94.97		94.06
			Khat =	86.25

For = Forested
NF = Not Forested
USER = Users Accuracy
PROD = Producers Accuracy
Khat = Kappa Statistic

The results outlined in Table E2 are less optimistic than the results posted in Table E1 as overall accuracies and K_{hat} statistics were lower for all three dates. However, despite the lower values, the numbers are still relatively high and suggest the selected classification method did a good job of identifying forested and non-forested areas on the regional landscape over time. One noticeable trend is the increase in producers, users, and overall accuracy measures and the

K_{hat} statistic over time. The 1973 image mosaic produced the least reliable results while the 1991 image mosaic produced the most reliable results. Perhaps this trend is a result of increasingly better technology used in newer satellite sensors. However, such a suggestion is speculation only: the real reason behind this trend is unknown and beyond the scope of this research. Regardless, the numbers posted in Table E2 allowed me to be confident in the classifications derived for each mosaic.

The wall-to-wall method compares every pixel in the classified image to every pixel in an image with a reference source (Lillesand and Kiefer, 1994). This methods avoids all the trappings of improper statistical sampling and class representation but, because of the massive amount of reference data needed to perform a wall-to-wall analysis during a regional analysis, this method is not usually preferred. Further, according to Lillesand and Kieffer (1994; p. 614) "reference land cover information for an entire project area is expensive and defeats the whole purpose of performing a remote sensing-based classification in the first place." However, in Michigan, such reference data are available to the public for a single date - 1978 (MIRIS, 1978). Therefore, I used the Michigan Resource Information System (MIRIS, 1978) land cover data to perform a wall-to-wall accuracy assessment of the 1980 target image. Table E3 highlights the wall-to-wall accuracy assessment results obtained during this analysis.

Table E3: Wall-to-wall accuracy assessment results.

	MIRIS DATA			
1985	NF	FOR	ROW	USER
NF	230827	126704	357531	64.56
FOR	55436	705421	760857	92.71
COL	286263	832125	1118388	
PROD	80.63	84.77		83.71

MIRIS classes	Image classes
Coniferous Forest Deciduous Forest Forested Wetlands	Forested
All Others	Non forested

For	=	Forested
NF	=	Not Forested
USER	=	Users Accuracy
PROD	=	Producers Accuracy
Khat	=	Kappa Statistic

Because wall-to-wall assessments make use of each entire image mosaic, K_{hat} statistics were determined unnecessary as no statistical sampling was performed and little to no chance was involved. The producers, users, and overall accuracies calculated during this assessment provide the least evidence to support the validity of the 1985 mosaic classification. Forested areas tended to be identified more consistently and more accurately than non-forested areas even though these numbers suggest the classification method produced an underestimation of forest cover for this region. Users could be 92% confident that a forest pixel on the MIRIS map was classified as forest on the image map. Regardless, although this wall-to-wall assessment produced lower accuracy results, I felt confident enough that the 1985 image mosaic sufficiently represented the larger forest stands contained in the MIRIS data and it probably did a better job of identifying smaller forest patches because of the images had better spatial resolutions and smaller minimum mapping units (one pixel). Furthermore, the MIRIS data and the image data were gathered on non-anniversary dates separated by at least 6 years. Because landscape change can take place within a six-year period, the results from this analysis should be used as only a general indicator of validity.

As mentioned above, the best method of comparing derived and reference data sets probably has yet to be determined. All three methods described above are commonly used, if any method is used at all, in the remote sensing literature to characterize the validity of any particular classification. As might have been expected, all three methods produced slightly different results but, all indicated that the derived classifications were reasonably good in the context of the subsequent analysis.

APPENDIX F: CORE FRAGMENTATION (CF) METRIC

Forest fragmentation is a "detaching or separation of expansive tracts of forest into spatially segmented tracts" (Bell, 1995:45) and is associated with an overall reduction of contiguous and homogeneous forest area. The end result of fragmentation may resemble a patchwork of small, isolated, habitat islands. Quantification of landscape fragmentation is difficult because landscape patterns can be very complex.

Interior core areas contain requisite energy, nutrients, materials, and gene pools necessary to allow forest patches and the plant and animal species associated with them to proliferate in perpetuity. Interactions between interior core areas and patch perimeters are also difficult to quantify because definitions of core area, patch perimeter, and associated edge effects are not mutually exclusive. However, many quantitative measures have been developed that try to measure particular aspects of landscape heterogeneity in an effort to objectively link landscape pattern to landscape process (Baker and Cai, 1992; McGarigal and Marks, 1995).

As mentioned in Section 4.4.5, I found it necessary to construct a landscape index of my own that could (1) be useful by itself, (2) be useful for describing conditions of forest fragmentation, and (3) have a direct relationship with degrees of fragmentation because no sufficient fragmentation metric existed. The core fragmentation (CF) index can be derived with the following equation, which is expressed here in condensed terms:

$$CF = \frac{CORE_{max} - CORE_{obs}}{CORE_{max}}$$

The best way to explain the CF metric is to describe its components using a series of illustrations. As I did in Chapter 2, I use the Whitewater Township landscape data to guide this example.

Figure F1 shows the distribution of Whitewater Township forest cover as it existed in 1973. The green areas represent forested land covers and yellow areas represent non-forested covers. Areas colored with blue represent open water areas. The outset map shows a close-up of one survey section. In it, one can see that much of the land area is covered by forest, although several non-forested fingers penetrate the forest from the east. Also, the land adjacent to the open water area (northwest corner) is generally non-forested and exists between water and forest boundaries. Interestingly enough, review of the original plat map data revealed a small narrow subdivision existed in this particular non-forested area.

Also illustrated in Figure F1 is the distribution of interior core areas (dark green). These interior areas are areas that remained after a 100 meter edge effect was removed from all forest edges. It is plain to see that the spatial extent of interior core area is much less than the spatial extent of total forested area.

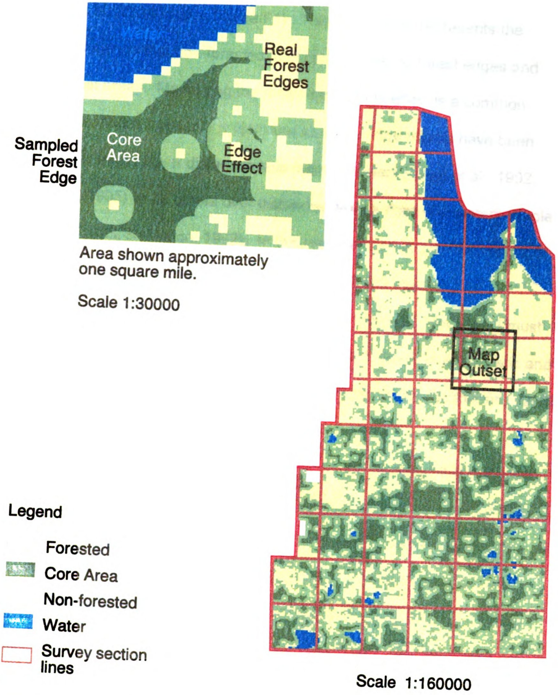


Figure F1: 1973 Forest cover - Whitewater Township.

This difference between interior core area and total forest area is most noticeable in locations where forest edges exist in close proximity to one another (see eastern side of outset map in Figure F1). This edge effect represents the disturbing influence that non-forested land covers have on forest edges and isolated forest areas. Measuring the magnitude of this effect is a common subject in the landscape ecology literature as some edge effects have been determined to extend over distances less than 50 meters (Chen et al., 1992; Vaillancourt, 1995) while others over distances greater than 500 meters (Skole and Tucker, 1993; Robinson, 1992). In this research, a 100 meter edge depth was used for calculation of CF indices; I considered 100 meters to be a conservative estimate of the forest edge depth environment. However, I must note here that edge depth is a species or process-dependent characteristic and should be changed accordingly to suit the analysis objectives (Gustafson, 1998).

The CF metric is designed to measure the relationship between the amount of interior core area observed and the maximum amount of interior core area possible should the total forested area exist in the least fragmented condition possible: a circle is the shape with the largest area-to-perimeter ratio and is therefore, the most compact patch shape subject to the least amount of edge effect. In order to calculate the CF metric, several measurements must be made: total forested area (A_f), total interior core area (A_h), sum of all forest area perimeters, which include both real edges and those imposed by the sample unit boundary (E_s), and sum of real forest area perimeters (E_r). Common core area metrics usually incorporate only E_s in metric calculations. However, the sum of all forest area perimeters does not distinguish between those edges that induce edge effects and those edges that are artificially created by sampling. Therefore, metrics that use E_s as the only estimation of forest edge will overestimate real edge effects and subsequently, overestimate forest fragmentation. Table F1 lists observed landscape measurements for the one square mile area highlighted in Figure F1.

Table F1: CF metric - observed components.

Variable	Notation	Value
Total land area as private	A_l	$2140000m^2$
Total private land area as forest	A_f	$1630000m^2$
Total interior core area	A_h	$690000m^2$
Sum of all forest patch perimeters	E_s	14200m
Sum of all real forest patch perimeters	E_r	11400m
Distance of edge effect	d	100m

The following section outlines the heuristics used to calculate the CF index. Figure F2 has been provided to illustratively guide the reader through the calculation procedure.

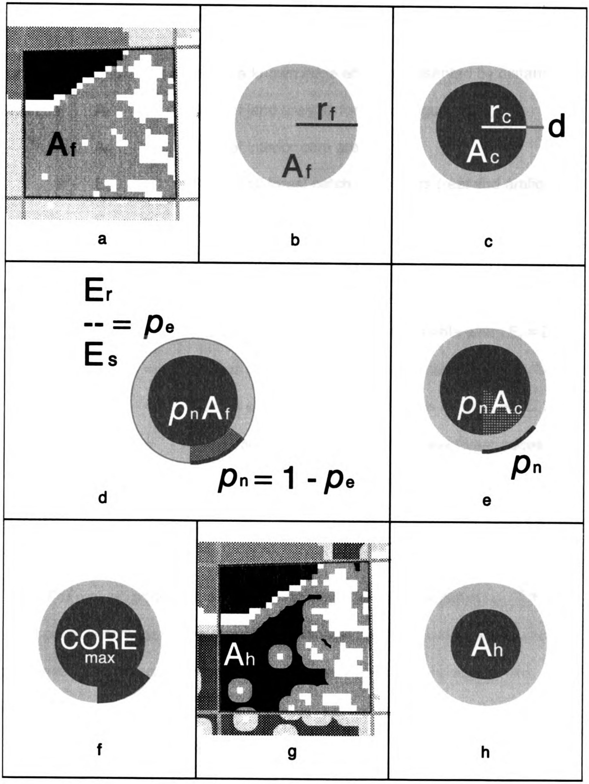


Figure F2: CF Metric calculations.

Section F2.1: The heuristics.

For a given sample unit area and a known edge effect represented by distance d.

Given:	A_f	=	Sum of land area as forested (Figure F2.a)
	A_h	=	Sum of interior core areas
	E_s	=	Sum of all forest patch perimeters (real and artificial)
	E_r	=	Sum of real forest patch perimeters
	d	=	Distance representing the edge effect.

The values for the example survey section have been provided in Table F1.

Let:	A_c	=	Maximum possible core area possible when $E_r = E_s$
	r_f	=	Radius of a circular patch with an area equal to A_f
	r_c	=	Radius of a circular core area with an area equal to A_c
	ρ_e	=	Proportion of all forest edges as real forest edges
	ρ_n	=	Proportion of all forest edges as artificial forest edges

Geometric Assumption:

For a given perimeter, a circle is the shape with the largest area. If a forest patch is arranged as compactly as possible, then it would be in the shape of a circle. The radius of such a circle would be equal to the following (see Figure F2.b):

$$
\begin{aligned}
r_f &= \sqrt{(A_f / \pi)} \\
&= \sqrt{(1630000\text{m} / \pi)} \\
&= \sqrt{518845\text{m}} \\
&= 720\text{m}
\end{aligned}
$$

If we subtract the 100 meter edge effect from radius r_f, then we can calculate the maximum possible core area, first assuming $E_r = E_s$. The size of such a core area can be calculated as follows (see Figure F2.c):

$$r_c = r_f - d$$

$$= 720\text{m} - 100\text{m}$$

$$= 620\text{m}$$

If $r_c > 0$ then let $A_c = \pi r_c^2$, else let $A_c = 0$.

620 > 0 TRUE

$$\text{Let } Ac = \pi r_c^2$$

$$= \pi \bullet 620^2$$

$$= \pi \bullet 384400$$

$$= 1207628\text{m}^2$$

Next, we calculate the proportion of all forest perimeters as real forest edges (see Figure F2.d).

$$\text{Let } \rho_e = E_r / E_s$$

$$= 11400 / 14200$$

$$= 0.80$$

The proportion of forest perimeters not inducing an edge effect is easily calculated by subtracting ρ_e from 1 (see Figure F2.d).

$$\text{Let } \rho_n = 1 - \rho_e$$
$$= 1 - 0.80$$
$$= 0.20$$

The term ρ_n represents the difference between real forest edges and total forest edges and is used to correctly adjust the fragmentation estimate in order to prevent sampled edges from biasing any calculations.

At this point we can combine terms in order to estimate the maximum possible core area if the observed forest area was arranged as compactly as possible and was influenced by the same proportion of negative edge effects. Such a maximum core area can be calculated as follows:

$$CORE_{max} = A_c + \rho_n A_f - \rho_n A_c$$
$$= 1207628 + 0.20\ (\ 1630000\ ) - 0.20\ (\ 1207628\ )$$
$$= 1207628 + 326000 - 241525$$
$$= 1292103$$

The third term, $\rho_e A_c$ (see Figure F2.e) represents the amount of overlap between A_c and $\rho_e A_f$ and is necessarily subtracted from the total in order to prevent overestimation of $CORE_{max}$ (see Figure F2.f).

With all of the requisite pieces calculated, we can calculate the CF metric that describes the proportion of potential core area that has been disturbed by shaped-induced edge effects. The observed core area amount (see Figure F2.g and related Figure F2.h) is subtracted from the maximum core area estimate. The result is then divided by the maximum core area estimate. The CF metric is calculated as follows (see Figure F3):

$$CF = (CORE_{max} - A_h) / CORE_{max}$$

$$= (1292103 - 690000) / 1292103$$

$$= 602103 / 1292103$$

$$= 0.466$$

$$\mathbf{CF = 0.466}$$

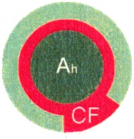


Figure F3: CF Index representation.

The value of the CF metric can be interpreted as follows (see Figure F3); approximately 47 percent of the potential core area in the observed survey section has not been realized because shaped induced edge effects have fragmented these forest areas.

LITERATURE CITED

LITERATURE CITED

Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer. R.E. 1976. *A Land Use and Land Cover Classification System for Use with Remote Sensor Data. U.S. Geological Survey Professional Paper 964.* U.S. Geological Survey, Reston.

Allen, T. and Starr, T. 1982. *Hierarchy: Perspectives for ecological complexity.* University of Chicago Press, Chicago.

Alonso, W. 1964. *Location and land use: Toward a general theory of land rent.* Harvard University Press, Cambridge.

Baker, W.L. and Cai, Y. 1992. The r.le programs for multiscale analysis of landscape structure using the GRASS geographical information system. *Landscape Ecology* 7(4): 291-302.

Barlowe, R. 1978. *Land Resource Economics.* Prentice-Hall, Inc., Englewood Cliffs.

Beale, C.L. 1977. The recent shift of United States population to nonmetropolitan areas, 1970 - 1975. *International Regional Science Review* 2(2): 113-122.

Bell, P.D. 1995. Forest fragmentation: Adverse effects on old growth forest biodiversity. Pages 45-47 in Blovin, G. (Ed.) *Forestry on the Hill, Old growth forests.* Canadian Forestry Association, Canada.

Birch, T.W. 1983. The forest-land owners of New York. *Resource Bulletin NE-66.* U.S. Department of Agriculture, Forest Service.

Brown. D.G. 1997. Regional patterns of parcel size change in the Upper Lake States, USA 1960-1990. Unpublished manuscript.

Brown, D.G. 1998a. Mapping historical forest types in Baraga County Michigan, USA as fuzzy sets. *Plant Ecology* 134: 97-111.

Brown, D.G. 1998b. Classification and boundary vagueness in mapping presettlement forest types. *International Journal of Geographical* Information Science 12(2): 105-129.

Brown, D.G., Duh, J.D., and S.A. Drzyzga. 2000. Estimating error in an analysis of forest fragmentation change using North American Landscape Characterization (NALC) Data. *Remote Sensing of Environment* Vol. 71(1):106-117.

Brown, D.G. and Vasievich, J.M. 1996. A study of land ownership fragmentation in the upper Midwest. *Proceedings. GIS/LIS '96 Annual Conference and Exposition*. Denver, CO. p. 1179-1186.

Casetti, E. 1971. Equilibrium land values and population densities in an ideal setting. *Economic Geography* 47:16-20.

Cawrse, D. 1994. Resource management perspective: Managing to minimize fragmentation of native hardwood forests. Pages 192-200 in Sample, V. Alaric (Ed.) *Remote sensing and GIS in ecosystem management*. Island Press, Washington, D.C.

Chappelle, D.E. 1997. A detailed examination of economic effects of growth in tourism and forest product sectors in the Lake States. Pages 228-248 in Vasievich, J.M. and Webster H.H. (Eds.) *Lake States Regional Forest Resources Assessment: Technical Papers*. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, St. Paul, MN.

Chen, J., J.F. Franklin, and T.A. Spies. 1992. Vegetation responses to edge in old-growth Douglas-fir forests. *Ecological Applications* 2: 387-396.

Comer, P.J., Albert, D.A., Wells, H.A., Hart B.L., Raab, J.B., Price, D.L., Kashian, D.M., Corner, R.A., and Schuen, D.W. 1995. *Michigan's Presettlement Vegetation, as Interpreted from the General Land Office Surveys 1816-1856*. Digital map. Michigan Natural Features Inventory, Lansing, MI.

Congalton, R.G. 1991. A review of assessing the accuracy of classification of remotely sensed data. *Remote Sensing of the Environment* 37: 35-46.

Conners, D. 1998a. 2,800 Acres of Pere Marquette Forest on the auction block. *Great Lakes Bulletin*. Summer/Fall 1998: 18-20.

Conners, D. 1998b. Large parcel of Au Sable Forest may be sold for industrial/commercial use. *Great Lakes Bulletin*. Summer/Fall 1998: 19-20.

Erickson, D.L. 1995. Rural land use and land cover change: Implications for local planning in the River Raisin watershed. *Land Use Policy* 12(3): 223-236.

ESRI Inc. 1995. *Arc/Info v. 7.0.3.* Environmental Systems Research Institute, Redlands.

Fahrig, L. and Merriam, G. 1994. Conservation of fragmented populations. *Conservation Biology.* 8(1): 50-59.

Forman, R. T. T. 1995. *Land Mosaics: The ecology of landscapes and regions.* Cambridge University Press, Cambridge.

Forman, R. T. T. and Godron. M. 1986. *Landscape ecology.* John Wiley & Sons, New York.

Fox, M.F. and Macenko, S.L. 1985. The agriculture-forest interface: An overview of land use change. A report of the Land Use Analysis Division, Land Use Policy and Research Branch and of the Canada Land Use Monitoring Program Land Resources and Data Systems Branch. *Working Paper No. 38.* Lands Directorate, Environment Canada, Canada.

Frohn, R.C. 1998. *Remote sensing for landscape ecology: New metric indicators for monitoring, modeling, and assessment of ecosystems.* Lewis Publishers, Washington, D.C.

Fuguitt G.V., Brown, D.L., and Beale, C.L. 1989. *The population of rural and small town America.* Russell Sage, New York.

Geolytics, Inc. 1996. Census CD, Version 1.1. [Compilation of 1990 U.S. Census Bureau statistics and access software on CDROM] Geolytics, Inc., East Brunswick.

Grand Traverse County Planning Commission. 1997. *Focus 2020: A County Master Plan, 1997.* [Online] Available at: http://www.grandtraverse.org/masterp/. (6 June. 1997)

Griffith D.A. 1987. *Spatial Autocorrelation: A Primer* Resource Publications in Geography. Association of American Geographers, Washington, D.C.

Griffith, D. A. and G. Armhein. 1991. *Statistical analysis for geographers.* Prentice-Hall, Inc., Englewood Cliffs.

Grigg, D. 1974. *The harsh lands: A study in agricultural development.* St. Martin's Press, New York.

Gustafson, E.J. 1998. Quantifying landscape spatial pattern: What is the state of the art? *Ecosystems* 1: 143-156.

Hargis, C.D., Bissonette, J.A., and David, J.L. 1998. The behavior of landscape metrics commonly used in the study of habitat fragmentation. *Landscape Ecology* 13(3): 167-186.

Hart, J.F. 1984a. Population change in the Upper Lakes States. *Annals, Association of American Geographers* 74(2): 221-243.

Hart, J.F. 1984b. Resort Areas in Wisconsin. *Geographical Review* 74: 192-217.

Hill D. 1985. Forest fragmentation and its implications in Central New York. *Forest Ecology and Management* 12: 113-128.

Holmberg A. and H. Dobyns. 1969. The Cornell program in Vicos, Peru. Pages 393-414 in Wharton, Jr., C.R. (Ed.) *Subsistence agriculture and economic development*. Aldine Publishing Co., Chicago.

Homer C.G., Ramsey, R.D., Edwards Jr., T.C., and Falconer, A. 1997. Landscape cover-type modeling using a multi-scene Thematic Mapper mosaic. *Photogrammetric Engineering and Remote Sensing* 63(1): 59-67.

Iida, S. and Nakashizuka, T. 1995. Forest fragmentation and its effect on species diversity in sub-urban coppice forests in Japan. *Forest Ecology and Management* 73: 197-210.

Iverson, L.R., Graham, R.L., and Cook, E.A. 1989. Applications of satellite remote sensing to forest ecosystems. *Landscape Ecology* 3: 131-143.

Jensen, J. R. 1996. *Introductory digital image processing: A remote sensing perspective, 2nd Edition*. Prentice-Hall, Inc., Upper Saddle River.

Johnson, K.M. 1989. Recent population distribution trends in Nonmetropolitan America. *Rural Sociology* 54(3): 301-326.

Johnson, L.B. 1990. Analyzing spatial and temporal phenomena using geographic information systems: A review of ecological applications. *Landscape Ecology* 4: 31-43.

Kleiman, R.E. and Erickson, D.L. 1996. Landscape change in an agricultural watershed: The effect of parcelization on riparian forest cover. *Environment and Planning B: Planning and Design* 23: 25-36.

Kufuor, O. K. 1981. *An analysis of private land fragmentation by holdings less than 11 acres in Michigan*. Ph.D. Dissertation. Department of Resource Development, Michigan State University, East Lansing, MI.

Leatherberry, E.C. 1994. *Forest statistics for Michigan's Northern Lower Peninsula Unit, 1993. Resource Bulletin NC-157*. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, St. Paul, MN.

Leibenstein, H. 1957. *Economic backwardness and economic growth*. Wiley & Sons, New York.

Li, H. and Reynolds, J.F. 1993. A new contagion index to quantify spatial patterns of landscapes. *Landscape Ecology* 8: 155-162.

Lillesand, R.M. and Kiefer, R.W. 1994. *Remote sensing and image interpretation, 3rd Edition*. Wiley & Sons, New York.

Lunetta, R.S., Lyon, J.G., Guindon, B., and Elvidge, C.D. 1998. North American Landscape Characterization dataset development and data fusion issues. *Photogrammeteric Engineering and Remote Sensing*. 64(8): 821-829.

MacKay, D.G. and Ellefson, P.V. 1997. A regional comparison of Public Forest Resources Management Programs in the United States. Pages 77-91 in J.M. Vasievich and H.H. Webster (Eds.) *Lake States Regional Forest Resources Assessment: Technical Papers*. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, St. Paul, MN.

McGrew Jr., J. C. and Monroe, C.B. 1993. *An Introduction to Statistical Problem Solving in Geography*. Wm. C. Brown Publishers, Dubuque.

McPherson, M.P. 1982. *Land fragmentation—a selected literature review. Development Discussion Paper #141*. Harvard Institute for International Development, Cambridge, MA.

McPherson, M.P. 1983. *Land fragmentation in agriculture: Adverse? Beneficial? And for whom? Development Discussion Paper #145*. Harvard Institute for International Development, Cambridge, MA.

McGarigal, K. and Marks, B.J. 1993. *Fragstats: Spatial pattern analysis program for quantifying landscape structure*. Oregon State University.

Meetenmeyer, V. 1989. Geographical perspectives of space, time and scale. *Landscape Ecology* 3: 163-173.

Merriam, G. and Wegner, J. 1992. Local extinctions, habitat fragmentation and ecotones. In Hansen, A.J. and Di Castri, F. (Eds.) *Landscape Boundaries*. Springer Verlag, New York.

Meyer M. and L. Werth. 1990. Satellite data: Management panacea of potential problem? *Journal of Forestry* 88(9): 10-13.

Michigan Resource Iinformation System (MIRIS). 1978. *Digital land use and land cover data* [CD-ROM not distributed] State of Michigan, Department of Natural Resources, East Lansing, MI.

Milne, B. T. 1991. Lessons from applying fractal models to landscape patterns. Pages 199-235 in Turner, M. G. and Gardner, R. H. (Eds.). *Quantitative methods in landscape ecology*. Springer-Verlag, New York.

Moran P. 1948. The interpretation of statistical maps. *Journal of Royal Statistical Society, Series B* 37: 243-251.

Muth, R.F. 1969. *Cities and Housing: The spatial pattern of urban residential land use.* University of Chicago Press, Chicago.

Norgaard, K.J. 1984. *Impacts of the Subdivision Control Act of 1967 on Land Fragmentation in Michigan's Townships*. Ph.D. Dissertation. Department of Agricultural Economics, Michigan State University, East Lansing, MI.

Odland, J. 1988. *Spatial autocorrelation*. Sage Publications, Beverley Hills.

Openshaw, S. 1984. Ecological fallacies and the analysis of areal census data. *Environment and Planning A* 16:17-31.

Papageorgiou, E. 1963. Fragmentation of land holdings and measures for Consolidation in Greece. Pages 543-548 in Parsons, K., Penn, R., and Raup, P. (Eds.) *Land Tenure*. University of Wisconsin Press, Madison.

PCI. 1997a. *ImageWorks Version 6.2*. PCI. Richmond, Ontario.

PCI. 1997b. XPace *Version 6.2*. PCI. Richmond, Ontario.

Potter-Witter, K. 1995. *Status and Potential of Michigan Natural Resources; Timber and timberland resources. Special Report 71*. Michigan Agricultural Experiment Station. Michigan State University, East Lansing, MI.

Riitters, K.H., O'Neill, R.V., Hunsaker, C.T., Wickham, J.D., Yankee, D.H., Timmins, S.P., Jones, K.B., and Jackson, B.L. 1995. A factor analysis of landscape pattern and structure metrics. *Landscape Ecology* 10: 23-40.

Robinson, S.K. 1992. Population dynamics of breeding neotropical migrants in a fragmented Illinois landscape. Pages 408-418 in Hagan, J.M. III and Johnston, D.W. (Eds.) *Ecology and conservation of neotropical migrant landbirds*. Manomet Bird Observatory, Manomet, MA.

Roche, J. 1963. Important aspects of consolidation in France. Pages 536-543 in Parsons, K., Penn, R., and Raup, P. (Eds.) *Land Tenure*. University of Wisconsin Press, Madison.

Rockford Map Publishers, Inc. 1969-1991. *Land Atlas and Plat Map Book*. Rockford Map Publishers, Inc., Rockford, IL.

Saunders, D. A., Hobbs, R.J., and Margules, C.R. 1991. Biological consequences of ecosystem fragmentation: A review. *Conservation Biology* 5: 18-32.

Saunders, D. A., Rowley, I., and Smith, C.T. 1985. The effects of clearing for agriculture on the distribution of cockatoos in the southwest of Australia. Pages 309-321 in Keast, A., Recher, H.D., Ford, H., and Saunders D. (Eds.) *Birds of eucalypt forests and woodlands: Ecology, conservation, management*. Royal Australian Ornithologists Union, Surrey Beatty and Sons, Chipping Norton, Australia.

Scheer, C.D. 1963. The Place of Tenancy in the Agriculture of the Netherlands. Page 519 in Parsons, K., Penn, R., and Raup, P. (Eds.) *Land Tenure*. University of Wisconsin Press, Madison.

Schultz, M.S. and Kasen, V.L. 1984. *Encyclopedia of Community Planning and Environmental Management*. Facts on File, Inc. New York.

Skole, D.L. and Tucker, C.J. 1993. Tropical deforestation and habitat fragmentation in the Amazon: Satellite data from 1978 to 1988. *Science*, 260:1905-1910.

Sommers, L., Darden, J.T., Harman, J.R., and Sommers, L.K. 1984. *Michigan, a geography*. Westview Press, Boulder, CO.

Stearns, F.W. 1997. Physical environment supporting Lake States Forests. Pages 1-7 in Vasievich, J.M. and Webster, H.H. (Eds.) *Lake States Regional Forest Resources Assessment: Technical Papers*. U.S. Department of Agriculture, Forest Service, North Central Research Station. St. Paul, MN.

Stewart, S. I. 1994. *The Seasonal Home Location Decision Process: Toward a Dynamic Model*. PhD. Dissertation. Department of Parks and Recreation, Michigan State University, East Lansing, MI.

Stynes, D.J., Zheng, J.J., and Stewart, S.I. 1997. *Seasonal homes and natural resources: patterns of use and impact in Michigan. General Technical Report NC-194.* U.S. Department of Agriculture, Forest Service, North Central Research Station. St. Paul, MN.

Theobald, D.M., Gosnell, H., and Riebsame, W.E. 1996. Land use and landscape change in the Colorado Mountains II: A case study of the East River Valley. *Mountain Research and Development* 16(4): 407-418.

Thrall, G. I. 1987. *Land Use and Urban Form: The Consumption Theory of Land Rent.* Methuen & Co., Ltd., London.

Thünen, J.H. von. 1842. *Der Isolierte Staat.* In Hall, P. (Ed.), *Von Thünen's Isolated State.* Pergamon. London.

Todaro, M. 1981. *Economic development in the Third World.* Longman, New York.

Tou, J.T. and Gonzalez, R.C. 1977. *Pattern recognition principles.* Wesley Publishing Co., Addison.

Turner, M.G. 1989. Landscape ecology: The effect of pattern on process. *Ann. Rev. Ecol. Syst.* 20: 171-197.

Turner, M.G. 1990. Spatial and temporal analysis of landscape patterns. *Landscape Ecology* 4: 21-30.

Turner, M.G., and Gardner, R.H. (Eds.) 1991. *Quantitative methods in landscape ecology.* Springer-Verlag, New York.

U.S. Department of Commerce. 1962. *1960 Census of Housing and Population.* U.S. Government Printing Office, Washington D.C.

U.S. Department of Commerce. 1972. *1970 Census of Housing and Population.* U.S. Government Printing Office, Washington D.C.

U.S. Department of Commerce. 1982. *1980 Census of Housing and Population.* U.S. Government Printing Office, Washington D.C.

U.S. Department of Commerce. 1992a. *1990 Census of Housing and Population.* U.S. Government Printing Office, Washington D.C.

U.S. Department of Commerce. 1992b. *1990 Census of Agriculture-Michigan.* U.S. Government Printing Office, Washington D.C.

U.S. Department of the Interior, U.S. Geological Survey. 1994. *7.5-Minute Digital Elevation Models (DEM) for Michigan.* [Online] Available at: http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/7_min_dem/states/MI.html (10 Dec. 1997).

U.S. Department of the Interior, U.S. Geological Survey. 1993. *1:100,000-Scale Digital Line Graph (DLG) Data: Hydrography and Transportation - Area 7 Northern Great Lakes States.* [CD-ROM] U.S. Department of the Interior, U.S. Geological Survey, National Mapping Division, Reston.

U.S. Department of the Interior, U.S. Geological Survey. 1990. *1:250,000 and 1:100,000 Scale Land Use and Land Cover and Associated Maps Digital Data* U.S. Department of the Interior, U.S. Geological Survey, National Mapping Division, Reston.

U.S. Environmental Protection Agency. 1993. *1:250,000 Scale Quadrangles of Landuse/Landcover GIRAS Spatial Data in the Conterminous United States* [Online] Available at: ftp://ftp.epa.gov/pub/spdata/EPAGIRAS/ (6 Jun. 1998).

U.S. Forest Service, Department of Agriculture. 1980 and 1993. Forest Inventory and Analysis DataBase Retrieval System. [Online] http://www.srsfia.usfs.msstate.edu/scripts/ew.htm. (10 Dec. 1997).

U.S. Forest Service, Department of Agriculture. 1997a. *Early settlement forest cover maps.* [Online] Available at: http://198.87.4.38/gla/histveg/details.htm. (6 Jun. 1998).

U.S. Forest Service, Department of Agriculture. 1997b. *Great Lakes Fires greater than 10 acres, 1985-1995.* [Online] Available at: http://198.87.4.38/gla/natdist/images/10fireglo.jpg. (12 Jun. 1999).

Vaillancourt, D.A. 1995. *Structural and microclimate edge effects associated with clearcutting in a Rocky Mountain forest.* Master's Thesis. University of Wyoming, Laramie, WY.

Vanderpol, P. 1963. Reallocation of land in the Netherlands. Pages 549-554 in Parsons, K., Penn, R., and Raup, P. (Eds.) *Land Tenure.* University of Wisconsin Press, Madison.

Vesterby, M. and Heimlich, R.E. 1991. Land use and demographic change: results from fast growing counties. *Land Economics* 67(3): 279-291.

Villard, M.A., Freemark, K.E., and Merriam, G. 1992. Metapopulation dynamics as a conceptual model for neotropical migrant birds: An empirical investigation. Pages 474-482 in Hagan, J.M. and Johnston, D.W. (Eds.) *Ecology and conservation of neotropical migrant landbirds*. Smithsonian Institution Press, Washington, D.C.

Vogelmann, J.E. 1995. Assessment of forest fragmentation in southern New England using remote sensing and geographic information systems technology. *Conservation Biology* 9(2): 439-449.

Vogelmann, J.E., Sohl, T. and Howard, S.M. 1998. Regional characterization of land cover using multiple sources of data. *Photogrammetric Engineering & Remote Sensing* 64(1): 45-57.

Warbach J.D. and Norberg, D. 1995. *Michigan Society of Planning Officials Trend Future Project: Public Lands and Forestry Trends Working Paper.* Michigan Society of Planning Officials, Rochester, MI.

Webster, H.H. 1997. Institutions for Managing Lake States Forests. Pages 253-264 in J.M. Vasievich and Webster, H.H. (Eds.) *Lake States Regional Forest Resources Assessment: Technical Papers.* U.S. Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN.

Winter, G.J. and J.S. Fried. 1997. Assessing the Benefits of Wildfire Risk Reduction: A Contingent Valuation Approach (PDF). *Proceedings of the 1996 Society of American Foresters National Convention.* p. 320-325.

Wolf, E. 1966. *Peasants.* Prentice-Hall, Inc., Englewood Cliffs.

Wyckoff, M.A. 1995. *Michigan Society of Planning Officials Trend Future Project: Final Report.* Michigan Society of Planning Officials, Rochester, MI.

Wyckoff, M.A. and Reed, R. 1995. *Michigan Society of Planning Officials Trend Future Project: Demographic Trends Working Paper.* Michigan Society of Planning Officials, Rochester, MI.

Yuan, D., Elvidge, C., Lunetta R., and Lyon, J. 1994. Issues on NALC Large Spatial and Long Temporal Change Detection. 1994 ASPRS/ACSM Annual Convention & Exposition, American Society for Photogrammetry and Remote Sensing Technical Papers, Reno, NV. p. 128-137.

MICHIGAN STATE UNIVERSITY LIBRARIES
3 1293 02092 6857