LAND COVER CHANGE IN THE GREAT LAKES REGION FROM MID-NINETEENTH CENTURY TO PRESENT

Authors: Susan Snetsinger and Steve Ventura

Susan Snetsinger is a former GIS Analyst with the U.S. Forest Service Great Lakes Assessment. Currently she is a GIS Analyst with the Arizona Game and Fish Department, Phoenix, Arizona.

Steve Ventura is Associate Professor of Environmental Studies and Soil Science at the University of Wisconsin, Madison.

ABSTRACT

This study analyzed changes in the forests of northern Minnesota and Wisconsin, by ecological units, from the time of original government land surveys (about 1830 – 1860) to present (1990). A method for relating these changes to key landscape factors such as ownership and landform was developed and evaluated. Such information provides important spatial and temporal context for implementing landscape level planning and management in the Great Lakes, and can be used in evaluating current, potential, and desired future landscape conditions.

Substantial changes in both composition and pattern were found in this area, as measured by percent change of land cover types across the region, the turnover in type and proportion of land cover classes within ecological units (measured by the Morisita-Horn similarity index), and change of diversity within ecological units (measured by Brillouin's diversity index). Analyses of degree of cover change by ownership and landform clearly showed a strong relationship to both factors.

Effects of differing data sources, resolutions, and classifications on the above measurements of land cover composition and change were also tested. Methods employed in this study for measuring land cover change are particularly suited to situations in which the existing data are of differing resolutions, and/or based on different data capture methods, and/or there is concern about spatial accuracy. It is expected that these methods could prove useful in the analysis of other landscapes, with such data restrictions, in the future.

TABLE OF CONTENTS

INTRODUCTION **3**
METHODS **6**
Overview of analytical approach 6
Study area 7
Data sources 8
Data resolution alteration and class aggregation 9
Change in forest cover and land cover types by ecological units 11
Change in overall land cover composition by ecological units 11
Land cover change by ownership 12
Land cover change by major landform type 12
Diversity and change in diversity by ecological units 14
RESULTS **14**
Effects of scale and classification on land cover measurements 14
Change in forest cover and land cover types by ecological units 16
Change in overall land cover composition by ecological units 19
Effect of TM versus AVHRR current land cover mapping 20
Change in land cover by ownership 22
Change in land cover by major landform type 26
Diversity and change in diversity by ecological units 28
Summary of results 28
DISCUSSION **29**
Effects of scale, classification, and data accuracy on results 30
Data accuracy and classification effects 30
Scale and majority filter effects 31
Major findings 32
Changes in overall forest cover and land cover composition 32
Changes in land cover composition by landform and ownership 35
Changes in landscape diversity 36
CONCLUSIONS **37**
ACKNOWLEDGEMENTS **39**
LITERATURE CITED **40**

INTRODUCTION

Significant changes have occurred in the forests of northern Minnesota, Wisconsin, and Michigan (Lake State forests) since the time of European settlement (henceforth also referred to as "settlement"). Notable among these are a major decrease in the amount of forest cover, and a transition in forest composition from northern hardwood and conifer types, to early successional species such as aspen. Other changes, such as a younger forest age structure, and increased fragmentation, have accompanied these transitions (Frelich, 1995).

The rate and degree of change occurring in the Lake States forests in the 150 years since settlement far exceed those occurring in the region within the previous 3,000-year period (Frelich, 1995). Thus, there is great potential for these changes to have a profound effect on the regional viability of species and on ecosystem processes, as well as future human consumptive and non-consumptive use of forest resources. Information on historic and present land cover, and degree of landscape change, provide an important frame of reference for the development of land management plans (Committee of Scientists, 1999), and can strengthen our capacity for making wise land use decisions.

A number of authors have previously studied changes in landscape structure since European settlement within the Lake States. Silbernagel et al. (1997) looked at historic and current vegetation composition and pattern in the Upper Peninsula of Michigan, but did not attempt to relate measures from the two time periods to each other due to concerns over differences in data sources and resolution. Changes in old forests and vegetation composition were studied for northern Minnesota, Wisconsin, and Michigan by Frelich (1995), however this study did not involve an explicit spatial component. Palik and Pregitzer (1992) conducted an analysis in northern Lower Michigan of two study areas that differed substantially in presettlement vegetation, but have since converged due to historic land use and management practices. Mladenoff and Howell (1980) looked at changes in upland forest composition and structure in the Gogebic Range of northern Wisconsin, for three time periods ranging from presettlement to present. Examination of spatial pattern and forest cover transition during a more recent and shorter time period, 1973-1983, was conducted by Hall et al. (1991) using satellite imagery, for a 900 sq. km study area in northern Minnesota.

While these previous works have provided a great deal of valuable information on changes in the Great Lakes forests, all have examined somewhat limited geographic areas or time periods, or were lacking a strong spatial component. The primary goal of this study was to describe, in a spatially explicit manner, the degree and types of landscape change occurring in a broad region of the Great Lakes forests since European settlement.

Such information is even more useful however, when placed in the context of important natural and human-related factors operating on the landscape. Clearly, human-related factors such as ownership and economics are major driving forces determining forest use, and thus the type and degree of landscape change. Environmental factors such as climate, soils, natural disturbance, and topography, which were determinants of presettlement vegetation, influence succession and recovery of forests, and also strongly influence current human land

use decisions. In order to provide important context for this study, as well as demonstrate a general approach for the analysis of human and environmental factors in relation to landscape change, this study has used two well-recognized variables, ownership and landform, for further examination of landscape change in the Great Lakes.

Few authors have attempted to relate landscape changes to human factors. However, in those studies that do exist, ownership is a commonly examined variable. Turner et al. (1996) looked at forest pattern changes in relation to ownership and other economically related factors, such as transportation networks and distance to major population centers, for an area in the southern Appalachians. Spies et al. (1994) looked at forest pattern changes in relation to wilderness, public non-wilderness, and private land ownerships in Oregon. Both of these papers dealt with recent, short-term landscape changes, rather than changes since presettlement times. Within the Great Lakes region, Padley and McWethy (1999) studied current vegetation composition and pattern of northern Wisconsin, and analyzed this in relation to ownership. Unlike the prior two studies, they found minimal differences in pattern among ownerships, though they emphasized that these preliminary results should be interpreted with caution. The results of Padley and McWethy (1999) were counter to the findings of Cardille and Ventura (1999) however. Working at a somewhat broader scale, Cardille and Ventura (1999) did find a relation between ownership and both forest composition and fire propensity in the Great Lakes.

In the Lake States, glacial landforms are well recognized as a dominant factor in determining potential natural vegetation (Pastor and Mladenoff, 1992). Glacial landforms strongly relate to soils, topography, and water availability, and thus vegetation. Some efforts have been made to analyze landscape changes in relation to major landforms. Silbernagel et al. (1997) looked at historic and current vegetation composition and pattern in Upper Michigan according to ecological units grouped by major landform type, but did not test statistically for association of observed patterns with these groups. White and Mladenoff (1994) examined upland forest landscape transitions in north central Wisconsin in relation to landforms and recent disturbance history for three points in time, from 1860 to present. They found that some positive associations of forest types and landforms (e.g., hardwood and moraine, hemlock and outwash) became negative at least once within this period, due to logging. In Illinois, Iverson (1988) looked at historic vegetation, current land use, and patterns of land-use change over the last 160 years in relation to soil and environmental landscape attributes. He found associations of environmental attributes with historic and current natural land use types, but much weaker associations with highly modified types such as urban areas.

As in the study by Silbernagel et al. (1997) of vegetation change in Michigan, USDA Forest Service delineated “ecological units” were chosen as the basic unit of analysis for this study. Ecological units are mapped regions based on relatively stable features of the environment, such as climate and physiography, and are intended to capture areas of similar ecological potential (Cleland et al., 1997). They are mapped at a range of scales, in a nested hierarchy. The three scales used in this study, from largest to smallest, are Sections (tens of thousands of sq. kilometers), Subsections (thousands of sq. kilometers), and Landtype Associations (LTAs) (thousands to tens of thousands of hectares). Sections are based on climate and

broad, physiographic features of the landscape, Subsections on smaller areas of similar surficial geology and subregional climate, and, in the Lake States, LTAs are generally based on specific glacial landforms or repeating patterns of landforms (Cleland et al., 1997).

Several reasons existed for choosing ecological units, and LTAs in particular, as the basic units of analysis. First, federal and state resource agencies are adopting these units as an ecologically based framework for land management decision-making within the Great Lakes (Cleland et al. 1997; Wisconsin Dept. of Natural Resources 1998a). Within the hierarchy, LTAs are considered to be the most useful scale for planning at the national or state forest level, and thus, there is great interest in increasing the amount of information available about them. In a more general sense, ecological units have also been described as being particularly appropriate as the basis for comparison studies, by controlling for mesoscale environmental factors which may differentially influence areas within a region (Silbernagel et al., 1997). O'Neill et al. (1996) noted the importance of using ecologically meaningful bounds for calculating landscape indices, such as those utilized in this study, as well. Finally, the overall purpose of this study was to convey information about general landscape relationships, rather than specific, individual parcels of land (data of sufficient resolution to work at this fine scale are not available across such a broad area). It is an assumption of this study that the ecological units, as drawn, are both ecologically meaningful and relevant to major landscape features and processes of interest to land managers.

The three major objectives of this study were:
1) To describe in a spatially explicit manner, the degree and types of landscape change occurring in the Great Lakes forests since European settlement (~1840);
2) To relate these changes to major human and environmental landscape factors (ownership and landform);
3) To increase the information content of ecological units within the Great Lakes, thus enhancing their utility for use in land management decision-making.

It was hypothesized that the degree of landscape change would vary among ownerships due to differences in land management objectives among owners. Public lands, which are generally managed for multiple uses and adhere to stricter laws and regulations (e.g., National Forests which are managed under the National Forest Management Act (NFMA), Endangered Species Act (ESA), and others), were expected to show less change than private lands. Among public lands, lands not managed for consumptive resource use, such as state parks and federal wild and scenic areas, were expected to show less change than areas managed at least partially for resource extraction (such as state forests). However, the relatively short time period of many ownerships in the region (many have been in place for less than half of the time period of this study) was recognized as a potentially confounding factor, perhaps reducing the effects of management over other factors in affecting the degree of landscape change.

Differences in the degree of change were also expected to vary among major landform types. Forman and Godron (1986) note that "Landscape attributes are important in explaining the human-derived land uses because naturally favorable attributes often dictate our selection of

particular landscapes for a specific land use." Landforms with generally favorable attributes such as flat topography, silty or loamy soils (e.g. Moraines), which are good for agriculture and other intense human uses, were expected to show a greater degree of change than landform categories such as Ice-contact, with generally less favorable attributes.

METHODS

Overview of analytical approach

Several types of analyses were used to address the broad objectives outlined above. All analyses were based on comparisons of current and historic land cover maps. A geographic information system and image processing methods were used to obtain common classifications and a similar data resolution. The last objective, of increasing the knowledge base of ecological units, was met by using Sections, Subsections, and LTAs as units of analysis.

The first objective, description of degree and types of landscape change occurring since settlement, was addressed in a several steps. Percent change of overall forest cover, and percent change of individual cover types by ecological unit were first calculated. Then, two general landscape indices were employed which described landscape change in terms of overall degree of land cover change, and diversity and change in diversity, by ecological units. In order to assess potential effects of resolution, classification system, and individual data sources on the results, the above calculations were done multiple times, using different data aggregations and data sources.

The second objective, relating landscape changes to major human and environmental landscape factors, involved the use of two representative variables, ownership and landform. For each of these variables, tests were conducted to determine whether statistically significant differences exist in the degree of landscape change (as measured by a landscape index) for different categories of that variable.

The intent of this study was to describe temporal changes in land cover pattern as well as composition of ecological units, as both of these factors are extremely important in affecting ecological processes and functioning (Turner, 1989). Unfortunately, differences in the historic and current land cover data sets were deemed too substantial and grain size too coarse to allow for analysis of landscape pattern using many common, patch-based metrics. O'Neill et al. (1996) note that indices based on land cover proportions are insensitive to bias introduced by coarse-grained data however, and provide reliable estimates of meso- and macro-scaled features. Diversity, one important measure of landscape pattern that is affected only by number and proportions of cover classes, was thus chosen for use in this study.

Other studies of land cover change have looked at transition probabilities of specific vegetation types to other types (Hall et al. 1991; White and Mladenoff 1994). This method of analysis detects vegetation change on a pixel-by-pixel basis, identifying historic and current vegetation types for the same spatial location, or pixel. Although this type of change

detection analysis can be quite informative, the potential for high error rates is of concern. As Host and Polzer (1996) note, original errors in classification can become compounded when the data sets are overlaid and analyzed in relation to each other. Due to concerns over potentially exceedingly high error rates, no effort to describe specific land cover type transitions was made. Rather, the data of this study reflect only major trends in the degree of land cover change from historic to present times, as measured by proportional composition and diversity.

Study area

The area encompassed by this study is the northern portion of Minnesota and Wisconsin. Specifically, it includes all lands within the Laurentian Mixed Forest Province (Bailey, 1976) of these two states (Figure 1).

Figure 1. Laurentian Mixed Forest Province of Minnesota and Wisconsin.

This area is dominated by mixed hardwood and coniferous forest, and is a transition zone between the coniferous, boreal forests of the north, and the eastern deciduous forest, and prairie parkland to the south. This study area, with the addition of northern Michigan, forms a distinct region due to its particular forest character and historical forest use (Flader, 1983). (Northern Michigan was not included in this study due to lack of data). Notable differences in vegetation occur across the study area, however. Much of northern Minnesota is currently dominated by early successional boreal forest, with significant areas of conifer swamp and peatlands. Northern hardwood forests, with a substantial aspen component, dominate northern Wisconsin. Most forests within both states have been logged at least once since European settlement, and the area as a whole has seen a large loss in overall forest cover and a strong conversion to early successional species, such as aspen. Glacial landforms are a conspicuous feature of the landscape, and exert a strong environmental influence in the area.

The climate is characterized by short, mild summers with long, cold winters, and a moisture gradient decreasing from east to west. The study area is 173,336 km^2 in size. It contains 8 Sections, 33 Subsections, and 314 LTAs (Minnesota Department of Natural Resources 1998; Wisconsin Department of Natural Resources 1998b).

Data sources

All data used in this study were obtained from the Great Lakes Ecological Assessment (Great Lakes Ecological Assessment, 1999), which previously acquired the data from a variety of sources, including the Minnesota and Wisconsin Departments of Natural Resources, the Natural Resources Research Institute (University of Minnesota-Duluth), the U.S. Environmental Protection Agency, and the University of California, Santa Barbara. Data themes, such as ecological units, which occurred separately for each state, were integrated across state boundaries. GIS layers (data themes) are listed in Table 1.

Table 1. Data sources.

Data Theme	Extent	Data type	Scale/ Resolution	Date of source info.	Data source	Reference
Ecological units	MN	polygon	unknown	variable	MN DNR	Minnesota DNR, 1998
Ecological units	WI	polygon	unknown	variable	WI DNR	Wisconsin DNR, 1998b
Current land cover - TM	MN	grid	28.5 m. cell	1987-1990	NRRI*	Wolter et al., 1995
Current land cover -TM	WI	grid	31.5 m. cell, 5 acre mmu#	1992	WI DNR	Wisconsin DNR, 1998c
Current land cover-AVHRR	MN & WI	grid	1 km cell	1990	U.S. EPA	Powell et al., 1992
Presettlement land cover	MN	polygon	unknown	1847-1907	MN DNR	Marschner, 1975
Presettlement land cover	WI	polygon	1/2 mile x 1/2 mile mmu	1832-1866	WI DNR	Finley, 1951
Landform	MN	polygon	unknown	unknown	MN DNR	-
Landform	WI	polygon	1:500,000	~1978	WGNHS+	-
Ownership	MN & WI	polygon	1:2,000,000	variable	UCSB-RSRU!	McGhie et al., 1996

* Natural Resources Research Institute (Univ. of MN - Duluth)

\# minimum mapping unit

+Univ. of WI - Extension, WI Geological and Natural History Survey

!Univ. of CA, Santa Barbara - Remote Sensing Research Unit

All data were obtained through the Great Lakes Ecological Assessment (1999), from the above original data sources.

Data capture methods, data accuracy, scale or resolution, and classification schema influence the utility of these presettlement and current land cover data sources, both as separate themes, and in conjunction with each other.

Methods of data capture differ greatly for the presettlement and current land cover data sets, a potential concern when comparing one data set to the other. The GLO-based presettlement maps were derived from field data, using data about canopy and sub-canopy trees recorded by early surveyors. Current land cover is based on satellite imagery, which captures only canopy cover. In a study within the Lakes States forests, Manies (1997) found little difference in vegetation maps derived from sample tree data using original GLO protocols that included only canopy, or canopy and sub-canopy trees, however. Some authors have discussed potential concerns in using General Land Office (GLO) survey data to derive presettlement vegetation maps. Overall however, GLO data are generally considered to provide a valuable and reliable record of presettlement vegetation (Whitney, 1986), and have been used in numerous studies of pre-European vegetation (Stearns 1949; Mladenoff and Howell 1980; Palik and Pregitzer 1992; and others). This study uses GLO-based data only to look at proportions of generalized vegetation types at a landscape scale, thereby reducing concerns over accuracy of fine vegetative class divisions and specific locational accuracy.

Two different data sources were available for current land cover – classified Landsat TM and classified AVHRR satellite imagery. Prior work has shown substantial differences in land cover as portrayed by the two data sets, particularly in the Aspen/birch vegetation class. The AVHRR data appears to over-represent Aspen/birch at the expense of Nonforest, Maple/beech/birch, and Spruce/fir classes (Host and Polzer, 1996). The TM data (Wisconsin Department of Natural Resources, 1998c) on the other hand, generally under-represents Aspen/birch, due to “missed” aspen occurring in mixed classes (Padley and McWethy, 1999).

In order to compare effects of data sources on analysis results, and set bounds on what is most likely the actual amount of Aspen/birch forest, some analyses were conducted twice, once using each data set. Current land cover was represented by the TM data throughout most of the study however, under the assumption that even with a rescaling of this data from a 30 meter to 805 meter (1/2 mile) resolution (in order to match the presettlement data), the TM data would have the highest overall accuracy. Classified TM data was missing for portions of northwestern Minnesota, and these areas are thus described or shown as “no data” for some analyses. Classification accuracies for the Minnesota and Wisconsin TM data are contained in Appendix A. For both states, forested classes were generally at least 80% accurate, with some classes exceeding 90%. Mixed forest and aspen classes tended to have lower accuracies, typically in the upper 60 to upper 70 percent range.

Data resolution alteration and class aggregation

Measures of composition and landscape indices are sensitive to grain (pixel resolution or patch size) and classification specificity (Turner et al., 1989). Before applying a metric, it is thus important to understand its behavior in relation to changes in resolution and

classification. Preliminary investigations were conducted to assess the effect of altering minimum mapping unit and classification schemes of the presettlement and current land cover data sets, in order to more closely match one with the other for comparison purposes.

The scale of the grid-based, TM current land cover data was much finer than that of the polygon-based presettlement land cover data sets. The Wisconsin presettlement land cover map had a minimum mapping unit of 1/2 mile x 1/2 mile (or 805 m. x 805 m.) (Finley, 1951). The minimum mapping unit for the Minnesota data was unknown, though visually, clearly much finer. Resolution of the TM current land cover data for Minnesota was approximately 30 m. x 30 m., though for Wisconsin, further processing resulted in an actual minimum mapping unit of about five acres (142.5 m. x 142.5 m.) (Wisconsin Department of Natural Resources, 1998c).

Class aggregation and a block majority filter were applied to the data sets in order to more closely approximate the resolution and minimum mapping unit of the Wisconsin presettlement data, the coarsest of the land cover data sets. For spatial aggregation, the presettlement data sets were gridded at a 30-meter cell size. Then, a majority block filter of 805 meters x 805 meters was applied to all land cover data sets. Cell blocks with no majority were assigned a “no data” value, which generally resulted in 5% or less of a calculated area having no data.

To integrate classification systems, all land cover data layers were reclassified using two common, derived classification schemes. Both schemes emphasize division of forest classes, and are intended to reflect primary environmental gradients of the area. The first scheme contains eight classes, and was developed by the Great Lakes Ecological Assessment for use in conjunction with AVHRR satellite based land cover data (Great Lakes Ecological Assessment, 1999). The second is a finer classification of 12 land cover types, which further divides the pine, spruce-fir, and nonforested classes of the coarser scheme. The fine and coarse classification schemes are listed in relation to each other in Table 2. Allocation of the original presettlement and current land cover classes into the fine and coarse groupings is detailed in Appendix B.

Table 2. Fine and coarse land cover classifications.

Coarse Classification	**Fine Classification**
White/red/jack pine	White/red pine Jack pine
Spruce/fir	Spruce-fir/other upland conifers Coniferous lowland
Oak/hickory	Oak/other hardwoods
Aspen/birch	Aspen/birch
Maple/beech/birch	Northern hardwoods
Elm/ash/cottonwood	Deciduous lowland
Nonforested	Nonforest lowland Nonforest upland Non-vegetated/developed
Water	Water

Percent composition of land cover types, the Morisita-Horn similarity index and Brillouin's diversity index, (the landscape measures used in this study, discussed in detail below), were calculated by LTA, using various combinations of the rescaled and reclassified data. Resulting shifts in the index values, and percent composition, were then visually assessed with the GIS and numerically compared.

Unless otherwise specified, all following analyses used the majority filtered data sets (approximately 1/2 x 1/2 mile spatial resolution), with the fine (12 class) classification scheme. The coarse classification scheme was used only for testing the effects of classification changes, and for analysis in conjunction with the AVHRR data set.

Change in forest cover and land cover types by ecological units

Area and percent composition of land cover types for ecological units at the Landtype Association, Subsection, and Section levels were calculated using the majority filtered data sets, with fine and coarse classifications schemes. Change in percent composition of each land cover type for ecological units was calculated by subtracting percent composition based on current land cover data, from percent composition for presettlement data. Land cover data were also regrouped into Forest and Nonforest classes. Percent presettlement and current forest cover, and change in forest cover were calculated for LTAs. Mean percent change in overall forest cover for the study area, and of individual land cover types for LTAs, were also calculated.

Change in overall land cover composition by ecological units

The degree of overall change in land cover composition was measured for LTAs using the Morisita-Horn similarity index (denoted C_{mH}) (Magurran, 1988).

$$C_{mH} = \frac{2\Sigma(an_i bn_i)}{(da + db)aN*bN}$$

aN = total number of individuals (or percent composition) in site (or time) A
bN = total number of individuals (or percent composition) in site (or time) B
an_i = number of individuals (or percent composition) in the *i*th species (or veg. type) in A
bn_i = number of individuals (or percent composition) in the *i*th species (or veg. type) in B

$$da = \frac{\Sigma an_i^2}{aN^2}$$

$$db = \frac{\Sigma bn_i^2}{bN^2}$$

For quantitative data with paired sites, similarity indices are one of the easiest ways to examine beta diversity (i.e., the diversity or change in composition between two different communities, or communities along a gradient) (Magurran, 1988). In this case, the index was used to measure the difference between land cover composition of an LTA from

presettlement to current times. Reviews of similarity measures have found the Morisita-Horn index to be much more satisfactory than other available, quantitative similarity indices (Wolda 1981; Magurran 1988). Although this index has also been criticized for being highly sensitive to the abundance of the most abundant species (Magurran, 1988), a close examination of the behavior of this index in relation to the land cover composition data found it to be satisfactory for the purposes of this study.

The Morisita-Horn index was calculated for LTAs three times, first using the fine classification and TM data to represent current land cover, then using the coarse classification and TM data, and finally using the coarse classification and AVHRR data.

Land cover change by ownership

Analysis was conducted to test the relationship of ownership type to the magnitude of change of land cover composition from presettlement to current conditions. First, LTAs were intersected with the ownership data in order to create another set of units for calculating the Morisita-Horn index. Resulting units were sub-divisions of LTAs within each named ownership area (e.g., the portion of LTA 212Ka06 within the Brule River State Forest). The Morisita-Horn index was calculated for each unit, and the units were then grouped by ownership type for analysis. Ownership categories were Federal other, Federal forest (i.e. National Forests), State other, State forest, Indian reservation, and Private. Federal other and State other categories consisted primarily of protected areas such as state parks or National Wild and Scenic River corridors. Units smaller than 1,000 hectares were excluded from analysis, resulting in a minimum unit size 15 times larger than the land cover minimum mapping unit (approximately 65 hectares). This is well above the “2 to 5 times larger” suggested by O’Neill et al. (1996), needed to avoid bias in calculating landscape indices.

A non-parametric equivalent of ANOVA, the Kruskal-Wallis H test, was used to analyze the data to accommodate the lack of normality and equal variance in the data. The Mann-Whitney U test, a nonparametric equivalent of the T-test, was then used for follow-up pair-wise comparisons of all ownership type category combinations (Siegel and Castellan Jr. 1988; Zar 1996). The Morisita-Horn index data was reclassified into Public (including Indian reservations) and Private land categories, and the Mann-Whitney U test was also used to compare change in the Morisita-Horn index between these two categories.

Land cover change by major landform type

Methods for testing the relationship of general landforms, or surficial geology, to the degree of change in land cover composition parallel those of the ownership analysis. LTAs were intersected with the surficial geology polygons, and the resulting units were used for calculation of the Morisita-Horn land cover change index. The units were then regrouped by major landform type for analysis (see Table 3 and Figure 2). The classification of the original surficial geology categories into major landform types is detailed in Appendix C. LTA-landform units smaller than 1,000 hectares were excluded from analysis. The Kruskal-Wallis H test (nonparametric equivalent of ANOVA) was used to test for significant

differences in degree of land cover change among landform types (Siegel and Castellan Jr. 1988; Zar 1996). Due to major differences in the type of classes used in the Wisconsin and Minnesota surficial geology maps, analysis was conducted separately for each state.

Table 3. Landform classes.

Wisconsin	Minnesota
Alluvium & colluvium	End/ground moraine
Calcareous loamy/sandy loamy till	Stagnation moraine
Clayey till	Outwash and alluvium
Ice-contact	Lake-modified till
Lake	Glacial lake sediment - clay/clayey silt
Non-calcareous sandy loamy till	Glacial lake sediment - silt/fine sand/gravel
Outwash	Mine pits and dumps
Peat and muck	Peat
Pre-wisconsonian	Terraces
	Water

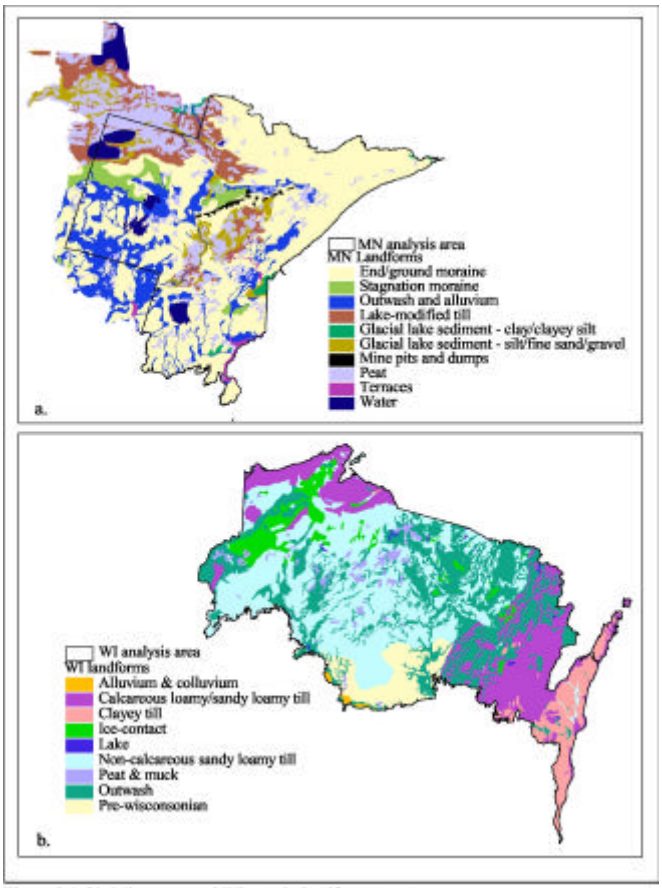


Figure 2 (a-b). Minnesota and Wisconsin landform maps.

Diversity and change in diversity by ecological units

Brillouin's diversity index was used to measure current and historic land cover diversity, and the relative magnitude and direction of change in diversity. Brillouin's index is similar to, and holds the same properties as the more widely applied Shannon's diversity index (Pielou, 1975). However, it is more appropriate than Shannon's index when the data consists of a complete inventory, rather than samples (Pielou 1975; Magurran 1988).

Brillouin's diversity index is a combined measure of both richness and evenness, and is calculated as:

$$HB = \frac{\ln N! - \Sigma \ln n_i!}{N}$$

N = total number of individuals
n_i = total number of individuals in class i

The index was calculated using percent composition, rather than numbers of individuals in each class. Thus for each ecological unit N was always equal to 100. Change in diversity was calculated by simply subtracting Brillouin's index values for current land cover from that for presettlement land cover. The diversity, and change in diversity values were mapped for LTAs, and used in a descriptive manner only.

RESULTS

Effects of scale and classification on land cover measurements

Prior to conducting other analyses, the effect of altering land cover data resolutions and classifications (in order to more closely match presettlement and current data sets to each other for comparison purposes), was examined. The effect of altering resolution via a ½ mile block majority filter was generally minimal. Its effects were most noticeable on the Landsat-based current land cover data set. As expected, coarsening resolution led to an increased representation of dominant cover types, and a slight decrease in rare types. The largest changes occurred in the Aspen/birch and Nonforest upland classes, which increased by 5% and 4%, respectively (see Table 4). Use of the coarser resolution data resulted in much greater differentiation among LTAs in terms of the diversity index for current land cover, and a slight overall decrease in Morisita-Horn index values, thus signifying a greater change from presettlement to current conditions (Figure 3).

Table 4. Changes in percent composition for current land cover in study area, after application of ½ mile majority filter.

	Nonforest lowland	Spruce-fir/other upland	Deciduous lowland	White/red pine	Oak/other hardwoods	Coniferous lowland	Non-vegetated/developed	Jack pine	Water	Northern hardwoods	Nonforest upland	Aspen/birch
% using 805 m. (1/2 mile) resolution data	9	1	1	1	0	7	2	2	7	20	27	25
% using 30 m. resolution data	11	3	3	2	1	8	3	2	6	17	23	20
Increase or decrease (-) in % after data coarsening	-2	-2	-2	-1	-1	-1	-1	0	1	3	4	5

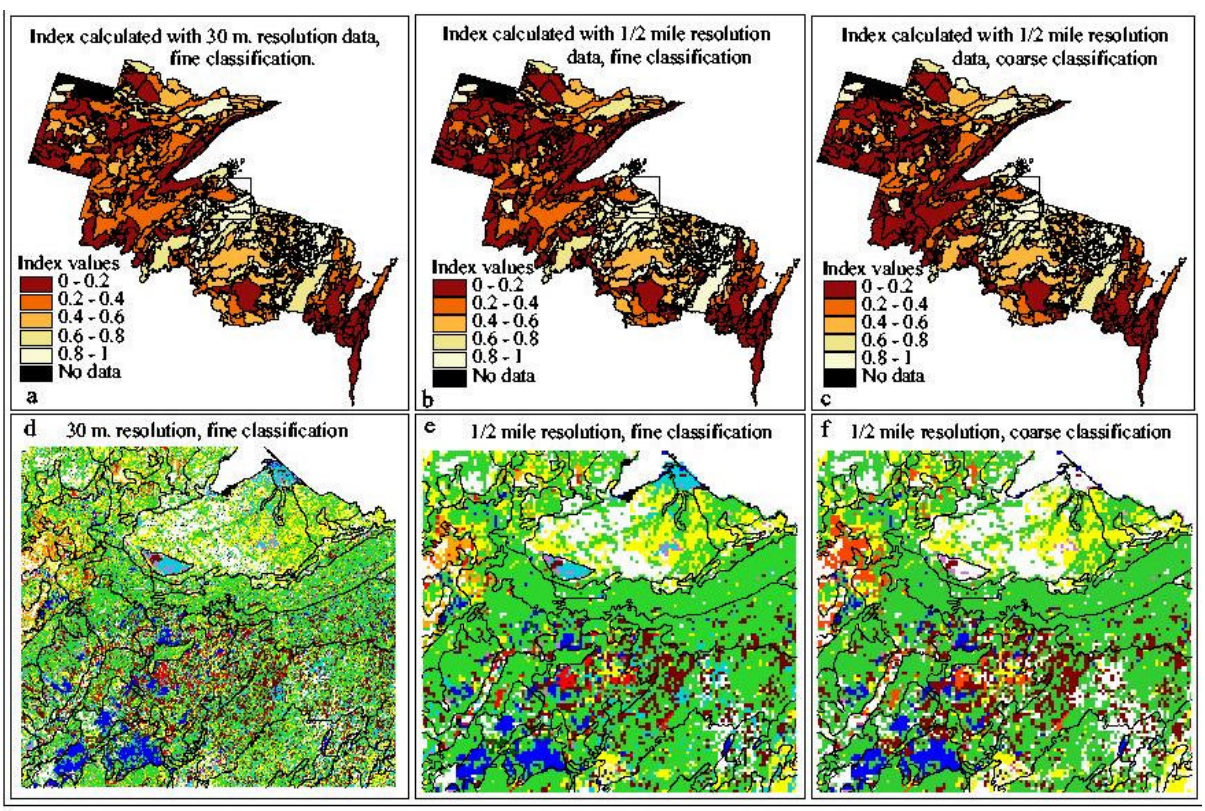


Figure 3. Maps illustrating effects of data resolution and classification on current land cover, and the Morisita-Horn (M-H) similarity index for LTAs. The M-H index represents degree of change in landscape composition since European settlement. Bottom row shows boxed area of the above maps.

The effect of applying the 12 class (fine) versus 8 class (coarse) land cover schemes was also generally minimal for both presettlement and current land cover. Brillouin's diversity index

was slightly higher using the fine classification; however, overall patterns of heterogeneity/homogeneity in the study area were not substantially altered. Use of the fine versus coarse classifications had little effect on the Morisita-Horn index for LTAs (Figure 3). The fine classification was chosen for use throughout the rest of the study, as classification effects were minimal, and this grouping appeared to represent the maximum, reliably distinguishable information on classes useful for forest study purposes.

Change in forest cover and land cover types by ecological units

Presettlement forest cover and current forest cover (in percent by LTA), and relative change in forest cover by LTAs are shown in Figure 4. All LTAs decreased in absolute amount of forest cover, with LTAs along the southern edge of the study area in Minnesota and Wisconsin having the greatest decrease. LTAs in northern-most Wisconsin, and northeastern Minnesota showed the least change. Overall change in forest cover for the entire study area was a 37% decrease, from 94% in historic times, to 57% at present. It is likely that these values are slightly exaggerated however, as explained in the discussion.

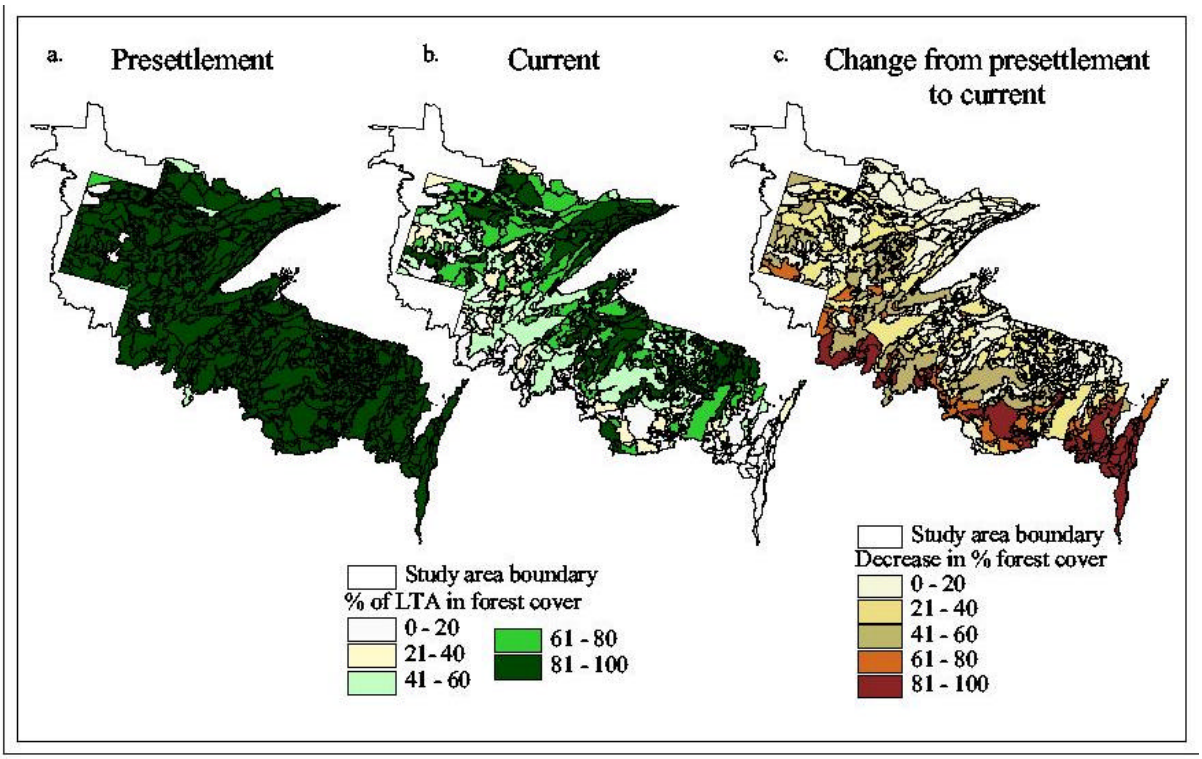


Figure 4 (a-c). Maps of percent presettlement and current forest cover, and forest cover change by LTAs.

Overall change in land cover by type for the study area is shown in Figure 5. Land cover classes which increased substantially since presettlement are Nonforest upland (26% increase), and Aspen/birch (23% increase). Nonforest lowland also shows a substantial increase (7%), but this is believed to be mostly an artifact of differences in data capture

methods of the data sources rather than a true increase. Classes showing substantial decreases are Coniferous lowland (-15%), White/red pine (-12%), and Northern hardwoods (-11%). Spruce-fir/other upland conifers shows a 13% decrease, though this value is likely exaggerated as explained in the discussion. Oak/other hardwoods and Jack pine show absolute decreases of only 3% and 6%, respectively. However, in relation to their originally small percent coverage (4% for Oak/other hardwoods and 8% for Jack pine), this is an effective 88% decrease in the amount of presettlement Oak/other hardwoods forest and a 79% decrease in amount of presettlement Jack pine forest. Figure 6 illustrates these changes in composition for each class as a proportion of the whole, for the study area.

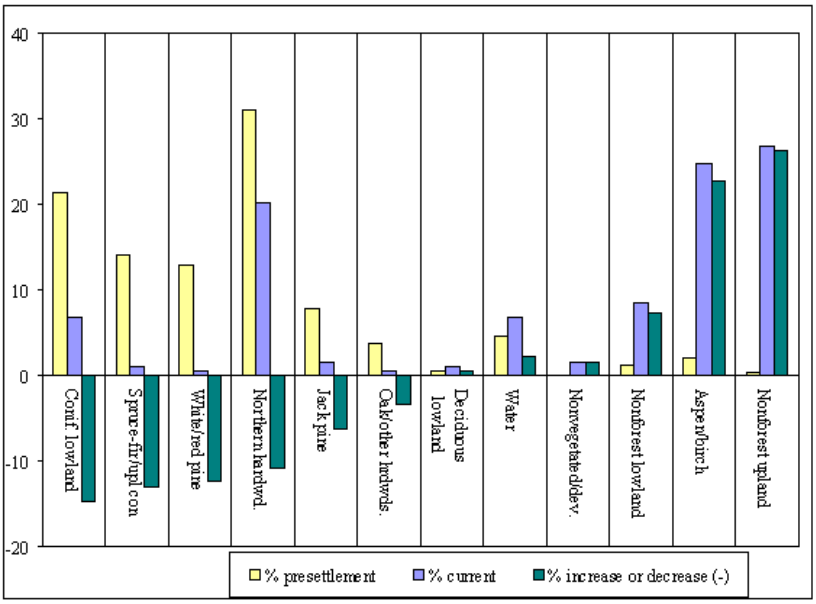


Figure 5. Absolute and relative percent change of land cover classes for northern Minnesota and Wisconsin, from presettlement to present.

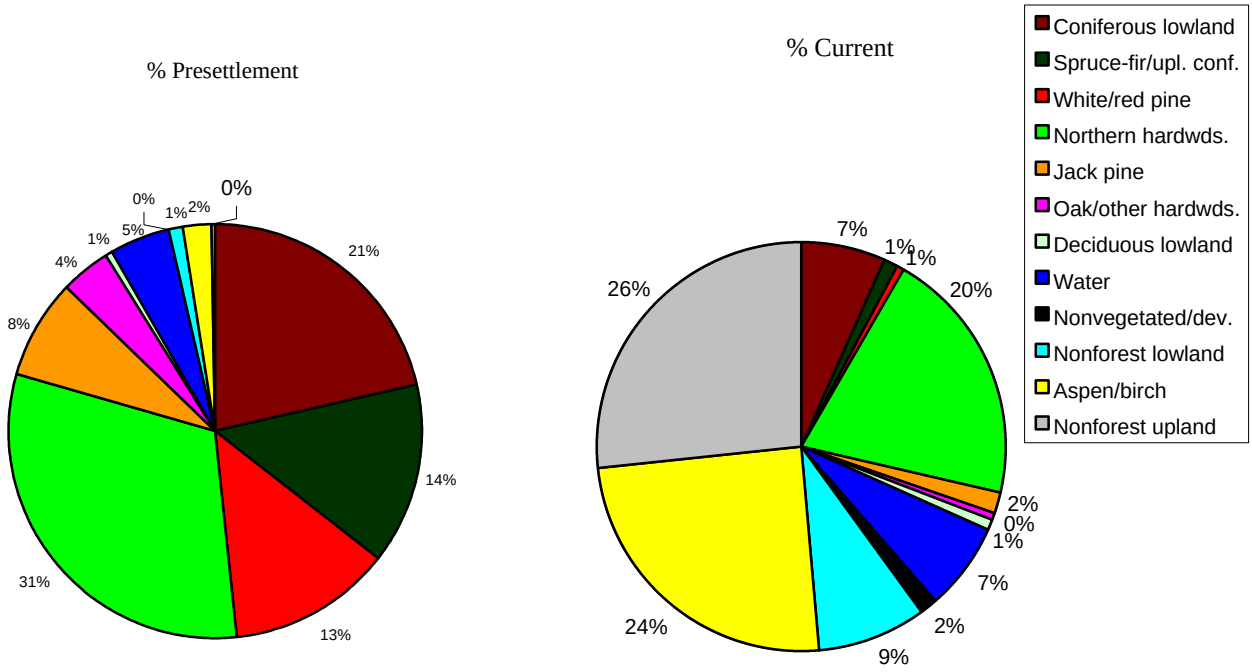


Figure 6. Percent composition of the study area, for presettlement and current land cover.

Patterns of change by ecological unit, for land cover classes showing a greater than 30% change for at least one LTA, are illustrated in Figure 7. Visual trends are a loss of Coniferous lowland from Minnesota and northern Wisconsin, and a dramatic decrease in Northern hardwoods from the southern portion of the Wisconsin study area (Figure 7, a & b). Minnesota shows a dramatic decrease in Spruce-fir/other upland conifers and increase in Aspen/birch (Figure 7, c & d), however this transitional pattern is exaggerated due to classification choices, as described in the discussion. Jack pine and Oak/other hardwoods show decreases in western Wisconsin and the southern edge of the Minnesota-Wisconsin border, respectively (Figure 7, e & f). Significant decreases in White/red pine occur throughout northern Minnesota and Wisconsin, and the southern portion of the study area shows a strong increase in Nonforest upland types (Figure 7, g & i). Current and presettlement land cover composition in terms of percent cover, using the fine classification and coarsened resolution data, is listed for all Landtype Associations, Subsections, and Sections in Appendix D.

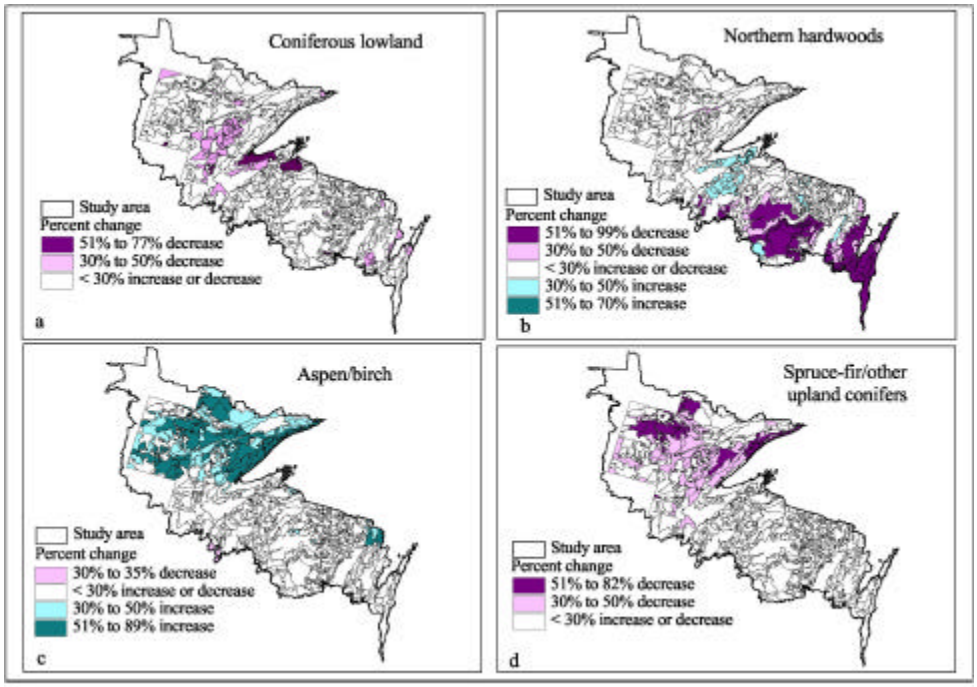


Figure 7 (a - d). Maps of percent change of land cover types from presettlement to current conditions, for LTAs.

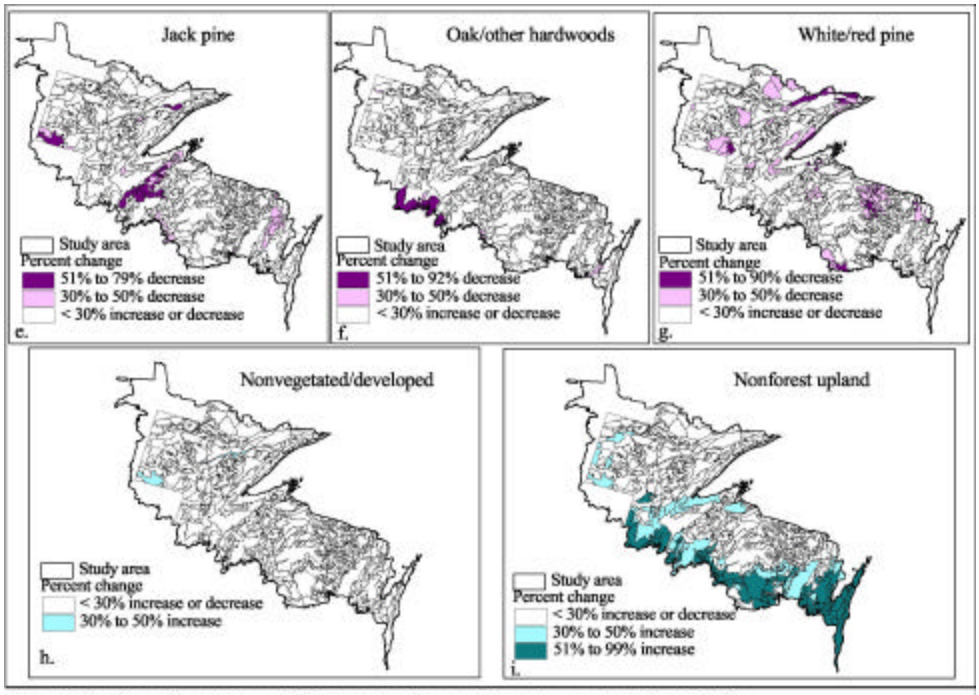


Figure 7 (e - i). Maps of percent change of land cover types from presettlement to current conditions, for LTAs.

Change in overall land cover composition by ecological units

Presettlement land cover, current land cover, and change in overall land cover composition for LTAs as measured by the Morisita-Horn similarity index is shown in Figure 8. A

generally greater degree of change is seen for Minnesota, eastern and southern Wisconsin LTAs. North, and north-central portions of the Wisconsin study area, which are and were generally dominated by northern hardwood forest, show comparatively lower levels of compositional change.

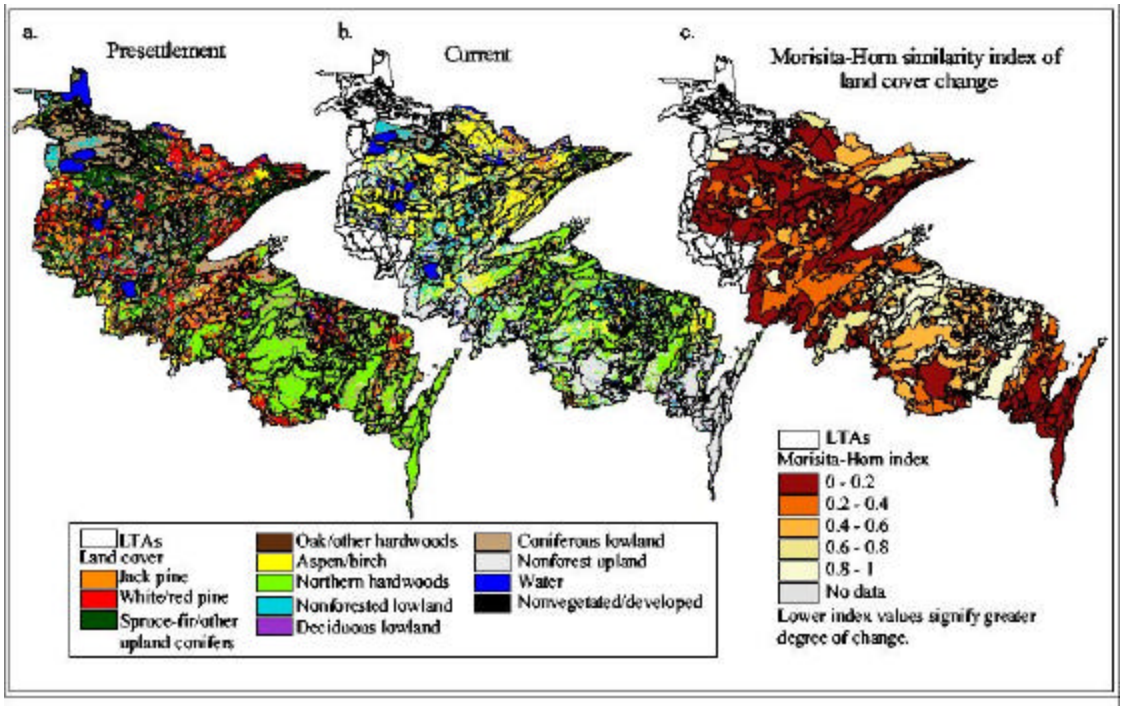


Figure 8 (a-c). Maps of presettlement and current land cover, and degree of change in composition as measured by the Morisita-Horn similarity index, for LTAs.

Effect of TM versus AVHRR current land cover mapping

Use of the classified Landsat TM versus AVHRR data had a reasonably strong effect on calculated current percent cover for some classes. Current land cover as represented by these two data sets is illustrated in Figure 9, and differences in resulting percent composition for the study area is shown in Figure 10. Greatest differences between the themes occur in the Aspen/birch and Nonforested classes, with differences of 15% and 17%, respectively. The AVHRR data contains the higher percentage of Aspen/birch, particularly in areas classified as Maple/beech/birch in Wisconsin, under the TM data. The TM data shows much more of the Nonforested class, primarily in Minnesota. Although percentages for Maple/beech/birch are relatively similar for the data sets (19% TM and 15% AVHRR), the distribution of this class varies significantly between the data sources (see Figure 9)

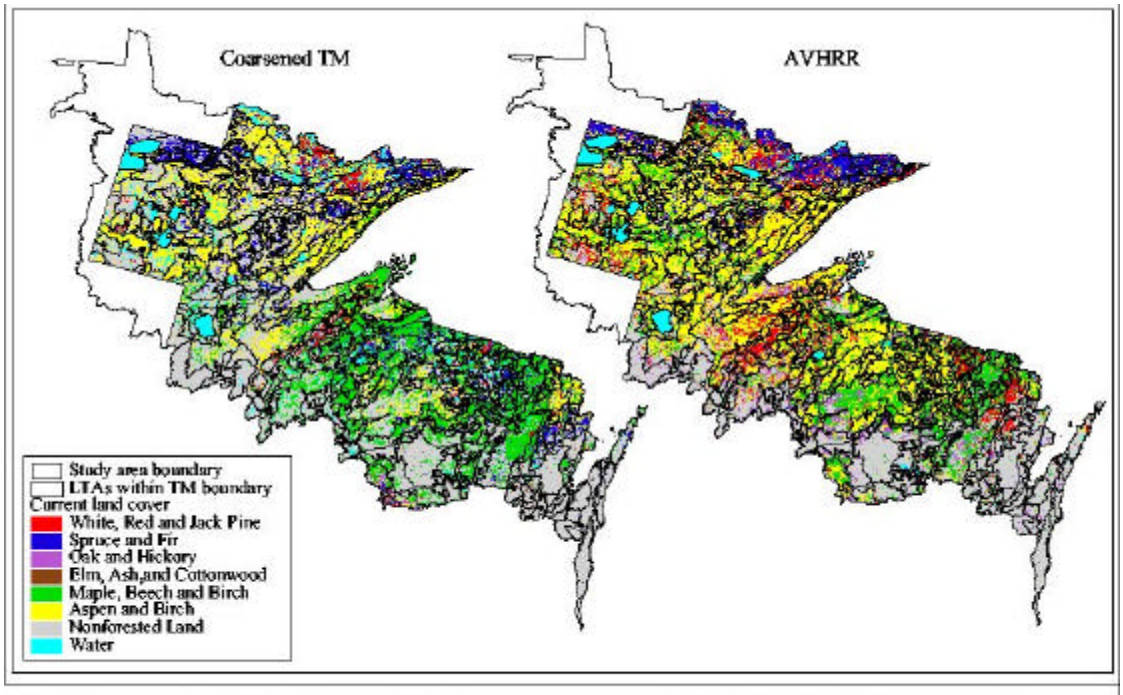


Figure 9. Maps comparing AVHRR and coarsened TM land cover maps, using coarse classification scheme. TM data was coarsened from original 30 m. cell size, using a 1/2 mile (or 805 meter) block majority filter. AVHRR data has a 1 km. cell size.

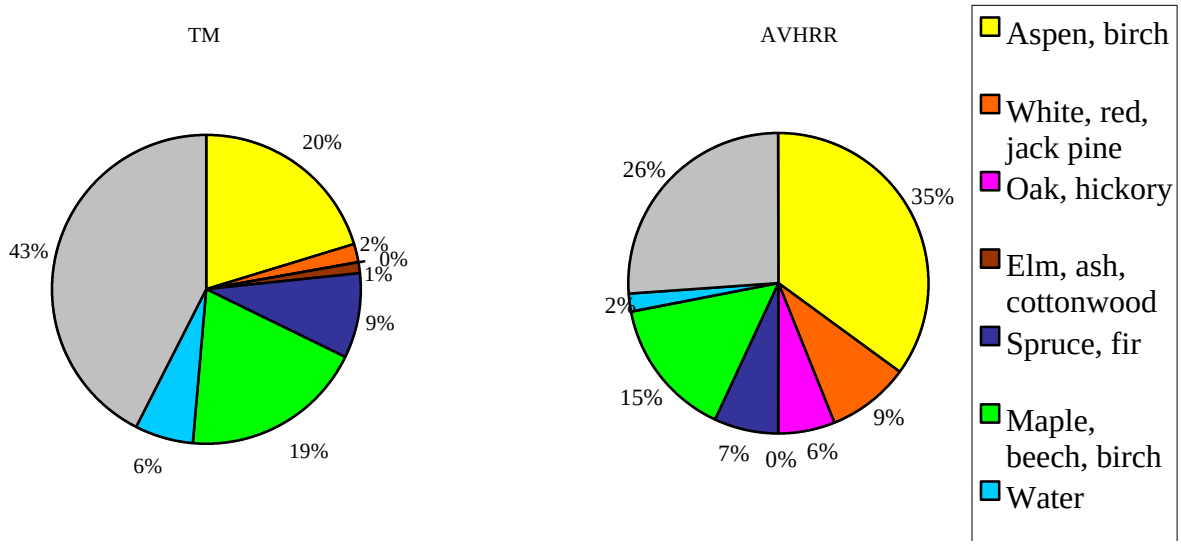


Figure 10. Differences in current land cover as represented by coarsened Landsat TM, and AVHRR data.

As would be expected, use of the two data sets as the basis for current land cover composition in calculation of the Morisita-Horn index also resulted in different patterns of this index in the study area (Figure 11). Given a scale range of 0.0 (maximum change) to 1.0 (no change) for the Morisita-Horn index, LTA index values varied by as much as 0.8 between the two data sources. LTAs in the north and north-central portion of the Wisconsin

study area showed substantially greater change according to the AVHRR data (which showed large amounts of Aspen/birch where the TM portrayed Maple/beech/birch). A number of LTAs in the northern and western portions of the Minnesota study area showed greater change according to the TM data. In these LTAs, the TM data tended to show high percentages of Nonforest where the AVHRR had a variety of forest types.

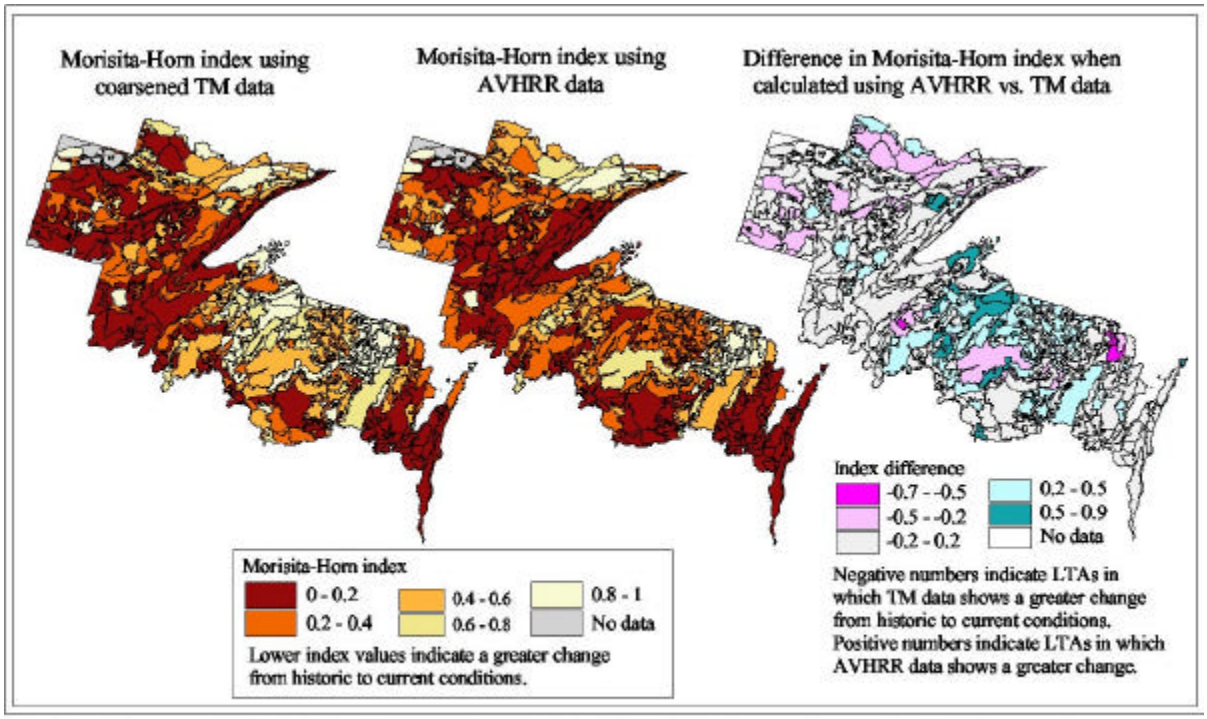
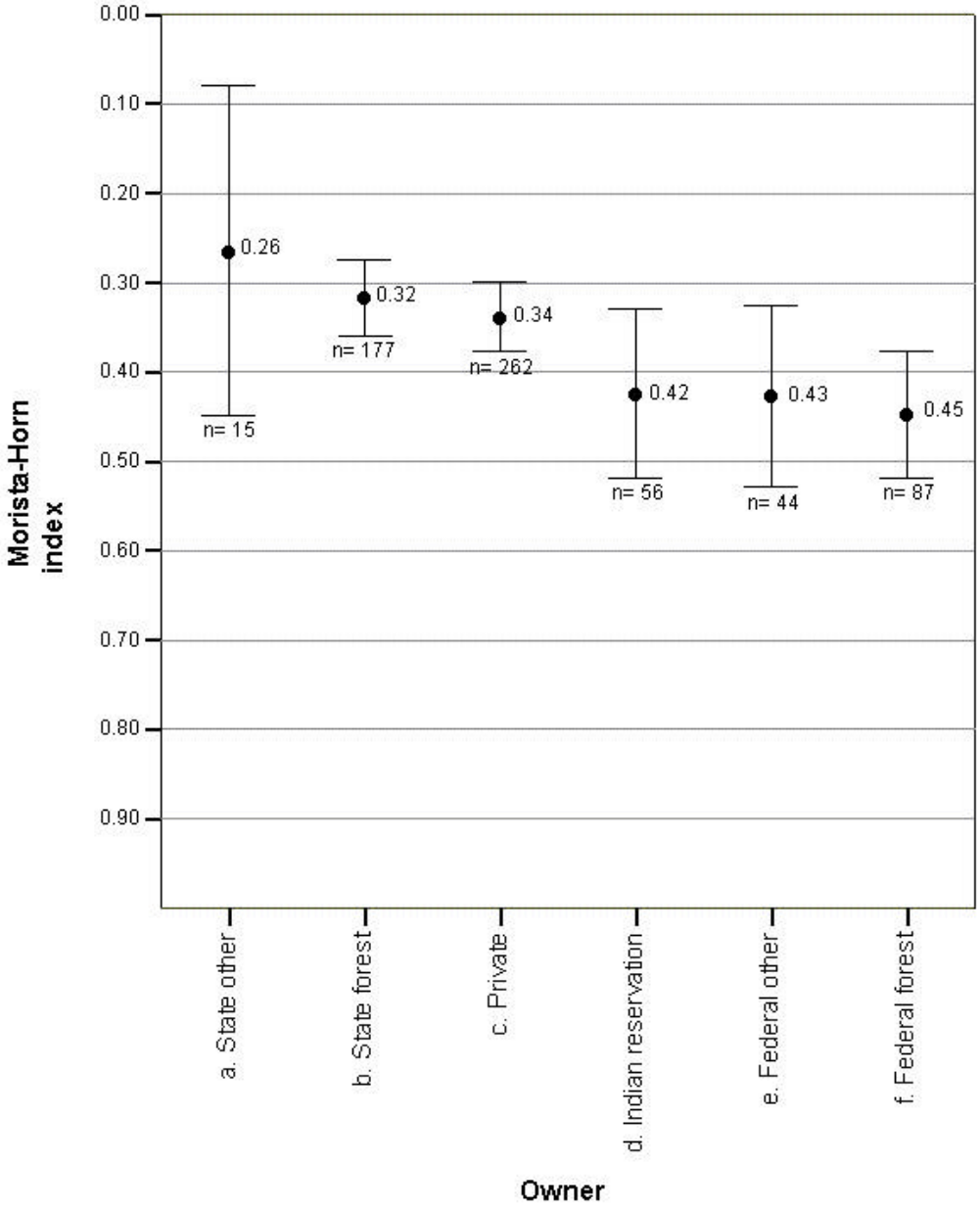


Figure 11. Maps comparing Morisita-Horn (M-H) similarity index values for LTAs, based on use of AVHRR vs.TM data for current land cover. The M-H index represents degree of change in land cover composition from presettlement to present times.

Change in land cover by ownership

Morisita-Horn mean index values with 95% confidence intervals for ownership categories (Figure 12) show Federal forest, Federal other, and Indian reservations as relatively less changed than Private, State forest, and State other. State other showed the greatest amount of change, though this category also had a small sample size ($n = 15$), and large error around the mean. Using the Kruskall-Wallis H test, a significant difference in the degree of change of land cover composition from historic to present conditions was found to exist among the six ownership types ($p < 0.001$). Follow-up analysis using the Mann-Whitney U test on all possible two-category combinations revealed significant differences between several ownership category pairs, and these are presented in Table 5. No significant difference was found however, when all public lands and Indian reservations were grouped, and compared with private lands.


0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
Morista-Horn index
0.26
0.32
0.34
0.42
0.43
0.45
n= 15
n= 177
n= 262
n= 56
n= 44
n= 87
a. State other
b. State forest
c. Private
d. Indian reservation
e. Federal other
f. Federal forest
Owner

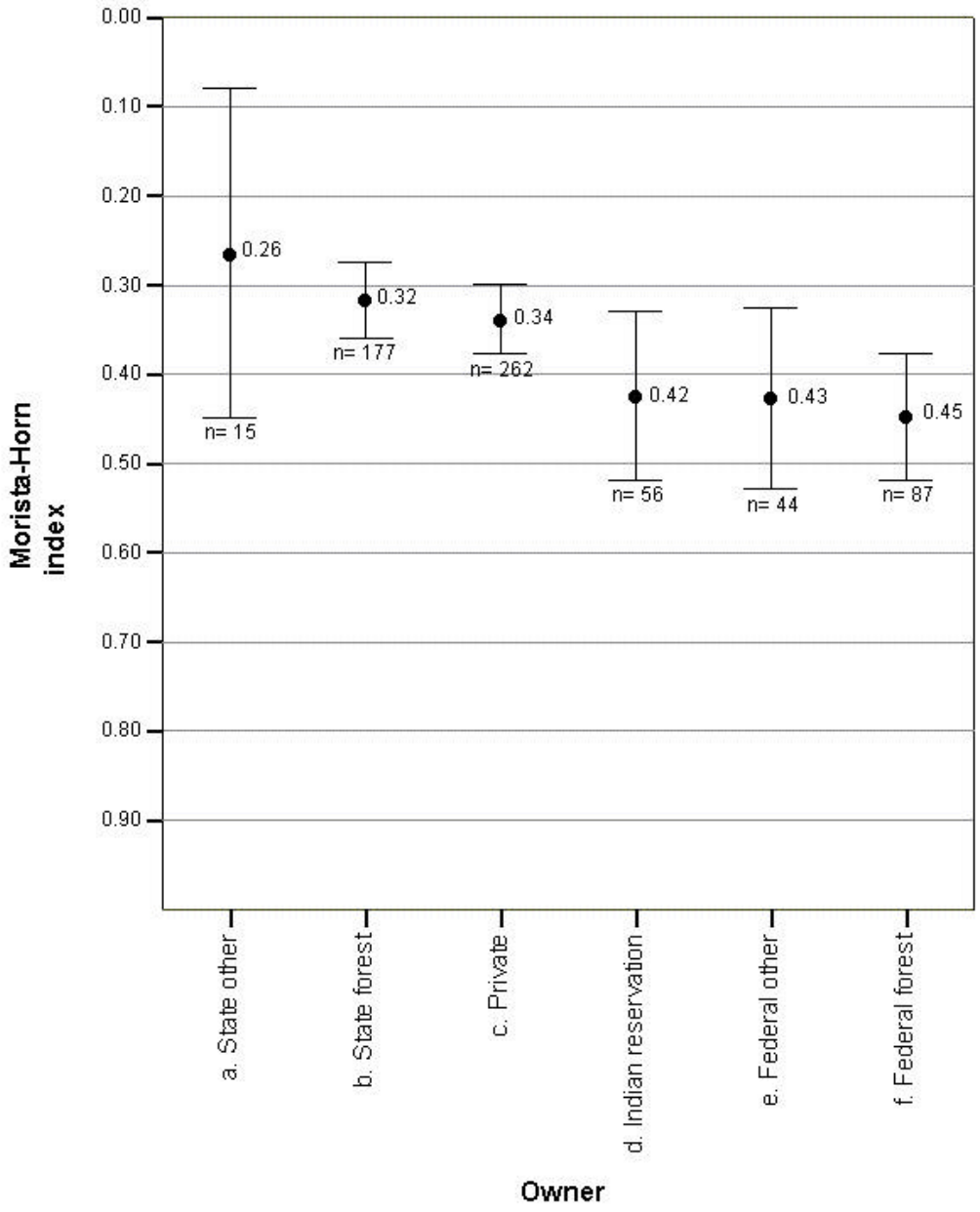


Figure 12. Mean and 95% confidence intervals of Morisita-Horn index for vegetation change by ownership. Lower values indicate a greater degree of change from historic conditions.

Table 5. Results of nonparametric statistical tests, for differences in Morisita-Horn index values according to ownership categories. Only statistically significant results at $p < 0.05$ are shown.

Ownership categories	**p-value**
All ownerships	0.000
Federal forest x State forest	0.000
Federal forest x State other	0.008
Federal forest x Private	0.003
Federal other x State forest	0.003
Federal other x State other	0.010
Federal other x Private	0.018
Indian reservation x State other	0.021
Indian reservation x State forest	0.024

Morisita-Horn index values overlaid by ownership boundaries are illustrated in Figure 13. This map gives an indication of the degree of land cover change for specific land areas. Abrupt changes in index values can be seen along the boundaries of some areas, such as the Menominee Indian Reservation in the southeastern portion of the Wisconsin study area (with notably less change than adjacent lands), while other ownerships do not appear distinct from neighboring areas. Also notable in this map is the variability in index values between different land areas within the same ownership categories, signifying substantial management differences and/or environmental influences within the six broad ownership categories used in the study.

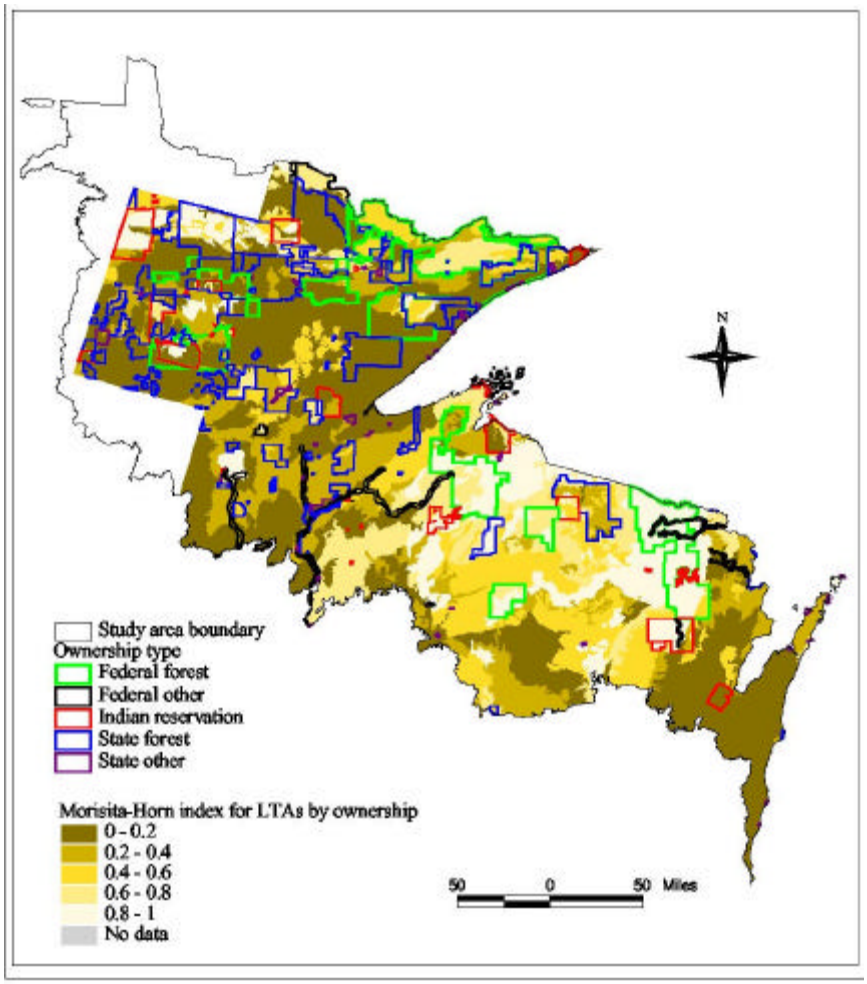


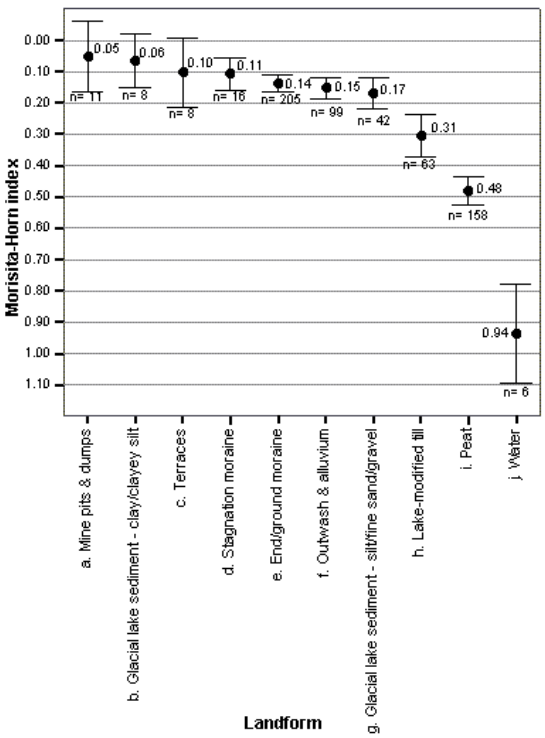
Figure 13. Map illustrating degree of land cover change from presettlement to current times, as measured by the Morisita-Horn index, for LTAs by ownership class. Lower index values indicate a greater change in composition, higher values indicate a lesser change.

Change in land cover by major landform type

A high degree of significance ($p < 0.001$) was found in differences of magnitude of land cover change from historic conditions, by major landform type, for both Minnesota and Wisconsin (which were analyzed separately). Differences in change between landform types were also significant at $p < 0.001$, when the Water or Lake categories (which showed dramatically less change than other landform types) were excluded. Of the few common categories between Minnesota and Wisconsin, outwash and alluvium types, which formerly contained substantial areas of pine forest and were thus expected to show relatively high degrees of change, ranked intermediate for both states. Peat varied considerably between the states, showing the least change (besides Water) in Minnesota, while ranking 3rd in nine categories for the greatest degree of change, in Wisconsin. The Minnesota data, as mentioned previously, show generally greater degrees of change than that for Wisconsin, and

this is reflected in the mean Morisita-Horn index values for landform types (Figure 14, a & b).

a. Minnesota



b. Wisconsin

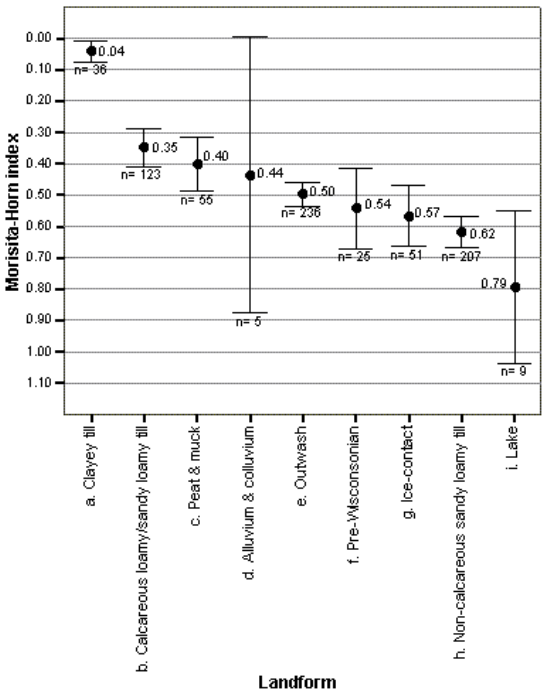


Figure 14 (a-b). Minnesota and Wisconsin Morisita-Horn index means and 95% confidence intervals for land cover change by landform type. Lower index values indicate a greater degree of change in land cover composition from presettlement to present conditions.

In Minnesota, those categories showing the greatest change were Mine pits & dumps (located in the Mesabi Iron Range in north-central Minnesota), and Glacial lake sediment – clay/clayey silt, which is found along the Superior shorelands of the Minnesota-Wisconsin border. Both of these categories make up an extremely small portion of the Minnesota study area however (0.5% and 0.6%, respectively). The next highest-ranking category, Terraces, also covered a very small land area (0.7%). These were former oak and pine sites located along the Mississippi River, which have since become nonforested. Peat and Lake-modified till, which are categories associated with the relatively intact peatlands and lowland conifer forests of the northwestern portion of the study area, showed the least amount of change (besides Water). All others were in an intermediate range.

In Wisconsin, the Clayey till of the former northern hardwood, but now primarily deforested Door Peninsula, showed by far the greatest degree of change of all landform categories. Calcareous loamy/sandy loamy till of eastern Wisconsin also showed a substantial amount of

change, primarily from northern hardwood to nonforest. Categories with the least relative amount of change (except Lake) were the jack pine dominated, Ice contact of northwestern Wisconsin, and the Non-calcareous sandy loamy till landforms found throughout northern Wisconsin, which still maintain a substantial amount of northern hardwood forest.

Diversity and change in diversity by ecological units

Patterns of LTA Brillouin's diversity index values for presettlement land cover, current land cover, and change from presettlement to current land cover, are illustrated in Figure 15. North-central Wisconsin LTAs have tended to become generally more heterogeneous since presettlement, while many Minnesota LTAs show little change or have became more homogeneous. LTAs becoming more homogeneous tended to change from a variety of forest types, to domination by either Aspen/birch, or Nonforest upland classes (as along the southern study boundary). LTAs that became more heterogeneous were generally dominated by northern hardwoods in presettlement times, and today consist of a mixture of Northern hardwood and Aspen/birch classes.

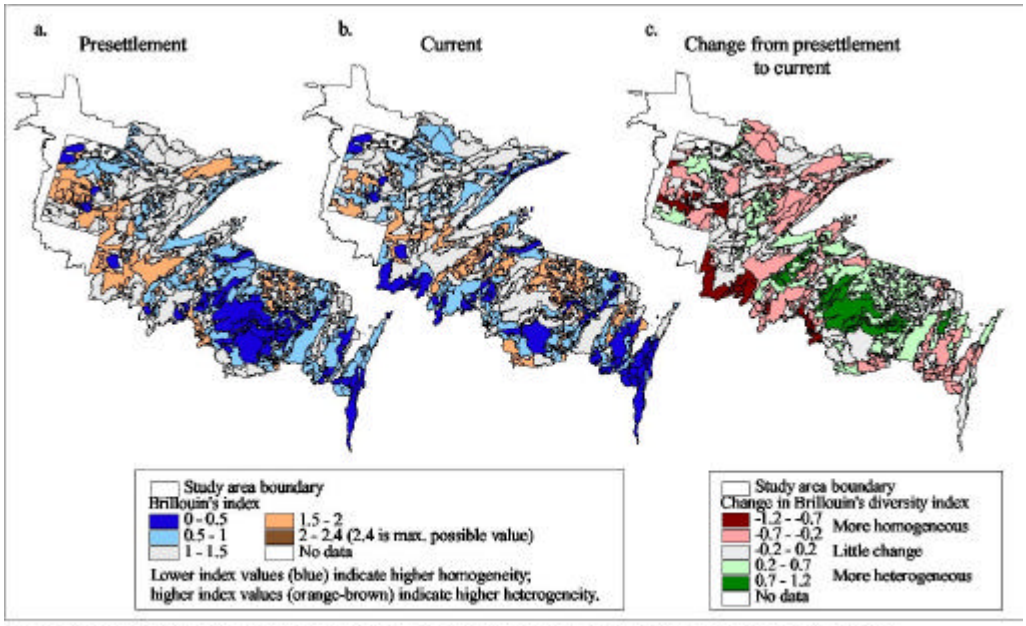


Figure 15 (a-c). Maps illustrating Brillouin's diversity index for presettlement and current land cover, and change in diversity from presettlement to current conditions, by LTA.

Summary of results

Investigation of the effects of coarsening the land cover data, on calculations of percent cover change and the Morisita-Horn and Brillouin index values, revealed relatively minor effects. However, in testing the effect of two different current land cover data sources (AVHRR versus TM) on calculations of land cover change, substantial differences were found for a number of LTAs. This was caused by significant differences in the amount and/or

distribution of several prominent cover classes, such as a higher presence of Aspen/birch and lower presence of Nonforest in the AVHRR, compared to TM data.

Using the TM data, a 37% decrease in overall forest cover from presettlement conditions was calculated for the study area, with most of this loss occurring in the southern half of the region. Specific cover types showing the greatest proportionate losses were Oak/other hardwoods, Spruce-fir/other upland conifers, and White/red pine. Cover types with the greatest absolute and proportionate increases were Nonforest upland and Aspen/birch. Patterns of overall degree of land cover change, as mapped using the Morisita-Horn index values of LTAs, showed the greatest change occurring in LTAs along the southern study boundary, in eastern Wisconsin, and in the central portion of the Minnesota study area. This generally corresponds to areas of forest clearing for agriculture. Patterns of diversity, and change in diversity also show southern boundary LTAs shifting substantially, becoming generally more homogeneous than in presettlement times. Many north-central Wisconsin LTAs on the other hand, show relatively greater diversity, having shifted from primarily Northern hardwoods, to a mix of Northern hardwood, Aspen/birch and Non-forest classes.

Degree of land cover change was found to vary significantly different between six broad ownership categories, with relatively less change occurring on Federal forest, Federal other, and Indian reservation lands, and greater change on Private, State forest, and State other lands. However, when these classes were aggregated, no significant difference was found in the degree of land cover change occurring between Private and Public (including Indian reservation) lands.

Significant differences in the magnitude of land cover change were found between major landform types in both Minnesota and Wisconsin. The Mesabi Iron Range, Glacial lake sediment-clay/clayey silt along Lake Superior, and the formerly oak and pine Terraces along the Mississippi River showed the greatest change in Minnesota. Peat and Lake-modified till, associated with the peatlands and lowland coniferous forest of northwestern Minnesota showed the least relative amounts of change (except Water). In Wisconsin, Clayey till of the Door Peninsula, and Calcareous loamy/sandy loamy till of eastern Wisconsin and the Superior shorelands had the highest degree of change, while the dominant, hardwood covered Non-calcareous sandy loamy till of northern Wisconsin showed the least change (except Lakes). For both states, outwash and alluvium types ranked intermediate.

DISCUSSION

This study addressed questions of landscape change in the Great Lakes forests. It also provides a frame of reference for interpreting results with a more complete understanding of the effects of data sources, classification, accuracy, and resolution. Such a frame of reference is extremely important for deciphering real trends from data artifacts.

Effects of scale, classification, and data accuracy on results

Spatial scale of data (sensor resolution, minimum mapping units, data aggregation methods) and the specificity of classification schemes influence the accuracy and interpretability of results. This influence is discussed below.

Data accuracy and classification effects

The influence of data accuracy and classification schema on the results of this study is easiest to understand in the context of examples. Wetlands are one class where other sources of data are available, and thus provide a basis for comparison. The Aspen/birch class is one of particular interest in the Great Lakes, due to the dramatic increase in this cover type since historic times, and thus also provides a useful example.

The results of this study indicate counter-intuitive trends for changes in percent composition of wetlands ("Nonforest lowland") in the study area, with an increase from 1% to 9% (Figure 5). An underestimate of wetlands in the original presettlement, General Land Office survey data combined with much more detailed wetlands mapping in the current land cover data may explain this increase. In Illinois, Iverson and Risser (1987) found presettlement General Land Office survey data underestimated wetlands by 20% to 50%, because of missed wetlands that were out of line of sight of the GLO survey transects. This type of error likely occurred in Minnesota and Wisconsin as well, and would have been compounded by the use of the much more thorough wetlands mapping, from the Wisconsin Wetlands Inventory, that was incorporated into the TM-based current land cover data for Wisconsin (Wisconsin Department of Natural Resources, 1998c). Other authors (Dahl 1990; Tester 1995) have reported significant declines in wetlands in the Great Lakes (although the peatlands of Minnesota, which occur primarily in the northwestern portion of the study area, are recognized as being generally intact (Tester, 1995)). In retrospect, the wetlands or "Nonforest lowland" category would better have been combined with one or more other nonforested categories in order to reduce this error, as well as any additional resultant error in the calculation of overall degree of land cover change and diversity.

Changes in percent composition of Aspen/birch as reported in this study are confounded by a number of factors, including original data accuracy and data reclassification. Estimates of current Aspen/birch vary from 20% as represented by TM data, to 35% according to AVHRR data. The Wisconsin TM data, with a user's accuracy of only 66% for the aspen class, tends to underestimate aspen compared with the field, plot-based data of the U.S. Forest Service's Forest Inventory and Analysis (FIA). This is likely due to the difficulty in differentiating reflectance values among types found in mixed stands (Padley and McWethy, 1999). The AVHRR data, on the other hand, tends to over-represent Aspen/birch at the expense of Nonforest, Maple/beech/birch, and Spruce-fir classes (Host and Polzer, 1996). A true value for the amount of current Aspen/birch forests probably lies somewhere between 20% and 35%.

Another complicating factor regarding the Aspen/birch class arises from classification choices, and results in a potentially skewed representation of both the amount of presettlement Aspen/birch, and the degree of change in Aspen/birch by state (Figures 7c and 8). These figures portray what is probably an exaggerated pattern of increase in Aspen/birch in the Minnesota portion of the study area compared with that in Wisconsin**.** Aspen/birch is an early successional forest type. Within the Great Lakes forests, it typically succeeds to either a northern hardwood or boreal forest type (i.e., the "Spruce-fir" class in this study). Presettlement land cover of Minnesota contained only one class to describe boreal forests ("Aspen-birch (succeeds to conifers)"), which covered 27% of the study area in Minnesota. Clearly, not all of Minnesota's boreal forest would have been in an early successional state at that point in time; however due to this lumped category there is no clear way to differentiate the amount of boreal forest that was in an earlier versus later successional state. In a study of Great Lakes forest transitions, Frelich (1995) chose to group "aspen-birch (succeeds to conifers)" with the spruce-fir type. This study followed suit. However, it is important to recognize the effect that both the original data classification, and subsequent reclassification have had on the portrayed results. Presettlement Aspen/birch in Minnesota is under-represented, as some of the boreal forest would surely have been in an early successional state from natural disturbances prior to European settlement. When compared with current data, which does allow for separation of Aspen/birch from later successional Spruce-fir, (although this separation is still somewhat arbitrary as most boreal forests falls along a continuum from aspen to conifer), the result is an exaggerated increase in Aspen/birch for the Minnesota portion of the study area.

Scale and majority filter effects

The effect of the majority filter was to generalize all cover types within an 805 meter x 805 meter (1/2 mile x 1/2 mile) area into a single dominant cover type. The bias introduced by this method is enhanced in regions where cover types are heterogeneous over fine spatial scales, and reduced in areas dominated by single cover types (Host and Polzer, 1996). The effect of coarsening resolution also acts differentially on individual cover types, depending on their initial proportions and spatial configuration. Patches that are large, relatively compact, and well connected tend to increase in size, while small, non-compact, isolated patches tend to shrink or disappear (Turner et al. 1989; Moody and Woodcock 1995; Benson and MacKenzie 1995). Cover types of this study generally behaved as expected with application of the majority filter, given their initial proportions and/or spatial arrangement.

One effect of the majority filter was thus an exaggeration of proportional changes in cover classes that were dominant in one time period, but rare in the other. For example, the majority filter slightly reduced the proportions of the Aspen/birch and Nonforest upland classes in the presettlement data, in which they were relatively rare (2% and 0%, respectively), and increased their representation in the current data, in which they were dominant (25% and 27%, respectively). As a result, Morisita-Horn index values also showed a slightly greater degree of change in composition from historic conditions, with application of the majority filter. Due to the dominance of forest over non-forest cover in presettlement

times, and reversal of this in present times, the change in overall forest cover as depicted in Figure 4 is probably also slightly exaggerated.

Scale issues and application of the majority filter also affected diversity index values. Use of the majority filter resulted in generally lower diversity values for ecological units, as was expected. In a study investigating the effects of scale changes on landscape indices, Turner et al. (1989) found a negative linear relationship between diversity and grain. They did not observe a strong effect or clear trend between changes in diversity and areal extent of the calculation unit however, though the number of land cover types present did increase with increasing extent. This property is important to note, given the wide range of size in calculation units (LTAs) of this study (from approximately 1,000 ha. to 380,000 ha.).

Use of the majority filter allowed for more appropriate comparisons to be made across the presettlement and current data sets, but clearly did have some effect on results, as discussed. The filter size was chosen in order to maintain the highest possible common resolution, and this choice was also supported by prior work in the area of resolution effects on landscape metrics. Delcourt and Delcourt (1996) used GLO data in a series of spatial landscape analyses with differing grains of resolution. They determined that a grain size of 1/2 mile x 1/2 mile up to 1 mile square gives a "conservative characterization of landscape heterogeneity using standard metrics and is therefore appropriate for use of GLO data to study historical landscape changes".

Given the many confounding factors which affect the calculated percent composition and landscape index values for LTAs, it is strongly recommended that these data be used primarily to look at relative differences in values throughout the study area, and resulting overall broad landscape patterns.

Major findings

Many of the landscape changes reported in this study are best discussed and understood in relation to the human, as well as natural history of the Great Lakes region. Clearly, change in the Great Lakes forests has been substantial and continuous since European settlement. White and Mladenoff (1994) divided the time since settlement into two periods, with changes in the first period being driven primarily by logging and resource exploitation, and changes in the second by succession. This study has analyzed changes only in relation to the two end-points of this time period (prior to settlement, and current condition), and thus does not capture the significant fluctuation in land cover composition that occurred during the middle of this time. However, the forests of today still reflect much of the history of the period, just as management of today's forests will be reflected in the forests of the future.

Changes in overall forest cover and land cover composition

This study found a decrease in overall forest cover of 37% from presettlement times, comparable to the 39.5% figure calculated by Frelich (1995), for northern Minnesota, Wisconsin, and Michigan, using Forest Service Forest Inventory and Analysis (FIA) plot data

(in lieu of TM data for current land cover). Although this figure is substantial, it likely represents some degree of forest recovery since the heavy logging era of the 1860's to 1930's. Indeed, the nationwide trend has been a net increase in forest cover, from regrowth of cutover land and forest succession on abandoned agricultural land, since the 1940's (Noss et al., 1995). The type of forest now occurring in the Great Lakes, however, has changed substantially, as discussed below.

This study has illustrated both a shift in dominant vegetation, from late to early successional types for the region, and a loss or dramatic reduction of other cover types. Aspen/birch and Nonforest upland are now greatly increased at the expense of Coniferous lowland, Spruce-fir/other upland conifers, White/red pine, and Northern hardwoods. Jack pine and Oak/other hardwoods are also substantially reduced, relative to their originally small proportions. These changes are closely tied to the logging history of the region, natural history traits of the tree species, and an alteration of disturbance regimes from presettlement times.

Following the early period of intense logging and subsequent slash fires, two factors strongly affected forest regeneration on these highly disturbed sites. One factor was a loss of seed sources from those species which had been most intensely exploited, such as white and red pine, and hemlock from the northern hardwood forests (White and Mladenoff, 1994). Second, site conditions now heavily favored species, which could exploit mineral soils or propagate vegetatively (Palik and Pregitzer, 1992). Species with greater sensitivity to exposure, fires, and drought, and an inability to resprout, were disfavored. On heavily disturbed and burned sites, these factors led to homogenous pioneer forests of aspen and birch. The prolific seed production and/or sprouting abilities of northern hardwood species such as maple, beech, basswood, and birch however, quickly allowed succession back to northern hardwood forests on prior hardwood sites, or immediate regeneration of hardwoods on unburned sites. Although, as noted by White and Mladenoff (1994) and Stearns (1949), the composition of the second growth northern hardwood forest may have changed somewhat, with an increase in dominance by sugar maple, and decrease in hemlock and yellow birch. This resilience of northern hardwood forests may in some respects account for the Morisita-Horn index values (Figure 8), which show substantially less change in LTAs formerly dominated by northern hardwoods (occurring primarily in Wisconsin), compared with those dominated by coniferous types (occurring primarily in Minnesota

Despite the recovery of northern hardwood forest in many areas, this class still experienced an 11% decrease since settlement. After the initial logging boom, which focused on white and red pine, many northern hardwood forests were cut to clear the land for agriculture. As can be seen in Figure 8, in the northern portion of Wisconsin where many farms failed, the area has regenerated to hardwood. To the south, where agriculture is much more viable, the loss of northern hardwoods to a nonforest cover type is quite apparent.

Changes in disturbance regimes have played, and continue to play a large role in determining forest composition. Prior to European settlement, forest types such as jack pine, white and red pine, and oak were maintained through a natural fire regime, with a relatively short return period (Frelich, 1995). A significant decline has occurred in these types since settlement, and

fire suppression policies, in addition to the factors mentioned above, may be useful in partially explaining this decline (Cardille and Ventura, 1999). In an analysis of remaining primary forest of the Boundary Waters Canoe Area Wilderness in Minnesota, Frelich (1995) found a substantial decrease in white and red pine and an increase in boreal forest. As this area had not been logged, changes were ascribed to an alteration of the historic fire patterns, which allowed the more shade-tolerant spruce and fir to dominate previous pine sites.

The non-recovery of white pine has also been affected by the introduction of white pine blister rust, a new disturbance in the region since its introduction in the 1900's. Not only has it taken a toll on the remaining white pines, its persistence has had strong indirect effects, by discouraging the planting of white pine for timber production or restoration purposes (Daniel and Sullivan, 1981).

Human disturbance by means of logging and/or management for certain species is also an important factor in determining forest composition changes. An abundant supply of aspen and birch trees has led to the development of a large pulp and paper industry in the North Woods. Thus, there exists a strong economic incentive to continue to manage private timberlands for these early successional species.

Data generated by this study on overall change in composition by land cover type (Figures 5 and 6) and the spatial display of this data by LTA (Figure 7), have shown some significant changes in the region, with strong potential implications for the conservation of regional biodiversity. Four of the twelve cover types used in this study have lost 75% or more of their previous extent (based on the 1/2 mile resolution data), and thus it may be expected that forest-dependent species and ecological functions may simultaneously have been diminished. Other species that thrive under the new conditions however, such as white-tailed deer, may now be found in super abundance.

A study on the status of ecosystems within the U.S. has classified ecosystems losing >98% of their presettlement extent as critically endangered, ecosystems with an 85%–98% decline as endangered, and a 70%-84% loss as threatened (Noss et al., 1995). With the information available to the authors at the time of the study, red and white pine forests in Minnesota were listed as endangered, and northern hardwoods, aspen parkland, and jack pine forest in Minnesota were listed as threatened. Given the above parameters, results of this study would suggest that within the northern Great Lakes forests of Minnesota and Wisconsin, candidates for listing as threatened or endangered ecosystems, or approaching such status, should include: Oak/other hardwoods (almost 100% decline), Spruce-fir/other upland conifers (93% loss), White/red pine (92% decline), Jack pine (75% decline), and Coniferous lowland (67% loss). However, a couple of qualifications should be attached to this list. First, given the potential for an inflated percent loss of Spruce-fir/other upland conifers, for reasons previously discussed, that particular category should first receive further consideration and study. Second, the Oak/other hardwoods category includes species whose presettlement extents were primarily to the south of the region analyzed in this study. Thus, it may be more appropriate to consider the threatened or endangered status of these forests in regards to a different geographical boundary.

Clearly, the proportional change of various cover types within the Great Lakes since settlement has resulted from the interaction of many factors, both anthropogenic and environmental, historic and current. The relative magnitude and spatial pattern of these changes is captured by the Morisita-Horn index. As can be seen in Figure 8, clear spatial patterns of change exist, with LTAs of similar index values often being clustered together. For example, the easternmost portion of the study area in Wisconsin has experienced a high degree of compositional change relative to areas just to the west of it. Interestingly, this region also happens to be quite distinct geologically from the rest of the study area, and is mapped as an individual "Section", within the ecological hierarchy. Upon initial examination of results, other clusters of high, moderate, or low index value LTAs also visually appeared to correspond to landforms or ownership boundaries. Thus, investigation was undertaken in order to examine these relationships, and shed further light on the spatial patterning of change within the Great Lakes forests.

Changes in land cover composition by landform and ownership

The overall relationship of ownership type with degree of change was, not surprisingly, found to be quite strong. An expected significant difference in the magnitude of change between public lands and private lands, however, was not found. Public lands were expected to show less change, due to the applicability of stricter laws and government regulations, than those that apply to the management of private lands. In addition, due to the fact that many current public lands were originally created by appropriation of unsuccessful, tax-delinquent farms, it seemed more likely that these areas, unsuitable for agriculture, would have succeeded back to forest cover and therefore shown less change than private lands (where a fair amount of agriculture still exists). Other unexpected results occurred in the relative ordering of ownership categories by degree of change (Figure 12). Private lands, which were expected to show the greatest change due to agriculture, tree farms, development, and other intense resource uses, showed up in the middle. State other and Federal other, which consist mostly of parks and scenic areas, showed more change than had been expected.

Some factors for consideration that may help explain these unexpected results include time period of ownership, the geographic and/or historical context of lands under different ownerships, and the resolution and accuracy of the ownership layer. In terms of forest succession, the time period since establishment of many public ownership boundaries has been relatively short. For example, state or federal lands established even as early as the 1910's or 1920's have only been managed under that ownership for 70 to 80 years. Thus, lands that are now considered protected, such as federal Wild and Scenic Areas, may still show strong signs of an earlier logging era. Additionally, it is possible that state parks and other protected lands were designated disproportionately in those areas most heavily scarred from earlier logging and slash fires or, in cover types with naturally slower recovery rates. This could lead these lands to show a greater degree of change from their presettlement condition, than others. Such designation of lands with particularly low economic value or productive capability for parks has been common throughout U.S. history. Further study on the degree of change, in relation to time since owner establishment, or presettlement

cover/landform type, would be helpful in clarifying these potential relationships. It seems quite reasonable that any of these factors may have a stronger effect on the degree of land cover change observed, than current management direction or emphasis of existing owners.

An additional consideration is the very coarse resolution (1:2,000,000) of the ownership layer used in the analysis. At this resolution, private inholdings in public lands, which may skew Morisita-Horn index values, do not show up. Also, boundaries may be somewhat offset from their true location on the ground. These problems would affect the error of index values for small areas much more strongly than for large areas. This effect influenced the Morisita-Horn index values for the State other category, for which the land areas are all generally quite small. Finally, the ownership layer distinguishes only six categories of ownership. As a result, Private serves as a catchall, including a significant proportion of other lands such as those owned by counties, and the forest industry. This high variability in the Private category affected the significance test for differences in degree of change for all public versus private lands.

The association between land cover change and landforms was also found to be very strong. This relationship was expected, based on several factors. Landform features strongly relate to soils and other conditions that affect potential vegetation. For example, northern hardwood forests are more often found in mesic sites, on moraine landforms, while pine and other conifers are more common in poorer, sandy sites such as outwash plain (Silbernagel et al., 1997). Due to the intensive selection for pine in the earlier logging era, it was expected that landform types with which these species are strongly associated might show high degrees of change in composition. Indeed, outwash and alluvium types do show a fair amount of change, although not the highest amounts relative to a number of other landform types (Figure 14). Landforms exert influences on natural disturbance regimes (Swanson et al. 1992) that also in turn affect potential vegetation. Again, landform types such as outwash and alluvium which historically were characterized by frequent fires, might be expected to have changed more in the recent era of fire suppression than those characterized by less frequent fire or wind disturbance. Finally, the geographic distribution of certain land use types, such as agriculture, relates closely to landform characteristics. Landforms with rich soils and moderate terrain, such as those in the eastern portion of the Wisconsin study area (i.e. clayey till, and calcareous loamy, sandy loamy till), show higher degrees of change. The interaction of all the above factors has likely affected the degree of change seen among the various landform types.

Changes in landscape diversity

Landscape diversity is used in this study as a simple, summary index for indicating overall amount and direction of change of landscape heterogeneity. This index is not particularly meaningful or significant when used alone. However, in conjunction with other information it can be useful in understanding the patterns and types of change occurring within a region. Diversity indices have received heavy criticism for combining richness and evenness however, since a single value can be obtained from a variety of situations (Baskent and Jordan 1995). Diversity index values can also be strongly affected by classification choices

and geographic resolution of the data (Aspinall, 1996). The LTA diversity values shown in Figure 15 are thus most appropriately used in a general, and relative sense.

Within the study area, several areas stand out as being substantially more homogeneous or more heterogeneous, than in historic times. At the spatial resolution, and coarse classification scale of this study, changes in one direction or the other cannot necessarily be compared quantitatively. Rather, it is most useful to focus on those areas showing the greatest degree of change in either direction, and identify potential factors influencing the observed patterns.

LTAs that have become more homogeneous are generally found in Minnesota, and along the southern and eastern edges of the study area in Wisconsin. These LTAs appear to fit one of two basic categories. Those in Minnesota and the northern part of the study area generally appear to have been mixed forest turned to aspen, while those along the southern edge of the study area in Wisconsin were forested, but have since been deforested and turned to agriculture or other nonforest upland cover types.

LTAs showing higher heterogeneity in present times appear to have increased in diversity due to a variety of vegetation transitions. In the central and northern Wisconsin study area, many LTAs characterized by large homogeneous expanses of Northern hardwoods in presettlement times, have since become interspersed with Nonforest and Aspen/birch. In Minnesota, and along the Minnesota-Wisconsin border, clusters of LTAs previously dominated by homogeneous forests of Jack pine, Spruce-fir, or Coniferous lowland now are mixed with developed areas, wetlands (as a result of improved wetlands mapping in the current land cover data), other nonforest types, and aspen. In these areas, it seems likely that a mixture of ownerships, with differing objectives and management practices, may be one of a variety of potential factors contributing to the higher diversity of cover types present.

CONCLUSIONS

This study has illustrated changes in the forests of northern Minnesota and Wisconsin, by ecological units, from historic (~1840) to present (~1990) times. It has also demonstrated a method for relating these changes to key human and environmental landscape factors, such as ownership and landform. Such information provides important spatial and temporal context for implementing landscape level planning and management in the Great Lakes, and can be used in evaluating current, potential, and desired future landscape conditions. It may also serve as a benchmark, by which to compare future landscapes. This information may be useful to landowners and managers as well, in identifying opportunities for restoration on a broad basis, and assessing the role that their lands may play in regional recovery efforts.

Substantial changes in the composition and pattern of historic forests were found in this study, with the primary shift being from late successional to early successional forest types. Patterns of vegetation diversity have also been altered, with many areas of previously expansive, primarily homogeneous vegetation (like the Northern hardwood forests of north

central Wisconsin) becoming more heterogeneous, and other areas of diverse, mixed forest transitioning to homogenous Aspen/birch forest or Nonforested lands. These dramatic changes in land cover composition and pattern are likely to be associated with changes in species' populations and ecosystem processes, and thus may hold strong implications for the conservation of regional biodiversity and ecological integrity of the Great Lakes forests.

Analysis of degree of land cover change in relation to ownership and landform clearly showed a strong relationship to both factors. State forest, Private, and State other show a greater degree of change from historic conditions than other owner types (Indian reservation, Federal forest, and Federal other). Unexpectedly, state and federal protected areas showed substantially different levels of change from each other, and did not show lesser degrees of change than other lands however. This may suggest that factors related to land use history, in addition to current land tenure, may be most useful in explaining differences in the degree of change observed. Regardless of the specific reasons, it appears that ownership lines, which may at one time have been purely arbitrary from an environmental perspective, now may hold at least some degree of ecological relevance. In addition, the strong association of degree of change by landform type found in this study signifies that, as would be expected, the observed changes (which over the last 100 years have been primarily human-induced) are clearly still tied to the dominant environmental features of the landscape as well.

As previously discussed, landforms and repeating patterns of landforms were the basis for the LTA mapping used in this study. The strong association of degree of land cover change with landforms, in addition to the spatial patterning of relatively distinct clusters of LTAs with similar Morisita-Horn and Brillouin diversity index values (Figures 8 and 15), provide some positive indication for the utility of these units in landscape analyses. Maps of ecological units are typically considered hypotheses to be tested (Cleland et al., 1997), and this study has shown that substantial differences in diversity and land cover change values do exist along LTA lines.

Information on presettlement conditions and the changes measured since that time provide a useful benchmark by which to gauge landscape potential and determine desired future conditions (Padley, 1998). In recent times, there has been increasing interest in the use of such information, for providing the spatial and temporal context necessary for the development of coordinated land management plans on a landscape scale basis (e.g. the Northwest Forest Plan (USDA Forest Service, 1992), the Interior Columbia Basic Ecosystem Management Project (USDA Forest Service, 1996), the Sierra Nevada Ecosystem Project (Erman, 1997), and others. The methods employed in this study, for examining land cover change over time, and relating these to key landscape factors, may be useful in the analysis of other landscapes in the future. The methods of this study are particularly suited to situations in which data for the time periods examined are of differing resolutions, and/or based on different data capture methods, and/or concern exists regarding the data's spatial accuracy.

ACKNOWLEDGEMENTS

Many thanks to Dave Cleland and Eunice Padley of the U.S. Forest Service for their support and assistance throughout this research project. This work was partially funded by the U.S. Forest Service, Great Lakes Assessment, and the Forest Service, North Central Research Station.

LITERATURE CITED

Aspinall, R. 1996. Some issues in measuring and modeling (bio)diversity. Pages 43-50 in I. A. Simpson, and P. Dennis, eds., *The Spatial Dynamics of Biodiversity*.

Bailey, R. G. 1976. *Ecoregions of the United States*. USDA Forest Service, Intermountain Region, Ogden, Utah.

Baskent, E., and G. Jordan. 1995. Characterizing spatial structure of forest landscapes. *Canadian Journal of Forest Research* 25: 1830-1849.

Benson, B. J., and M. D. MacKenzie. 1995. Effects of sensor spatial resolution on landscape structure parameters. *Landscape Ecology* 10(2): 113-120.

Cardille, J. A., and S. A. Ventura. 1999. Occurrence of wildfire in the northern Great Lakes region: effects of land cover and land ownership assessed at multiple scales. *International Journal of Wildland Fire.*

Cleland, D. T., P. E. Avers, W. H. McNab, M. E. Jensen, R. G. Bailey, T. King, and W. E. Russell. 1997. National Hierarchical Framework of Ecological Units. Pages 181-200 in M. Boyce and A. Haney, eds., *Ecosystem Management: Applications for Sustainable Forest and Wildlife Resources.* Yale University Press, New Haven & London.

Committee of Scientists. 1999. *Sustaining the People's Lands: Recommendations for Stewardship of the National Forests and Grasslands into the Next Century*. U.S. Dept. of Agriculture, Washington D.C.

Dahl, T. E. 1990. *Wetland Losses in the United States 1780's to 1980's*. U.S. Fish and Wildlife Service, Washington, D.C.

Daniel, G., and J. Sullivan. 1981. *A Sierra Club Naturalist's Guide: The North Woods of Michigan, Wisconsin, Minnesota, and Southern Ontario*. Sierra Club Books, San Francisco, California.

Delcourt, H. R., and P. A. Delcourt. 1996. Presettlement landscape heterogeneity: Evaluating grain of resolution using General Land Office Survey data. *Landscape Ecology* 11(6): 363-381.

Erman, D. C., ed. and the SNEP team. 1997. *Status of the Sierra Nevada: the Sierra Nevada Ecosystem Project.* U.S. Dept. of Interior, U.S. Geological Survey, Denver, CO.

Finley, R. W. 1951. Original vegetation cover of Wisconsin. Diss, University of Wisconsin, Madison, Wisconsin.

Flader, S. L. 1983. An ecosystem perspective on environmental and social change. Pages xix-xxxii in S. L. Flader, ed., *The Great Lakes Forest: An Environmental and Social History*. University of Minnesota Press, Minneapolis, Minnesota.

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

Frelich, L. E. 1995. Old forest in the Lake States today and before European settlement. *Natural Areas Journal* 15(2): 157-167.

Great Lakes Ecological Assessment. 1999. Great Lakes Ecological Assessment Home Page. Http://econ.usfs.msu.edu/gla/glahome.htm.

Hall, F. G., D. B. Botkin, D. E. Strebel, K. D. Woods, and S. J. Goetz. 1991. Large-scale patterns of forest succession as determined by remote sensing. *Ecology* 72(2): 628-640.

Host, G. E., and P. L. Polzer. 1996. *A Comparison of Forest Cover Classifications in the Great Lakes Region Based on AVHRR and Landsat Thematic Mapper Imagery*. Technical report to The Great Lakes Assessment, NRRI Technical Report, NRRI/TR-96/xx. NRRI, Duluth, MN. 22 pp.

Iverson, L. R. 1988. Land-use changes in Illinois, USA: The influence of landscape attributes on current and historic land use. *Landscape Ecology* 2(1): 45-61.

Iverson, L. R., and P. G. Risser. 1987. Analyzing long-term changes in vegetation with geographic information system and remotely sensed data. *Advances in Space Research* 7(11): 183-194.

Magurran, A. E. 1988. *Ecological Diversity and Its Measurement*. 1988. Princeton University Press, Princeton, New Jersey.

Marschner, F. J. 1975. *The Original Vegetation of Minnesota*. Map. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Sta., St. Paul, Minnesota.

McGhie, R. G., J. Scepan, and J. E. Estes. 1996. A comprehensive managed areas spatial database for the conterminous United States. *Photogrammetric Engineering & Remote Sensing* 62: 1303-1306.

Minnesota Department of Natural Resources. 1998. *Ecological Units of Minnesota*. Digital map. Minnesota Department of Natural Resources, St. Paul, Minnesota.

Mladenoff, D. J., and E. A. Howell. 1980. Vegetation change in the Gogebic Iron Range (Iron County, Wisconsin) from the 1860's to present. *Transaction of the Wisconsin Academy of Sciences, Arts, and Letters* 68: 74-89.

Moody, A., and C. E. Woodcock. 1995. The influence of scale and the spatial characteristics of landscapes on land-cover mapping using remote sensing. *Landscape Ecology* 10(6): 363-379.

Noss, R. F., E. T. LaRoe III, and J. M. Scott. 1995. *Endangered Ecosystems of the United States: A Preliminary Assessment of Loss and Degradation*. U.S. Dept. of the Interior, National Biological Service, Washington D.C.

O'Neill, R. V., C. T. Hunsaker, S. P. Timmins, B. L. Jackson, K. B. Jones, K. H. Ritters, and J. D. Wickman. 1996. Scale problems in reporting landscape pattern at the regional scale. *Landscape Ecology* 11(3): 169-180.

Padley, E. A. 1998. *General assessment range of natural variability for ecosystems of northern Wisconsin*. Draft report. Madison, Wisconsin.

Padley, E. A. and D. McWethy. 1999. *Analyses of forest type composition and landscape patterns in northern Wisconsin using classified LANDSAT Thematic Mapper satellite data.* Draft report. U.S Forest Service, Madison, Wisconsin.

Palik, B. J., and K. S. Pregitzer. 1992. A comparison of presettlement and present-day forests on two bigtooth aspen-dominated landscapes in northern Lower Michigan. *The American Midland Naturalist* 127: 327-338.

Pastor, J., and D. J. Mladenoff. 1992. The southern boreal-northern hardwood forest border. Pages 216-240 in H. H. Shugart, R. Leeman, and G. B. Bonans, eds., *A Systems Analysis of the Global Boreal Forest*. Cambridge University Press, Cambridge, UK.

Pielou. 1975. Indices of diversity and evenness. Pages 5-18 in *Ecological Diversity*. John Wiley & Sons.

Powell, D. S., J. L. Faulkner, D. R. Darr, Z. Zhu, and D. W. MacCleery. 1992. *Forest Resources of the United States*. General Technical Report, USDA Forest Service General Technical Report, RM-234.

Siegel, S. and Castellan Jr., N. J. 1988. Nonparametric Statistics for the Behavioral Sciences. McGraw-Hill, Inc., New York.

Silbernagel, J., J. Chen, M. R. Gale, K. S. Pregitzer, and J. R. Probst. 1997. *An Interpretation of Landscape Structure from Historic and Present Land Cover Data in the Easter Upper Peninsula of Michigan*. General Technical Report. North Central Forest Experiment Station.

Spies, T. A., W. J. Ripple, and G. A. Bradshaw. 1994. Dynamics and pattern of a managed coniferous forest landscape in Oregon. *Ecological Applications* 4(3): 555-568.

Stearns, F. W. 1949. Ninety years change in a northern hardwood forest in Wisconsin. *Ecology* 30(3): 350-358.

Swanson, F. J., S. Wondzell, and G. Grant. 1992. Landforms, disturbance, and ecotones. Pages 304-323 in A. J. Hansen, Hansen, and F. di Castri, eds., *Landscape Boundaries*: Consequences for Biotic Diversity and Ecological Flows. Springer-Verlag, New York.

Tester, J. R. 1995. *Minnesota's Natural Heritage: An Ecological Perspective*. University of Minnesota, Minneapolis, Minnesota.

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

Turner, M. G., R. V. O'Neill, R. H. Gardner, and B. T. Milne. 1989. Effects of changing spatial scale on the analysis of landscape pattern. *Landscape Ecology* 3(3/4): 153-162.

Turner, M. G., D. N. Wear, and R. O. Flamm. 1996. Land ownership and land-cover change in the southern Appalachian highlands and the Olympic Peninsula. *Ecological Applications* 6(4): 1150-1172.

USDA Forest Service. 1992. *Final Environmental Impact Statement on Management for the Northern Spotted Owl in the National Forests: States of Washington, Oregon and California.* USDA Forest Service, Portland, Oregon.

USDA Forest Service, Pacific Northwest Region and USDA Bureau of Land Management, Oregon and Washington. 1996. *Eastside Draft Environmental Impact Statement.* USDA Forest Service and USDA Bureau of Land Management, Portland, Oregon.

White, M. A., and D. J. Mladenoff. 1994. Old-growth forest landscape transitions from pre-European settlement to present. *Landscape Ecology* 9(3): 191-205.

Wisconsin Department of Natural Resources. 1998a. *Wisconsin's Northern State Forest Assessments*. Draft. Wisconsin Department of Natural Resources.

Wisconsin Department of Natural Resources. 1998b. *Ecological Units of Wisconsin*. Digital map. Wisconsin Department of Natural Resources, Madison, Wisconsin.

Wisconsin Department of Natural Resources. 1998c. *WISCLAND Land Cover*. Digital map. Wisconsin Department of Natural Resources, Madison, Wisconsin.

Wolda, H. 1981. Similarity indices, sample size and diversity. *Oecologia* 50: 296-302.

Wolter, P. T., D. J. Mladenoff, G. E. Host, and T. R. Crow. 1995. Improved forest classification in the northern lakes States using multi-temporal Landsat imagery. *Photogrammetric Engineering & Remote Sensing* 61(9), Sep.: 1129-1143.

Zar, J. H. 1996. *Biostatistical analysis.* Prentice Hill, New Jersey.

Appendix A. Accuracy assessment information for current land cover data. (Refer to Appendix B for reclassification scheme applied to data, for use in this study).

WISCONSIN

Compilation provided by the Wisconsin DNR for WISCLAND data. August 4 1998. This document is a brief summary, but is NOT a complete accuracy assessment table, and should NOT be used as accuracy assessment percentages for any particular area of the WISCLAND Land Cover dataset. Refer to the WISCLAND Metadata for the appropriate and detailed accuracy assessment matrices.

Class	**Mean (User's)**
Level II - Upland Classes	
Agriculture	1,428/1,573 = 91%
Grassland	407/572 = 71%
Coniferous Forest	655/699 = 94%
Deciduous Forest	2,348/2,524 = 93%
Mixed Coniferous/Deciduous Forest	75/139 = 54%
Open Water	230/230 = 100%
Barren	94/130 = 72%
Shrubland	46/71 = 65%
Overall…… 5,283 / 5938 = 89%	
Level III - Upland Classes	
Corn	520/589 = 86%
Other Row Crops	160/212 = 75%
Forage Crops	423/578 = 73%
Jack Pine	67/85 = 79%
Red Pine	403/459 = 88%
Mixed/Other Coniferous	109/145 = 75%
Aspen	220/335 = 66%
Oak	313/475 = 66%
Maple	125/190 = 66%
Mixed/Other Deciduous	1,091/1,486 = 75%
Overall…… 3,431 / 4554 = 75%	
Urban	
Rural Other	268/289 = 93%
High Intensity	248/258 = 96%
Low Intensity	275/283 = 97%
Overall…… 791 / 830 = 95%	
Wetland Classes	
Emergent/Wet Meadow	1,477/1695 = 87%
Lowland Shrub	362/482 = 75%
Broad-leaved Deciduous Shrub	807/1,103 = 73%
Broad-leaved Evergreen Shrub	180/221 = 81%
Needle-leaved Deciduous Shrub	15/25 = 60%
Broad-leaved Deciduous Forested Wetland	1,289/1593 = 81%
Coniferous Forested Wetland	924/1085 = 85%
Mixed Deciduous/Coniferous Forested Wetland	468/647 = 72%
Open Water	545/615 = 89%
Overall……. 6,067 / 7,466 = 81%	

MINNESOTA

User's accuracy levels, provided by NRRI for Landsat TM mapping in Minnesota. (Data not available for Chippewa scene).

	User's accuracy			
Class description	**Eveleth scene**	**Superior scene**	**St. Croix scene**	**Mean**
jack pine	79	84	91	85
jack pine - hardwood mix, JP dominated	96	98	71	89
red pine	79	63	82	75
red pine - hardwood mix, RP dominated	89	81	84	85
spruce/fir mixtures	63	51	89	68
spruce/fir - hardwood, SF dominated	77	77	30	61
northern white-cedar	63	43	57	54
northern white-cedar - hardwood, C dominated	80	79	56	72
tamarack	68	73	41	61
black spruce	88	71	67	75
acid bog conifer, stagnant: black spruce, tamarack and cedar	74	84	78	79
black ash	86	76	74	79
black ash - conifer, BA dominated	76	72	80	76
black ash - conifer, conifer in understory (supressed)	85	68	-	77
aspen/birch	67	66	66	66
aspen/birch - conifer, AB dominated	65	60	75	66
aspen/birch - conifer, conifer in understory (supressed)	84	57	-	71
northern hardwoods, mostly Acer spp.	72	78	81	77
northern hardwoods - conifer	90	71	-	81
northern hardwoods - conifer, conifer supressed	71	77	-	74
transitional hardwoods, sparse hardwoods and brush mixed	85	82	74	80
hardwood regeneration	82	69	79	77
bare ground, soil and/or rock outcrop	78	55	92	75
open water	89	91	89	89
aquatic emergent, pond lilly, wild rice, etc.	94	60	66	73
emergent	92	79	83	85
Sphagnum spp.	90	84	82	85
grasses, upland	35	50	62	49
grasses, lowland	51	68	93	71
agriculture	94	87	91	90
brush, upland	43	78	60	60
brush, lowland	67	61	55	61
brush, ericacious	51	92	-	71
developed or built-up	95	93	82	90
paved roads	92	95	99	95
hardwoods, low density	90	65	72	75
conifers, low density (e.g., jack pine on rock outcrops)	85	77	71	77
conifer, regeneration	-	-	78	78
Oak	-	-	73	73
Oak - conifer, oak dominated	-	-	81	81
Overall	**75**	**73**	**72**	**73**

Appendix B. Original presettlement & current land cover classes, with fine & coarse reclassification schemes and percent cover.

PRESETTLEMENT LAND COVER							CURRENT LAND COVER (FROM TM)						
Fine code & descr	**% of study area within state**	**State**	**Original code**	**Original description**	**Coarse code**	**Coarse description**	**Fine code & descr**	**% of study area within state**	**State**	**Original code**	**Original description**	**Coarse code**	**Coarse description**
0	**No data**						**0**	**No data**					
	0%	WI	99	No data or unknown	0	No data		0%	MN	0	Out	0	No data
								0%	MN	47	Cloud & cloud shadow	0	No data
1	**Jack pine**						**1**	**Jack pine**					
	7%	MN	12	Jack pine barrens	1	White, red, jack pine		2%	MN	1	Jack pine	1	White, red, jack pine
	8%	WI	6	Jack pine, scrub (hill's) oak forests and barrens	1	White, red, jack pine		0%	MN	2	Jack pine - hardwood	1	White, red, jack pine
								0%	MN	3	Jack pine - oak	1	White, red, jack pine
								2%	WI	162	FOREST: jack pine	1	White, red, jack pine
2	**White/red pine**						**2**	**White/red pine**					
	1%	MN	10	White pine	1	pine		1%	MN	4	Red pine	1	jack pine
	16%	MN	11	Mixed white pine and Norway pine	1	White, red, jack pine		0%	MN	5	Red pine - hardwood	1	White, red, jack pine
	9%	WI	5	White pine, red pine	1	White, red, jack pine		2%	WI	163	FOREST: red pine	1	White, red, jack pine
3	**Spruce-fir/other upland conifers**						**3**	**Spruce-fir/other upland conifers**					
	0%	MN	13	Pine flats (hemlock, spruce, fir, cedar, & white pine)	2	Spruce, fir		2%	MN	6	Spruce-fir	2	Spruce, fir
	28%	MN	14	Aspen-birch (eventually succeed to conifers)	2	Spruce, fir		3%	MN	7	Spruce-fir - hardwood	2	Spruce, fir
								0%	MN	14	Conifer, regeneration	2	Spruce, fir
								0%	WI	161	FOREST: coniferous	2	Spruce, fir
								0%	WI	166	FOREST: white spruce	2	Spruce, fir

								2%	WI	173	FOREST:mixed/other coniferous	2	Spruce, fir
4	**Oak/other hardwoods**						**4**	**Oak/other hardwoods**					
	1%	MN	5	Oak opening and barrens	3	Oak, hickory		1%	MN	25	Red oak	3	Oak, hickory
	4%	MN	6	Big woods - oaks, elm, basswood, ash, maple, etc.	3	Oak, hickory		0%	MN	26	Oak - pine	3	Oak, hickory
	3%	WI	10	Oak-white oak, black oak, bur oak	3	Oak, hickory		0%	MN	48	Pin oak	3	Oak, hickory
	0%	WI	11	Oak openings-bur oak, white oak, black oak	3	Oak, hickory		1%	WI	177	FOREST: oak	3	Oak, hickory
								0%	WI	179	FOREST: northern pin oak	3	Oak, hickory
								0%	WI	180	FOREST: red oak	3	Oak, hickory
5	**Aspen/birch**						**5**	**Aspen/birch**					
	1%	MN	4	Aspen-oak land	6	Aspen, birch		14%	MN	19	Aspen-birch	6	Aspen, birch
	2%	MN	8	Aspen-birch (eventually succeed to hardwoods)	6	Aspen, birch		10%	MN	20	Aspen-birch - conifer	6	Aspen, birch
	2%	WI	7	Aspen, white birch, pine	6	Aspen, birch		1%	MN	21	Aspen-birch - conifer understory	6	Aspen, birch
								4%	MN	28	Hardwood, regen. (primarily aspen)	6	Aspen, birch
								11%	WI	176	FOREST: aspen	6	Aspen, birch
6	**Northern hardwoods**						**6**	**Northern hardwoods**					
	4%	MN	9	Mixed hardwood and pine	5	Maple, beech, birch		5%	MN	22	Northern hardwoods	5	Maple, beech, birch
	5%	WI	2	Beech, hemlock, sugar maple, yellow birch, white pine, red pine	5	Maple, beech, birch		0%	MN	23	Northern hardwoods - conifer	5	Maple, beech, birch
	32%	WI	3	Hemlock, sugar maple, yellow birch, white pine, red pine	5	Maple, beech, birch		0%	MN	24	Northern hardwoods - conifer understory	5	Maple, beech, birch
	11%	WI	4	Sugar maple, yellow birch, white pine, red pine	5	Maple, beech, birch		0%	MN	27	Hardwood, transitional	5	Maple, beech, birch
	5%	WI	8	Beech, sugar maple, basswood, red oak, white oak, black oak	5	Maple, beech, birch		0%	WI	175	FOREST: broad-leaved deciduous	5	Maple, beech, birch

	4%	WI	9	Sugar maple, basswood, red oak, white oak, black oak	5	Maple, beech, birch		3%	WI	183	FOREST: maple	5	Maple, beech, birch
								1%	WI	185	FOREST: sugar maple	5	birch
								19%	WI	187	FOREST: mixed/other broad-leaved deciduous	5	Maple, beech, birch
								5%	WI	190	FOREST: mixed deciduous/conifer	5	Maple, beech, birch
7	**Nonforest lowland**						**7**	**Nonforest lowland**					
	2%	MN	2	Wet prairie	7	Nonforested		0%	MN	31	Emergent, aquatic	7	Nonforested
	0%	MN	16	Open muskeg	7	Nonforested		1%	MN	32	Emergent	7	Nonforested
	0%	WI	16	Marsh and sedge meadow, wet prairie, lowland shrubs	7	Nonforested		0%	MN	33	Sphagnum spp.	7	Nonforested
								3%	MN	35	Grass, native(lowland)	7	Nonforested
								1%	MN	39	Brush, alder (lowland)	7	Nonforested
								2%	MN	41	Brush, willow (lowland)	7	Nonforested
								5%	MN	43	Brush, misc. (lowland)	7	Nonforested
								1%	MN	44	Brush, ericacious	7	Nonforested
								2%	WI	211	WETLAND: emergent/wet meadow	7	Nonforested
								0%	WI	212	WETLAND: floating aquatic herbaceous vegetation	7	Nonforested
								2%	WI	217	WETLAND: lowland shrub	7	Nonforested
								3%	WI	218	WETLAND: lowland shrub: broad-leaved deciduous	7	Nonforested
								0%	WI	219	WETLAND: lowland shrub: broad-leaved evergreen	7	Nonforested
								0%	WI	220	WETLAND: lowland shrub: needle-leaved	7	Nonforested
8	**Deciduous lowland**						**8**	**Deciduous lowland**					
	1%	MN	7	River bottom forest	4	Elm, ash, cottonwood		2%	MN	15	Black ash	4	Elm, ash, cottonwood

	0%	WI	15	Lowland hardwoods-willow, soft maple, box elder, ash, elm, cottonwood, river birch	4	Elm, ash, cottonwood		1%	MN	16	Black ash - conifer	4	Elm, ash, cottonwood
								0%	MN	18	Hardwoods, misc. (lowland)	4	Elm, ash, cottonwood
								4%	WI	223	WETLAND: broad-leaved deciduous	4	Elm, ash, cottonwood
9	**Coniferous lowland**						**9**	**Coniferous lowland**					
	26%	MN	15	Conifer and bog swamps	2	Spruce, fir		1%	MN	8	Cedar	2	Spruce, fir
	15%	WI	14	Swamp conifers-white cedar, black spruce, tamarack, hemlock	2	Spruce, fir		0%	MN	9	Cedar - hardwood	2	Spruce, fir
	3%	WI	1	White spruce, balsam fir, tamarack, white cedar, white birch, aspen	2	Spruce, fir		2%	MN	10	Tamarack	2	Spruce, fir
								3%	MN	11	Black spruce	2	Spruce, fir
								3%	MN	12	Acid bog conifer, stagnant	2	Spruce, fir
								0%	MN	13	Conifer, misc. (low density)	2	Spruce, fir
								4%	WI	229	FORESTED WETLAND: coniferous	2	Spruce, fir
								3%	WI	234	FORESTED WETLAND: mixed deciduous/conifer	2	Spruce, fir
10	**Nonforest upland**						**10**	**Nonforest upland**					
	0%	MN	1	Prairie	7	Nonforested		5%	MN	34	Grass, native	7	Nonforested
	0%	MN	3	Brush prairie	7	Nonforested		3%	MN	36	Grass, cool season	7	Nonforested
	0%	WI	12	Prairie	7	Nonforested		4%	MN	37	Grass, domestic	7	Nonforested
	1%	WI	13	Brush	7	Nonforested		0%	MN	38	Brush, alder	7	Nonforested
								1%	MN	40	Brush, willow	7	Nonforested
								3%	MN	42	Brush, misc.	7	Nonforested
								0%	WI	110	AGRICULTURE: general	7	Nonforested
								2%	WI	111	AGRICULTURE: herbaceous/field crops	7	Nonforested

								3%	WI	112	AGRICULTURE: primary row crops	7	Nonforested
								5%	WI	113	AGRICULTURE: corn	7	Nonforested
								2%	WI	118	AGRICULTURE: other row crops	7	Nonforested
								8%	WI	124	AGRICULTURE: forage crops	7	Nonforested
								0%	WI	148	AGRICULTURE: cranberry bog	7	Nonforested
								8%	WI	150	GRASSLAND	7	Nonforested
								1%	WI	250	SHRUBLAND	7	Nonforested
11	**Water**						**11**	**Water**					
	7%	MN	17	Lakes	8	Water		10%	MN	30	Water	8	Water
	2%	WI	97	Open water	8	Water		3%	WI	200	OPEN WATER	8	Water
12	**Non-vegetated/developed**						**12**	**Nonvegetated/developed**					
								2%	MN	29	Bare ground	7	Nonforested
								1%	MN	45	Developed	7	Nonforested
								1%	MN	46	Roads	7	Nonforested
								0%	WI	101	URBAN/ DEVELOPED: high intensity urban	7	Nonforested
								0%	WI	104	URBAN/ DEVELOPED: low intensity urban	7	Nonforested
								0%	WI	105	URBAN/ DEVELOPED: golf course	7	Nonforested
								1%	WI	240	BARREN	7	Nonforested

Appendix C. Minnesota and Wisconsin original landform classes, with reclassification scheme and percent coverage. (Percent is based only on that portion of study area used in analysis).

WISCONSIN			MINNESOTA		
LANDFORM	**Original class**	**%**	**LANDFORM**	**Original class**	**%**
1. ALLUVIUM & COLLUVIUM		**0**	**1. END/GROUND MORAINE**		**57**
	Alluvium	0		Alexandria ground moraine	0
	Colluvium & sheet wash alluvium	0		Big Stone ground moraine	0
2. CALCAREOUS LOAMY/SANDY LOAMY TILL		**19**		Cloquet ground moraine	1
	Calcareous loamy till (end moraine)	0		Culver end moraine	3
	Calcareous loamy till (ground moraine)	0		Culver ground moraine	1
	Calcareous sandy loamy till (attenuated drift)	2		Erskine ground moraine	5
	Calcareous sandy loamy till (end moraine)	1		Itasca end moraine	2
	Calcareous sandy loamy till (ground moraine)	1		Itasca ground moraine	2
	Lake silt & clay	5		Mille Lacs-Highland end moraine	4
	Loamy till (end moraine)	1		Mille Lacs-Highland ground moraine	6
	Loamy till (ground moraine)	8		Nashwauk ground moraine	1
3. CLAYEY TILL		**6**		Nickerson end moraine	0
	Clayey till (end moraine)	3		Nickerson ground moraine	1
	Clayey till (ground moraine)	3		Pine City end moraine	1
4. ICE-CONTACT		**5**		Pine City ground moraine	1
	Ice-contact sand	4		St. Croix end moraine	1
	Ice-contact sand & gravel	1		St. Croix ground moraine	4
5. LAKE		**0**		Sugar Hills end moraine	3
	Lake	0		Sugar Hills ground moraine	1
6. NON-CALCAREOUS SANDY LOAMY TILL		**35**		Vermilion end moraine	1
	Non-calcareous sandy loamy till (end moraine)	11		Vermilion ground moraine	14
	Non-calcareous sandy loamy till (ground moraine/1-3 m)	11	**2. STAGNATION MORAINE**		**4**
	Non-calcareous sandy loamy till (ground moraine/1-4 m)	7		Big Stone stagnation moraine	1
	Non-calcareous sandy loamy till (stagnation)	5		Cloquet stagnation moraine	0

7. OUTWASH	**27**	Erskine stagnation moraine	1
Outwash sand	3	Nashwauk stagnation moraine	1
Outwash sand & gravel	23	**3. OUTWASH AND ALLUVIUM**	**13**
Lake sand	0	Outwash associated with the Des Moines Lobe	6
8. PEAT & MUCK	**3**	Outwash associated with the Rainy Lobe	1
Peat & muck	3	Outwash associated with the Superior Lobe	3
9. PRE-WISCONSONIAN	**6**	Outwash associated with the Wadena Lobe	3
Pre-wisconsinan loamy till (weathered)	4	Alluvium	0
Pre-wisconsinan non-calcareous loamy till (ground moraine/<2 m)	2	**4. LAKE-MODIFIED TILL**	**6**
		Culver moraine - lake-modified till	2
		Erskine moraine - lake-modified till	4
		5. GLACIAL LAKE SEDIMENT - CLAY/CLAYEY SILT	**1**
		Glacial lake sediment associated with the Des Moines Lobe - clay and clayey silt	0
		Glacial lake sediment associated with the Superior Lobe - clay and clayey silt	0
		6. GLACIAL LAKE SEDIMENT - SILT/FINE SAND/GRAVEL	**3**
		Glacial lake sediment associated with the Superior Lobe - sand and gravel	0
		Glacial lake sediment associated with the Des Moines Lobe - sand and gravel	2
		Glacial lake sediment associated with the Des Moines Lobe - silt and fine sand	1
		7. MINE PITS & DUMPS	**1**
		Mine pits and dumps	1
		8. PEAT	**12**
		Peat	12
		9. TERRACES	**1**
		Terraces	1
		10. WATER	**3**
		Water	3

Appendix D. Presettlement and current land cover composition, landscape indices, and size of unit for LTAs, Subsections, and Sections. Calculations based upon majority filtered (1/2 mile or 805 meter resolution) data. Index values are based upon those portions of the unit containing data for both presettlement and current land cover, and are calculated only for units with >50% data ("0" values represent #'s between 0 and 0.5, blanks signify 0 or total absence, "-" signifies no data).

	Size	Indices				Presettlement land cover														Current land cover													
							1	2	3	4	5	6	7	8	9	10	11	12			1	2	3	4	5	6	7	8	9	10	11	12	
	Unit size (within study area) in hectares. (Some units extend beyond study area bounds).	Morisita-Horn similarity index	Presettlement Brillouin's diversity index	Current Brillouin's diversity index	Change in diversity index	No data	Jack pine	White/red pine	Spruce-fir/other upland conifers	Oak/other hardwoods	Aspen/birch	Northern hardwoods	Nonforested lowland	Deciduous lowland	Coniferous lowland	Nonforest upland	Water	Non-vegetated/developed	Total	No data	Jack pine	White/red pine	Spruce-fir/other upland conifers	Oak/other hardwoods	Aspen/birch	Northern hardwoods	Nonforested lowland	Deciduous lowland	Coniferous lowland	Nonforest upland	Water	Non-vegetated/developed	Total
LTAs																																	
212Hb01	56486	0.03	0.9	0.5	0.4		0	0		5	3	68	0	1	23		0		100				0			2	2	5	2	88	0	2	100
212Hb02	38287	0.05	1.0	0.9	0.1			1				48		10	42				100							1	15	16	1	67		0	100
212Hb03	30155	0.19	1.3	1.3	0.0		7	9		1		47		5	31		0		100				1			11	18	18	1	50	1	0	100
212Hb04	16310	0.00	0.5	0.3	0.2							81		1	18				100								0	6		94		0	100
212Hb05	135236	0.08	0.9	0.4	0.5			1			2	65			28	4	0		100				0			2	1	3	2	92	0	0	100
212Hb06	31355	0.15	0.8	0.9	-0.1		1	6				72			20		0		100				1	0	0	8	1	1	13	75	1		100
212Hb07	55542	0.01	0.5	0.3	0.1							81			19				100				0		0	1	1	3	1	93	0		100
212Hb08	27466	0.22	0.7	0.7	0.0		1	2		3		80			13	1			100				0			16	0	4	1	78	0	1	100
212Hb09	37176	0.21	1.4	0.8	0.5		18	11		1	0	47		0	19	4	0		100				1	0		13	1	6	3	75	0	1	100
212Hb10	37178	0.47	1.5	2.0	-0.5		32	7				28			23	1	9		100			0	8	4	3	21	4	7	11	28	12	2	100
212Hb11	15417	0.27	0.9	1.0	-0.1		20	0				67			13				100				4	1	0	19		1	9	67	0		100
212Hb12	41770	0.34	0.8	1.5	-0.7		0	3				66			30		0		100	0	0		1		24	6	4	1	33	31	1		100
212Hb13	23979	0.00	0.4	0.1	0.3							85	0		15				100							0	1	1		97		1	100
212Hb14	15588	0.05	1.0	0.8	0.2							55		19	26				100								14	11	1	73		1	100
212Hc01	28009	0.08	1.3	0.7	0.6	7	3	3		27		48	2	1		4	4		100							0				72	3	26	100
212Hc02	16893		0.8	0.4	0.4	0		4		4		77		2	13		0		100											89		11	100

212Hc03	11919		0.11	0.7	0.6	0.0			8	1		0		82	0		4	3	1		100								6		1		79		14	100
212Hc04	16992		0.00	0.5	0.2	0.3						13		84		3			0		100								0				96	0	4	100
212Hc05	4682			0.9	0.6	0.2						34		60	6						100												72		28	100
212Hc06	7982		0.23	1.4	1.5	-0.1				3		11		10	38		34	2	2		100								3	14	19		32	2	30	100
212Hc07	28940		0.55	0.5	1.0	-0.5								83			17		1		100			0	1			38	1	5	1	53	1	0	100
212Hc08	10534		0.04	0.7	0.4	0.3								69	1		30				100							4	0	6		89	0		100
212Hd01	123510		0.02	0.3	0.3	0.0								94	1	2	3	0	0		100				0			1	0	1		92	0	6	100
212Hd02	25968		0.02	0.2	0.7	-0.5								94			5		0		100				0			2	1	3	1	81	0	13	100
212Hd03	3641		0.29	0.7	1.6	-0.9								66			33		2		100				9			2	7	5	31	23		24	100
212Hd04	46059		0.00	0.2	0.1	0.1								96		0	4		0		100				0			0	0	1	0	98			100
212Hd05	11316		0.01	0.6	0.5	0.1								75			25				100				1				1	5	4	89			100
212Hd06	24081		0.00	0.8	0.5	0.3						1		73		5	20		2		100								10	3	0	87		0	100
212Hd07	39496		0.00	0.7	0.5	0.2		0						77		15	8		0		100								11	2	0	86		2	100
212Hd08	25411		0.01	0.5	0.4	0.1								77			23				100								2	4	3	90			100
212Hd09	51389		0.02	0.6	0.1	0.5						6		85			7	1			100							0	0	1	0	98		1	100
212Hd10	12869		0.04	0.9	0.6	0.3						39		55			6				100				1			4	1	2	0	84		8	100
212He01	24164		0.00	0.1	0.1									99	0		1				100								0	0	0	99		1	100
212He02	17534		0.03	0.7	0.5	0.2								72	3		25				100								1	4	7	88		0	100
212He03	28475		0.04	0.7	0.5	0.2						1		51			48				100				0			1	0	5	5	88	0	1	100
212He04	35821		0.03	0.7	0.3	0.4						2		70			27				100				0			3	0	2	1	94			100
212He05	11880		0.06	0.7	0.7	0.0						2		72			27				100				2			5	0	4	2	83		4	100
212He06	5203		0.77	0.4	1.6	-1.2								5			89		6		100				4			11	7	7	45	16	6	4	100
212He07	63204		0.25	0.7	1.1	-0.4				1				75			23		1		100				7			15	1	0	9	65	1	2	100
212He09	65		1.00											100							100							100							100
212He10	36747		0.26	1.4	1.7	-0.3			10	1		5		22	11		49		1		100		0		1	2	1	20	21	18	0	31	2	4	100
212Ia02	21515		0.97	0.8	0.4	0.4				3			1	75			16	5			100			0	0		4	90	1		2	2	0	0	100
212Ja01	148574		0.06	1.0	1.5	-0.5		0	1	10	13	1	1	5			69	1	0		100		0		1	0	23	23	9	1	1	37	2	3	100
212Ja02	87085		0.81	1.2	0.9	0.4			0	18		2	4	50			26		0		100			0		0	12	73	1	0	0	13	0	1	100
212Ja03	102999		0.27	1.0	1.3	-0.3				19			0	28	0		53				100			0			29	33	4	1	0	31	0	1	100
212Ja04	15014		0.74	0.7	0.9	-0.2				4				72			24				100		0			2	42	53		0	0	3	0	0	100
212Ja07	5719		0.19	0.5	1.3	-0.8				5				9			86				100						3	9	57	14	11	6			100
212Ja08	6622		0.46	1.1	1.3	-0.2				25					28		47				100						5	27	52	6	4	2	4	0	100
212Ja09	17966		0.23	1.4	1.4	0.0			3	17	19		0	36			25				100			0	2		33	13	4	1	5	42	0		100
212Ja10	6530		0.11	1.3	1.4	-0.1			11	30	16			1			42				100		1		6		21	0	20	1	5	45			100
212Jb01	61233		1.00	0.2	0.4	-0.1								94			6		0		100						3	93	0	0	1	2	0	0	100
212Jb02	8587		0.98	0.8	1.1	-0.3								71			16		13		100						2	65	5		7	4	19		100
212Jb03	6973		0.39	0.7	1.2	-0.5				5				73			21				100		0				45	25	1	3	0	27	0		100
212Jb05	20114		0.90	0.5	1.1	-0.6							1	84			15				100				1	0	19	62	0	0	3	15	0		100
212Jc01	156317		0.92	0.8	1.3	-0.5				0			0	55			44		1		100			0	1	0	8	54	7	0	22	6	2	0	100

212Jc02	39445	0.96	0.7	1.2	-0.5			1			80			8		11		100		0		0		10	63	3		7	1	16		100
212Jc03	19995	0.30	1.0	1.7	-0.6			11		0	63			19		7		100			1			39	14	13	0	4	19	9	2	100
212Jc04	189698	0.71	1.0	1.7	-0.7		2	3		0	55			37	0	3		100		0	4	1		22	31	18	0	14	4	6	0	100
212Jc05	106495	0.98	0.9	0.7	0.1		0	4	1	1	69			25		1		100	0	0	0	0		3	80	2	0	12	1	1		100
212Jc06	36784	0.81	1.3	1.3	0.0		16	33	1		42			4	2	2		100		6	6	3		7	66	0	1	3	4	4	0	100
212Jc07	30417	0.85	1.2	0.8	0.5		12	28	1	2	53			1		2		100			5	3	0	2	81	1	0	1	4	3	0	100
212Jc08	6705	0.27	1.3	1.6	-0.3		17	6			34			41		3		100		1	2	4		49	10	16	1	11	2	2	2	100
212Jc10	62580	0.57	1.5	1.6	-0.1		17	38	1	0	21			4		19		100		0	3	5	0	3	40	2	0	5	15	26	1	100
212Jc11	51466	0.75	1.7	1.1	0.6		16	17	5	4	36			15	3	4		100		0	0	0	2	4	72	3	1	7	5	5		100
212Jc12	11103	0.87	1.1	0.9	0.2		0	20			45			34		0		100						1	69	3	1	23	3			100
212Jc13	14324	0.90	1.0	0.4	0.6		1	17		1	64			16	2			100			0			6	90	1		2	1			100
212Jd01	240090	0.70	1.2	1.0	0.3		8	8	10	4	64		0	2	0	3		100		0	0	0	0	1	46	2	0	0	45	4	0	100
212Jd02	18556	0.15	0.6	0.6	0.0		4		0	2	85	1		6		2		100					0	0	13	2			83	2	0	100
212Jd03	20967	0.87	1.1	0.5	0.6		8	26	4		59			1		2		100					1	1	87	0	0	2	4	4		100
212Jd04	15797	0.03	1.0	0.3	0.7				26	6	62			1		4		100							3	0			94	3	0	100
212Jd05	25982	0.71	0.6	0.8	-0.2		0	0	10	7	82			1	0	0		100						0	50	0	0		48	1		100
212Jd06	34103	0.62	1.3	1.0	0.3		7	19	8	8	54			3	0	1		100					0	1	43	3	0	0	48	4	1	100
212Jd07	34123	0.64	1.1	0.5	0.6				24	34	0				41	0		100	0		0				17				81	1	0	100
212Je01	31157	0.99	0.6	0.8	-0.1		3	7	4	0	85			1		0		100			1	0	0	9	80	2		3	3	1		100
212Je02	162460	0.85	0.5	1.3	-0.8			0		0	81			19		0		100			0	0		22	52	9	0	7	8	0	0	100
212Je03	102269	0.70	0.6	1.5	-0.9			4			84			9		3		100			0			17	40	9	0	5	24	3	1	100
212Je04	38547	0.40	1.1	1.5	-0.4		1	29			58			5		8		100						18	22	15	0	1	36	8	0	100
212Je05	381639	0.50	0.5	1.5	-0.9		0	1		0	82			17		0		100		0	0	0	0	27	28	14	1	3	26	1	0	100
212Jf01	29929	1.00	0.4	0.4	0.0		2	6		0	90					2		100					1	3	92	0	0	0	2	2		100
212Jf02	36525	0.99	0.2	0.3	-0.2		0	3	1		96			0		0		100					0	0	91	0			8			100
212Jf03	77968	0.52	0.7	0.9	-0.2			6	2	0	80		0	12		1		100			0		0	0	37	3	1	0	58	1	0	100
212Jf04	42966	0.90	1.2	1.0	0.2		3	11	11		61			12		2		100			0			5	65	3	0	0	21	4	0	100
212Jf05	64586	0.89	0.3	1.2	-1.0						93			7		0		100		0		1	2	15	61	3	1	4	12	1	0	100
212Jf06	31947	1.00	0.5	0.5	0.0			0		2	85			12		1		100			0			4	88	2		4	1	1	0	100
212Jf07	13109	0.97	0.6	0.7	-0.1						75			24		1		100						5	84	4	0	5	2	1	0	100
212Jf08	21052	0.99	0.5	0.9	-0.4			1		1	86			11		1		100			1			3	76	5	0	7	4	1	2	100
212Jf09	39534	0.96	0.4	0.9	-0.5						88			11		1		100					0	16	72	1	1	7	2	1		100
212Jf10	18949	1.00	0.5	0.5	0.0		0			5	86			8		1		100						6	88	1		3	1	1	0	100
212Jf11	9966	0.35	0.4	1.5	-1.1						88			12				100				1	1	9	20	8	2	11	47	1		100
212Jf12	11502	0.88	0.7	1.2	-0.5			4		1	79			17		0		100						24	57	1	0	6	11	1		100
212Jg01	57850	0.17	0.5	0.5	0.0		4	4	0		89	1		2		1		100						0	15	0			83	1	0	100
212Jg02	51115	0.27	1.4	0.9	0.5		8	16	10	2	53			5		6		100			0			1	21	1		0	69	7	2	100
212Jg03	11300	0.77	0.9	0.9	0.0		13	1	13		69			4				100						5	53	2			40			100
212Jg04	91846	0.17	1.8	1.1	0.7		36	12	19	6	8			7	6	6		100			1			1	12	4	1	0	67	8	7	100

212Jg05	98268		0.29	0.7	0.7	0.0			1	9		6	1	81	0	1	2				100				0		1	0	23	1	1	0	74		1	100
212Jg06	20828		0.38	1.6	0.6	1.0			4	0		32	14	30			4	16			100				0		0		15	2			82	0	1	100
212Jg07	20698		0.86	0.4	0.9	-0.5				15				84			0		0		100				0		0		62	1	6	0	30	1	0	100
212Jh01	71507		0.46	1.4	1.6	-0.2			12	33		37	0	11			7	0			100			3	1	0	19	4	45	8	7	3	10	0		100
212Jh02	51634		0.27	1.1	1.8	-0.7			2	55		31		5			8				100			3	0	1	22	13	26	14	2	1	17	0	0	100
212Jh03	78539		0.37	1.3	1.1	0.2				12		27		47	0	1	13				100						1	1	29	8	4	0	57	0	0	100
212Jh04	22478		0.57	1.3	1.7	-0.4			14	40		26					19		1		100			23	0	4	42	9	6	4	1	5	3	2	0	100
212Ji01	15468		0.81	0.5	1.3	-0.9								83			17				100							3	51	20	9	1	15	0		100
212Ji02	104729		0.49	0.5	0.9	-0.4			0	2		0		86		0	9		2		100				0		0	0	35	1	1	0	59	2	1	100
212Ji03	63643		0.14	1.0	0.6	0.3				6		8		65			22		0		100				0				12	4	2	0	82	0		100
212Ji04	5780		0.95	0.7	0.8	-0.1			0	7				77			17				100				0				75	2	2		17	0	4	100
212Ji05	37390		0.55	1.3	1.7	-0.4			5	12		3	1	61		0	6	1	10		100				1	0	0		26	6	7	1	34	10	15	100
212Ji06	10094		0.09	0.6	1.3	-0.8						0		18			80		2		100								13	53	20	3	6	5		100
212Ji07	11524		0.73	1.6	1.6	0.0			7	5		7		47	6		16	3	9		100					0			33	9	14	0	23	13	8	100
212Ji08	42360		0.90	0.7	0.8	-0.2			3	4		7		82	0		4		0		100				0	0	0		65	2	2	0	29	0	2	100
212Jj01	284777		0.82	0.8	1.1	-0.3			2	2		1	1	77	0		15	2	0		100				1	0	2	1	52	1	1	6	35	1	0	100
212Jj02	44105		0.85	1.4	0.8	0.6			20	6			2	48			16	8	0		100				0	0	3	4	79	0	0	8	5	0	0	100
212Jj03	58237		0.65	0.6	1.0	-0.4			2	4		1		85			9		0		100						1		44	2	0	5	48	0		100
212Jj04	6294		0.13	1.5	0.9	0.5			38	15		4		26			16		2		100						0		7	2	2	19	69	1		100
212Jk01	4660		0.80	1.5	1.1	0.3			11	19			22	39			9		0		100			0				32	43			0	25			100
212Jk02	11775		0.55	1.5	1.3	0.2			34	25			23	14			2		2		100		0	1	2			45	34			1	11	5	1	100
212Jk03	57400		0.36	1.1	2.0	-0.9			50	5				12			32		2		100			5	2	13	3	16	14	9	2	15	18	2		100
212Jk04	22331		0.41	1.4	1.7	-0.4			41	6				27			22		5		100			0	3	14	2	25	33	1	0	4	12	7		100
212Jk05	36863		0.63	1.4	1.3	0.1			13	26			4	44			13		0		100			1	0			40	37	1		8	11	1	1	100
212Jk06	48350		0.14	1.2	1.4	-0.1			42	34			0	7			17		0		100			4	2			59	13	5	0	9	8	0		100
212Jk07	18877		0.35	1.3	1.3	0.0			46	14			1	20			18		0		100			0	0	1	1	19	47	0		7	22	2		100
212Jk08	14064		0.28	1.2	1.8	-0.6			45	2				9			37		7		100			0	1	2	2	17	4	5	3	18	36	8	3	100
212Jk09	8957		0.47	1.0	1.3	-0.2			9	4				48			40				100							11	12	1	1	29	47		0	100
212Jk10	12103		0.17	1.2	1.4	-0.3			7	54				21			18		0		100		1		1			36	7	3	1	19	30	1	1	100
212Jk11	41728		0.37	1.2	1.2	0.0			20	11			1	55			14		0		100		0	1	1			58	22	0		9	8	0	1	100
212Jk12	12048		0.20	1.1	1.0	0.1				34			1	25			40				100							67	17	6		8	2	0		100
212Jl01	110943		0.96	0.9	0.8	0.1			0	4			3	68			23	0	1		100		0	0	0	1		5	79	4	0	5	2	2	1	100
212Jl02	110438		0.94	1.1	1.5	-0.5			0	4			2	51			37	1	5		100		0	1	2	2		4	49	8	0	21	6	6	0	100
212Jl03	30680		0.95	1.2	1.4	-0.2			3	10			2	56			26		3		100			1	1	1		3	54	7		16	13	4	1	100
212Jl04	30638		0.98	0.8	0.9	-0.1				3			0	73			18		5		100			1	2	0		2	77	4		5	1	8		100
212Jl05	83706		0.97	0.8	1.0	-0.1				3			2	67			27		1		100		0		2	1		3	73	3	0	11	5	1	0	100
212Jl06	41740		0.99	0.4	0.3	0.1			0	0			1	85			14				100				0			1	92	0	0	3	2		0	100
212Jl07	53226		0.98	0.6	0.7	-0.1				2				80			18		0		100			0	1			6	82	2	0	3	4	0	0	100
212Jl08	25841		0.97	0.6	0.4	0.2				3				78			18		1		100				0			3	91			2	3	1		100

212Jl09	14908		0.88	0.9	0.5	0.4				25				62			13				100				0			8	87	1		3	1	0		100
212Jl10	12724		0.35	1.1	1.3	-0.2				54			2	20			22		2		100			1	2			35	46	2		5	6	3		100
212Jm01	124835		0.75	1.5	1.8	-0.3			6	15			3	34			32		9		100			1	1	1		12	31	17		13	9	13	2	100
212Jm02	73126		0.46	1.4	1.5	-0.1			5	48			2	21			12		12		100			4	1	0		12	48	8	0	6	2	18	0	100
212Jm03	214459		0.56	1.6	2.0	-0.4			16	34			1	15	0		20	1	13		100			11	1	1		11	23	15	0	12	6	18	3	100
212Jm04	6417		0.80	1.4	0.8	0.5				12				3	41		28		16		100							2	2	74		4	1	17		100
212Jm05	61964		0.47	1.2	1.3	0.0			5	53			1	29			5		7		100			1	0			15	61	2	0	4	3	10	3	100
212Jm06	4777		0.02	0.4	1.0	-0.6				90				2			6		3		100			4		1		10	71	3		2	0	7	1	100
212Jm07	48114		0.39	1.5	1.8	-0.3			15	45			4	16			19		3		100			1	0			18	33	12	0	17	7	6	6	100
212Jm08	20198		0.83	1.5	1.5	-0.1			8	20			1	43			21		7		100			1				21	43	6		16	5	8	0	100
212Js01	273462		0.06	0.5	0.4	0.1				4		0	0	89	1	1	5		0		100				0	0	0	0	5	2	1	0	90	0	1	100
212Js02	161858		0.55	0.2	1.1	-0.9								95			5		0		100				0	0	0	6	38	2	1	2	50	0	1	100
212Js03	81254		0.38	0.6	1.6	-1.0				0				79			20		1		100				0	0	0	12	19	5	5	12	43	0	2	100
212Js04	20492		0.06	0.1	0.4	-0.3								98			2				100								5	0	1		89		4	100
212Ka01	57093		0.29	1.0	1.7	-0.7			72	3	0	1	0	1	14	3	4		2		100			10	4		2	6	15	24	2	0	36	1	0	100
212Ka02	11715		0.17	1.6	1.3	0.3			7	27		4	5	29	0		22		6		100								14	21	7	1	51	6	0	100
212Ka03	51831		0.10	0.8	1.5	-0.8			80	5		0		5			5	2	3		100			2	1		1	6	42	7	1	3	31	5	1	100
212Ka04	151652		0.40	1.3	1.7	-0.4			56	22		7	1	4		0	6	1	3		100			15	6	1	2	14	40	3	0	2	11	6	0	100
212Ka05	64571		0.21	0.8	1.8	-1.0			81	4		0	1	1		0	7	0	6		100			10	2	0	5	6	42	7	1	5	12	10	0	100
212Ka06	76087		0.48	0.8	1.8	-1.0			79	6	0	1	1	1		0	9	2	2		100			24	5	1	3	8	18	4	1	3	31	3	0	100
212Ka07	19936		0.12	1.2	1.0	0.1			17	60		13	0	6			3		1		100			4	1			21	66	0			7	1		100
212Ka08	5145		0.14	1.0	1.1	-0.1				64			11	4			21				100						1	26	55	1		3	13			100
212Ka09	41811		0.06	1.2	1.5	-0.3			62	15				2		10	6		6		100			1	1		1	2	41	17	2	1	27	8	0	100
212Ka10	17228		0.04	0.7	1.6	-0.9			79							10	2		8		100			0	1		1	3	40	12	0	10	20	13		100
212Kb01	107982		0.32	1.4	1.4	0.0			0	28	4	2	12	9	1	0	43		1		100				0	0	1	26	46	13	1	5	7	1		100
212Kb02	320025		0.25	1.7	1.5	0.2			0	23	21	3	10	6	1	4	32	0	0		100			0	0	0	0	38	16	13	2	3	25	1		100
212Kb03	18920		0.08	1.4	1.5	0.0			1	15	19	8	1		4		47		4		100							9	6	31	5	1	41	8		100
212Kb04	16220		0.39	1.6	1.7	0.0				15	13		2	33	3		28		6		100						3	14	21	34	1	1	18	9	0	100
212Kb05	27774		0.17	1.5	1.5	0.1				3	30	5	0	20	5		35		2		100							12	14	20	2	2	45	5		100
212Kb06	18922		0.36	0.7	1.4	-0.7				1	13			0	8		78				100							4	7	51	11	17	11	0		100
212Kb07	236039		0.27	1.6	1.5	0.1				8	26	7	1	23	3	0	32		0		100						0	22	21	16	2	2	36	1		100
212Kb09	155319		0.05	1.4	0.3	1.1				1	2	54	18	3	7	0	13	2			100							1	1	4			93	0	0	100
212Kb10	34663		0.14	1.7	1.5	0.2			2	24	24	2	1	3	5		29		10		100		0					11	12	16	0	0	42	19		100
212Kb11	104703		0.09	1.9	0.9	1.1			4	10	17	10	20	7	7	1	20	2	1		100		2		0	0		7	5	9		0	74	2		100
212Kb12	49745		0.12	1.5	1.4	0.1			0	15	39	1	8	4	3	0	30		0		100					1	0	22	12	10	5	2	47	1	0	100
212Kb13	16788		0.24	1.7	1.7	0.0			39	13	15	0	2	1	2	3	20		6		100			6	4	3		10	1	14	2	6	42	13	0	100
212Kb14	62616		0.12	1.5	1.6	0.0			2	35	17	2	0	16	1		24		2		100			0	0	2	0	29	4	12	1	7	39	5	1	100
212Kb16	51281		1.00	0.1	0.0	0.0					0	1	0	0	0		0		99		100							0	0	0			0	100		100
212Kb18	17963		0.46	1.7	1.7	0.0			12	29	3		11	6	0	28	8	0	0		100			2	0		1	24	36	5	14	4	10	3		100

212Kb20	25515		0.01	1.2	0.5	0.6					5	56		4	6	1	27				100							1	0	13			84	2	0	100
212Kb21	27770		0.03	1.2	0.3	0.8					4	66	12	1	5	2	7	1	1		100							3	0	4			92	1		100
212Kb23	19683		0.00	1.6	0.4	1.2				10	19	39	1	21	1	5	3		0		100							2	1	2			93	2	1	100
212Kb25	54848		0.00	1.5	0.7	0.7				8	33	21		3	1	1	33		0		100						0	11	0	11	0		77	0		100
212Kb26	79558		0.02	1.3	0.5	0.8					7	59	8	2	4	0	18	1	2		100							3	0	3	0	0	88	5	0	100
212Kb27	12452		0.13	1.3	1.6	-0.3			25	1	41	0			6	1	16	2	7		100		2				0	27	9	22			24	17		100
212Kb28	24793		0.27	1.7	1.7	0.0				25	20	18	3	1	3		20		11		100						7	19	24	13	0	1	12	24		100
212Kb31	23775		0.05	1.1	0.7	0.4						51	35		0		4		10		100							2		2			76	19	1	100
212Kb32	20233		0.00	0.4	0.2	0.1						92	1		5		3		0		100							4		1			94	1		100
212La07	60406		0.04	1.3	1.0	0.3			23	43	23				1		5		5		100			2		3		72		3		3	6	10	0	100
212La08	58947		0.54	1.3	1.2	0.1			26	43	13						2		17		100			42	0	1		21		1		1	1	33		100
212La09	80879		0.70	1.4	1.2	0.2			20	21	10			1	2		2		44		100		0	3		1		34		4	0	2	3	52	0	100
212La11	17217		0.48	1.1	1.3	-0.2				26	22						51		1		100				0	32		43	2	1		18	1	3		100
212La13	183636		0.70	1.6	1.4	0.2			27	10	32		18				5		8		100			22	0	8		45		1		5	0	17	0	100
212La14	33179		0.41	0.8	1.3	-0.6				73	13						1		13		100		1		13	24		28		0		1		33	0	100
212La15	163926		0.41	1.5	1.5	0.0			34	26	18						11		10		100			21	1	2		44		4		5	4	18	0	100
212La16	120346		0.04	1.3	0.8	0.5			7	49	23		0				14		6		100				0	1		77	0	3	0	6	3	9	0	100
212La17	94016		0.07	1.1	0.8	0.3			2	18	55		1		0		23		1		100		0			2		77		2	0	8	10	1	0	100
212La21	21074		0.51	1.3	1.5	-0.2			6	49	10		2				6		27		100		8	14		23		7		0		8	3	36		100
212La22	22739		0.72	0.6	1.2	-0.6				11	82						1		6		100			1		45		34		0		2		17		100
212La23	94713		0.21	1.4	1.3	0.1			3	54	14		4				11		14		100			11	0	3		50		1		3	1	29	1	100
212La24	37596		0.42	1.6	1.5	0.1			18	18	26			1			22		16		100			15	0	1		39		3		11	4	25	1	100
212La34	38172		0.69	1.3	1.0	0.3			2	16	24			2			9		47		100				0	0		37		1	0	5	3	52	1	100
212La35	28132		0.41	1.2	1.2	0.1			5	40	23						32		0		100			0	1	51		34	0	0		8	3	1	1	100
212La36	23250		0.48	1.2	1.3	-0.1				35	35						25		5		100				1	34		42		1		10	1	11	0	100
212La37	44275		0.36	1.0	1.0	0.0			0	55	35		0				7		3		100					42		47	0	0		0	0	10	0	100
212Lb01	49924		0.00	0.7	0.9	-0.2				78	14	0		7			1		0		100					0		72	0	0		0	9	6	12	100
212Lb02	60966		0.01	0.6	0.3	0.2				15	82			2			1		0		100		1		1	0		92	2	0	0	1	0	0	1	100
212Lb03	143936		0.04	1.4	1.1	0.3				26	39	0		10	0	0	21		3		100				0	0		68	2	7	0	5	11	4	2	100
212Lb04	56889		0.10	1.5	1.1	0.4			4	30	33	0		4		1	19		9		100			1	0	1		66	0	5		10	2	14	0	100
212Lb05	29104		0.06	1.0	0.7	0.3				24	53						23		0		100							79	1	3		15	1	1	0	100
212Lb08	43198		0.19	1.0	1.0	0.0				11	65		0	2			19		3		100			0		10		70	2	0		13	0	4	0	100
212Lb10	96835		0.04	1.2	0.7	0.5				39	36			12			13		1		100		0		0	1		79	12	0	0	2	1	2	2	100
212Lb11	46314		0.05	1.0	0.7	0.3				23	63		0	7			6		1		100					0		64	33	1		1	0	1		100
212Lb20	44877		0.32	1.3	1.5	-0.2			0	7	31	6	1	7	0		47		2		100					1		42	7	23	2	18	5	3		100
212Lb21	27944		0.25	1.5	1.6	-0.1			7	13	30	0		11	1		37		1		100					3		30	1	25	2	13	23	2	2	100
212Lc05	74528		0.22	1.5	1.4	0.1			19	21	24		1	1			33		1		100			1	1	0		53	0	13	0	17	8	3	3	100
212Lc06	28773		0.25	1.4	1.1	0.4			20	33	9		3				34		1		100				0	1		64		6	0	20	5	2		100
212Lc07	24266		0.13	1.3	1.0	0.3			19	5	30						44		3		100					0		71		7	1	12	4	4	0	100

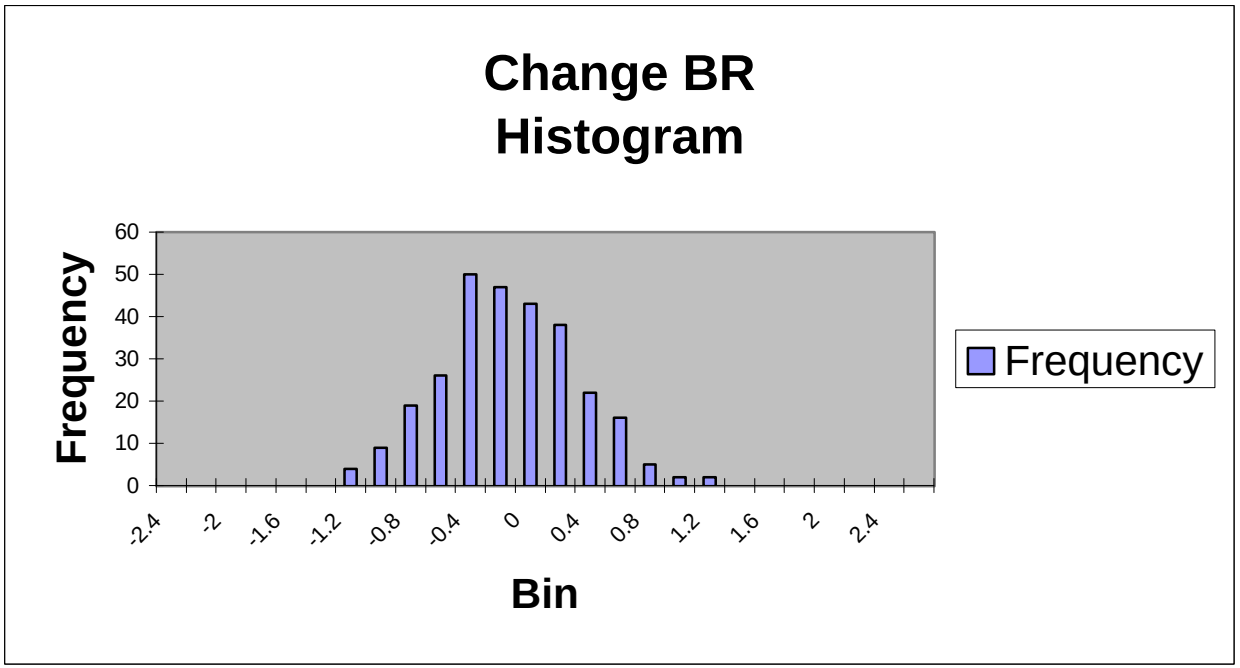
212Lc10	47349		0.03	1.4	1.2	0.2			1	25	28	2		37	2		6		0		100							50	3	1		0	9	3	35	100
212Lc20	108906		0.05	1.4	1.3	0.1			10	16	47		0	1	1	0	24		2		100			0	0	0		63		10	1	6	9	5	5	100
212Lc21	44252		0.02	1.4	1.4	0.0				18	45	0		11	1		23		2		100							39	0	4		1	18	11	26	100
212Ld01	137402		0.10	1.2	0.9	0.3			1	12	51		0	1	1	1	32		2		100			0	0	0		75	1	4	0	14	2	3	0	100
212Le01	42083		0.17	1.5	0.9	0.6			29	26	24		5				15		1		100			0	3	0		75		5		13	1	3	0	100
212Le02	36318		0.30	1.2	1.4	-0.2			57	1	18		6				16		2		100			5	8	2		48		3		28	2	5		100
212Le03	20476		0.19	1.0	0.5	0.5			10	5	69		11				1		3		100				1	3		87		0		2		7	0	100
212Le04	20329		0.38	1.2	1.4	-0.2			18	23	51						7		2		100			0	3	19		44	0	2		23	2	6		100
212Le08	12000		0.95	0.9	0.8	0.1			8	5	13						73		0		100			0				4		18		75	0	3		100
212Le09	5266		0.85	0.7	1.1	-0.3				4	28						68				100							8		24		62	5	2		100
212Le10	50380		0.45	1.1	1.2	-0.1			1	7	48						41		4		100			0	0	0		42		8		41	2	6		100
212Le11	42842		0.29	1.3	1.2	0.2			15	24	21			0			39		1		100			1				57		4		24	1	2	11	100
212Ma01	107467		0.82	0.9	1.2	-0.3			2	1	18		2	0	0	1	73		3		100		0	0		0		12		29	1	50	2	6	0	100
212Ma02	27307		0.05	0.6	1.2	-0.6					71		4	1	0		24		1		100		0					57		11	1	12	17	3		100
212Ma03	93273		0.16	0.8	1.1	-0.2			0		62					6	32		0		100		2	0	0			60		10	0	21	7		0	100
212Ma04	34429		0.83	0.6	0.9	-0.4			1	1	14		1	0		0	83		0		100		1	0	0	1		7		33	0	57	0	0		100
212Ma10	5349		0.03	1.0	0.4	0.6				11	45			2			42				100							90		2	0	5	1	1		100
212Ma13	23706		0.47	0.9	1.0	-0.1			1	2	50		3				44				100				0	1		50		6	0	42	1			100
212Ma14	16316		0.75	1.0	0.9	0.2				0	38		46				16				100					1		75		8		7	9		0	100
212Ma15	7399		0.10	0.8	0.7	0.1				6	75		6				13				100				12			79	0	0	0	7	1			100
212Ma16	22151		0.40	1.2	1.4	-0.2			14	7	39					2	39				100		2	3	2			46		7	1	31	7		1	100
212Ma18	134065		0.09	0.9	1.0	0.0			1	3	59	0	0	0	1	1	35		0		100			0	0	0		69	0	8	1	12	9	0	0	100
212Ma19	82512		0.51	1.4	1.3	0.2			15	4	32		17	0			32		0		100		0	1	0	1		53		9	1	20	15	0	0	100
212Ma21	39424		0.46	1.4	1.3	0.1			7	9	36		12				36				100					0		39		7	0	23	28		1	100
212Mb01	133539		-	-	-	-			4	0	13		0		11	0	70	1	1		100		100													
212Mb03	13099		-	-	-	-			1		6		3		26		65	0			100		100													
212Mb04	379010		-	-	-	-			1	0	15	0	0		2	0	81		0		100		0		0			2		34	0	60	3	0		100
212Mb05	168236		-	-	-	-					3	0	0		17		80	0	0		100		4					0		70		24	0	1		100
212Mb06	5395		-	-	-	-									74	6	3	17			100		100													
212Mb07	37625		-	-	-	-			0		46				1		52	0	1		100		100													
212Mb08	75908		-	-	-	-			3	0	46				0	3	47				100		100													
212Mb09	58668		-	-	-	-			21		35		2		1		42				100		100													
212Mb10	30434		-	-	-	-					6		10		14	10	5	56			100		100													
212Mb11	8207		-	-	-	-					62						34		4		100		100													
212Mb16	165230		-	-	-	-			15	0	22		5		4	0	50	3	2		100		0		1			26		34	1	34	3		0	100
212Mb17	3746		0.11	0.6	1.2	-0.6					71						29				100		6					21		45	11	17				100
212Mb18	75672		0.00	0.8	1.1	-0.3			1	2	76		0	9		1	11				100			0				42	1	11	0	1	43	0	1	100
212Mb19	45949		0.29	1.6	1.3	0.4			5	2	29	1	17	0	7	2	30	5	3		100		0					42	0	37	1	3	10	5	1	100
212Mb20	7967		0.05	1.3	0.7	0.6				13	41	37	3		0		3		4		100				3			80		12			0	6	1	100

212Mb24	6645	-	-	-	-		3		36		34		2		19	3	3		100	100															
212Mb25	124144	-	-	-	-		2	0	45		4		2	3	42	0	1		100	100															
212Mb26	100927	-	-	-	-				9	1	3		56	0	28	3	0		100	100															
212Mb30	126474	-	-	-	-		0		0		0		1	0	0	0	98		100	100															
212Mb50	114977	1.00	0.1	0.0	0.0		0		0	0	0		0	0	1		98		100	0					0		1		0	0	99	0	100
212Na01	42221	1.00	0.3	0.2	0.1		0	1	0	2		0	1		1		95		100					0	1		2		0	0	96		100
212Na02	24728	1.00	0.3	0.1	0.2		1	0	1	1			1		3		93		100			0			0		1			0	98		100
212Na03	48810	0.03	1.8	1.0	0.8		4	24	12	23		13	3		17		4		100		0	0		0	72	1	6		4	10	6	1	100
212Na04	35660	0.06	1.7	1.1	0.7		20	19	21	25	3	1	2		9		0		100		0				50	1	4		0	38	1	6	100
212Na07	212822	0.32	1.7	1.8	-0.1		32	8	19	2	1	1	4	1	18		13		100	0	5	4	0		26	0	16		4	21	20	5	100
212Na08	37663	0.33	1.3	1.4	-0.1		17		31	1		0	6		43		2		100		0	2			34		39		17	3	4	0	100
212Na09	114938	0.25	1.5	1.5	0.0		4	3	34	4	0	2	8		38		7		100		0	0			42	0	22	0	11	12	11	1	100
212Na10	25214	0.79	1.1	1.3	-0.2		2	3	9			2	14		68		3		100						19		33	0	40	3	4	0	100
212Na11	752	0.03	1.2	0.6	0.5				45	25			26				4		100						71		1				28		100
212Na16	117635	0.03	0.9	1.2	-0.3		1	1	72	1	1	3	0		17		3		100		0	0			58	0	12	0	3	19	6	0	100
212Na18	123253	0.10	1.8	1.4	0.4		3	26	22	4	1	11	2	0	25		6		100		0	0	0		49	0	15		4	19	12	0	100
212Na19	31235	0.30	1.7	1.0	0.7		10	23	24	13	18	1	0		7		4		100	2					65	3	3			18	9		100
212Na20	50809	-	-	-	-		4	35	8	7	35				9		1		100	3					43		5			48	1	0	100
212Na21	79565	0.03	1.6	1.2	0.3		5	21	45	6	1		3		17		1		100	2	0	0			32	3	11		0	47	3	1	100
212Na22	26170	0.05	1.6	1.1	0.4		30	26	25	4	2		0		10		3		100		1	0			58	2	4		0	28	5	2	100
212Nb02	141045	0.23	1.8	1.7	0.0		1	28	23	5	2	6	5	0	22	0	6		100	0		0	0	0	27	22	11	2	4	18	15	0	100
212Nb03	35901	0.06	1.7	1.0	0.7			27	23	18		11	1		14		6		100			0			71	12	2		1	5	9		100
212Nb05	55819	0.09	1.6	1.5	0.1		1	21	32	18		1	1	1	18		8		100			0			48	5	3	0	4	18	16	5	100
212Nb06	34930	0.23	1.2	1.4	-0.2		4	10	45	1			1	1	38		1		100		1	0	1		50		18	1	20	5	4		100
212Nb07	110422	0.05	1.4	0.9	0.5			34	38	3	0	3	0	0	12		9		100		0	0	0		72	1	3	0	1	4	17	0	100
212Nb08	48167	0.09	1.1	0.9	0.2		3	12	54		0	0			30		3		100		0	0	0		72		5		13	4	5	0	100
212Nb09	29771	0.01	1.5	0.9	0.7			23	30	22		2	2	2	18		0		100						75	6	2		3	12	2	0	100
212Nb10	48192	0.23	1.6	1.5	0.0		1	10	35	3	4	0	2	1	33		10		100				0		47	11	8	5	6	4	18		100
212Nb11	29098	0.21	1.0	1.6	-0.7			0	33	1	1	3	1		59		2		100						13	8	31	5	11	29	3		100
212Nb12	45579	0.14	1.7	0.9	0.7		0	13	31	7	5	4	4		34		3		100			0			74	2	9	0	4	8	3	0	100
212Nb13	31269	0.17	1.5	1.7	-0.2			34	9	5		2	9		36		5		100						17	23	18	3	5	29	4		100
212Nb15	15433	0.02	1.2	1.2	0.0			31	38			1			28		2		100						55		6		2	27	5	5	100
212Nb19	41856	0.35	1.1	1.6	-0.5			9	36			6	2		46		0		100						8	26	21	2	17	25	1		100
212Nc01	88973	-	-	-	-		36	10	21	4		0	4	1	3		22		100	2	0			0	52	0	1		0	5	34	5	100
212Nc02	83452	-	-	-	-		4	27	33	7	2	15	1	0	4	0	7		100	1					92		2		0	0	5	0	100
212Nc03	37070	-	-	-	-		7	27	36	4	7		5		14		0		100	100													
212Nc04	48221	-	-	-	-		32	2	8	7	1	2	5	15	13	12	1		100	100													
212Nc05	11960	-	-	-	-			45	6	16	3	6	2	4	13	0	5		100	100													
212Nc06	27874	-	-	-	-		7	19	29	9	9	9	2	8	8		0		100	100													

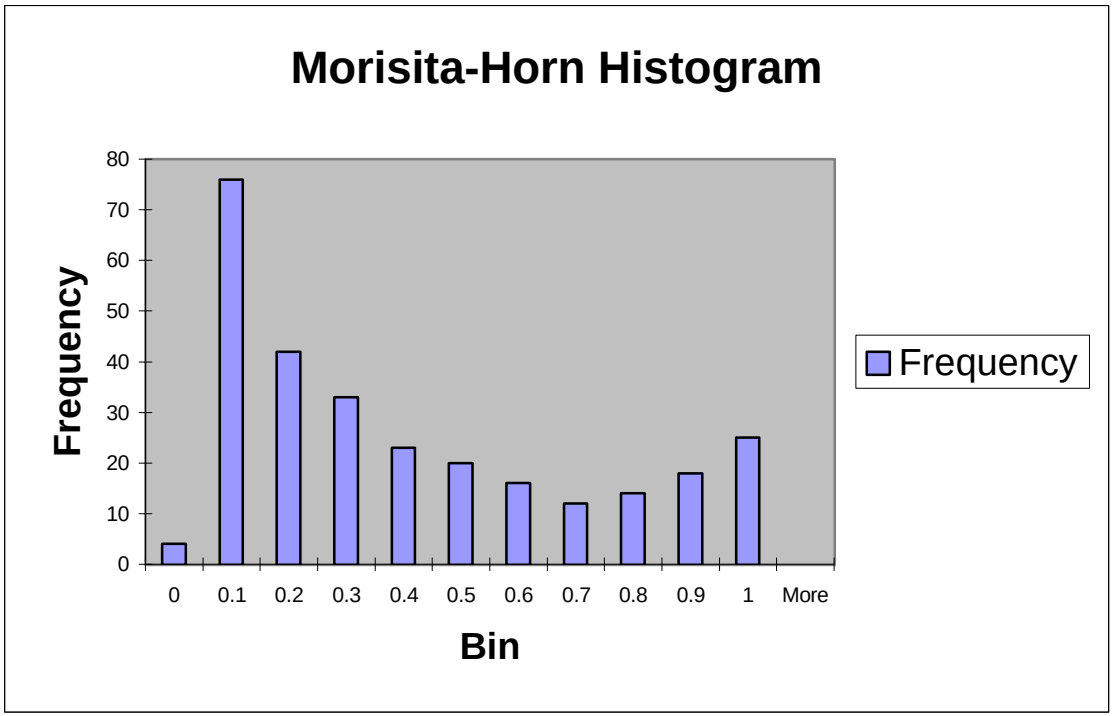
212Nc07	41413	-	-	-	-		15	3	7	22	21		12	1	11	8			100	100															
212Nc08	16162	-	-	-	-		55	0	15				14	4	12				100	100															
212Nc09	65698	-	-	-	-		3	1	32	8	25		10	1	18	1	0		100	100															
212Nc10	56960	-	-	-	-		23	4	23			3	9	3	34				100	100															
212Nc11	152678	0.09	1.2	1.6	-0.4		55	3	24	0	0	0	6	0	7	0	5		100	0	3	1	0		14	0	5		0	30	14	32	100
212Nc12	22359	0.08	1.4	1.5	-0.1		26	5	37		2	0	8	2	16	2	1		100	2					30		15		0	30	5	18	100
212Nc13	48871	0.02	1.5	0.9	0.6		3	41	13	1		20	1	0	16		6		100	0		0		0	75	0	7		2	5	9	2	100
212Nc14	34356	0.06	1.3	1.3	0.0		1	52	20	0		6	0		15		4		100				0	1	56	19	9	2	4	1	9	0	100
212Nc16	111272	0.11	1.7	1.1	0.6		6	34	19	4	0	11	1		10		13		100		0	0		0	61	0	6		1	6	22	3	100
212Nc28	49673	-	-	-	-		1	25	38	1	12		2		10	0	10		100	8					51		12		2	16	11	1	100
212Nc29	84921	-	-	-	-		4	10	33	14	9		8		21	1	0		100	2	10				8		4			63	0	13	100
212Nc30	96775	0.02	1.4	0.7	0.6		27	30	35	0	1	1	0		3	0	4		100	0		0		0	81	3	2		0	5	7	1	100
212Nc31	53319	0.04	1.3	1.4	-0.1		42	23	23		0		0		5		5		100	1	1	0	0		43	1	12		1	23	14	4	100
212Nc32	20235	-	-	-	-		4	72	15	1	7				1		1		100	100															
212Nc33	15136	-	-	-	-		21	40	3	0	10				9		17		100	100															
212Nc34	20696	-	-	-	-		3	62	12	4	7				6		7		100	100															
212Nd01	93395	0.48	1.3	1.4	-0.1		2	4	8	1	2	0	19	3	61		0		100			0			16	1	50	3	13	15	1		100
212Nd02	42698	0.15	1.4	1.3	0.1		2	17	21	1	2	1	0	7	48		1		100			0			51	0	20	0	8	17	3	0	100
212Nd03	125176	0.52	0.7	1.0	-0.3			0	11	0	0	0	9	0	79		0		100				0		8	0	60	1	29	2	0	0	100
212Nd04	166326	0.18	1.1	1.4	-0.3		1	3	38	0	0	1	2	3	51		0		100				0		41	0	23	1	11	21	1	1	100
212Nd05	111621	0.12	1.4	1.2	0.1		1	18	44	0	2	1	2	1	30		2		100		0	0	0		61	0	8	0	9	12	5	4	100
212Nd06	14818	0.16	1.3	1.5	-0.3		39	5	34					1	20		1		100		3	0	0		38		4		17	29	4	6	100
212Nd08	59129	0.18	1.5	1.4	0.1		0	8	11	10	0		17	4	49		1		100				0		7	5	20	3	5	55	6	0	100
212Ob02	6621	0.92	0.3	0.7	-0.4							91			9				100				2			72					0	26	100
212Ob03	1147	0.96	0.8	0.5	0.3			16				71					13		100							86				3	11	0	100
Subsections																																			
212Hb	561947	0.12	1.0	1.0	0.1		4	3		1	1	63	0	2	24	1	1		100	0	0	0	1	0	2	6	4	5	5	75	1	1	100
212Hc	125952	0.15	1.1	0.9	0.2	2	1	2		10		68	3	1	11	1	1		100			0	0			10	1	3	0	73	1	12	100
212Hd	363740	0.01	0.5	0.4	0.1	0				2		86	1	3	8	0	0		100				0			1	2	2	1	91	0	4	100
212He	223095	0.14	0.9	1.0	-0.2		2	1		1		63	2		31		1		100	0			2	0	0	8	4	5	5	72	1	2	100
212Ia	21515	0.97	0.8	0.4	0.4			3			1	75			16	5			100			0	0		4	90	1		2	2	0	0	100
212Ja	390511	0.33	1.3	1.4	-0.1	0	1	15	6	1	1	25	0		51	0	0		100	0	0	0	1	0	23	37	7	1	1	28	1	1	100
212Jb	96907	0.98	0.4	0.8	-0.3			0			0	88			10		1		100	0			0	0	9	79	1	0	2	7	2	0	100
212Jc	725329	0.93	1.2	1.5	-0.2		5	10		1	1	53			26	0	4		100	0	0	2	1	0	11	54	8	0	12	5	6	0	100
212Jd	389309	0.67	1.4	1.0	0.4		6	8		11	7	60	0	0	2	4	3		100	0	0	0	0	0	1	43	2	0	0	50	4	0	100
212Je	716072	0.66	0.6	1.5	-0.8		0	3		0	0	81			15		1		100		0	0	0	0	23	37	12	1	4	21	1	0	100
212Jf	398033	0.94	0.6	1.1	-0.5		0	3		2	0	84		0	9		1		100		0	0	0	0	7	67	2	0	3	19	1	0	100
212Jg	351905	0.31	1.5	0.9	0.6		12	9		10	3	56	0	0	4	3	2		100			0		0	1	21	2	1	0	70	3	2	100
212Jh	224158	0.51	1.5	1.7	-0.2		6	32		31	0	21	0	0	11	0	0		100		4	0	1	15	5	31	9	4	2	28	0	0	100

212Ji	290988		0.54	0.9	1.2	-0.3			1	5		4	0	73	0	0	14	0	3		100				0	0	0	0	34	6	4	0	50	3	3	100
212Jj	393413		0.84	0.9	1.1	-0.2			5	3		1	1	74	0		14	2	0		100				1	0	2	1	53	1	1	6	34	1	0	100
212Jk	289158		0.40	1.4	1.7	-0.3			32	18			2	25			21		1		100		0	2	1	4	1	37	22	3	1	10	15	2	0	100
212Jl	514843		0.97	0.9	1.1	-0.1			0	5			2	66			25	0	2		100		0	1	1	1		5	72	4	0	10	4	3	0	100
212Jm	553889		0.59	1.5	1.8	-0.3			11	35			2	22	1		20	0	10		100			5	1	1		13	34	13	0	11	6	14	3	100
212Js	537066		0.23	0.4	1.0	-0.6				2		0	0	89	1	0	7		0		100				0	0	0	4	17	2	2	3	71	0	1	100
212Ka	497068		0.29	1.2	1.8	-0.6			65	14	0	3	1	3	2	2	7	1	4		100			11	4	0	2	9	35	8	1	2	22	6	0	100
212Kb	1527589		0.18	2.0	1.5	0.5			1	13	16	17	8	8	3	2	26	1	5		100		0	0	0	0	0	19	13	12	2	2	46	6	0	100
212La	1122504		0.34	1.6	1.5	0.2			16	31	26		3	0	0		11		12		100		0	11	1	9		49	0	2	0	5	3	20	0	100
212Lb	599988		0.06	1.3	1.1	0.2			1	28	44	1	0	7	0	0	18		2		100		0	0	0	1		69	6	5	0	6	5	4	2	100
212Lc	328074		0.10	1.5	1.4	0.1			11	19	34	0	0	7	1	0	26		2		100			0	0	0		56	0	8	1	9	10	5	11	100
212Ld	137711		0.10	1.2	0.9	0.3			1	12	51		0	1	1	1	32		2		100			0	0	0		75	1	4	0	14	2	3	0	100
212Le	229694		0.35	1.5	1.3	0.2			20	14	33		3	0			28		2		100			1	2	2		53	0	5		28	2	4	2	100
212Ma	593399		0.39	1.1	1.3	-0.1			4	2	43	0	5	0	0	1	43		1		100		0	0	0	0		50	0	13	0	25	10	1	0	100
212Mb	1681851		-	-	-	-			3	0	20	0	2	0	8	1	49	2	15		100		1	0	0			13	0	28	0	26	9	22	0	100
212Na	971475		0.23	1.9	1.5	0.3			11	13	28	5	3	3	3	0	21		12		100		0	1	1	0	0	40	1	14	0	5	18	17	2	100
212Nb	667484		0.13	1.6	1.6	0.1			1	22	32	6	1	3	2	0	26	0	5		100		0	0	0	0	0	49	10	9	1	6	13	11	1	100
212Nc	1188073		-	-	-	-			20	20	24	4	4	4	4	1	11	1	6		100		1	1	0	0	0	52	2	7	0	1	13	14	9	100
212Nd	613163		0.33	1.3	1.5	-0.2			2	7	25	1	1	1	7	2	53		1		100			0	0	0		32	1	31	1	14	18	2	1	100
212Ob	7768		0.94	0.5	0.7	-0.3				2				88			8		2		100					2			74				0	2	22	100
Sections																																						
212H	1274734		0.09	0.9	0.9	0.0		0	2	1		2	0	70	1	2	19	1	1		100		0	0	0	1	0	1	5	3	4	3	79	1	3	100
212I	21515		0.97	0.8	0.4	0.4				3			1	75			16	5			100				0	0		4	90	1		2	2	0	0	100
212J	5871581		0.79	1.2	1.5	-0.3		0	5	10	0	3	1	59	0	0	17	1	2		100		0	1	1	1	1	10	42	6	1	5	28	3	1	100
212K	2024657		0.23	2.0	1.7	0.4			17	13	12	14	6	7	3	2	21	1	4		100		0	3	1	0	1	16	19	11	1	2	40	6	0	100
212L	2417971		0.20	1.6	1.5	0.1			11	26	33	0	2	3	0	0	17		7		100		0	5	1	5		57	2	4	0	8	4	12	2	100
212M	2275250		-	-	-	-			3	1	26	0	3	0	6	1	47	1	11		100		1	0	0	0		32	0	20	0	25	9	11	0	100
212N	3440195		0.18	1.9	1.6	0.2			11	16	27	4	3	3	4	1	24	0	7		100		0	1	0	0	0	43	3	16	1	7	16	11	3	100
212O	7768		0.94	0.5	0.7	-0.3				2				88			8		2		100					2			74				0	2	22	100

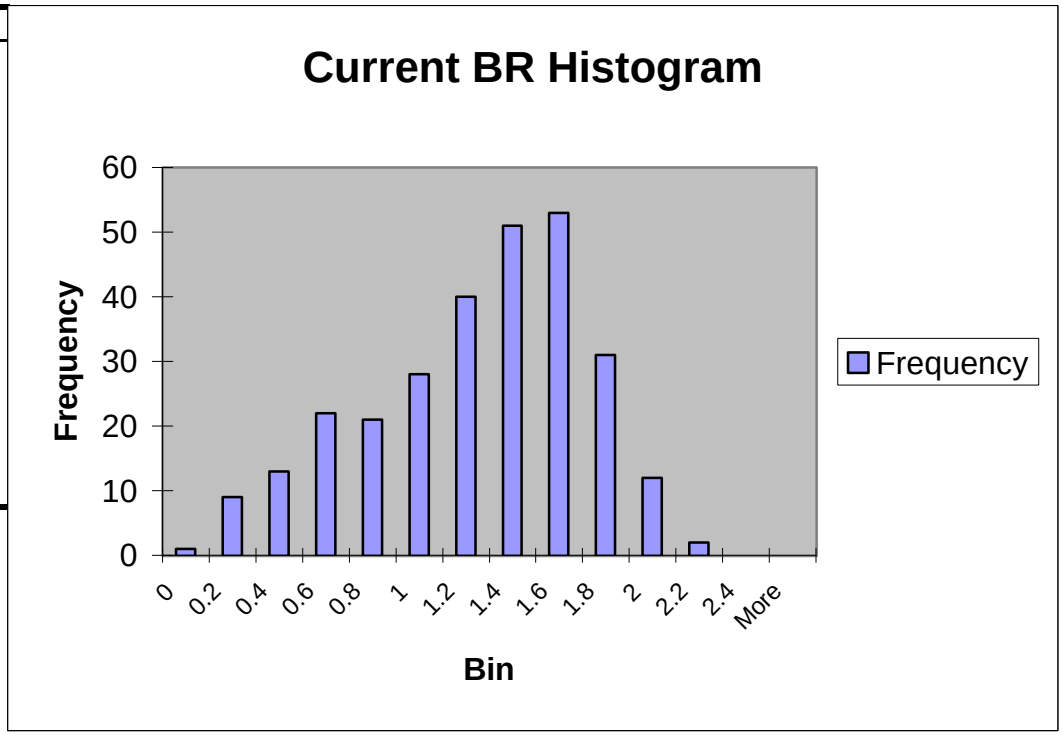
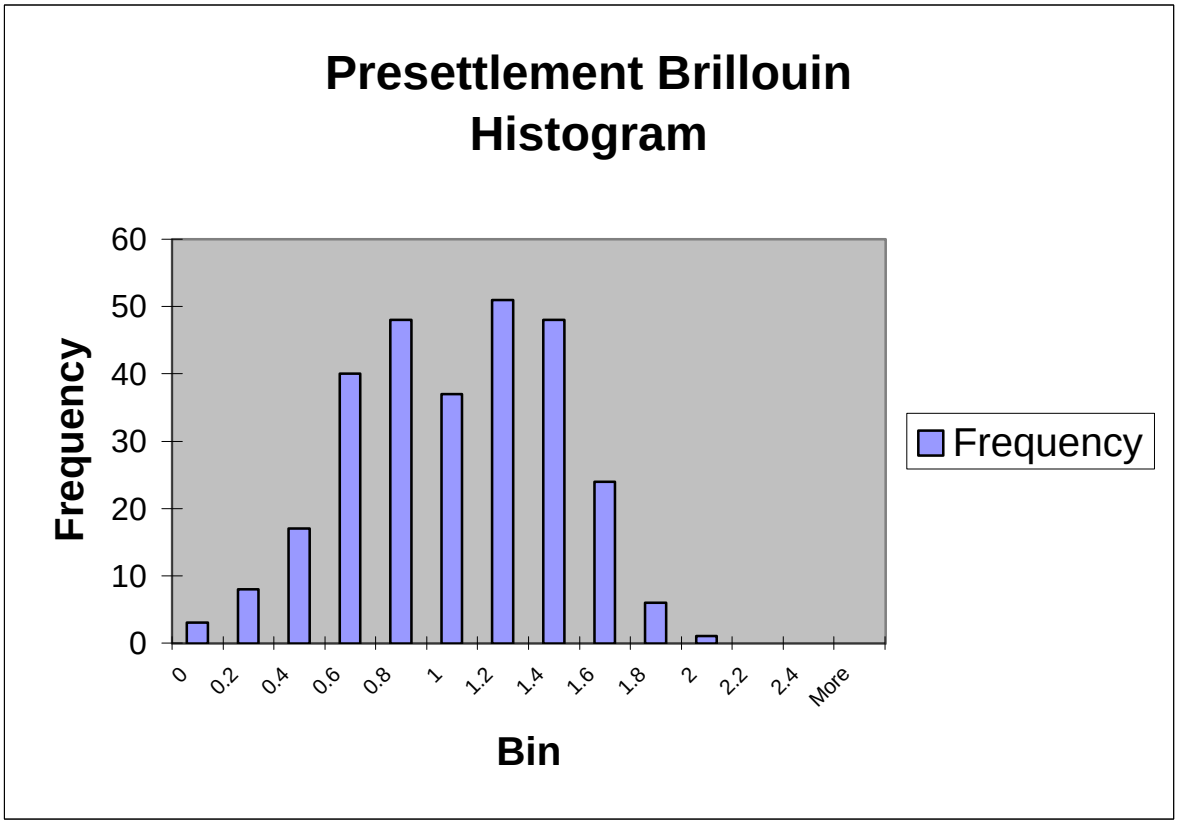
Bin	Frequency
-2.4	0
-2.2	0
-2	0
-1.8	0
-1.6	0
-1.4	0
-1.2	4
-1	9
-0.8	19
-0.6	26
-0.4	50
-0.2	47
0	43
0.2	38
0.4	22
0.6	16
0.8	5
1	2
1.2	2
1.4	0
1.6	0
1.8	0
2	0
2.2	0
2.4	0
More	0



Bin	*Frequency*
0	4
0.1	76
0.2	42
0.3	33
0.4	23
0.5	20
0.6	16
0.7	12
0.8	14
0.9	18
1	25
More	0



Bin	Frequency
0	1
0.2	9
0.4	13
0.6	22
0.8	21
1	28
1.2	40
1.4	51
1.6	53
1.8	31
2	12
2.2	2
2.4	0
More	0



Bin	Frequency
0	3
0.2	8
0.4	17
0.6	40
0.8	48
1	37
1.2	51
1.4	48
1.6	24
1.8	6
2	1
2.2	0
2.4	0
More	0