USDA United States Department of Agriculture

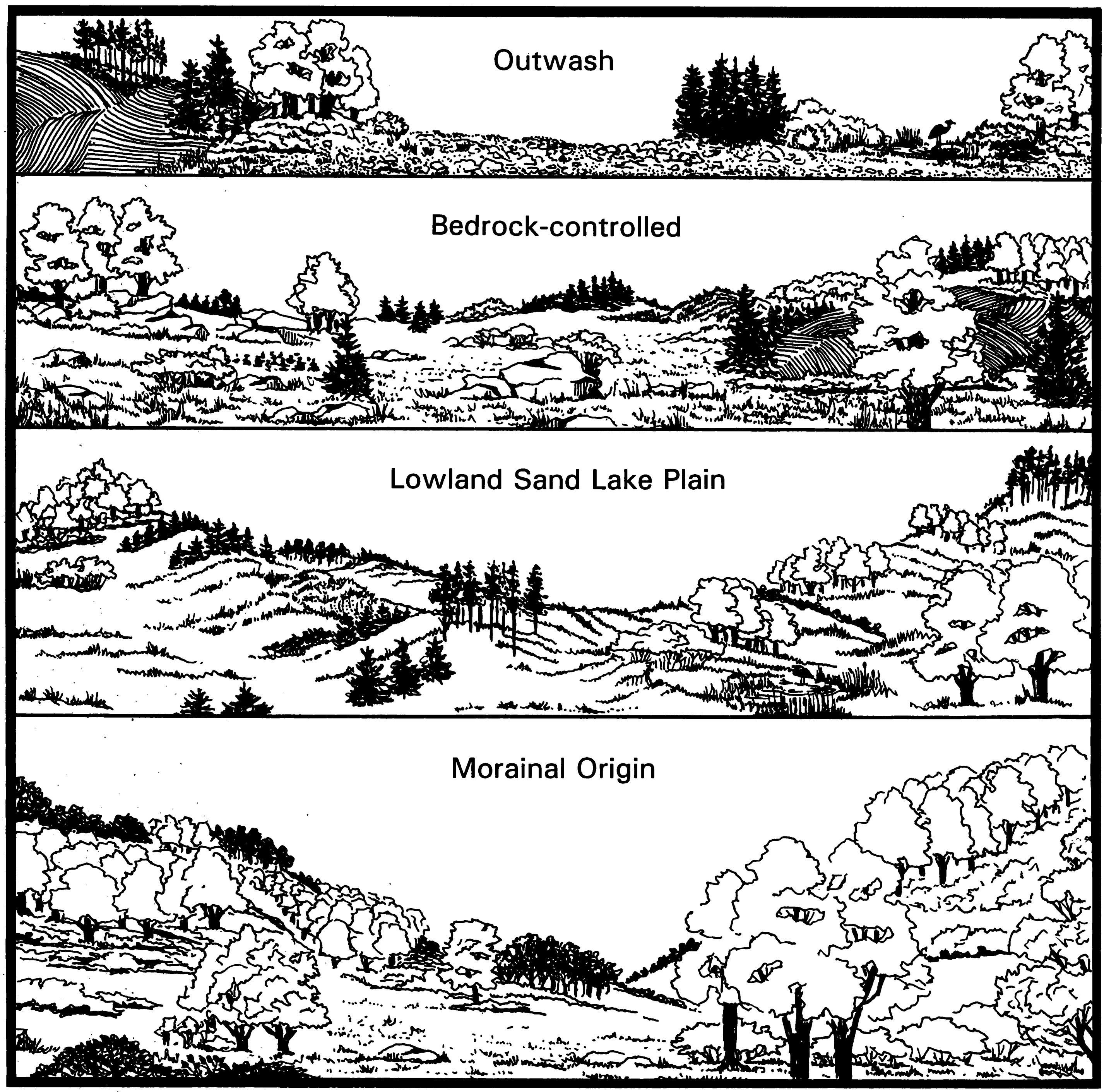
Forest Service

North Central Forest Experiment Station

General Technical Report NC-192

An Interpretation of Landscape Structure from Historic and Present Land Cover Data in the Eastern Upper Peninsula of Michigan

Janet Silbernagel, Jiquan Chen, Margaret R. Gale, Kurt S. Pregitzer, and John Probst



North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication July 31, 1997
1997

An Interpretation of Landscape Structure from Historic and Present Land Cover Data in the Eastern Upper Peninsula of Michigan

Janet Silbernagel, Jiquan Chen, Margaret R. Gale, Kurt S. Pregitzer, and John Probst

Policy makers and planners dealing with broad scale issues must account for landscape and regional scale factors in their design. In light of contemporary broad-scale environmental issues, landscape pattern analysis has become a necessity for both resource managers and scientists. Questions such as ... "how will managing a 40-ha tract affect adjacent areas or regions?..." have promoted new approaches to society's dilemmas like air and water quality, species and habitat losses, and increased carbon dioxide levels (King 1993). Maps of regional- and landscape-scale ecological units are available to, and now frequently used by, policy decision-makers and land managers to approach these sorts of issues. Regional and landscape ecological units based on biophysical factors provide an ecologically based framework for land use decisions. However, for many of these ecological units, measurable descriptions of pattern, composition, and other characteristics are lacking. Measures that quantify and describe landscape structure (pattern and composition) improve knowledge of ecological units and strengthen the framework on which both finer resolution landscape decisions may be based. Already there have been rigorous efforts linked with physical geography to describe land surface patterns (Golley 1995). But, many of these studies, regardless of the investigator's perspective, have been of limited extent (Pastor and Broschart 1990, Simpson *et al.* 1994), low resolution (Dunn *et al.* 1991, Hulshoff 1995, O'Neill *et al.* 1988), or of narrow temporal scale (Luque *et al.* 1994, Muller and Middleton 1994, Simpson *et al.* 1994, Turner and Ruscher 1988). What is needed are works that can increase spatial and temporal extent while maintaining high resolution so that results can be applied to a larger area and provide a longer frame of reference, yet still be meaningful for site level assessments.

There has been significant interest in landscapes surrounding the Great Lakes, where land use has had a particularly large influence on the lake ecosystems (e.g., Upper Great Lakes Biodiversity Committee; Lake Superior Binational; SOLEC, in press). Fluctuations in human population in the Lake States since European settlement have played a role in development of current forest patterns and have been the focus of several research programs. For instance, Frelich (1995) documented the amount of "old forest" in historic and present forests of the Lake States, including amounts present in various land cover types. He defined "old forest" as both old growth (forests dominated by long-lived species beyond 120 years) and old-seral forests (dominated by short-lived species that are relatively old at age 80). The results showed that about 5.2 to 8.3 percent of the Lake States forest is now old forest, compared with

---

Janet Silbernagel is with the Department of Horticulture and Landscape Architecture, Washington State University, Pullman, WA 99164.

Jiquan Chen, Margaret Gale, and **Kurt Pregitzer** are with the School of Forestry and Wood Products, Michigan Technological University, Houghton, MI 49931.

John Probst is with the Forestry Sciences Laboratory, USDA Forest Service, North Central Forest Experiment Station, Rhinelander, WI 54501-9128

an estimated 68 percent before European settlement. Frelich also found that in the largest single block of remaining unlogged forest in the Lake States, Minnesota's Boundary Waters Canoe Area Wilderness, the spatial pattern, age structure, and species composition have been significantly altered since the 1800's. Still, Frelich's study was limited to assessment of "old forest," was coarse in resolution (errors of +/- 50 percent for forest areas 400 ha in size or less), and did not quantify spatial pattern to augment additional landscape analyses.

The distinction of this study from important works like Frelich's and others' lies in its geographic size, its sequence of time, and its provisional assessment units. We chose landtype association groups as the basis for comparison to control for broad physiographic patterns, while strengthening the knowledge base of these units and their value as planning elements (McNab 1996, Sims *et al.* 1996). Many previous landscape assessments have been based on administrative or arbitrary boundaries (e.g., 7.5' USGS quadrangle maps), rather than an ecological framework. Without such a framework, it is not possible to account for variation in the physical environment.

I. OBJECTIVES

The objective of this report was to:

Compile quantitative information, or landscape metrics, to supplement existing qualitative descriptions of landtype associations in the study area. Compare the distribution of landscape measures among landtype association groups in historic and present landscapes.

This study occurred in the context of a larger research project whereby historic and contemporary landscape variability was described and quantified, landscape change was assessed over a 150-year time period, cultural settlement patterns were assessed over a 3,000-year time period, and the landscape change was discussed in terms of the combination of biophysical and cultural factors. This report addresses the first portion of the research: description and quantification of historic and contemporary landscape patterns.

II. BACKGROUND

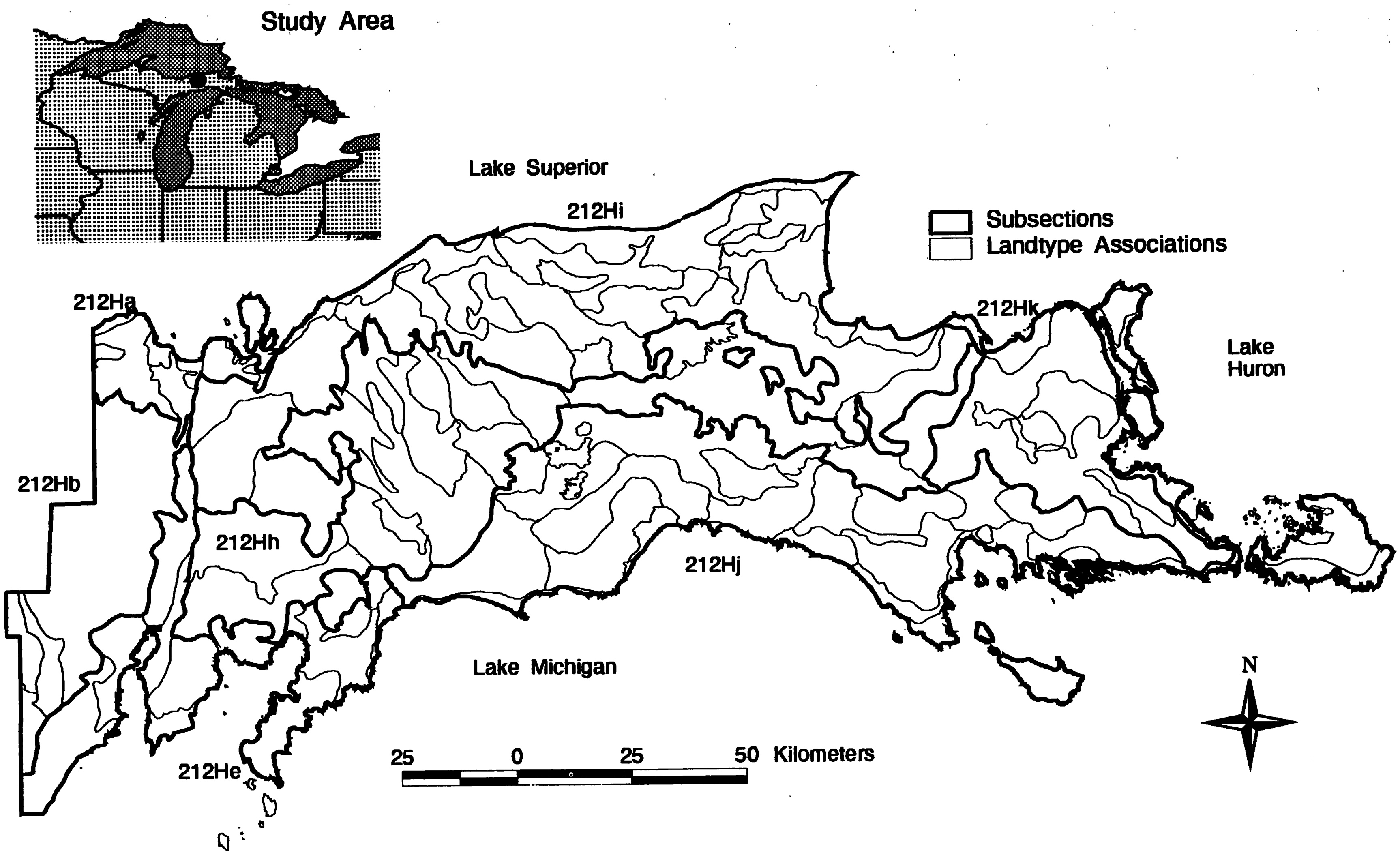
A. Study Area

1. Geographic location: The study area is the Eastern Upper Peninsula of Michigan, comprising six counties: Alger, Chippewa, Delta, Luce, Mackinac, and Schoolcraft; and 1,795,524 ha[1]. The area is bordered by three Great Lakes—Huron, Michigan, and Superior—and is characterized by lake-moderated climates and land types including hardwood forest on glacial moraines; pine barrens on outwash and beach ridges; coastal marshes; interior bogs, fens, and swamps; and limestone outcrops (Peterson 1986). The area lies completely within the Northern Great Lakes Ecological Section (map 1), (Bailey *et al.* 1994, McNab and Avers 1994).

2. Physiographic setting: The Northern Great Lakes Section is a level to gently rolling lowland of flat outwash or lacustrine plain with dune fields near the Great Lakes. Partially buried end moraines protrude from the lowlands roughly parallel to the lakes. A large portion of the area is covered by Pleistocene stratified drift, mostly outwash sand. Lacustrine deposits occur between morainal ridges and are widespread in the Eastern Upper Peninsula. Pleistocene and Holocene sand dunes occur near the Great Lakes (Martin 1957). Silurian limestones and dolomites are locally exposed along Lakes Huron and Michigan, while Cambrian and Precambrian sandstone outcrops occur along Lake Superior. The dominant geomorphic processes for this area are fluvial erosion, transport, and deposition; lake-shore erosion and deposition; and minor dune construction (Albert 1995, McNab and Avers 1994).

3. Land ownership: Much of the Eastern Upper Peninsula is public land including the Hiawatha National Forest, Lake Superior State Forest, Seney National Wildlife Refuge, Pictured Rocks National Lakeshore, and Tahquamenon State Park. Other large land holdings belong to The Nature Conservancy and three major industrial landowners. Together these holdings make up about 12 percent of Michigan's land area in one of the most undeveloped portions of the Eastern United States.

[1] *One hectare equals 2.471 acres.*



Map 1.—*Landtype associations (LTAs) within ecological subsections of the Eastern Upper Peninsula (Ball & Padley 1993). More than 100 unique LTAs were delineated within six subsections as mapped by Albert (1995) and the Eastern Region of the Forest Service.*

B. Ecological Classification

Because of the infinite complexity inherent in any ecosystem, land areas are often categorized into discrete units so that biophysical components can be measured and understood (Allen and Starr 1982, Klijn and Udo de Haes 1994, Urban *et al.* 1987). Unified functional ecosystems are divided and categorized into similar and dissimilar pieces at various scales, in the interests of description and understanding (Rowe 1996, 1991). A hierarchical framework of ecological units was developed for the United States, from which units for this study were based (ECOMAP 1993). The *Framework* was modeled after the multi-factor, multi-scale approach to understanding ecosystem structure and function pioneered in Baden-Wurttemberg, Germany (Albert 1995, Barnes 1984, Spurr and Barnes 1980). At the broadest scale of the framework, global ecosystems were identified, within which a series of finer scale ecoregions are nested (Bailey *et al.* 1994, Bailey 1996). Next, Albert *et al.* (1986, 1995) mapped regional landscape ecosystems of Michigan, Minnesota, and Wisconsin to the subsection level, based on climatic and broad physiographic factors. The finest level units of their work provided the framework for subdivision into local landscape ecosystem units characterized by topography, microclimate, soil, and vegetation (Albert *et al.* 1986).

III. METHODS

A. Data Assembly

1. Landtype association: Landscape ecosystems, defined as "a cluster of interacting ecosystems repeated in similar form throughout," (Crow 1991; Forman and Godron 1986; Jordan *et al.*, in prep.) provide a spatial footprint that can account for mesoscale physical environmental factors. They are a useful size for many analyses because they are commonly based on easily identifiable physiographic factors, they are well-suited to scales of modern inventory technology (remote sensing, GIS, etc.), and they can be easily recognized from automobile or airplane (Smith and Carpenter 1996). Boundaries separating landscapes are distinct, as often seen in satellite images, due to geomorphology and human activity (Forman 1995). Within a relatively short time, landscape ecosystems can be delineated and described across large areas (multiple States), yet still provide enough information to identify differences in ecological potential or trends and to improve coordinated management among multiple land owners or regulatory agencies (Cleland pers. comm., ECOMAP 1993).

Through an interagency effort, a first approximation of landtype associations (LTA's) were mapped across the Eastern Upper Peninsula to help coordinate natural resource stewardship (map 1). The LTA's were identified in accordance with concepts and methods described in *The National Hierarchical Framework of Ecological Units* (ECOMAP 1993, Ball and Padley 1993, Uhlig and Jordan 1996).

The delineation process is iterative, using both top-down (regionalization) and bottom-up (classification) information. At this stage, the delineations have been based primarily on intuitive and visual methods. However, bottom-up ecological classification and research such as in this report contribute to, refine, and validate the landscape boundary locations. Similarly, macroscale research (e.g., regional climatic data) is underway that will provide quantitative top-down contributions. Preliminary delineation criteria included terrain (major slope and elevation changes or escarpments, variability of slope) from 1:250,000 USGS topography maps; geology (bedrock type, surficial geology, major glacial features, paleoshorelines) from Anderton (1993), Martin (1957), and Farrand (1982); soil (communities of soils, drainage, texture, depth to bedrock, source and mode of deposition) from county-level soil association maps; localized climate (lake effect wind-blown sand and wave action, major cold air drainages, etc.) from Santer (1977); large lakes or open water systems; watersheds (drainage pattern, water level, and fluctuation variability); and vegetation (LANDSAT 1984 image, pre-European settlement vegetation from General Land Office surveyors notes, aerial photography); existing subsection maps; plot data; and personal experience (Jordan *et al.*, in prep.).

For this study, LTA's were intuitively grouped into the following eight categories based on dominant physiographic similarities: bedrock-controlled, lowland sand lake plain, morainal origin, outwash, clay lake plain, ground moraine, transitional/complex, and inland lake (Gary *et al.* 1974). The groupings are comparable to Michigan's Land Types mapped by the

Michigan Department of Natural Resources (Santer 1977). We used only four of the eight groupings: bedrock-controlled, lowland sand lake plain, morainal origin, and outwash for analysis because we believed they were the most internally consistent and because they occurred repeatedly across the study area (map 2).

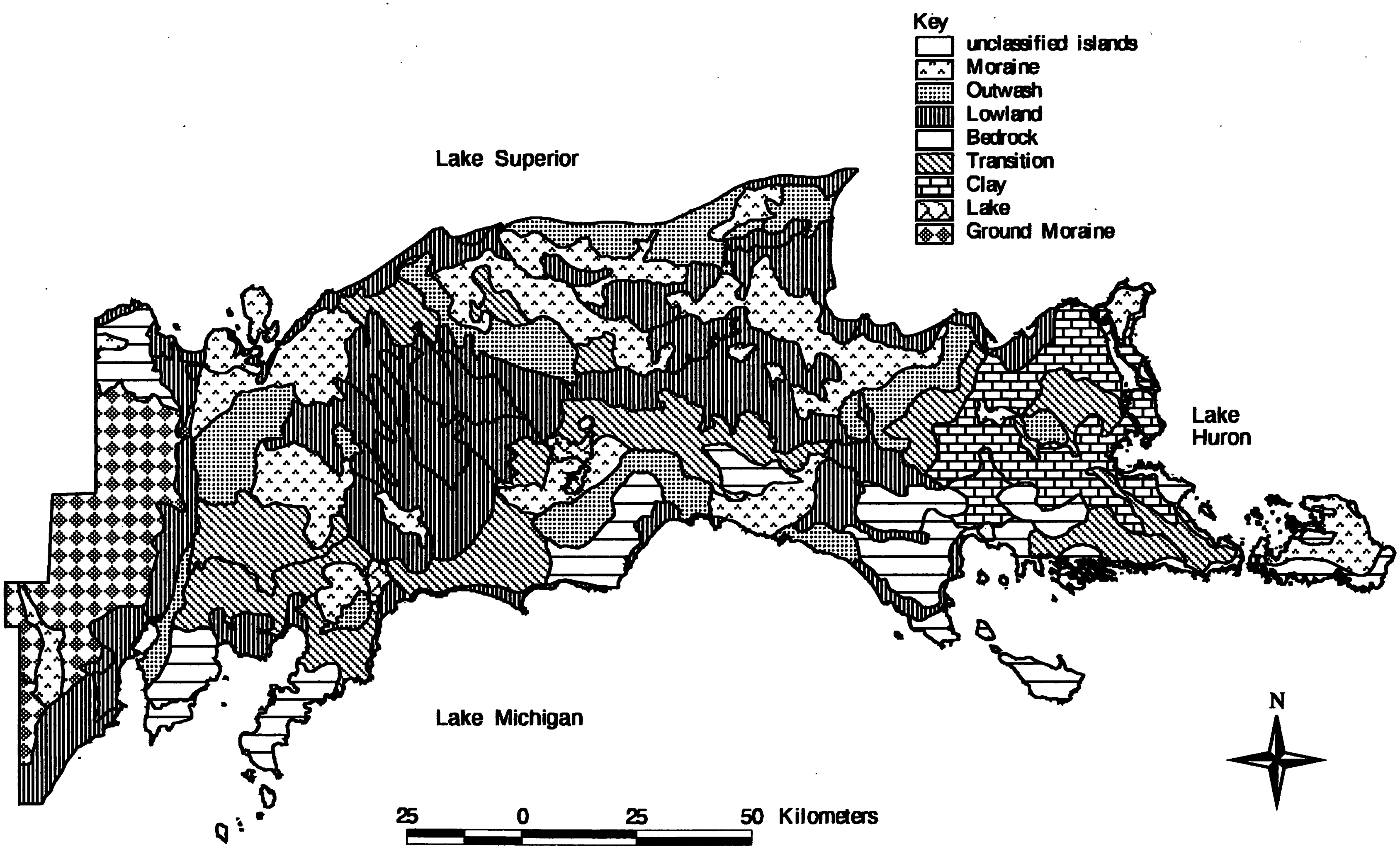
2. *Present land cover:* Land cover data derived from Landsat Thematic Mapper (TM) satellite imagery were used to measure present landscape structure. The TM imagery was classified into land cover categories for the entire Upper Peninsula with 60-m resolution. Maclean Consultants, Ltd. of Houghton, Michigan, obtained Landsat Thematic Mapper (TM) imagery for the Upper Peninsula of Michigan from Eosat, Inc., in contract with the Michigan Department of Natural Resources, to classify TM images into land cover categories (Maclean 1994). Images were selected to provide: (1) complete coverage of the Upper Peninsula; (2) minimal cloud cover; (3) coverage no earlier than 1990; and (4) data from the correct time of the growing season for best species differentiation (June 1 through July 31). Classification accuracy was presented in the form of contingency tables that showed both errors of omission and errors of commission (Maclean 1994). The result was a complete land cover classification for the entire Upper Peninsula with an average 90.2-percent correct (accuracy) within a 95-percent confidence interval.

3. *Historic land cover:* General Land Office (GLO) survey records have been commonly used in historic vegetation and landscape assessment studies. Early uses of these records involved reconstruction of pre-European settlement forests in the form of maps and compositional descriptions (Curtis 1959, Veatch 1959). The suitability of survey records for quantitative analysis of historic vegetation was first documented by Bourdo (1956). Subsequent studies by Lorimer (1977, 1980), Canham (1978), Canham and Loucks (1984), Noss (1985), and Whitney (1986) described the use of GLO notes and other historic records in characterizing historic forests and critiqued the various approaches. In a more recent application of historic data in the Lake States, Baker (1991) simulated effects of settlement and fire suppression by using a GIS-based spatial model and historical data on fire size and frequency.

Pre-European settlement landscape data based on the GLO survey notes were used as the historical dataset of land cover for this study (Ewert, pers. comm.; Albert, pers. comm.; MNFI 1994). Surveyors of Michigan in the early 1800's took detailed notes on the location, species, and diameter of each tree used to mark section lines and corners. Their notes also detailed landscape features such as lakes, wetlands, fields, natural disturbances, trails, and settlements. For our study, advantages of these records were: (1) they are available in digital format for the entire Upper Peninsula of Michigan, (2) original field work was conducted according to a predetermined plan, and (3) the surveys constitute a systematic aligned sample of the historic forest species and thus are useable for quantitative analysis (Bourdo 1956, Price 1994).

Land cover maps were compiled by the Michigan Natural Features Inventory on 1:24,000 USGS topographic maps. Section line information recorded by land surveyors in the early 1800's was plotted onto the USGS maps. Cover type boundaries between each section line were interpolated using elevation lines, surface geology maps, and other early vegetation maps; the resulting resolution was definable to 259 ha, although many smaller polygons were delineated. Cover classes were based on expanded Michigan Resource Information System (MIRIS) land cover codes. Small cover types not transected by the surveyors were probably not recorded. Bias in tree species selected by surveyors has been documented (Bourdo 1956) and was assumed in map production (MNFI 1994). Nevertheless, previous investigations have concluded that the GLO records could be used to reconstruct historic vegetation (Bourdo 1956, Curtis 1959). In fact, in a study by Price (1994) of composition, structure, and disturbance regimes of historic forests in western Chippewa County, Michigan (within the Eastern Upper Peninsula), tests found only moderate bias toward the 15- and 20-cm diameter classes in the mixed conifer/deciduous lowland forest type. Therefore, Price concluded that GLO records from western Chippewa County were largely free of bias toward any specific diameter classes or tree species.

Each layer was compiled in digital format and georeferenced to Universal Transverse Mercator projection on a Unix platform ARC/INFO Geographic Information System. A legend defining the cover types was included with both the



Map 2.—*Groupings of landtype associations based on physiographic similarities within the Eastern Upper Peninsula.*

historic and present coverages (tables 1 and 2). Because the two legends were not identical, they had to be combined so that cover types in one coverage matched those in the other, or in some cases, a cover type was renamed (table 3). Of the total 24 cover types in the combined legend, 10 were selected for analysis based on the following criteria: the type was present in both time periods in at least two of the LTA groups; the types represented a broad range of land cover classes indicative of the region and pertinent to the objectives of this study (e.g., mixed conifer and cedar were selected, but white spruce was not); based on our familiarity with the two datasets, the type seemed to be relatively consistent between and within the two datasets (e.g., herbaceous shrub and openlands were inconsistent, particularly in the historic set); or the type was of particular importance to land use change questions (e.g., agriculture).

B. Data Analysis

Indices measuring several components of landscape pattern and composition together are a means to quantify structure and change (Hess 1994, Milne 1991, O'Neill *et al.* 1988). Indices and basic metrics (measures of pattern and composition) can be computed for three scales: patch, class, and landscape. Patch-scale metrics are primarily used as building blocks to calculate class and landscape metrics, and relate to an individual patch or stand of a relatively homogenous (consistent) cover type. Class statistics relate to individual land cover classes, or cover types, based on dominant overstory species within a landscape and include: number of patches, percent of a class in a landscape, mean patch size of the class, and average perimeter/area ratios (shape indices). Class metrics are known for their application in estimating levels of fragmentation or in determining the degree to which the matrix (most connected) class is fragmented by another class type. Landscape statistics relate to the landscape or LTA group as a whole and include number of patches, total area, mean patch size, and patch size variability; diversity of classes, dominance of one class over others, and shape, or fractal indices. Landscape-scale metrics are used to examine landscape diversity and structure of an entire landscape, or to compare landscapes of different time periods or location (MacGarigal and Marks 1993).

Metrics can be categorized according to what they measure. Some metrics measure pattern, others measure composition. We used the FRAGSTATS Spatial Pattern Analysis Program (MacGarigal and Marks 1993) to quantify and describe patterns within and among LTA groups in the historic and present land covers. In this report, we focus on the following landscape metrics: number of patches (N), total area (TA), mean patch size (MPS), patch size coefficient of variation (PSCV), largest patch index (LPI), patch density (PD), and Shannon's diversity index (SHDI), the combination of which we believed best represented aspects of landscape structure. Largest patch index indicates the contribution of the largest patch to total area. Patch size coefficient of variation provides a measure of relative variation. Patch density is the number of patches per 100 ha, and Shannon's diversity index indicates the amount of different class types in a landscape. Equations for each of the indices used are provided in Appendix A.

Class statistics and indices calculated for this report included class area (CA), N, MPS, landscape similarity index (LSIM), LPI, PD, PSCV, and mean shape index (MSI). Landscape similarity index measures the proportion of a class area to the total landscape area. Mean shape index is a ratio of patch area to patch perimeter. Selected landscape and class calculations were tabulated and graphed by LTA group.

There is a limitation to conclusions that may be drawn from comparing historic to present data due to methodological and resolution differences between the two. The objectives of this paper do not include comparisons over time, and inappropriate inferences should be avoided.

IV. RESULTS AND DISCUSSION

A. Landscape Composition

1. Historic Landscape Composition: No areas were mapped as "urban" in MNFI's transcription of the GLO maps as we have for the present cover; rather, a separate map layer was created by MNFI showing cultural settlements, primarily Indian villages. Non-vegetated areas did not occur in the outwash group, and agriculture did not occur in any of the four groups. Herb/openland occurred only in outwash, and shrub land did not occur in any of the groups studied. Oak cover type was absent in all LTA groups. Neither dry nor wet hardwood-conifer mixes were found in the historic datasets. Red pine was not found in the bedrock group, and white spruce was absent from the historic lowland landscape (map 3a, table 4).

2. Present landscape composition: The present coverage was substantially more detailed due to the higher resolution from the Thematic Mapper (TM) classification (map 3b. However, a few cover types were absent in the LTA groups considered (table 4). There were no oak, balsam fir, or hemlock types in any of the present datasets. In the original present legend, most conifer types were coded into two classifications: <70-percent but >40-percent canopy closure contributed by that species, and >70 percent canopy closure contributed by that species. In the LTA groups assessed, cedar occurred only in the >70-percent canopy closure class, except for the lowland group, where it occurred only in the <70-percent class. In other words, in the bedrock, moraine, and outwash groups, all cedar patches in the present land cover were quite dense, and dominated by cedar. In the lowland group, however, cedar stands were less dense, or included other species.

B. Landscape Measures

1. Historic Landscape Metrics: Of the four LTA groups studied, the lowland group was largest in total area (509,511 ha), with 5,409 patches, and the outwash group was smallest (198,831 ha), with 1,640 patches (table 5). In the historic landscape, LPI was highest in the moraine group (10.280), with a mean patch size of 121 ha and lowest in the lowland group (2.757, MPS = 94 ha), although the other three groups (bedrock, lowland, and outwash) were relatively close (table 5, fig. 1). Because LPI in the lowland group was lower than in the other groups, we can determine that the lowland MPS was less affected by a single large patch (table 5). The four groups had relatively close values for PD and SHDI. PD was highest in the lowland group (1.062) and lowest in the bedrock group (0.631). Outwash had the highest diversity historically (SHDI = 2.069), and lowland had the lowest (0.520).

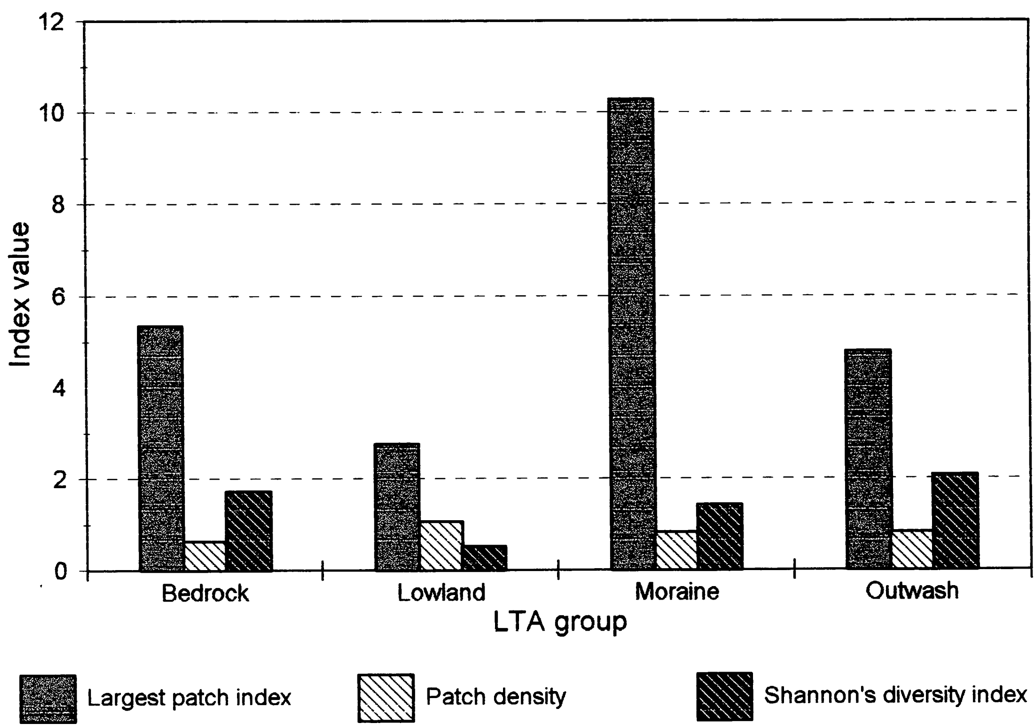


Figure 1.—*Values for three landscape level indices: largest patch index (LPI), patch density (PD), and Shannon's Diversity Index (SHDI) calculated by LTA group on the historic land cover.*

Map 3.—*An example of a) historic and b) present land cover of the Eastern Upper Peninsula within one moraine landtype association. Historic cover was derived from translated and interpolated General Land Office surveyors' notes of the 1840's by MNFI (1994). Present cover was derived from 1992 Landsat TM imagery (Maclean 1994).*

2. *Present Landscape Metrics:* Similar results were obtained for the present landscape, in which the lowland group had the greatest number of patches (63,994), and the remaining three groups all had approximately 25,000 patches. LPI was highest in the moraine group (5.631), but due to the higher resolution, MPS was only 11 ha (fig. 2). Lowland had the lowest LPI again (1.170, MPS = 8 ha). MPS for all four groups was between 8 and 11 ha. Present PD was highest in the lowland group (12.560) and lowest in the moraine group (9.056), although all four groups reflected high PD due to higher resolution data. Diversity for all groups in the present landscape was low (0.578 - 0.615) (table 5, fig. 2).

C. Class Measures

Northern hardwoods, especially, and mixed conifer to a lesser extent were the most prevalent (LSIM) of the 10 classes analyzed in the historic moraine landscape. Historic bedrock had a relatively high amount of mixed conifer, northern hardwoods, and cedar, while historic outwash had more mixed pine than other groups, with no one class being as dominant. The lowland group was historically more dominated by mixed conifer and wetlands (fig. 3a).

In the present moraine landscape, northern hardwoods were most prevalent (LSIM). In present bedrock, northern hardwoods and mixed conifer were still important, but agriculture was as well, rather than cedar. The present outwash landscape was quite well distributed among several classes including northern hardwoods, mixed pine, mixed conifer, white pine, wetlands, and agriculture. The lowland group, presently, was weighted to mixed conifer and northern hardwoods, primarily, followed by wetlands and mixed pine (fig. 3b).

Classes with high LPI historically in the moraine group were northern hardwoods, mixed conifer, mixed pine, and cedar. The wetlands class had the highest LPI in historic lowland. In the bedrock and outwash groups, the classes were less driven by single large

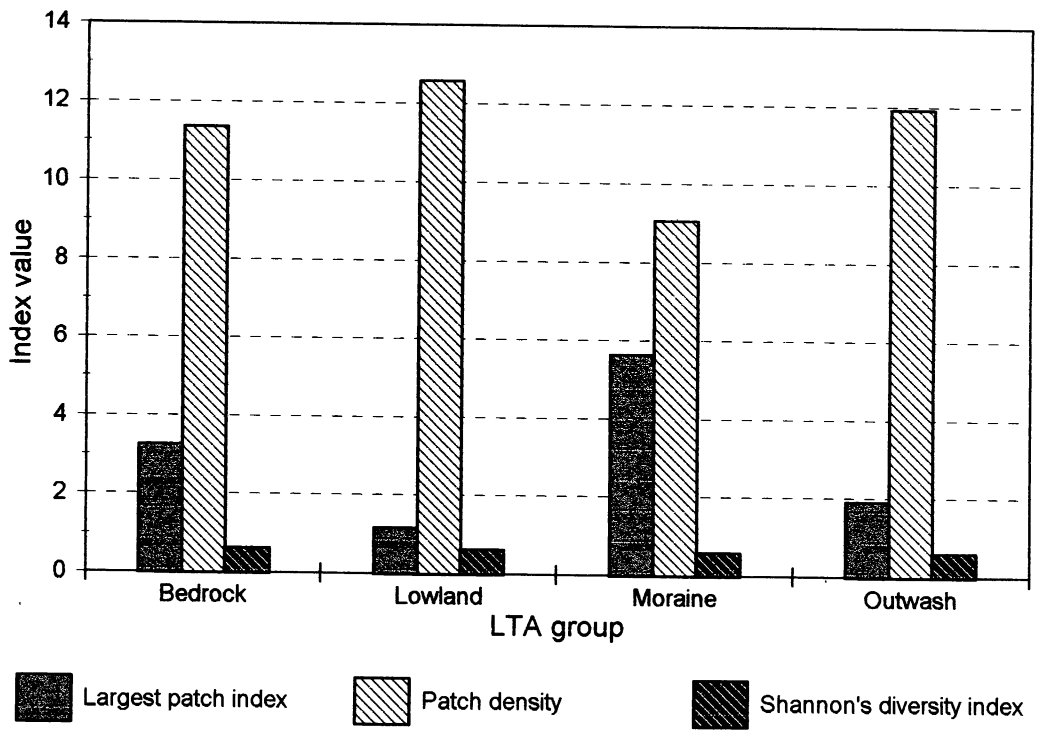


Figure 2.—*Values for three landscape level indices: largest patch index (LPI), patch density (PD), and Shannon's Diversity Index (SHDI) calculated by LTA group on the present land cover.*

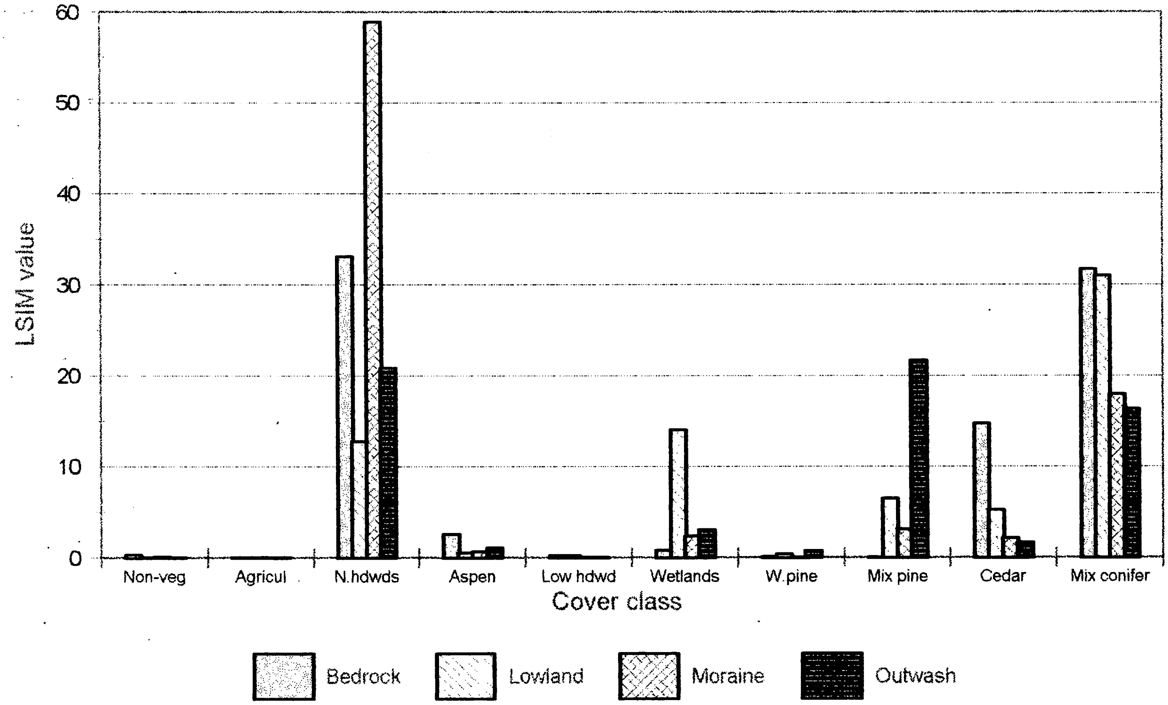


Figure 3a.—*Landscape similarity index (LSIM) calculated by cover type for each LTA group using the historic landscape dataset (MNFI 1994). LSIM measures the proportion of one cover type in area per the total landscape (LTA group) area.*

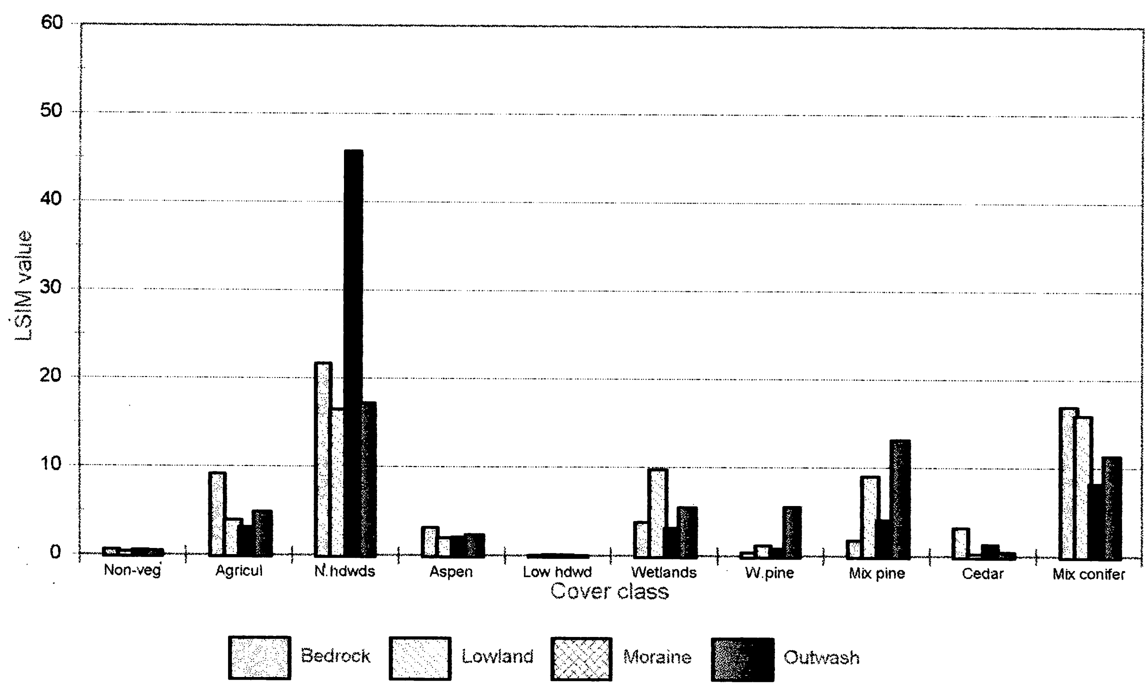


Figure 3b.—*Landscape similarity index (LSIM) calculated by cover type for each LTA group using the present landscape dataset (Maclean 1994). LSIM measures the proportion of one cover type in area per the total landscape (LTA group) area.*

patches. In historic bedrock and outwash, classes with high LPI were northern hardwoods, mixed conifer, cedar, and mixed pine (table 6). In present bedrock and outwash, classes with high LPI included northern hardwoods, agriculture, mixed pine and white pine (table 7). Of all four groups in the present coverage, wetlands had the highest LPI in the lowland group, indicating larger interior wetland areas within the lowland group. Overall, the moraine group had the largest single patches among all cover types, but especially in northern hardwoods, which suggests a greater amount of core areas/ interior habitats in the moraine landscapes. In the bedrock and moraine landscapes, MPS was very high in the northern hardwoods class, but both groups also had high LPI and PSCV, which implies there might be a few very large patches and many small patches in these groups.

The greatest number of patches for any one class type was 6,076 patches of mixed pine in the present lowland landscape (tables 6 and 7). This was believed to be a reflection of the lowland sand ridge-swale complexes found within this LTA group, in which a mosaic wetland/bog landscape is interspersed by a pattern of linear sand ridges vegetated with jack pine and other seral species. Patch density indicates how fine the pattern of landscape is, or how much it is fragmented into many small patches. PD is measured as the number of patches per 100 ha. In all LTA groups, except lowlands, historically and presently, mixed conifer had the highest PD. In the lowland group, mixed pine, wetlands, and northern hardwoods had high PD (tables 6 and 7). Also, in the historic bedrock group, non-vegetated areas had very high PD, even though the mixed conifer class was highest (fig. 4a). PD was much lower in historic data due to the resolution differences and should not be compared to the present data. In the present landscape, all LTA groups had high mixed conifer PD, although in the lowland group, wetlands and mixed pine were also quite high. All four groups reflected similar moderate PD values in the agriculture, northern hardwoods, aspen, and mixed pine classes (fig. 4b).

We refined our measure of landscape pattern by considering how regular or variable the pattern is. PSCV measures patch size standard deviation divided by mean patch size and is weighted per unit area. In historic bedrock, mixed conifer, cedar, and northern hardwoods had the most variable pattern. Historic outwash was similar with mixed conifer, northern hardwoods, and mixed pine having the highest PSCV. But, in historic moraine, northern hardwoods and wetlands had the most variable size pattern, while wetlands and mixed pine had high PSCV in historic lowlands (table 6). Presently, the moraine and outwash groups had variable patterns of mixed and white pine and northern hardwoods. However in present bedrock, northern hardwoods and agriculture were most variable, and in present lowlands, northern hardwoods had high PSCV (table 7).

Mean shape index (MSI) was fairly even in the historic landscape among landscape groups and cover classes, except that the non-vegetated had much higher MSI values in all but the outwash group (fig. 5a). Present shape indices were also quite even among groups and classes, with non-vegetated class generally slightly higher. In the present landscape high MSI for non-vegetated areas was attributed to the inclusion of roadways within the spectral class, which have high perimeter to area ratios, and therefore, high MSI. Aspen was generally the lowest in MSI of the 10 classes, and all landscape groups reflected nearly the same MSI value in aspen (fig. 5b

D. Assumptions About the Data and Inherent Bias or Limitations

This project used three different geographi datasets, each developed by different meth As a result, each land cover layer had uni limitations. The LTA coverage, discussed previously, was derived from intuitive ma procedures in which the boundaries repre sented intangible ecological transitions. result, neither map error nor accuracy co be estimated for this layer. Nevertheless, a meaningful framework for landscape as ments and planning, and one that can be strengthened by studies of this type. Th units, like regional ecosystems, should b considered hypotheses for testing, devel from ecological theory and knowledge of landscape. By using the units for studi such as this, we can identify units that functionally different versus those that respond to landscape disturbances in s ways (Albert 1995).

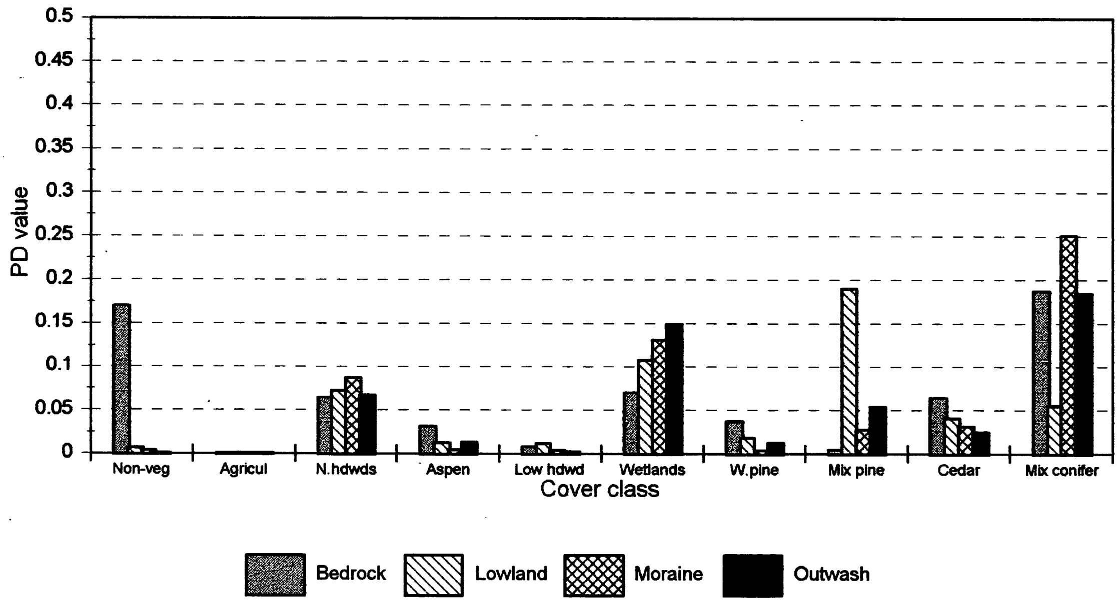


Figure 4a.—*Patch density, the number of patches per 100 ha, calculated by cover type as a function of LTA group using the historic landscape dataset (MNFI 1994).*

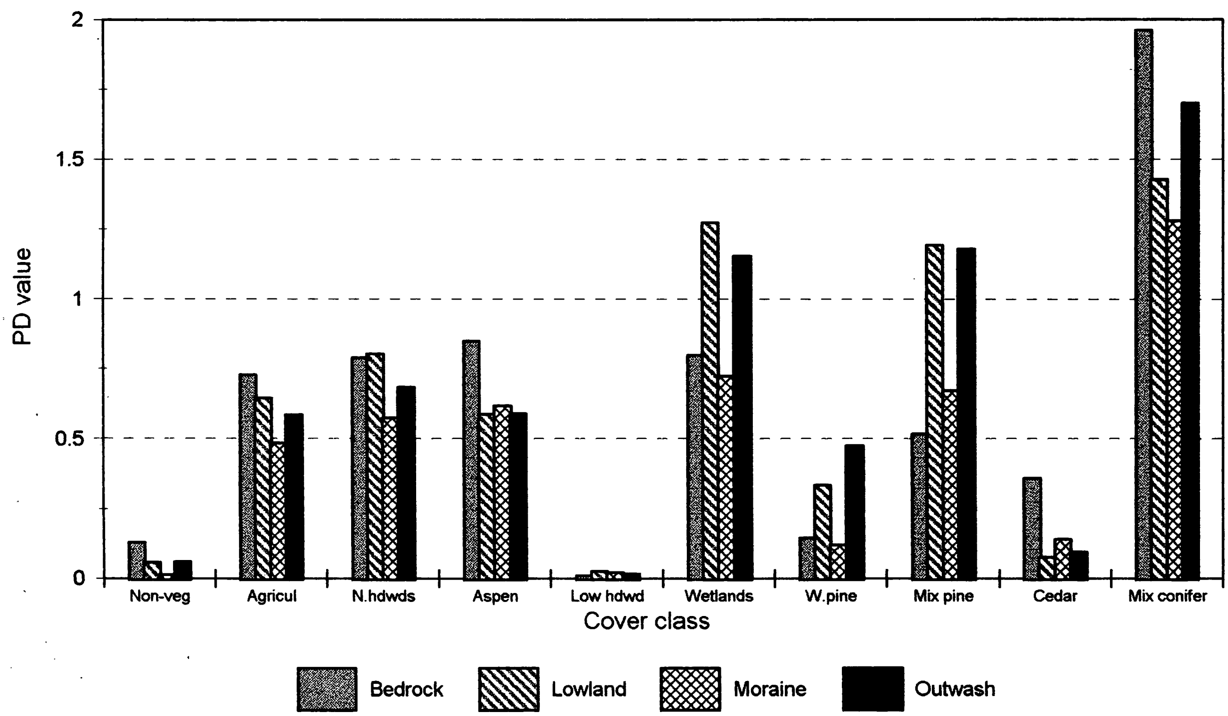


Figure 4b.—*Patch density, the number of patches per 100 ha, calculated by cover type as a function of LTA group using the present landscape dataset (Maclean 1994).*

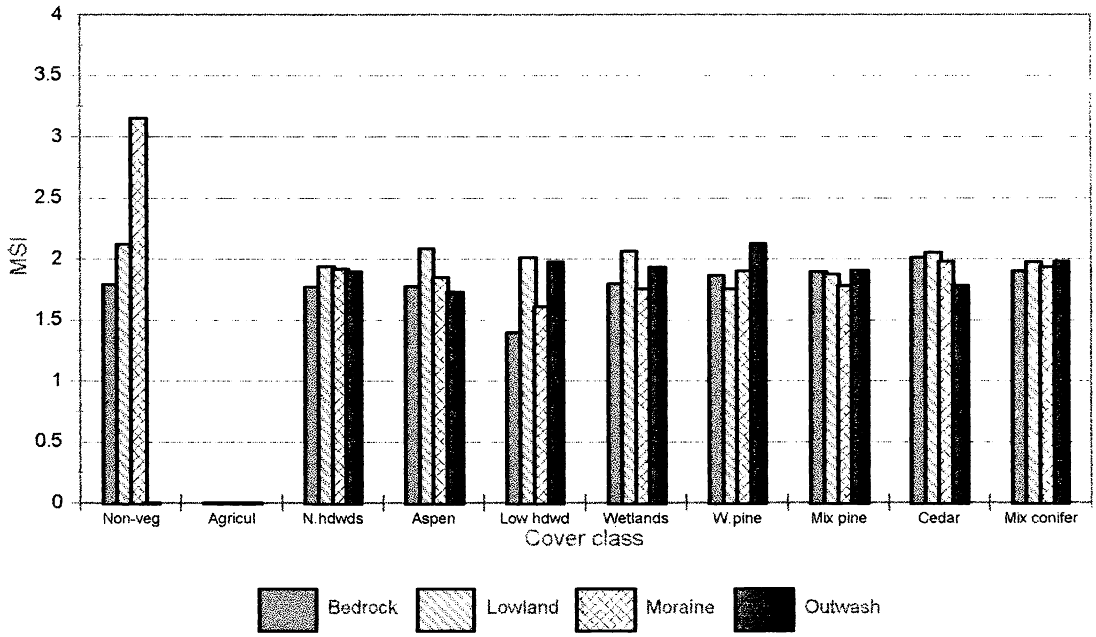


Figure 5a.—***Mean shape index, a perimeter to area ratio, calculated by cover type as a function of LTA group using the historic landscape dataset (MNFI 1994).***

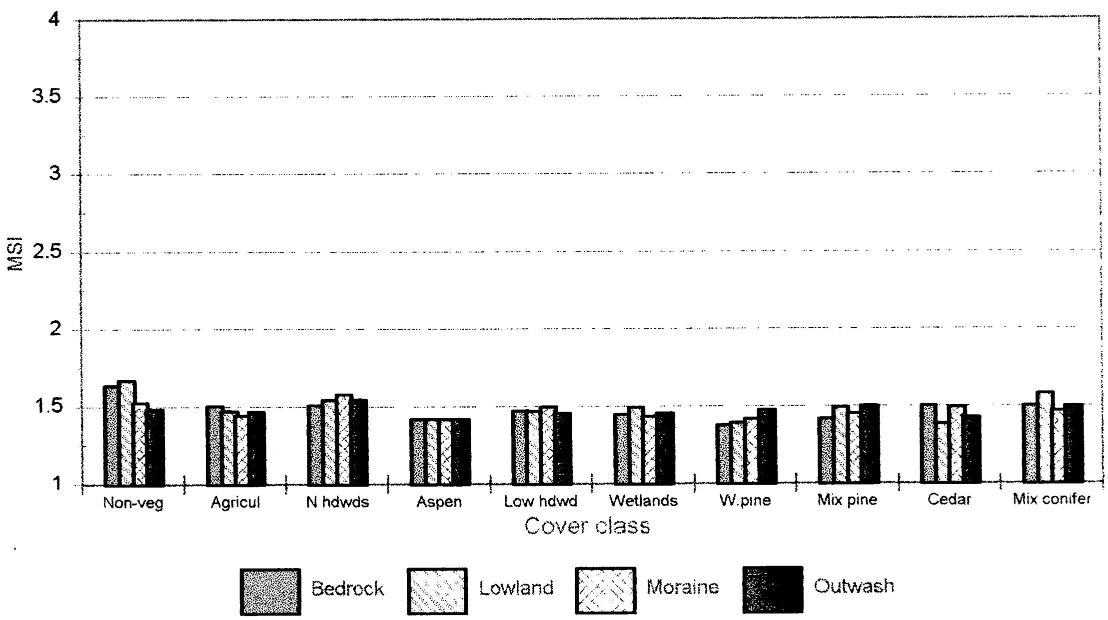


Figure 5b.—***Mean shape index, a perimeter to area ratio, calculated by cover type as a function of LTA group using the present landscape dataset (MNFI 1994).***

Sampling completeness of the land cover datasets was another concern. The historic coverage was based on the equivalent of a systematic aligned sampling strategy. The surveyors walked and recorded trees along the township and section survey lines (1-mile intervals). The transcribed digital data from MNFI, however, contained little attribute information, or legend about the cover types derived from the original line tree data, except the compositional information derived from this study, and its resolution was definable only to 1 square mile. These data limitations are not uncommon to landscape research, however. Frelich's (1995) study of "old forest" changes in the Lake States over the past 150 years relied on historic vegetation maps by Veatch (1928), who inductively mapped historic vegetation from GLO notes and his knowledge of soil patterns at a broader scale than the maps by MNFI.

The present coverage was derived from different methodology: classification of satellite imagery, which comprehensively recorded land cover in the total study area based on the spectral signature of vegetation types within the image area, rather than a sample. Resolution was as high as 60 m to an accuracy of 90.2 percent. However, some types, such as non-vegetated, had an accuracy as low as 28.6-percent correct. Furthermore, the present coverage, like the historic, lacked a compositional/structural legend for the cover classes. Neither historic or present datasets described, or were intended to describe, vertical structure. Nor did they provide detailed species composition information, beyond the compositional assessment included in this study, as would maps developed from plot samples and quantitative ecological classification techniques.

V. CONCLUSIONS

This study has quantified landscape patterns for four physiographically based landtype association groups across the Eastern Upper Peninsula of Michigan from historic (1840's) and current (1990-1992) datasets. Prevalence or dominance of cover classes was based on class area (CA) and landscape similarity index (LSIM), or class area weighted by total landscape area. In the four groups studied—bedrock-controlled, lowland sand lake plain, morainal origin, and outwash—northern hardwoods and mixed conifer were the most prevalent cover types of the 10 studied, historically and currently. Northern hardwoods were especially prevalent in the moraine group, while the mixed conifer type was more prevalent in the bedrock group. Wetlands and mixed pine, in addition to northern hardwoods, were also prominent in the lowland group. In the outwash group, these types were also present but mixed and white pine were more prevalent. Largest single patches (LPI) were found to be redundant to LSIM, and therefore were not assessed to the same extent as other indices. However, in comparisons of mean patch sizes (MPS) of classes, LPI can be used to gage how much MPS is determined by a single large patch. LPI also may suggest areas with more interior habitat. The highest LPI values were found in northern hardwoods within the moraine group. Patch density was useful in comparing the scale of pattern within landscapes. The bedrock group had the lowest patch density, or coarsest (least patchy) pattern historically, yet in general, mixed conifer, which was a dominant class in the bedrock group, tended to have higher patch density than other cover types. Generally, cover types in the moraine group had the most variable (least regular) pattern, but no one cover class was consistently more variable than others.

Shape indices, based on perimeter to area ratios, were relatively consistent across landscape groups and cover classes, with the exception of the non-vegetated class. Non-vegetated areas had higher shape indices in both historic and present coverages. In the present coverage, this finding was attributed to inclusion of roadways, which have high perimeter/area values in the non-vegetated cover class. However, it is not clear what factors would have contributed to high shape indices in historic non-vegetated areas.

Diversity, based on Shannon's Diversity Index, was highest in the outwash group and lowest in the lowland group of the historic landscapes. In present landscapes, diversity was very similar among the four groups; it was only slightly higher in the lowland group and lower in the moraine group than in others.

Conclusions about a specific cover type may be drawn by referring to tables 6 and 7. These tables should be a reference for land managers and planners making decisions based on knowledge of actual landscape structure. The broad landscape data in this report may be used in conjunction with similar landscape studies in the Lake States or in other areas with similar biophysical landscape units to estimate patterns beyond northern Michigan.

ACKNOWLEDGMENTS

Partial support and funding were provided by the Michigan Department of Natural Resources, the National Council for Air and Stream Improvement, The Nature Conservancy, Michigan Technological University, the Hiawatha National Forest, and Washington State University. Recognition for development of spatial land cover datasets goes to Dr. A. Maclean and Maclean Consultants, Ltd., and to Dr. D. Albert of Michigan Natural Features Inventory. Dr. E. Padley and J. K. Jordan, with the Eastern Region of the Forest Service, and R. L. Watson, initially developed the landtype association mapping on Forest Service lands in this region, and collaborated on expansion of the map units across the study area. We also appreciate the vision of D. Howlett, Ecosystem Team Leader, to extend the landtype association mapping beyond the boundaries of the Hiawatha National Forest. A number of other people on the Hiawatha National Forest, especially W. F. Spinner, D. Evans, J. Schultz, D. Gerdes, K. Seleen, and R. Brittain greatly advanced the landtype association delineation program. Appreciation also goes to J. Johnson and J. Durbin, of Mead Paper, Inc., in Escanaba, Michigan, and to Q. Zhang, C. Herlevich, Q. Zhao, and M. Hyslop of Michigan Technological University, for GIS preparation, and Dr. N. Crookston, of the Intermountain Forest Experiment Station in Moscow, for computer support. Special thanks to Dr. T. Crow of the Forestry Sciences Laboratory, North Central Forest Experiment Station, in Rhinelander, Wisconsin for his support and many suggestions on this project.

LITERATURE CITED

Albert, Dennis A. 1995. **Regional landscape ecosystems of Michigan, Minnesota, and Wisconsin: a working map and classification**. Gen. Tech. Rep. NC-178. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 250 p.

Albert, Dennis A.; Denton, Shirley R.; Barnes, Burton V. 1986. **Regional landscape ecosystems of Michigan**. Ann Arbor, MI: University of Michigan, School of Natural Resources. 32 p.

Allen, T.F.H.; Starr, Thomas B. 1982. **Hierarchy: perspectives for ecological complexity**. Chicago, IL: University of Chicago Press. 30 p.

Anderton, John A. 1993. **Paleoshoreline geoarchaeology in the Northern Great Lakes: Hiawatha National Forest**. Heritage Program Monograph No. 1.

Bailey, Robert G. 1996. **Multi-scale ecosystem analysis**. Environmental Monitoring & Assessment. 39: 21-24.

Bailey, R.G.; Avers, P.E.; King, T.; McNab, W.H., eds. 1994. **Ecoregions and subregions of the United States**. Washington, DC: U.S. Department of Agriculture, Forest Service, ECOMAP Team. 1 map (1:7,500,000).

Baker, William L. 1991. **Effects of settlement and fire suppression on landscape structure**. Ecology. 73: 1879-1887.

Ball, Janet; Padley, Eunice A. 1993. **Draft delineation of landtype associations in the Eastern Upper Peninsula of Michigan**. On file, Hiawatha National Forest.

Barnes, Burton V. 1984. **Forest ecosystem classification and mapping in Baden-Wurttemberg, West Germany**. In: Bockheim, J.G., ed. Proceedings of the symposium on forest land classification: experience, problems, perspectives; 1984 March; Madison, WI. NCR-102. 276 p.

Bourdo, Eric A., Jr. 1956. **A review of the General Land Office survey and of its use in quantitative studies of former forests**. Ecology. 37(4): 754-768.

Canham, Charles D. 1978. **Catastrophic windthrow in the hemlock-hardwood forest of Wisconsin**. Madison, WI: University of Wisconsin. 94 p. M.S. thesis.

Canham, Charles D.; Loucks, Orie L. 1984. **Catastrophic windthrow in the pre-settlement forests of Wisconsin**. Ecology. 65(3): 803-809.

Crow, Thomas R. 1991. **Landscape ecology: the big picture approach to resource management**. In: Decker, Daniel J., *et al.*, eds. Challenges in the conservation of biological resources: a practitioner's guide. Boulder, CO: Westview Press: 55-65.

Curtis, John T. 1959. **Vegetation of Wisconsin**. Madison, WI: University of Wisconsin Press. 657 p.

Dunn, Christopher P.; Sharpe, David M.; Guntenspergen, Glenn R.; Stearns, Forrest; Yang, Zhao. 1991. **Methods for analyzing temporal changes in landscape pattern**. In: Turner, Monica G.; Gardener, Robert H., eds. Quantitative methods in landscape ecology. Ecol. Stud. 82. New York, NY: Springer-Verlag: 173-198.

ECOMAP. 1993. **National hierarchical framework of ecological units**. Washington, DC: U.S. Department of Agriculture, Forest Service.

Farrand, W.R. 1982. **Quaternary geology of Michigan**. Ann Arbor, MI: State of Michigan Department of Natural Resources, Geological Survey, University of Michigan. 2 maps

Forman, Richard T.T. 1995. **Some general principles of landscape and regional ecology**. Landscape Ecology. 10(3): 133-142.

Forman, Richard T.T.; Godron, Michael. 1986. **Landscape ecology**. New York, NY: John Wiley and Sons, Inc. 619 p.

Frelich, Lee E. 1995. **Old forest in the Lake States today and before European settlement**. Natural Areas Journal. 15: 157-167.

Frelich, Lee E.; Lorimer, Craig G. 1991. **Natural disturbance regimes in hemlock-hardwood forests of the upper Great Lakes region**. Ecological Monographs. 61(2): 145-164.

Gary, Margaret; McAfee, Robert, Jr.; Wolf, Carol L., eds. 1974. **Glossary of geology**. Washington, DC: American Geological Institute. 805 p.

Golley, Frank B. 1995. **Reaching a landmark**. Landscape Ecology. 10(1): 3-4.

Hess, George. 1994. **Pattern and error in landscape ecology: a commentary**. Landscape Ecology. 9(1): 3-5.

Hulshoff, Maureen R. 1995. **Landscape indices describing a Dutch landscape**. Landscape Ecology. 10(2): 101-111.

Jordan, James K.; Padley, Eunice; Cleland, David T.; Gates, Joseph A.; Hoppe, David J.; Kempf, Leonard S.; Leuelling, Barbara; Seleen, Kirstin L.; Shadis, David A.; Silbernagel, Janet. In prep. **Landtype associations—origin, concepts, mapping, and application in the Lake States National Forests**. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station.

King, A.W. 1993. **Consideration of scale and hierarchy**. In: Woodley, S.; Roy, J.; Francis, G., eds. Ecological integrity and the management of ecosystems. Delray Beach, FL: St. Lucie Press. 220 p.

Klijn, Frans; Udo de Haes, Helias A. 1994. **A hierarchical approach to ecosystems and its implications for ecological land classification**. Landscape Ecology. 9(2): 89-104.

Li, Habin; Reynolds, James F. 1993. **A new contagion index to quantify spatial patterns of landscapes**. Landscape Ecology. 8(3): 155-162.

Li, Habin; Reynolds, James F. 1994. **A simulation experiment to quantify spatial heterogeneity in categorical maps**. Ecology. 75(8): 2446-2455.

Lorimer, Craig G. 1977. **The presettlement forest and natural disturbance cycle of northeastern Maine**. Ecology. 58: 139-148.

Lorimer, Craig G. 1980. **The use of land survey records in estimating presettlement fire frequency**. In: Stokes, M.A.; Dieterich, J.H., eds. Proceedings of the Fire history workshop; 1980 October 20-24; Tucson, AZ. Gen. Tech. Rep. GTR-RM-81. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 142 p.

Lorimer, Craig C. 1984. **Methodological considerations in the analysis of forest disturbance history**. Canadian Journal of Forest Research. 15: 200-213.

Luque, Sandra S.; Lathrop, Richard G.; Bognar, John A. 1994. **Temporal and spatial changes in an area of the New Jersey Pine Barrens landscape**. Landscape Ecology. 9(4): 287-300.

MacGarigal, Kevin; Marks, Barbara J. 1993. **FRAGSTATS: spatial analysis program for quantifying landscape structure**. Corvallis, OR: Oregon State University. 62 p.

Maclean, Gordon, A. 1994. **Inventory of deer habitat in Michigan's Upper Peninsula utilizing Landsat thematic mapper data**. Final report for Michigan Department of Natural Resources, Lansing, MI.

Martin, Helen M. 1957. **Map of the surface formations of the Northern Peninsula of Michigan**. Publ. 49. Michigan Department of Conservation, Geological Survey Division. 1 map.

McNab, W. Henry. 1996. **Classification of local- and landscape-scale ecological types in the Southern Appalachian Mountains**. Environmental Monitoring & Assessment. 39: 215-229.

McNab, W. Henry; Avers, Peter E., eds. 1994. **Ecological subregions of the United States: section descriptions**. WO-WSA-5. Prepared in cooperation with Regional Compilers and the ECOMAP Team of the Forest Service.

Milne, Bruce T. 1991. **Lessons from applying fractal models to landscape patterns**. In: Turner, Monica G.; Gardener, Robert H., eds. Quantitative methods in landscape ecology. Ecol. Stud. 82. New York, NY: Springer-Verlag: 199-235.

MNFI. 1994. **Pre-European settlement landscape of Michigan**. Lansing, MI: Michigan Natural Features Inventory.

Nature Conservancy. 1993. **Landscape conservation—the next big step**. News from the Michigan Chapter of The Nature Conservancy, Autumn.

Muller, Michael R.; Middleton, John. 1994. **A Markov model of land-use change dynamics in the Niagara Region, Ontario, Canada**. Landscape Ecology. 9(2): 151-157.

Noss, Reed F. 1985. **On characterizing presettlement vegetation: how and why**. Natural Areas Journal. 5: 5-19.

O'Neill, R.V.; Drummel, J.R.; Gardner, R.H.; Sugihara, G.; Jackson, B.; DeAngelis, D.L.; Milne, B.T.; Turner, M.G.; Zygmunt, B.; Christensen, S.W.; Dale, V.H.; Graham, R.L. 1988. **Indices of landscape pattern**. Landscape Ecology. 1(3): 153-162.

Pastor, John; Broschart, Michael. 1990. **The spatial pattern of a northern conifer-hardwood landscape**. Landscape Ecology. 4(1): 55-68.

Peterson, W.L. 1986. **Late Wisconsinan glacial history of Northeastern Wisconsin and Western Upper Michigan**. USGS Bull. 1652. Washington, DC: U.S. Geological Survey. United States Government Printing Office. 14 p.

Price, David L. 1994. **An ecological study of the composition, structure and disturbance regimes of the pre-European settlement forests of western Chippewa County, Michigan**. East Lansing, MI: Michigan State University, Department of Forestry. 214 p. M.S. thesis.

Rowe, J. Stan. 1991. **Forests as landscape ecosystems: implications for their regionalization and classification**. In: Symposium: Ecological land classification: applications to identify the productive potential of southern forests; 1991 January 7-9; Charlotte, NC. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 149 p.

Rowe, J. Stan. 1996. **Land classification and ecosystem classification**. Environmental Monitoring & Assessment. 39: 11-20.

Santer, Richard A. 1977. **Michigan: heart of the Great Lakes**. Dubuque, IA: Kendall/Hunt Publishing Co. 364 p.

Simpson, John W.; Boerner, Ralph E.J.; DeMers, Michael N.; Berns, Leslie A.; Artigas, Francisco J.; Silva, Alejandra. 1994. **Forty-eight years of landscape change on two contiguous Ohio landscapes**. Landscape Ecology. 9(4): 261-270.

Sims, Richard A.; Corns, Ian G.W.; Klinka, Karel. 1996. **Introduction—global to local: ecological land classification**. Environmental Monitoring & Assessment. 39: 1-10.

Smith, Marie-Louise; Carpenter, Constance. 1996. **Application of the USDA Forest Service national hierarchical framework of ecological units at the sub-regional level: the New England-New York example**. Environmental Monitoring & Assessment. 39: 187-198.

SOLEC. In Press. **Impacts of changing land use**. In: Thorp, Steve; Rivers, Ray; Pebbles, Victoria, eds. Proceedings of the 1996 State of the Lakes ecosystem conference; 1996 November; Windsor, Ontario. EPA 905-D-96-001e. Windsor, Ontario: Environment Canada and U.S. Environmental Protection Agency.

Spurr, S.H.; Barnes, Burton V., eds. 1980. **Forest ecology**. 3d ed. New York, NY: John Wiley and Sons. 687 p.

Turner, Monica G.; Ruscher, C. Lynn. 1988. **Changes in landscape patterns in Georgia, USA**. Landscape Ecology. 1(4): 241-251.

Uhlig, Peter W.C.; Jordan, James K. 1996. **A spatial hierarchical framework for the co-management of ecosystems in Canada and the United States for the Upper Great Lakes Region**. Environmental Monitoring & Assessment. 39: 59-73.

Urban, Dean L.; O'Neill, Robert V.; Shugart, Herman H., Jr. 1987. **Landscape ecology: a hierarchical perspective can help scientists understand spatial patterns**. Bioscience. 37: 119-127.

USGS. 1990. In: Anderson, James R., *et al.*, eds. **A land use and land cover classification system for use with remote sensor data**. Reston, VA: U.S. Geological Survey.

Veatch, J.O. 1928. **Reconstruction of forest cover based on soil maps**. Quarterly Bulletin of the Michigan Agricultural Experiment Station. 10: 116-126.

Veatch, J.O. 1959. **Presettlement forests of Michigan**. East Lansing, MI: Department of Natural Resources, Michigan State University. Map.

Whitney, Gordon G. 1986. **Relation of Michigan's presettlement pine forests to substrate and disturbance history**. Ecology. 67: 1548-1559.

APPENDIX A:

Formulae used to calculate landscape, class, and relative indices

Landscape Indices:

1. Number of Patches = N(ij)
2. Total Area = SUM a(ij) = A (ha)
3. Mean Patch Size (MPS) = SUM a(ij)/N(ij)
4. Largest Patch Index (LPI) = max a(ij)/A * 100
5. Patch Density (PD) = n(ij)/A * 10000 * 100 (# per 100 ha)
6. Diversity (SHDI) = -SUM (P(i) * log P(i))

Class Indices:

1. Number of Patches = N(j)
2. Class Area = SUM a(j) = CA (ha)
3. Mean Patch Size (MPS) = SUM a(j)/N(i)
4. Landscape Similiarity Index (LSIM) = SUM a(j)/A * 100, or CA/A * 100
5. Largest Patch Index (LPI) = max a(j)/CA * 100
6. Patch Density (PD) = n(j)/CA * 10000 * 100 (# per 100 ha)
7. Patch Size Coefficient of Variation (PSCV) = patch size standard deviation / mean patch size
8. Mean Shape Index (MSI) = SUM (p(j)/2sqrt(pie*a(j))) / N(j)

a(ij) = area of patch ij
p(ij) = perimeter of patch ij
P(i) = proportion of patch type I = a(ij)/A

Table 1.—*List of cover classes and numerical codes for historic land cover map developed by MNFI (1994) from GLO surveyors' notes of 1840's; legend is based on expanded Michigan Resource Information System (MIRIS) legend of land use/land cover classes*

Category	1st order	2nd order	3rd order	4th order	Land cover class description
Palustrine					
		62			Non-forested Wetland
			622		Emergent marsh/meadow/prairie
				6221	Eemergent marsh
				6222	Great lakes marsh
				6223	Interdunal wetland
				6224	Wet meadow
				6225	Inland salt marsh
				6226	Llakeplain prairie
				6227	Inland wet prairie
				6228	Intermittent wetland
			623		Mud flats
				6231	Marl flats
			612		Shrub-dominated wetland
				6121	Bog
				6122	Alder/willow/Bog birch thicket
				6123	Bottonbush/Dogwood/Willow swamp
				6124	Patterned peatland
				6125	Muskeg
		91			Landscape Complex
			911		Wooded dune/swale complex
	4				Forested Wetlands
		41			Hardwood/Conifer - Hardwoods predominating
			414		Lowland hardwood (broadleaf)
				4141	Ash
				4142	Elm
				4143	Silver/Red maple
				4144	Cottonwood
				4145	Balsam poplar
				4146	Aspen
				4147	White birch
				4148	black willow
		42			Hardwood/Conifer - Conifers predominating
			423		Lowland conifer
				4231	Cedar
				4232	black spruce
				4233	Tamarack
				4234	Balsam fir/White spruce
				4235	Balsam fir
				4236	Jack pine
				4237	Hemlock
				4238	White pine
Lacustrine and Riverine					
		51			Major River
		52			Lake or Pond
		53			Great Lakes

(table 1 continued on next page)

(table 1 continued)

Category	1st order	2nd order	3rd order	4th order	Land cover class description
Terrestrial					
	3				Non-Forested (grassland - savannas)
		31			Herbaceous - Upland Grassland
		32			Shrub - Shrub Savanna
		33			Tree Savanna
			331		Lakeplain oak opening
			332		Oak barrens
			333		Pine barrens
			334		Oak/pine barrens
			335		Bur oak savanna
			336		Oak opening
	4				Forested
			411		Northern hardwoods
				4111	Sugar maple, Beech
				4119	Beech, Hemlock
			412		Central hardwoods
				4121	Beech, Sugar maple, Basswood, Red oak
				4122	White oak, Hickory, Black oak
				4123	Black oak, White oak
				4124	Pin/Black oak
			413		Aspen/White birch
			421		Pine
				4211	White pine
				4212	Red pine
				4213	Jack pine
				4215	Red pine/Jack pine
				4216	Red pine/White pine
				4217	White pine/White oak
				4218	Red pine/Oak
				4219	White pine/Beech/Maple
			422		Other upland conifer
				4221	White spruce
				4223	Fir/Spruce/Cedar
				4226	Hemlock
				4227	Hemlock/White pine
				4228	Hemlock/Sugar maple
				4229	Hemlock/Yellow birch
Open, Little/No Vegetation					
		72			Beach, Riverbank
		73			Open Sand Dune
		74			Exposed Bedrock
			741		Alvar
			742		Bedrock glade
			743		Sinkhole
			744		Limestone ledge/Outcrop
			745		Sandstone ledge/Outcrop
			746		Igneous-met. ledge/Outcrop

(table 1 continued on next page)

(table 1 continued)

Category	1st order	2nd order	3rd order	4th order	Land cover class description
Natural Disturbances/ Cultural Feature					
		92			Wildfire
		93			Windthrow
		94			Beaver Flooding
		95			Great Lakes Level Change
		96			Cultural Features
		97			Jack Pine Thicket
Wetland Grade		I			Intact
		D			Degraded
		E			Eliminated
		M			Manipulated

Table 2.—*List of cover classes and numerical codes for present land cover map (Maclean 1994) through classification of 1991 Thematic Mapper satellite imagery*

Category	Cover type name	Cover class	Numerical code
Non-Coniferous			
	Urban		1
	Non-vegetative		2
	Agricultural- cropland		3
	Herbaceous openland		4
	Shrubland		5
	Northern hardwood		6
	Oak		7
	Aspen/birch		8
	Lowland hardwoods		9
	Dry hardwood/conifer mix		10
	Wet hardwood/conifer mix		11
	Wetlands		12
	Water		13
Coniferous			
	Pines	Red pine	14
		Jack pine	15
		White pine	16
		Other (mixed pine)	17
	Tamarack		18
	Hemlock	<70% crown closure	19
		>70% crown closure	20
	Black spruce	<70% crown closure	21
		>70% crown closure	22
	White spruce	<70% crown closure	23
		>70% crown closure	24
	Balsam fir	<70% crown closure	25
		>70% crown closure	26
	White cedar	<70% crown closure	27
		>70% crown closure	28
	Mixed conifer	<70% crown closure	29
		>70% crown closure	30

Table 3.—*List of 24 cross-listed cover classes used to compare historic and present land cover maps*

MNFI Code[1]	TM code[2]	Class name
not applicable	1	Urban
72	2	Non-vegetated
73	2	
74	2	
741	2	
742	2	
743	2	
744	2	
745	2	
746	2	
not applicable	3	Agriculutral cropland
31	4	Herbaceous openland
32	5	Shrubland
4111	6	Northern hardwoods
4119	6	
332	7	Oak
4121	7	
4122	7	
4123	7	
4124	7	
413	8	Aspen/Birch
41	9	Lowland hardwoods
414	9	
4141	9	
4142	9	
4143	9	
4144	9	
4145	9	
4146	9	
4147	9	
4148	9	
not applicable	10	Dry hardwood-conifer mix
42	11	Wet hardwood-conifer mix
6121	12	Wetlands
6122	12	
6124	12	
6125	12	
6221	12	
6222	12	
6223	12	
6224	12	
6227	12	
6228	12	
6231	12	
51	13	Water
52	13	
54	13	
4212	14	Red pine
4211	15	Jack pine
4238	15	
333	16	White pine
334	16	
4213	16	
4236	16	
4215	17	Mixed pine
4216	17	
4217	17	
4218	17	
4219	17	
4233	18	Tamarack
4226	19	Hemlock
4227	19	
4228	19	
4229	19	
4237	19	
4232	21	Black spruce
4242	21	
4221	23	White spruce
42	25	Balsam fir
4234	25	
4235	25	
4231	27	White cedar
423	29	
4223	29	Mixed conifer

[1]Michigan Natural Features Inventory (MNFI 1994) code from historic cover class legend (table 1).
[2]Thematic Mapper code from present cover class legend (Maclean 1994, table 2).

Table 4.—*Presence/absence of cover types in historic and present landscape groups based on the respective cover classifications (tables 1, 2, 3)*[1]

	Historic Bedrock	Present Bedrock	Historic Lowland	Present Lowland	Historic Moraine	Present Moraine	Historic Outwash	Present Outwash
Urban		X		X		X		X
Non-veg	X	X			X	X		X
Agriculture		X				X		X
Herb-openland		X				X	X	X
Shrubland		X				X		X
N. hardwoods	X	X	X		X	X	X	X
Oak								
Aspen	X	X	X		X	X	X	X
Low hardwoods	X	X	X		X	X	X	X
Dry hardwood-conifer mix		X				X		X
Wet hardwood-conifer mix		X				X		X
Wetlands	X	X	X	X	X	X	X	X
Water	X	X	X	X	X	X	X	X
Red pine		X	X		X	X	X	X
Jack pine	X	X	X		X	X	X	X
White pine	X	X	X		X	X	X	X
mixed pine	X	X	X		X	X	X	X
tamarack	X	X	X		X	X	X	X

[1] A cover type's absence from a landscape does not necessarily mean that the species itself was absent.

(table 4 continued on next page)

(table 4 continued)

	Historic Bedrock	Present Bedrock	Historic Lowland	Present Lowland	Historic Moraine	Present Moraine	Historic Outwash	Present Outwash
hemlock <70%[2] crown closure	X		X		X		X	
hemlock >70% crown closure								
black spruce <70% crown closure	X	X	X		X	X	X	X
black spruce >70% crown closure		X				X		X
white spruce <70% crown closure	X	X			X	X	X	X
white spruce >70% crown closure		X				X		X
balsam fir <70% crown closure	X		X		X		X	
balsam fir >70% crown closure								
cedar <70% crown closure	X		X	X	X		X	
cedar >70% crown closure		X				X		X
mixed conifer <70% crown closure	X	X	X		X	X	X	X
mixed conifer >70% crown closure		X				X		X

[2] Histroic conifer types were not differentiated by percent crown closure as were present types.

Table 5.—*Absolute and relative landscape metrics calculated for each landscape group as a whole from both the historic and present landcover datasets Formulae for each metric are given in Appendix A.*

	Landtype Association Group							
	Historic				**Present**			
	Bedrock	**Lowland**	**Moraine**	**Outwash**	**Bedrock**	**Lowland**	**Moraine**	**Outwash**
No. of patches	1,322	5,409	2,599	1,640	24,368	63,994	28,577	23,774
Total area (ha)	209,415	509,511	314,539	198,831	214,912	509,522	315,571	199,476
Mean patch size (MPS) (ha)	158.400	94.197	121.000	121.200	8.819	7.962	11.043	8.390
Largest patch index (LPI)	5.346	2.757	10.280	4.777	3.243	1.170	5.631	1.905
Patch density (PD)	0.631	1.062	0.826	0.825	11.339	12.560	9.056	11.918
Shannon's diversity index (SHDI)	1.717	0.520	1.422	2.069	0.612	0.615	0.578	0.606

Table 6.—*Class level metrics for historic landscape*

Group	Class									
Bedrock	**Non-veg**	**Agricul**	**N.hdwds**	**Aspen**	**Low hdwd**	**Wetlands**	**W.pine**	**Mix pine**	**Cedar**	**Mix conifer**
No. of patches	36	0	135	64	16	147	4	8	134	391
Class area (ha)	653.000	0.000	69,363.000	5,343.000	518.000	1,691.000	211.000	113.000	30,770.000	66,487.000
Mean patch size (ha)	18.137	0.000	513.797	83.481	32.370	11.504	52.662	14.077	229.628	170.043
Landscape similarity	0.312	0.000	33.122	2.551	0.247	0.808	0.101	0.054	14.693	31.749
Largest patch index	0.068	0.000	5.346	0.349	0.125	0.061	0.037	0.023	3.438	4.046
Patch density	0.170	0.000	0.064	0.031	0.008	0.070	0.037	0.004	0.064	0.187
Patch size CV*	150.803	0.000	282.471	191.857	194.200	182.292	56.442	140.464	302.812	377.073
Mean shape	1.789	0.000	1.771	1.774	1.395	1.798	1.866	1.892	2.012	1.898
Lowland										
No. of patches	33	0	367	61	55	545	92	966	208	282
Class area (ha)	224.937	0.000	64,786.170	2,797.401	1,369.521	71,169.707	1,938.156	33,234.948	26,553.882	49,012.607
Mean patch size (ha)	6.816	0.000	176.529	45.859	24.900	130.587	21.067	34.405	127.663	173.804
Landscape similarity	0.044	0.000	12.715	0.549	0.269	13.968	0.380	6.523	5.212	30.952
Largest patch index	0.011	0.000	0.612	0.056	0.044	1.416	0.090	1.072	1.061	0.647
Patch density	0.006	0.000	0.072	0.012	0.011	0.107	0.018	0.190	0.041	0.055
Patch size CV*	1.768	0.000	2.164	1.480	1.650	4.863	2.941	6.139	3.290	2.560
Mean shape	2.122	0.000	1.937	2.085	2.009	2.062	1.755	1.876	2.054	1.975
Morainal										
No. of patches	8	0	273	14	9	413	11	86	98	788
Class area (ha)	238.000	0.000	185,204.000	2,039.000	146.000	7,308.000	139.000	9,803.000	6,788.000	56,349.000
Mean patch size (ha)	29.702	0.000	678.402	145.662	16.259	17.694	12.674	113.993	69.265	71.509
Landscape similarity	0.076	0.000	58.881	0.648	0.047	2.323	0.044	3.117	2.158	17.915
Largest patch index	0.038	0.000	10.280	0.296	0.011	0.271	0.029	0.537	0.155	1.442
Patch density	0.003	0.000	0.087	0.004	0.003	0.131	0.003	0.027	0.031	0.251
Patch size CV*	123.712	0.000	441.260	181.298	72.618	409.485	203.363	236.849	145.249	360.593
Mean shape	3.148	0.000	1.917	1.850	1.606	1.751	1.901	1.779	1.977	1.933
Outwash										
No. of patches	0	0	133	26	4	296	23	107	49	365
Class area (ha)	0.000	0.000	41,444.000	2,148.000	38.000	6,046.000	1,465.000	43,103.000	3,317.000	32,435.000
Mean patch size (ha)	0.000	0.000	311.612	82.616	9.443	20.425	63.698	402.829	67.696	88.862
Landscape similarity	0.000	0.000	20.844	1.080	0.019	3.041	0.737	21.678	1.668	16.313
Largest patch index	0.000	0.000	3.572	0.190	0.013	0.233	0.203	3.323	0.270	2.145
Patch density	0.000	0.000	0.067	0.013	0.002	0.149	0.012	0.054	0.025	0.184
Patch size CV*	0.000	0.000	273.158	114.644	97.623	216.507	182.500	221.399	182.080	369.697
Mean shape	0.000	0.000	1.894	1.726	1.974	1.929	2.127	1.903	1.781	1.980

*coefficient of variation

Table 7.—*Class level metrics for present landscape*

Group	Class									
Bedrock	**Non-veg**	**Agricul**	**N.hdwds**	**Aspen**	**Low hdwd**	**Wetlands**	**W.pine**	**Mix pine**	**Cedar**	**Mix conifer**
No. of patches	278	1,562	1,696	1,824	20	1,720	309	1,113	770	4,216
Class area (ha)	1,308.105	19,582.970	46,623.870	6,679.783	33.352	8,163.045	819.973	3,729.674	6,829.823	36,311.260
Mean patch size (ha)	4.705	12.537	27.490	3.662	1.668	4.746	2.654	3.351	8.870	8.613
Landscape similarity	0.609	9.112	21.694	3.108	0.016	3.798	0.382	1.735	3.178	16.896
Largest patch index	0.032	0.969	3.243	0.106	0.008	0.116	0.014	0.750	0.168	0.398
Patch density	0.129	0.727	0.789	0.849	0.009	0.800	0.144	0.518	0.358	1.962
Patch size CV*	1.862	6.539	9.255	2.924	2.370	2.941	1.452	2.448	2.755	4.120
Mean shape	1.631	1.500	1.503	1.416	1.469	1.444	1.370	1.415	1.496	1.499
Lowland										
No. of patches	293	3,284	4,096	2,997	134	6,482	1,699	6,076	382	9,031
Class area (ha)	1,891.895	20,011.092	84,006.617	10,106.323	448.178	49,726.364	5,897.847	45,932.084	1,185.630	229,177.290
Mean patch size (ha)	6.457	6.094	20.509	3.372	3.345	7.671	3.471	7.560	3.104	25.376
Landscape similarity	0.371	3.927	16.487	1.983	0.088	9.759	1.158	9.015	0.233	15.866
Largest patch index	0.058	0.082	1.170	0.054	0.010	0.419	0.072	0.660	0.021	0.410
Patch density	0.058	0.645	0.804	0.588	0.026	1.272	0.333	1.192	0.075	1.429
Patch size CV*	3.443	2.842	7.918	2.457	1.996	5.404	0.402	7.576	2.232	4.199
Mean shape	1.665	1.469	1.539	1.413	1.466	1.490	1.391	1.488	1.384	1.575
Morainal										
No. of patches	45	1,533	1,810	1,946	66	2,277	374	2,123	445	4,040
Class area (ha)	164.943	9,866.908	144,365.472	6,458.561	205.369	9,790.194	2,529.576	12,948.002	4,190.343	25,921.281
Mean patch size (ha)	3.665	6.436	79.760	3.319	3.112	4.300	6.764	6.099	9.417	6.416
Landscape similarity	0.520	3.127	45.747	2.047	0.065	3.102	0.802	4.103	1.328	8.214
Largest patch index	0.017	0.113	5.631	0.053	0.018	0.092	0.247	0.674	0.330	0.266
Patch density	0.014	0.486	0.574	0.617	0.021	0.722	0.119	0.673	0.141	1.280
Patch size CV*	2.350	3.794	9.813	2.605	2.315	2.792	7.058	8.485	5.709	4.003
Mean shape	1.523	1.438	1.574	1.413	1.495	1.430	1.414	1.450	1.488	1.466
Outwash										
No. of patches	120	1,170	1,369	1,177	32	2,299	947	2,351	188	3,392
Class area (ha)	969.894	9,622.225	34,308.320	4,565.776	112.275	10,895.819	10,955.080	26,209.843	908.763	23,784.120
Mean patch size (ha)	8.082	8.224	25.061	3.879	3.509	4.739	11.568	11.148	4.833	7.012
Landscape similarity	0.486	4.824	17.199	2.289	0.056	5.462	5.492	13.139	0.456	11.293
Largest patch index	0.232	0.432	1.412	0.093	0.015	0.345	0.950	1.905	0.044	0.262
Patch density	0.060	0.587	0.686	0.590	0.016	1.153	0.475	1.179	0.094	1.700
Patch size CV*	5.334	4.794	5.762	2.456	2.008	4.165	6.577	8.805	2.376	3.200
Mean shape	1.480	1.463	1.544	1.414	1.452	1.451	1.470	1.499	1.423	1.492

*coefficient of variation

Printed on recyclable paper.

☆U.S. GOVERNMENT PRINTING OFFICE: 1997-557-052

Silbernagel, Janet; Chen, Jiquan; Gale, Margaret R.; Pregitzer, Kurt S.; Probst, John.
1997. **An interpretation of landscape structure from historic and present land cover data in the Eastern Upper Peninsula of Michigan**. Gen. Tech. Rep. NC-192. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 30 p.

Compares historic and present landscape structure among four landtype association groups in Upper Michigan. Provides an example of a landtype association framework for assessing landscape composition and pattern.

KEY WORDS: Landtype association framework, landscape composition, landscape pattern.

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.

NORTH CENTRAL FOREST EXPERIMENT STATION