CHANGES IN FOREST SPATIAL PATTERNS FROM THE 1930S TO THE PRESENT IN NORTH CENTRAL AND NORTHEASTERN MINNESOTA: AN ANALYSIS OF HISTORIC AND RECENT AIR PHOTOS

George E. Host and Mark A. White
Natural Resources Research Institute
University of Minnesota, Duluth
5013 Miller Trunk Highway
Duluth, MN 55811

December 2003

Submitted to:

Dr. Jim Manolis, Spatial Analysis Project Manager

Contract # MNDNR/A21767

For the
Minnesota Forest Resources Council

Minnesota Forest Resources Council Report LT-1203c

Abstract

The spatial arrangement, age structure, and species composition of forest patches has significant implications for maintaining the sustainability and integrity of forest ecosystems. We assessed historical trends in landscape pattern in 42 plots stratified across ecological subsections of northern Minnesota. Aerial photographs from the 1930s, 1970s, and 1990s were used to assess post-settlement spatial patterns. Forest patches were classified according to composition, growth stage, and originating disturbance. Spatial pattern metrics included mean patch size and patch size distribution, edge density, shape metrics, and measures of compositional adjacency and contagion.

The numerous landscape pattern metrics calculated in this study provide different lines of evidence for the same trend – that over a 60 year time span in the mid to late 1900's, there has been a widespread shift toward a more finely-divided landscape. This is evidenced in smaller average patch sizes, a greater patch density, a shift in the patch size distribution toward smaller classes of patches, increased edge density and perimeter area ratios, and other factors. The difference in mean patch size was approximately two-fold, decreasing from 20 ha in the 1930s data set to 10-12 ha in the later data sets. Understanding presettlement disturbance patterns and postsettlement changes in landscape pattern provides land managers with information on the potential of the forest to provide coarse and fine-grained spatial structures. Since these patterns vary by ecological subsection, there is an opportunity to tailor forest management plans to best reflect the varying potentials of the landscape.

Keywords: spatial analysis, landscape pattern, Minnesota forests, edge density, forest management

Introduction

The spatial arrangement, age structure, and species composition of forest patches have significant implications for maintaining the sustainability and integrity of forest ecosystems. The amount of edge, size of forest interior patches, and adjacency of forest types are among many factors that contribute to the survival or decline of numerous forest-dwelling plant and animal species. While forest fragmentation historically addresses cover type changes from forest to agricultural or urban land use, the changes in patch structure within a forested matrix, such as the forest landscape of northern Minnesota, may equally affect native wildlife populations.

In the early 1990's, the State of Minnesota, under recommendation from the Environmental Quality Board, commissioned a Generic Environmental Impact Study (GEIS) to assess the collective effects of simultaneous mill expansions, and thus increased timber demand, on numerous forest attributes, such as forest and soil productivity, wildlife, biodiversity, economics, and other factors (Poyry 1994). The study lead to the formation of the GEIS Implementation Strategy Roundtable, which generated a series of plans for implementing GEIS recommendations, and ultimately the passage of the Minnesota's 1994 Sustainable Forest Resources Act. One of the key recommendations of the Roundtable was the need to conduct a spatial analysis of Minnesota forest landscapes to understand historic changes and future trends in forest spatial patterns. The present study reports on the first part of this mission: an assessment of trends in spatial pattern based on trend analysis of historic aerial photographs. Companion studies report on patterns of disturbance in the presettlement forest (White and Host 2003) and future spatial patterns derived from simulation modeling (Frelich et al. 2003) and linear programming (Hoganson et al. 2003).

In this analysis, we present a set of core landscape metrics for forested lands in two ecological sections of northern Minnesota: the Northern Superior Uplands and the Drift and Lake Plains. Sample plots were stratified across ecological subsections, which are defined by variations in climate and landform, and thus provide some information on the underlying spatial structure of the landscape as imposed by differences in physiographic and soil conditions (Host et al. 1996). Metrics were selected to represent the range of descriptors commonly used in landscape analyses (Crow et al. 1999, Gustafson 1998) that cover different aspects of spatial pattern (Fuller, 2001, Ritters et al. 1995). Moreover, these descriptors have been shown in the literature to relate to viability of plant and animal communities (e.g., McIntyre 1995, Trzcinski et al. 1999). These metrics include indices of patch area, shape complexity, edge density, relationships across spatial scales, and forest interior habitat. While indices are often highly correlated (e.g., edge density and mean patch area), we attempted to include indices from groups that are relatively orthogonal (i.e., uncorrelated) with each other, *sensu* Ritters et al. 1995. These groups include perimeter/area metrics, patch shape complexity, diversity of attribute classes, and scaling relationships.

Methods

Study design

Historical trends in landscape spatial patterns were assessed in 42 plots distributed across the Northern Superior Uplands and Drift and Lake Plains Sections of Northern Minnesota (Figure 1). Sample plots, which were 9 mi^2 or 144 mi^2 for airphoto and line note analyses, respectively, were allocated within ecological subsections proportionately by size, with a minimum of four plots per subsection. To randomize plot locations, we generated 1000 random pairs of XY coordinates using the uniform distribution, based on the bounding rectangle of the Drift and Lake Plains (DLP) and Northern Superior Uplands (NSU) Ecological Sections. Three by three-mile sample polygons were generated from each random XY pair. Polygons were then clipped to the NSU-DLP boundary, resulting in an initial set of 377 polygons across both sections. Polygons that were greater than or equal to 50% water or less than 75% within one subsection were excluded from the selection, reducing the candidate pool to 311 plots.

Because the companion Government Land Office line note sample plots consist of four townships surrounding each aerial photo plot, plot boundaries had to be separated by at least 12 miles (White and Host 2003). We applied a Vornoi tessellation (ESRI 2002) to the original set of random samples using a 12-mile minimum distance. This produced a set of polygons in which the minimum distance between polygons is 12 miles. The 12-mile distance limit resulted in a final set of 66 potential plots distributed across the NSU and DLP. The 42 plots used in the study were selected at random from this pool, with the additional constraint that the aerial photographs were available.

Airphoto Analyses

Aerial photographs from the 1930s, 1970s and 1990s were interpreted and used to assess post-settlement changes in landscape pattern. Plots for the air photo analysis were nine square miles (quarter-townships) in area, and were centered within the presettlement plots (White and Host 2003). The total sample area for the study was 97,900 ha. Landscape patches were classified according to forest or land cover type, growth stage, and, when possible, type of originating disturbance. The landscape patches analyzed below were defined by two factors. First, we created an aggregated "Anderson Level II" land and forest type classification (Table 1). The 'unknown regeneration' class was used to identify forest patches that were occupied by regenerating forest, but could not yet be identified by forest type – this was common in many of the 1930s photographs. The forested land classes in this Anderson II classification were further modified by growth stage. The growth stages follow Oliver (1981), as modified by Frelich (2002) for the cold-temperate southern boreal transition zone that characterizes northern Minnesota. This system recognizes four developmental stages following a stand-replacing disturbance. The Initiation (I) phase consists of a cohort of seedlings, sprouts or advance regeneration immediately after disturbance. In the Stem Exclusion (C) phase, the dominant cohort forms a continuous closed canopy – a phase characterized by densitydependent mortality. We combined two late-successional stages – the Demographic Transition phase, which describes forests beginning to develop canopy gaps and develop multiple cohorts, and a Multi-aged stage that describes forests with multiple age and size classes (Frelich 2002). These classes were combined because we believe they were difficult to differentiate in the historical air photos. In the plates and figures that describe growth stages, non-forest types are represented by the symbol 'O'. All landscape metrics presented below are based on patches defined in terms of growth stages crossed with the 12 Anderson II cover type classes.

Photointerpreted cover types and growth stages for the 1930's, 1970's and 1990's were digitized into an ArcView GIS database (ESRI 2002). Landscape metrics were calculated either by direct analysis of GIS data, or using the spatial analysis program APACK, (Boeder et al.1995). APACK was originally developed to process output from LANDIS, a model designed to simulate changes in landscape spatial patterns under natural and anthropogenic disturbances (Mladenoff et al. 1996). APACK was used to calculate most of the patch-related landscape descriptors, including edge density statistics, patch shape indices, contagion, and others.

APACK operates on a rasterized (gridded) landscape – we converted the ArcView polygon coverage to a 10 m grid, a resolution that effectively preserved patch boundaries while maintaining reasonable file sizes and processing times. Instruction sequences describing the desired metrics and outputs were coded into batch files and run for all subsections. Direct analyses of the GIS database were used to calculate means and distributional statistics for patch size and interior forest area, as well as information on composition shifts by cover type and aggregated classification units. Outputs were summarized in Excel in graphic and tabular form. Data were summarized at several scales, including both Ecological Section and Subsections, and by individual or Anderson Level II cover types. Several analyses, such as the core area analyses, were based on this latter cover type classification.

Results

Forest Composition

There were no strong overall shifts in forest composition from the 1930's to the 1990s. Upland hardwoods and upland mixed forest were the dominant cover types in all time periods, both increasing slightly from 1930 to 1990 (Figure 2). The spike in upland hardwoods in the 1970s is likely due to lands classified as 'unknown regeneration' in the 1930s moving into this category. Lowland grasses and lowland conifers were other dominant categories, both changing less than 2% in area over the time interval. Agriculture declined by 2% between the 30s and 90s.

As shown in our previous Landsat-based analysis (Host and White, 2002), forest composition widely varied across subsections. The Tamarack Lowlands, Pine Moraines, and other subsections of the Drift and Lake Plains had significant proportions of agriculture, which was relatively uncommon in the Northern Superior Uplands. The proportions of lowland conifers also varied widely as a function of the dominant topography of the subsection. Subsection-level details on cover class composition and mean patch size by cover type and subsection are presented in Appendix A.

Patch size

Over the landscape as a whole, average patch sizes (defined by forest/land cover type and growth stage) showed a sharp decrease from 19.7 ha in the 1930 data set to 12.7 ha in the 1970 and 1990 data sets. This trend was particularly strong in the Northern Superior Uplands, where mean 1930 patch sizes ranged from 19.6 to 23.0 ha, compared with 10.0 to 14.6 for the later data sets (Figure 3). In the Drift and Lake Plains Section, the Tamarack Lowlands had the largest average patch size observed in the study – 28.2 ha in 1930; these declined to 16.8 and 17.6 ha in the 1970s and 1990s, respectively (Figure 4). The Pine Moraines and Outwash Plains subsection showed a less pronounced trend, declining from 17.1 ha in 1930 to 13.1 ha in 1990.

In terms of forest cover, the upland forest categories (hardwood, mixed, and unknown regeneration) had the highest mean patch sizes (Figure 5a; Appendix A). Of these, the upland mixed forest of the NSU in the 1930's had the greatest average patch size, exceeding 40 ha. This dropped sharply to 15 ha in the 1970's and increased to 18 ha in the 1990s. Unknown regeneration in the DLP showed a similar sharp decrease in patch size between 1930 and 1970; as noted above, the net amount of this category decreased in this time period as well (Figure 5b, Appendix A).

Only one land use type showed a consistent increase in mean patch size from 1930 to 1990 – agriculture in the DLP increased from 29 ha to approximately 40 ha in this time period (Figure 5b).

Plates 1-7 provide a visual display of the trends in patch size over time for representative subsections. In many cases, 2-3 single large patches dominate the image – these become progressively divided with continued harvesting, road development, settlement, and natural disturbances.

Patch size distribution

The decrease in patch sizes corresponded to an increase in the numbers of patches within the same unit area, from the 4975 patches found in the 1930 data set to 7695 and 7690 patches in the 1970 and 1990 data sets, respectively. In terms of patch size distribution, a strong increase from 1930 occurred in the smaller patch size classes; primarily in patches that were 16 ha or less in area (Figure 6). There were almost twice as many patches in the 8 ha size class in 1990 compared with 1930. Differences between 1970 and 1990 were not as extreme, but the 1970's showed more patches in the smallest size classes (1-2 ha), whereas the 1990s had more patches in the 4-32 ha size class.

Interior Forest Area

Interior forest area was calculated by subtracting a 100 m buffer from each forested polygon and determining the remaining area. As noted above, interior areas were summarized by the combined forest cover/growth stage patches. Approximately 14% of the forested landscape (excluding grasslands, agriculture, water, developed, and other categories) was classified as interior forest in 1930. This amount decreased to approximately 9% of the landscape in the 1970 and 1990 data sets.

Most of the interior forest area, as well as the largest area-based declines in forest interior occurred in the upland hardwood and upland mixed categories, which lost 577 and 1640 ha respectively (Figure 7). There was also a large drop in the unknown regeneration interior space between 1930 and 1970, but much of this was due to these lands becoming classified forest types in the later surveys.

Edge Density

Edge density is defined as the length of edge per unit area, where edge is defined as the boundary between two different patches. As noted above, we defined patches in terms of both composition and growth stage, so that the border between a regenerating aspen forest and a closed canopy aspen forest is counted as edge. Edge densities increased across all subsections, from a 15% increase in the Border Lakes to 37% increases in the Laurentian and Toimi Uplands and North Shore Highlands. Edge densities in the 1930s data set ranged from 66 to 97 m/ha, while densities in the 1990s data set 88 to 122 m/ha (Figure 8). The Tamarack Lowlands had the lowest overall edge density, the Chippewa Plains and the Laurentian, Nashwauk and Toimi Uplands had the highest.

Perimeter Area Ratio

The Perimeter/Area Ratio is an index of patch shape complexity – more complex shapes have greater PA ratios. Four subsections (the Border lakes, Chippewa Plains, Laurentian Uplands and Pine Moraines) showed a trend toward an increased PA ratio from 1930 to the later time periods (Figure 9). The other subsections showed flat to slightly declining responses over time.

Fractal Dimension

The fractal dimension is a multiscale description of patch shape complexity, and scales between 1.0 and 2.0 for two-dimensional objects (e.g., map polygons). Higher fractal dimensions indicate more complex polygons – this metric is typically correlated with edge density. In addition, high fractal dimensions tend to be negatively associated with interior space, as a convoluted or complex edge structure tends to reduce the amount of area that is a specified distance from the edge. The Tamarack Lowlands stood out has having the lowest fractal dimensions among all subsections in all time periods (Figure 10). In all cases, fractal dimensions increased from 1930 to1990, although the Laurentian Uplands and North Shore Highlands, fractal dimension values were higher in the 1970s data sets.

Shannon-Weaver Index

The Shannon-Weaver Index integrates the number and the relative proportions of patch types in an area to provide a single index of landscape compositional diversity. Eight of the nine subsections showed slight to moderate increases in the Shannon index; the greatest changes, 12 and 11%, occurred in the Laurentian Uplands and the North Shore Highlands, respectively (Figure 11). The Border Lakes showed a 10% decrease between 1930 and 1990, reflecting the increased dominance of the older upland mixed forest classes (the Shannon index decreases as individual classes become more dominant).

Contagion (Li's relative)

Contagion measures the degree to which cover classes are clumped into patches (Mladenoff and DeZonia, 2000). Li's relativized contagion index scales between 0.0 and 1.0, and is the ratio of the measured diversity of landscape relative to the maximum possible diversity. In this metric, diversity is expressed by the adjacency matrix.

The changes in contagion were relatively small, both over time and among subsections. The patterns of change over time follow that of the Shannon index: the Laurentian Uplands and the North Shore Highlands showed 11 and 9% decrease in contagion, respectively, and Border Lakes had a 9% increase (Figure 12). High contagion values indicate a landscape that tends to be made up of predominantly a few cover classes, whereas lower values represent landscapes made up of a larger number of classes relatively equal in proportion.

Angular Second Moment

Angular Second Moment (ASM) is metric derived from image processing, and provides a description of image texture, specifically the homogeneity of the image (Musik and Grover 1991). AMS also ranges between 0.0 and 1.0, where 0.0 reflects a landscape characterized by many cover types and little aggregation, and 1.0 would represent a single large homogeneous cover type. Like contagion, ASM is based on an analysis of the adjacency matrix based on the rasterized landscape.

ASM exhibited a broader range of variation than the contagion or Shannon indices. Nine of the ten subsections showed a trend toward increasing heterogeneity, with the Laurentian Uplands and North Shore Highlands showing the greatest increase in ASM (51 and 42%, respectively; Figure 13). As with other metrics, the Border Lakes showed an opposite trend, with a 9% increase in ASM, reflecting a trend toward greater homogeneity.

Aggregation Index

The Aggregation Index (AI) is a landscape or class-level metric that quantifies the total number of edges shared by a particular class, and avoids some of the problems associated with the shape index and other adjacency metrics (He et al. 2000). Specifically, resolves issues related to varied levels of aggregation, varied numbers of patches, or different spatial resolutions. AI ranges from 0.0 – 1.0, where an AI of 1.0 represents a class or landscape where the grid cells share the most possible edges. The landscape version of AI is an area-weighted sum of AI's of the individual classes (He et al. 2000).

The landscape aggregation index showed relatively little variation over time, or across subsections; the change from 1930 to 1990 was generally 2% or less (Figure 14). In most subsections, the trend was toward a less aggregated state; the Border Lakes again were an exception to this rule.

Discussion

The numerous landscape pattern metrics calculated in this study provide different lines of evidence for the same trend – that over a 60 year time span in the mid to late 1900's, there has been a widespread shift toward a more finely-divided landscape. This is evidenced in smaller average patch sizes, a greater patch density, a shift in the patch size distribution toward smaller classes of patches, increased edge density and perimeter area ratios, and other factors.

Forman and Boerner (1981) note that decreases in mean patch sizes occur with increased human activity, as the landscape becomes subdivided into smaller patches. While human settlement and land cover conversions from forest to non-forest uses are important contributors to change, the analyses above indicate that forest management activities are one of the dominant causes this reduction in patch sizes. Part of this is operational: timber is typically sold and harvested in relatively small blocks. Some common forest management policies in place over this time period result in reduced patch sizes. The long-standing policy of adjacency constraints, which are spatial restrictions that preclude harvest in forest stands adjacent to those which have been recently harvested (generally 10-15 years), has a net effect of creating a more fine-grained landscape in terms of age-class and potentially compositional diversity.

Other common forest management practices, such as delineating stand maps and planning silvicultural activities around these maps, further contribute to smaller patch sizes. Roads are often used as stand or compartment boundaries. There is evidence from several plots that a forest type that spans a road is often subdivided into separate stands on either side of the road, and the managed differently (Plates 4,5, and 7).

While the trends in forest spatial patterns were strong, the compositional effects were not; there were few strong changes in forest cover types between the 1930s and 1990s. There is a well-documented effect on the shift from a conifer dominated landscape to one more strongly dominated by deciduous species, but this transition occurred during the major logging that occurred at the turn of the century (Williams 1989, Whitney 1987). The 1930s landscape had extensive areas of ‘unknown regeneration’, much of which became mixed hardwoods in the latter data sets. Similarly, there were no strong shifts in the relative proportions of age classes over this time period.

There are two interesting attributes of the trends. First, in most cases, the change from the 1930s to the 1970s was much greater than the change from the 1970s to the 1990s. A number of factors may contribute to this. This is due in part to the somewhat longer time interval between the 30s and 70s (although most of the photographs were taken in the late 30s). Another key reason is that the 1930s landscape represents the state of the forests as they were responding to the previously mentioned large-scale logging at the turn of the century. These extensive harvests were followed by slash fires that further created a series of relatively large, even-aged patches on the landscape (Frelich 2002). A third reason for the smaller changes from the 70s to the 90s was that by this time many stand and compartment lines had been drawn, and forests are managed on a stand – by –stand basis. Consequently, a more persistent patch structure had been established, which would reduce the rate of change imposed by forest management (but not by disturbance, land conversion, or the other agents of landscape change).

A second trend was that many of the metrics showed a non-monotonic response over the three time periods – often metrics from the 1970s were higher or lower than the 1930 and 1990s. This is true of patch sizes in the smallest size classes, as well as edge densities and fractal dimensions in several subsections (Border Lakes, Laurentian Uplands, Tamarack Lowlands and Toimi Uplands). While the three time periods used in this study is insufficient to clearly map this trend, this provides some evidence that after the 1970s, there was a reversal of certain trends in landscape pattern.

There are a number of caveats to be considered in interpreting this data. A primary consideration is the inherent error in mapping forest cover types on historic aerial photography. We attempted to overcome this limitation by using relatively broad categories for classifying cover types and growth stage classes. The selection of the cover classes, in fact, was done specifically by the Spatial Analysis Technical Team to balance the resolution needed for the study with what the team believed to be interpretable from older aerial photography. An independent inspection of the mapped types by SA Technical Team member Bill Befort of the MN Dept. of Natural Resources reported that the mapping was as good as could be expected from the data (B. Befort, personal communication).

A second potential source of error is in the relatively small size of the photointerpreted plots relative to the scale of landscape patches. While natural disturbances, particularly fire, occurred over extensive areas in the presettlement forest (White and Host 2003), the patterns produced by forest management are relatively fine-scale, typically not exceeding 60 ac. The 5760 ac size of individual the analysis plots is therefore a reasonable size to quantify the fine-scale effects of forest management, development and other human activities on landscape pattern.

Data errors in the project were minimized; strict quality control procedures were in place for both the photointerpretation and analytical phases of the project. We carefully the 128 GIS coverages for coding errors prior to submitting them to APACK or other analyses. The APACK program itself is an established and widely used program; we feel there is little chance for computational error in the program.

The study has a number of implications for ongoing forest management. We have shown that there have been large changes in landscape patterns over the course of the century, and, in conjunction with the companion report on presettlement patterns, large differences in scale between natural and human-induced patterns in the landscape. The fundamental trend has been toward smaller patch sizes, with an increase in the amount of edge in the landscape and a reduction in the overall area of interior forest conditions. But the analyses also show that the subsections show some variation in their response. The Border Lakes subsection, which includes plots both inside and outside the Boundary Waters Canoe Area Wilderness, showed an opposite trend in several metrics. The Tamarack Lowlands also stood out as having larger patch sizes and lower edge densities than other subsections. As in our previous analysis based on satellite photography across the entire landscape (Host and White, 2002), there appear to be differences among subsections that have implications for forest management. Some subsections are innately fine-grained – the Pine and St. Louis Moraines, for example, had small patch sizes in all time periods. In developing forest management strategies, it is important to work with the innate structure of the landscape, which is primarily defined by the dominant physiography and soils that define landscape units (Host and White 2002, Host et al, 1996). A 'one size fits all' approach (e.g. blanket strategies to create more large patches ore more edge), will not work in the physiographically diverse landscape of northern Minnesota. Using ecological stratifications at an appropriate spatial scale (Landtype Phase, Landtype Association, or minimally, Subsections) would greatly improve the ability of management plans to work in concert with the existing potential of the landscape.

Summary

The numerous landscape pattern metrics calculated in this study provide different lines of evidence for the same trend – that over a 60 year time span in the mid to late 1900's, there has been a widespread shift toward a more finely-divided landscape.

This is evidenced by:

- smaller average patch sizes –overall decrease from 20 to 13 ha
- a shift in the patch size distribution toward smaller classes of patches
- increased edge density, perimeter area ratios, and fractal dimension
- an overall decrease in the amount of interior forest condition (defined by a 100 m buffer), from 14% of the forested landscape in 1930 to 9% in 1990.

In most cases, the subsections showed similar trends over time. The Border Lakes subsection, however, was an exception – this subsection showed opposite trends in metrics related to compositional diversity and adjacency. The Shannon and Contagion indices, for example, both decreased in the Border Lakes, indicating a trend toward larger patch sizes and an increased dominance by individual cover types – in this case, an increase in older coniferous patches.

While the direction of trends was similar among subsections, the magnitude of trends often differed. The North Shore Highlands and Laurentian Uplands, for example, often exhibited greater range of change than other subsections. While the reasons for these differences are complex (differences in physiognomy or geomorphic complexity, different patterns of human activity, and interactions among these factors), the fact that this variability exists has implications for forest management – specifically that subsections should be treated separately, and the strategic plans should consider the unique attributes of each subsection.

Acknowledgements

This study was funded by the Minnesota Forest Resources Council through the MN Department of Natural Resources. The Spatial Analysis Project Technical Team provided invaluable support throughout the design and development process. The interpretation of historic and recent air photos was conducted by J.W. Sewall and Associates. Ms. Megan Forbes of the Natural Resources Research Institute provided technical support for data management.

Literature Cited

Boeder, J. E., Y. Xin, M. A. White, D. J. Mladenoff, and G. E. Host. Spatial Analysis Package (APACK): User's Guide and Technical Documentation. Natural Resources Research Institute, Duluth, MN. NRRI/TR-95/26:1-16, 1995.

Crow, T. R., G. E. Host, and D. J. Mladenoff. 1999. Ownership and ecosystem as sources of spatial heterogeneity in a forested landscape, Wisconsin, USA. Landscape Ecology 14:449-463.

Gustafson, E.J. 1998. Clustering timber harvests and the effect of dynamic forest management policy on forest fragmentation. Ecosystems 1:484-492.

ESRI, 2002. ArcView User's manual. Redmond, CA

Frelich, L. 2002. Forest Dynamics and Disturbance Regimes: Studies from Temperate Evergreen-Deciduous Forests. Cambridge University Press.

Frelich et al. 2003. Spatial Analysis technical report.

Forman, R. T. and R E. Boerner. 1981. Fire frequency and the Pine Barrens of New Jersey. Bull. Of the Torrey Botanical Club 108:34-50.

He, H. S., B. E. DelZonia, and D. J. Mladenoff. 2000. An aggregation index (AI) to quantify spatial patterns of landscapes. Landscape Ecology 15:591-601.

Hoganson et al. 2003. Spatial Analysis technical report.

Host and White 2002. Landscape composition and spatial metrics for the Northern Superior Upland and Drift and Lake Plains Sections of Northern Minnesota. NRRI Technical Report NRRI/TR-2002/21.

Host, G. E., P. L. Polzer, D. J. Mladenoff, M. A. White, and T. R. Crow. 1996. A quantitative approach to developing regional ecosystem classifications. Ecological Applications 6:608- 618.

McIntyre, N E. 1995. Effects of forest patch size on avian diversity. Landscape Ecology 10:85-99.

Mladenoff, D.J., G. E. Host, J.E. Boeder, and T.R. Crow. 1996. LANDIS: A spatial model of forest landscape disturbance, succession, and management. Pages 175-180 In: M. F. Goodchild, L. T. Steyaert, B. O. Parks, C. A. Johnston, D. Maidment, M. Crane, and S. Glendinning, editors. GIS and Environmental Modeling: Progress and Research Issues. GIS World Books, Fort Collins, CO.

Musik, H. M. and H. D. Grover. 1991. Image textural measures as indices of landscape pattern. In: (Turner, M.G. and R. H. Gardener, eds) Quantitative Methods in Landscape Ecology, Springer-Verlag, 536 p.

Oliver 1981. Forest development in North America following major disturbances. Forest Ecology and Management 3:153-168.

Poyry, J. 1994. Final Generic Environmental Impact Statement study on timber harvesting and forest management in Minnesota. Executive Summary. MN Environmental Quality Board, St. Paul, MN 57 p

Trzcinski, M. K., Fahrig, L., and Merriam, G. 1999. Independent effects of forest cover and fragmentation on the distribution of forest breeding birds. Ecological Applications 9:586-593.

White, M. A. and G. E. Host. 2003. Changes in disturbance frequency, age, and patch structure from pre-European to settlement to present in the Mixed Forest Province of Minnesota. Submitted to MN Forest Resources Council.

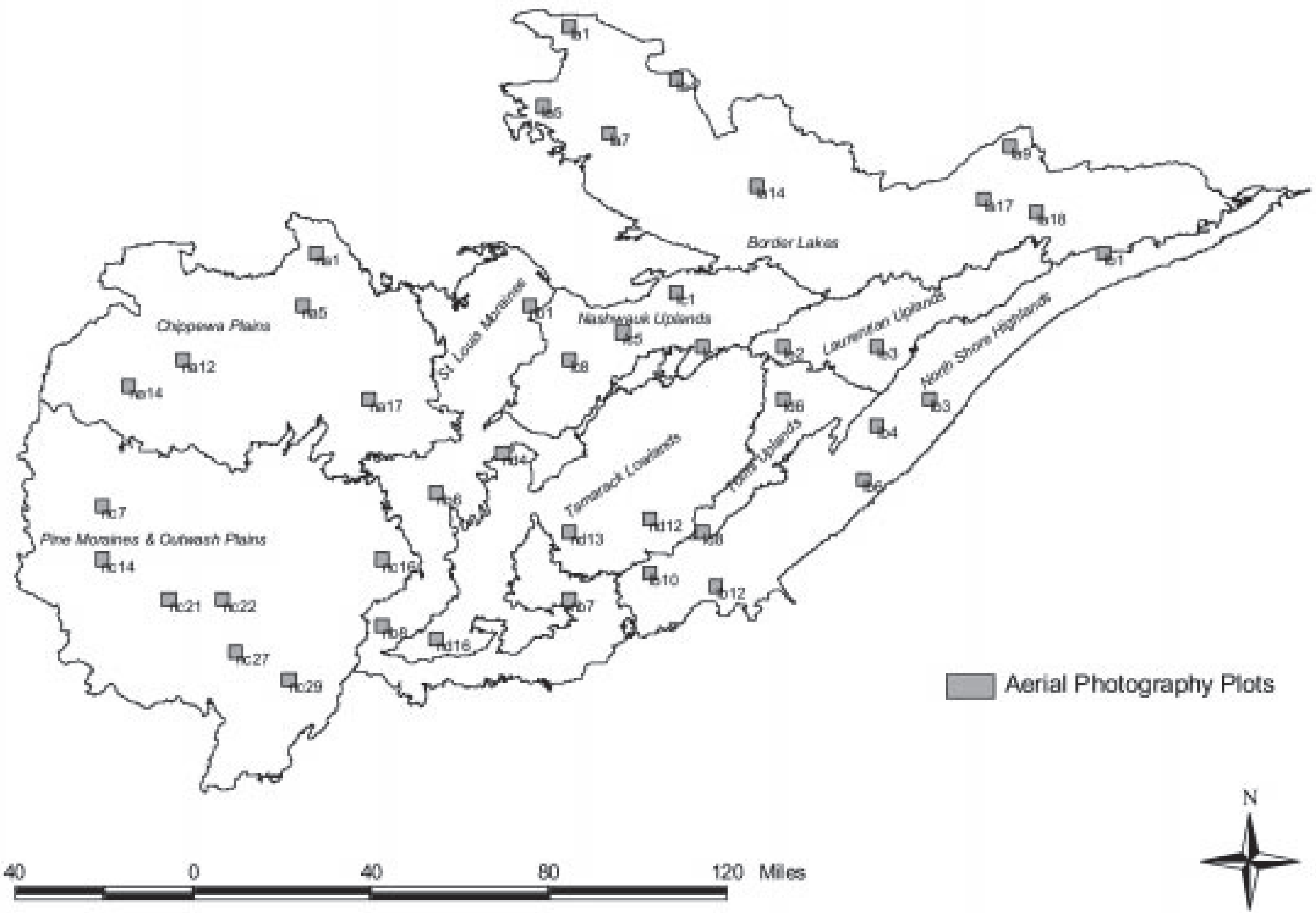
Whitney, G. G. 1987. An ecological history of the Great Lakes Forest of Michigan. J. of Ecology 75:667-684.

Williams, M. 1989. The lumberman’s assault on the forests of the Lake States, 1860-1890. In: Americans and Their Forests: A historical geography, Cambridge U. Press, pp 193-237.

Table 1. Airphoto interpretation cover type codes and cross-classification to aggregated classes.

Cover value	Class Code	Cover Type description	Anderson II Type	Anderson II Code	Anderson II Description
1	JP	Jack Pine	uc	1	upland conifer
2	PI	Red-White Pine	uc	1	upland conifer
3	SF	Spruce-Fir	uc	1	upland conifer
4	AS	Aspen	uh	2	upland hardwood
5	WB	Paper birch	uh	2	upland hardwood
7	NH	Northern Hardwood	uh	2	upland hardwood
6	MB	Aspen-Birch-Spruce-Fir	um	3	upland mixed
10	UM	Upland mixed hwd/con	um	3	upland mixed
8	LC	Lowland conifer	lc	4	lowland conifer
9	LH	Lowland hardwood	lm	5	lowland mixed
11	LM	Lowland mixed hwd/con	lm	5	lowland mixed
13	UR	Unknown regeneration	ur	6	unknown regen
14	UG	Upland grass	ug	7	upland grass/brush
15	UB	Upland brush	ug	7	upland grass/brush
16	LB	Lowland brush	lg	8	lowland grass/brush
17	LG	Lowland grass	lg	8	lowland grass/brush
18	SP	Sphagnum/emergent	lg	8	lowland grass/brush
19	AG	Agriculture	ag	9	agriculture
20	HD	High density dev.	dd	10	developed
21	LD	Low density dev.	dd	10	developed
22	WA	Water	wa	11	water
23	BA	Bare ground (barren)	ot	12	other
24	DH	Dead hardwood	ot	12	other
25	DC	Dead conifer	ot	12	other
26	NC	Not classified	ot	12	other

Figure 1. Aerial photography plot locations in the Northern Superior Uplands and Drift and Lake Plains.



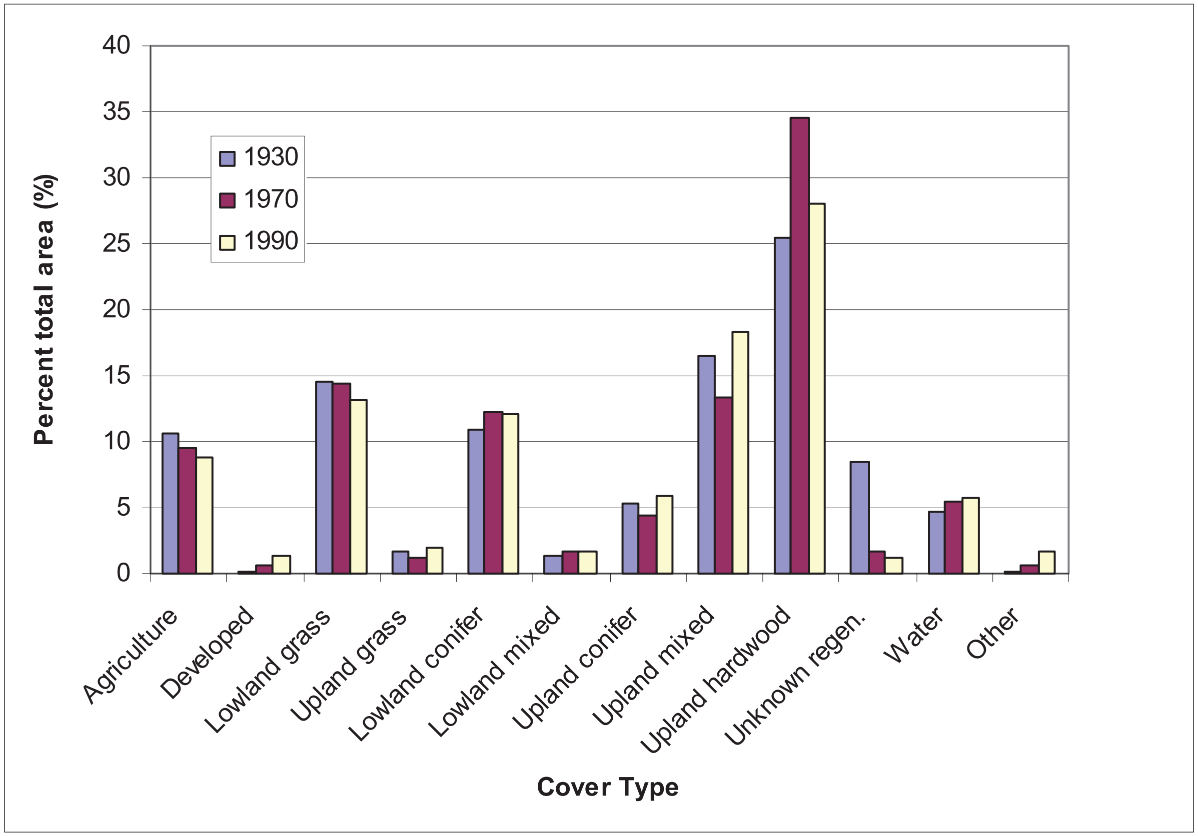


Figure 1 Proportions of forest and land cover classes for three time periods.

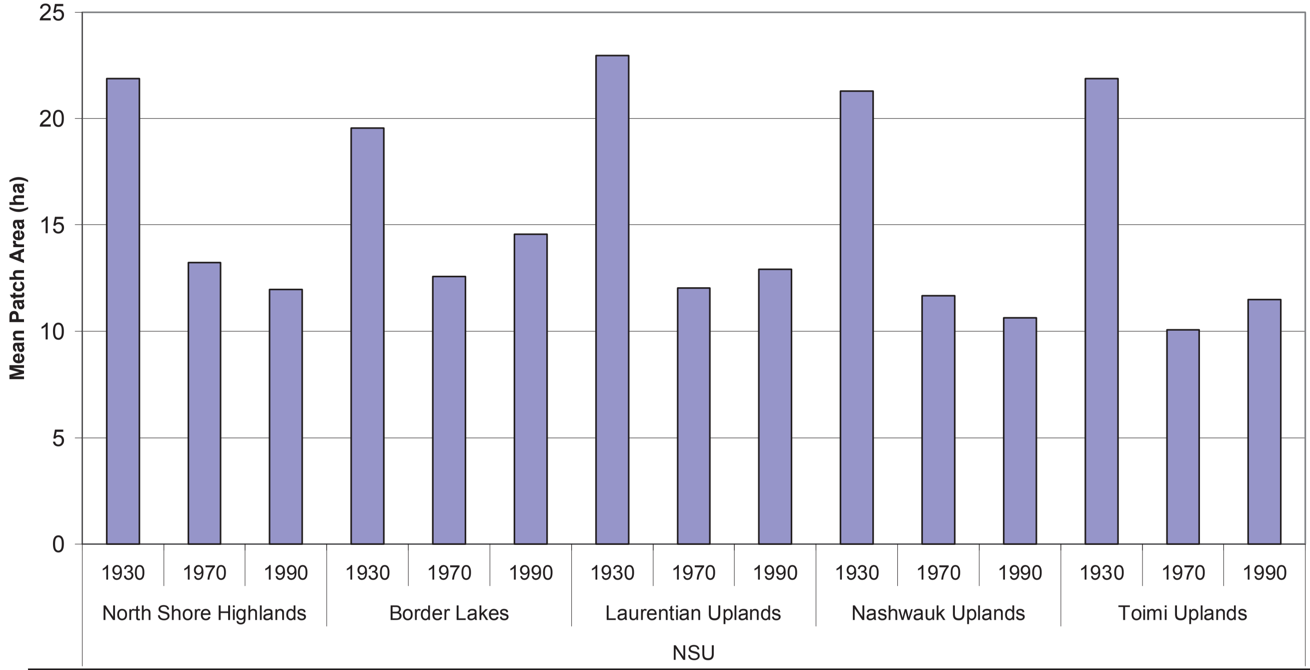


Figure 2 Mean patch size for subsections of the Northern Superior Uplands from 1930 to 1990

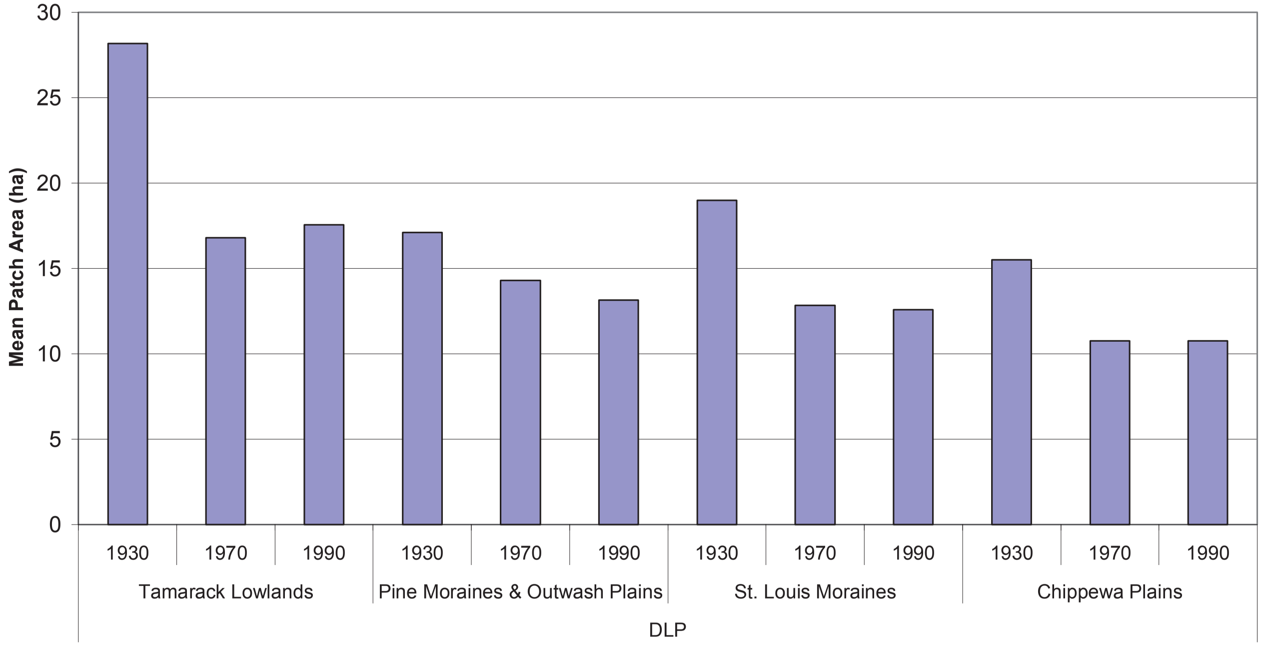


Figure 3 Mean patch size for subsections of the Drift and Lake Plains from 1930 to 1990

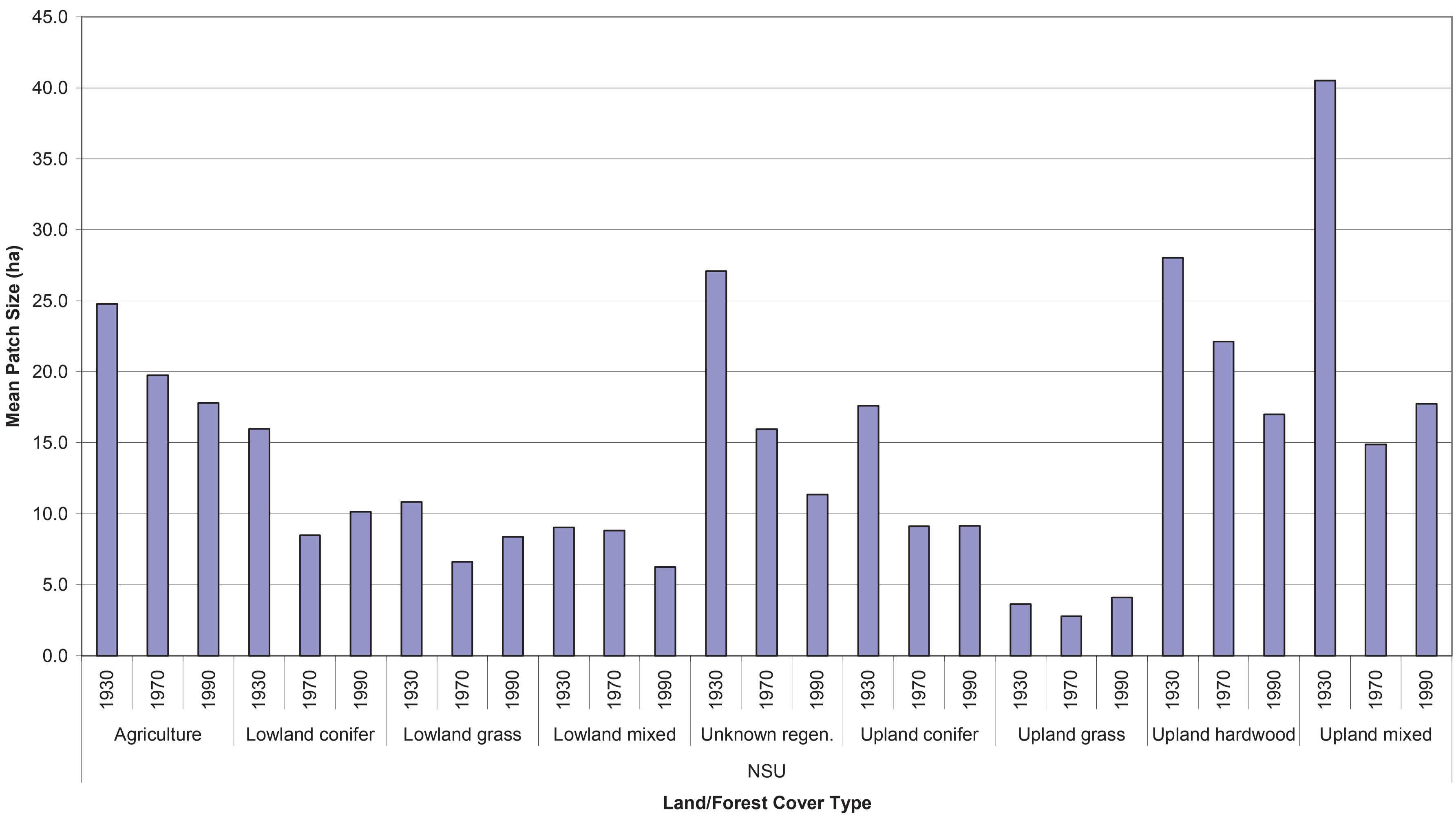


Figure 4a Mean patch size by land cover type (combined growth stages), Northern Superior Uplands

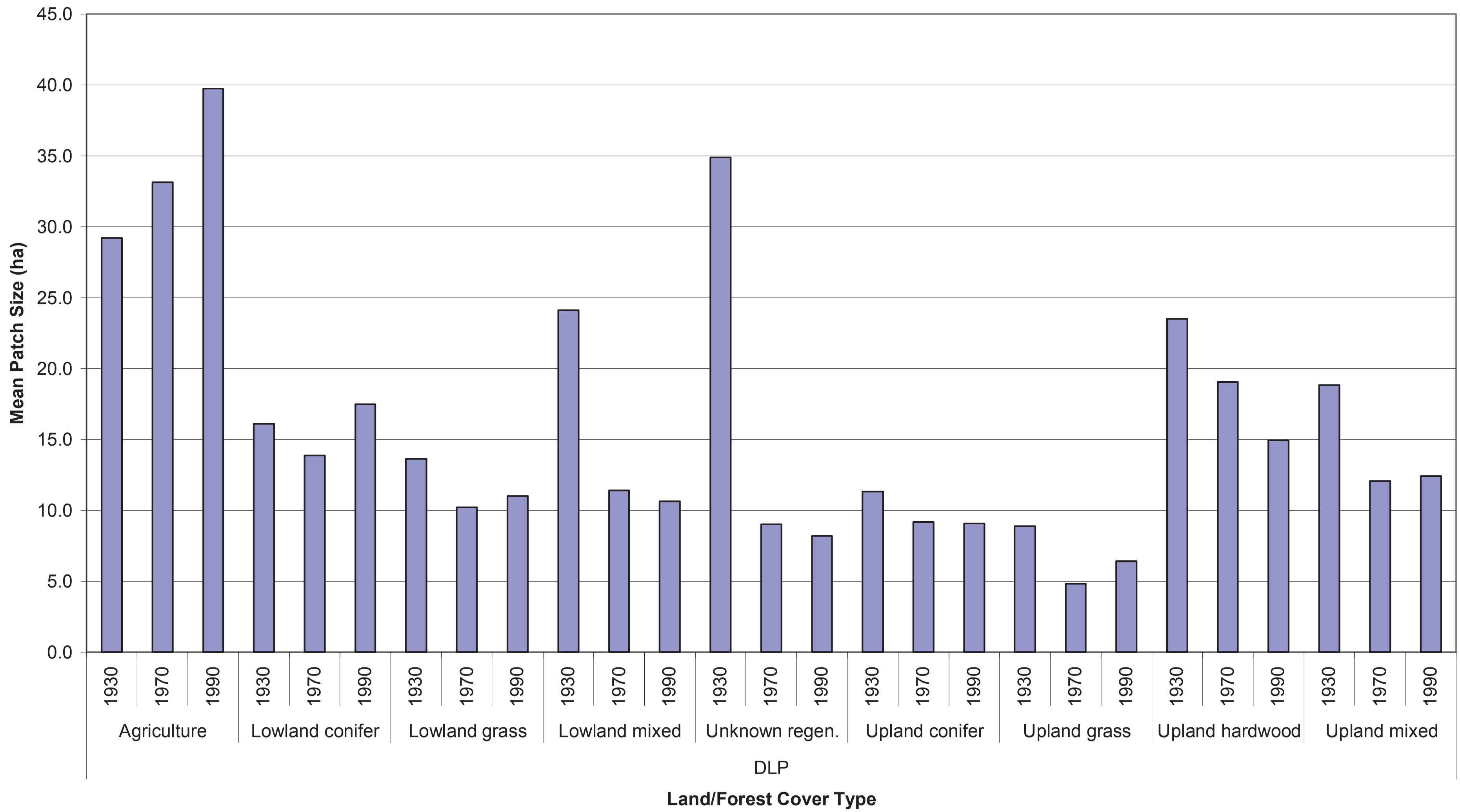


Figure 5b Mean patch size by land cover type (combined growth stages), Drift and Lake Plains

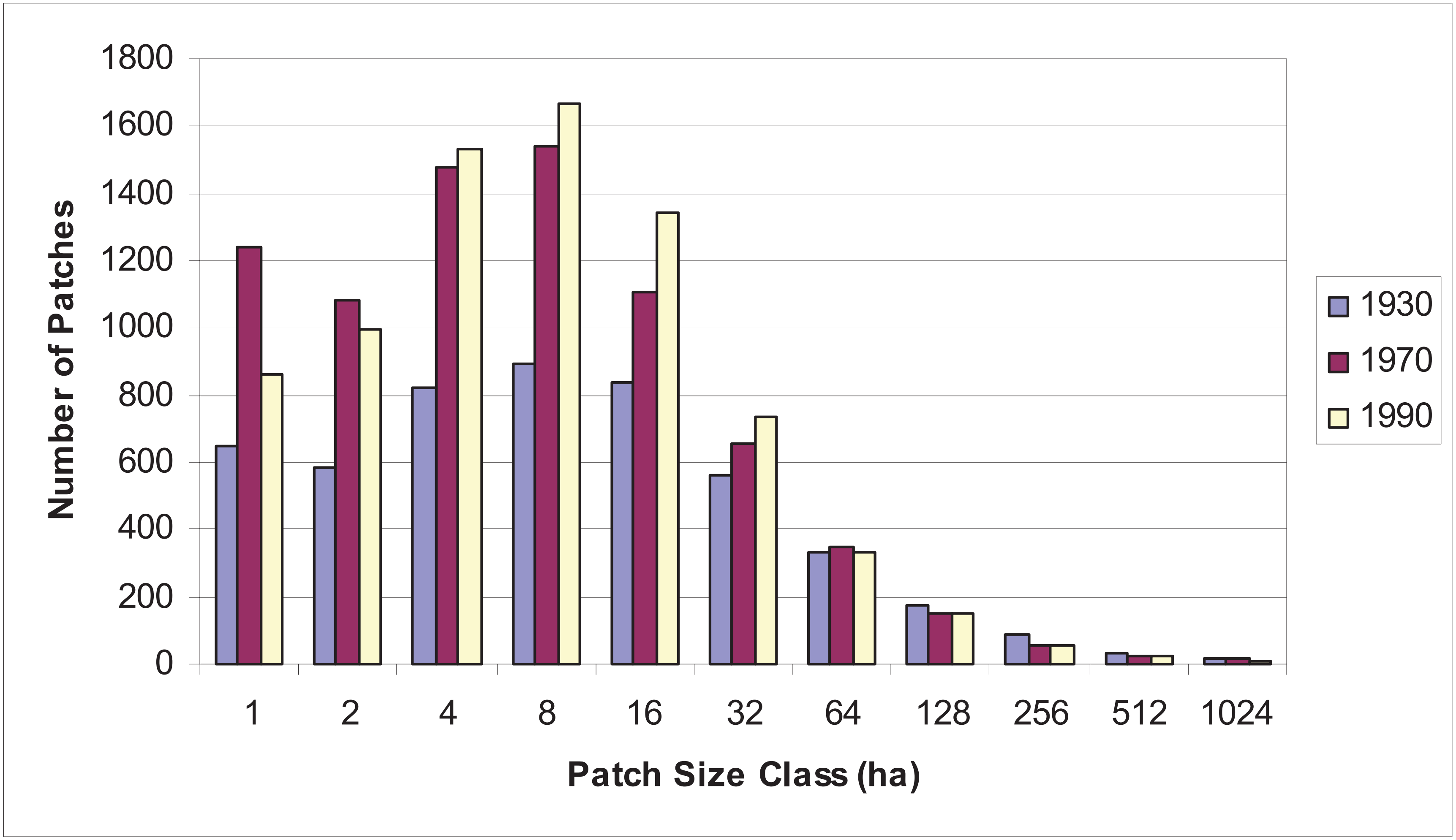


Figure 5 Patch frequency by size class, all subsections combined.

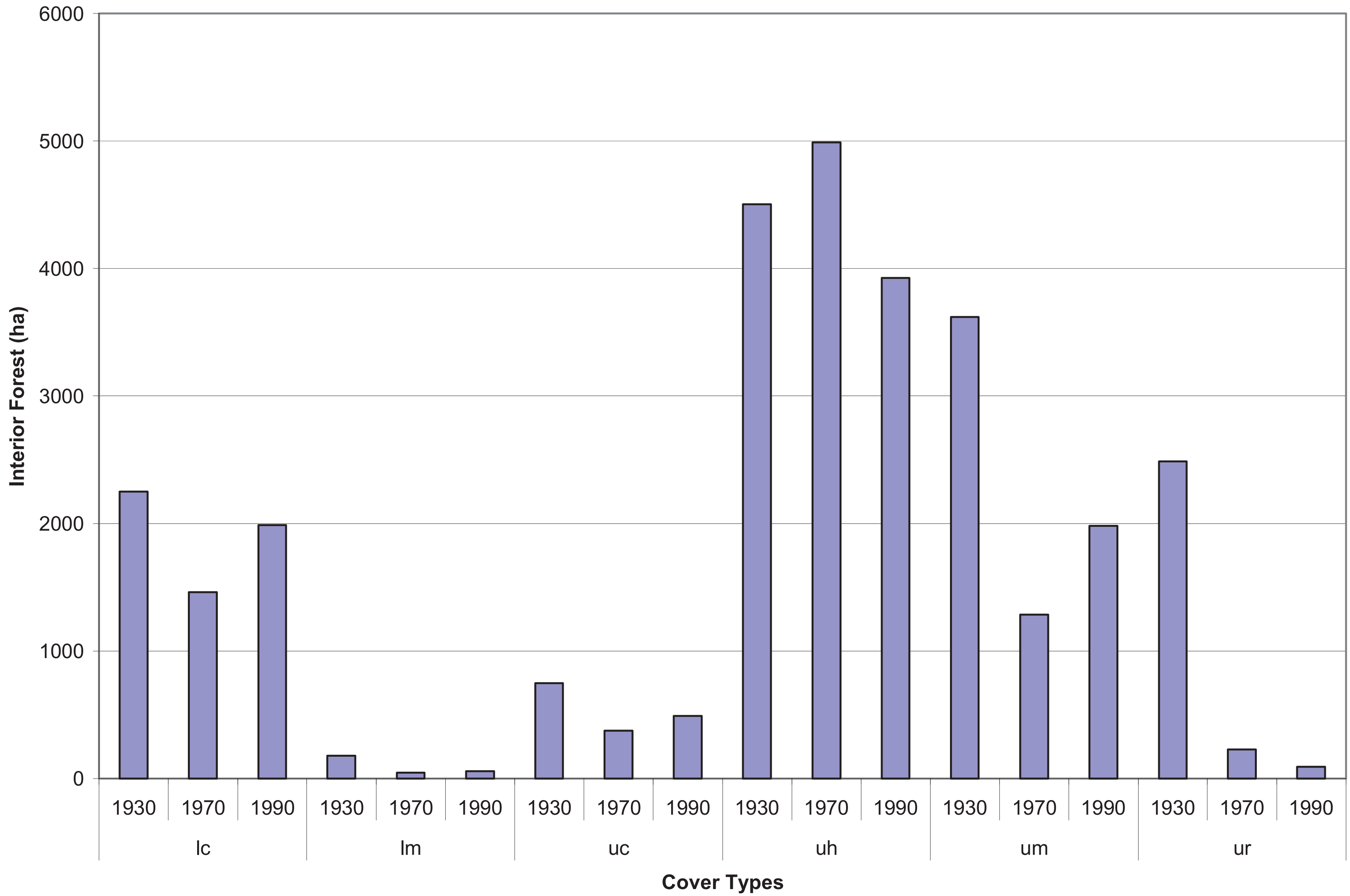


Figure 6 Total area in interior conditions by cover type, all subsections combined

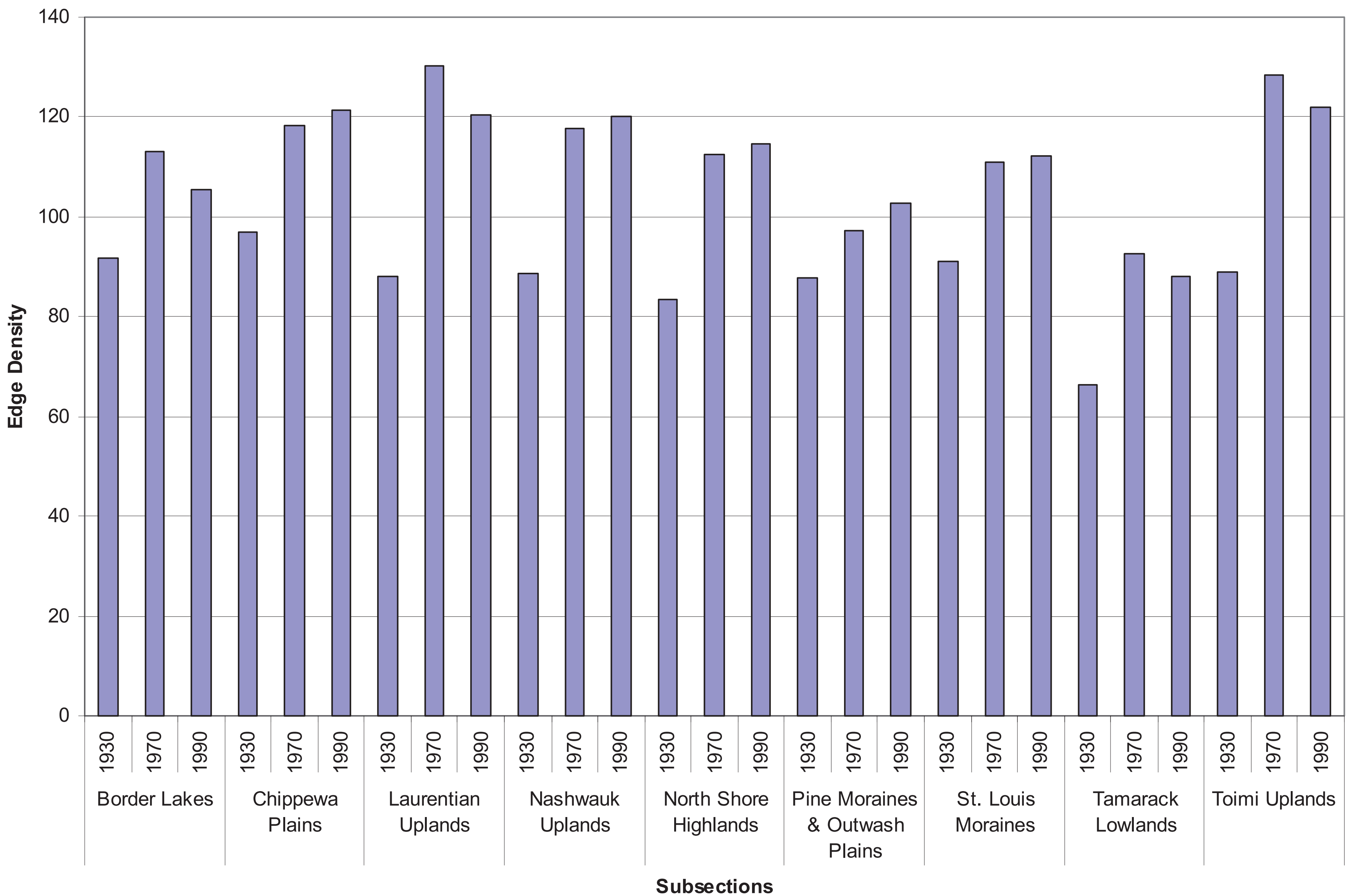


Figure 7 Edge density (m/ha) for ecological subsections of northern Minnesota from 1930 to 1990.

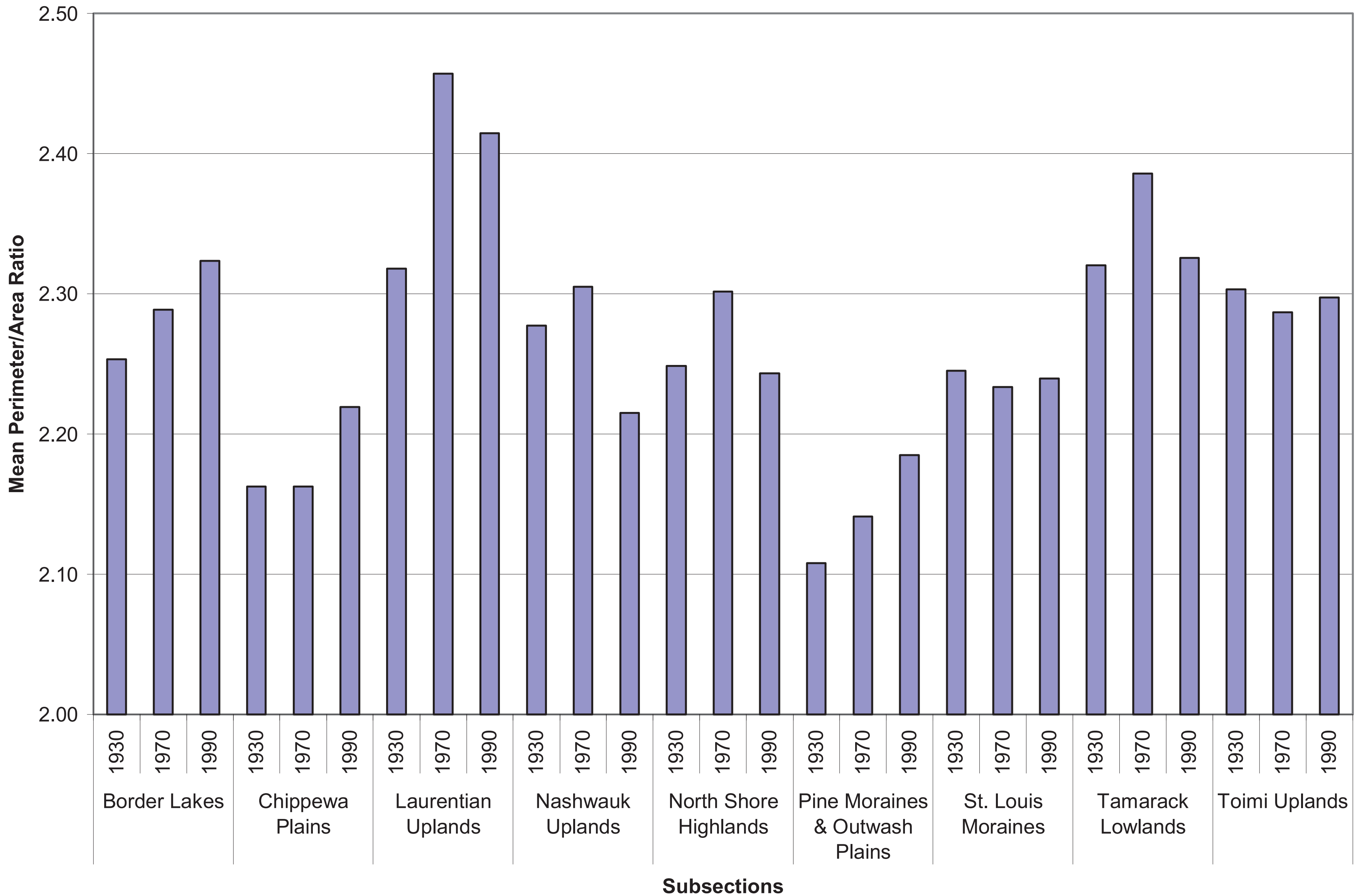


Figure 8 Mean perimeter/area ratio by subsection.

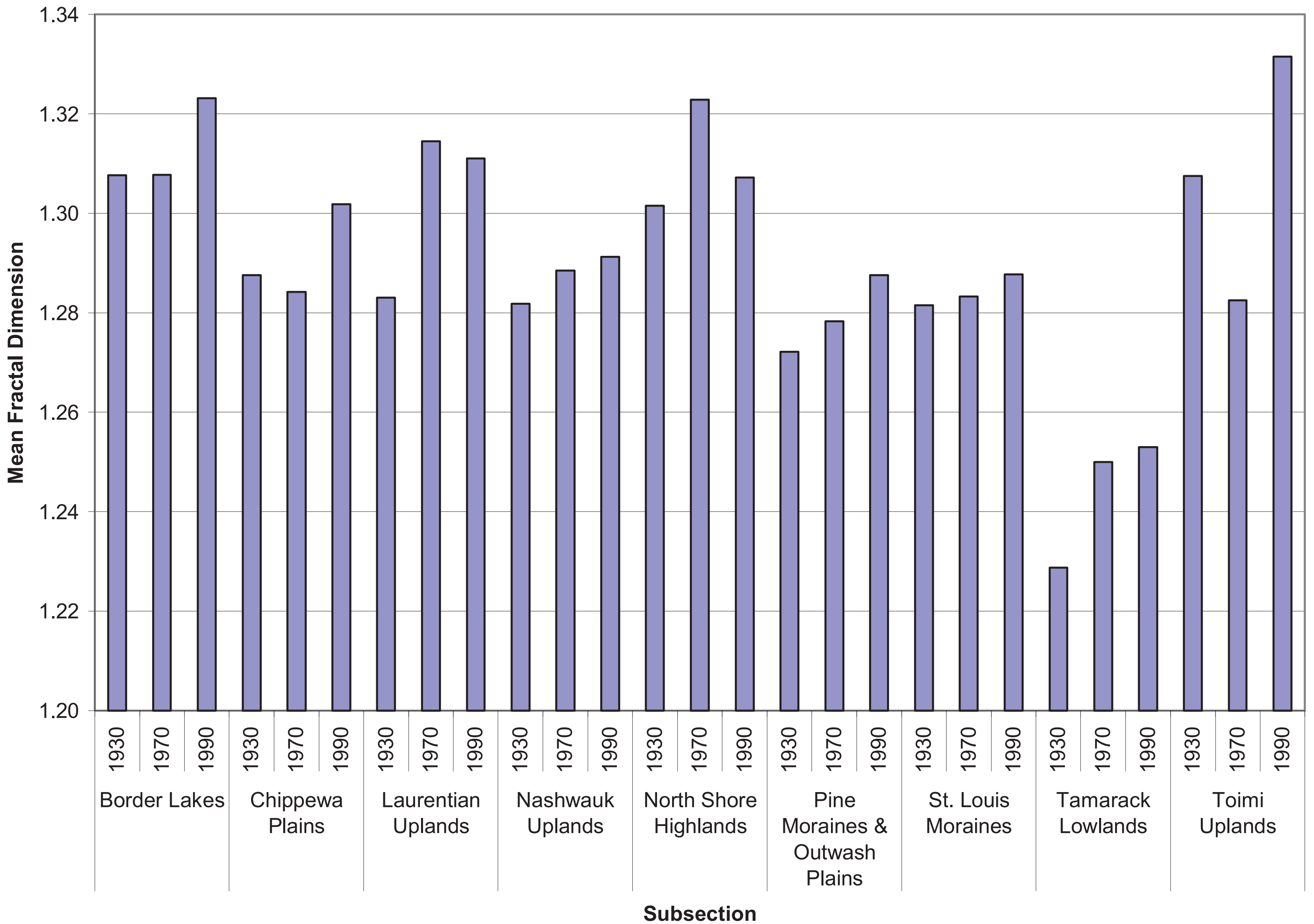


Figure 9 Mean fractal dimension for ecological subsections of northern Minnesota from 1930 to 1990.

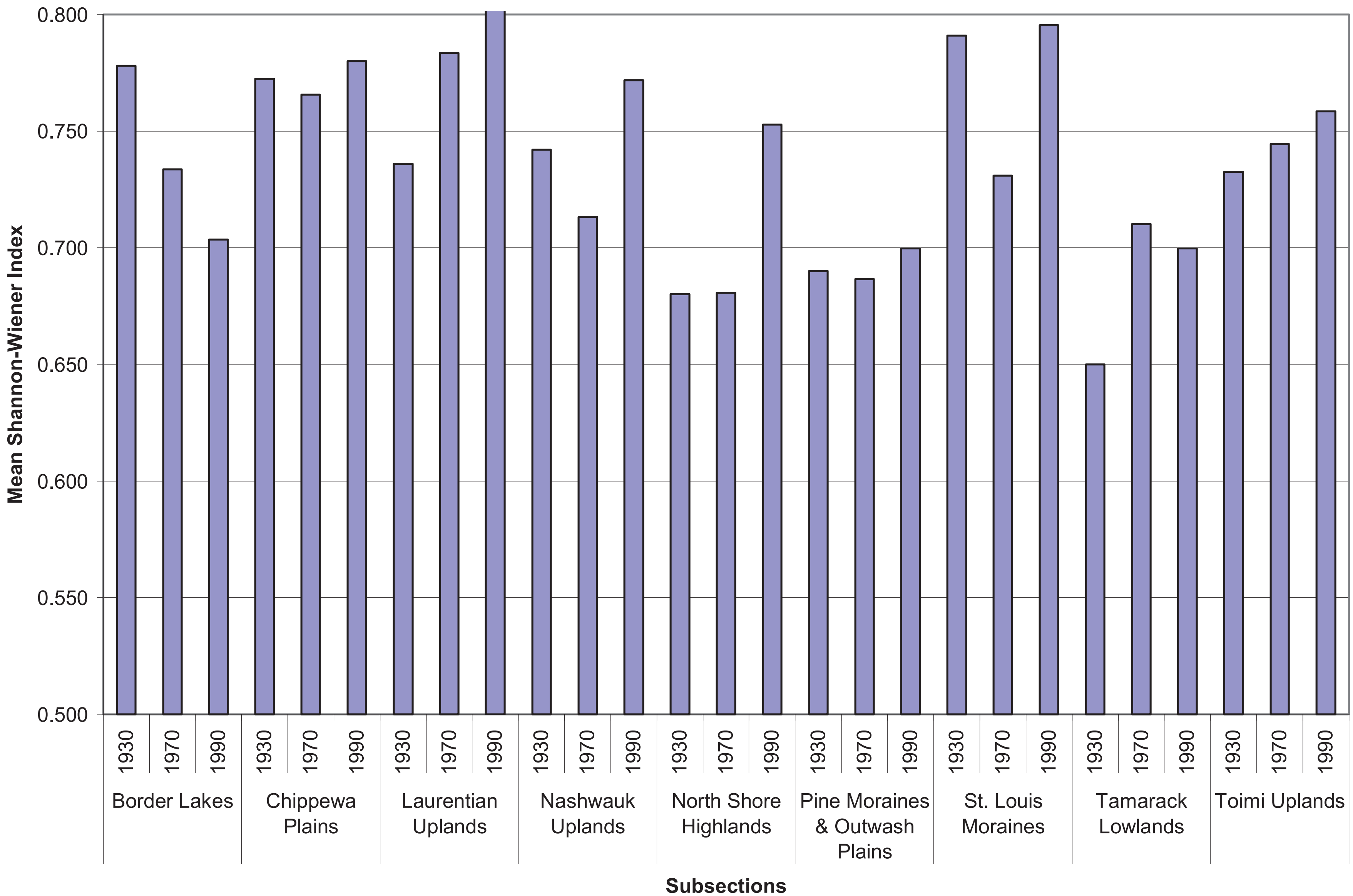


Figure 10 Mean Shannon-Weiner Index for ecological subsections of northern Minnesota from 1930 to 1990.

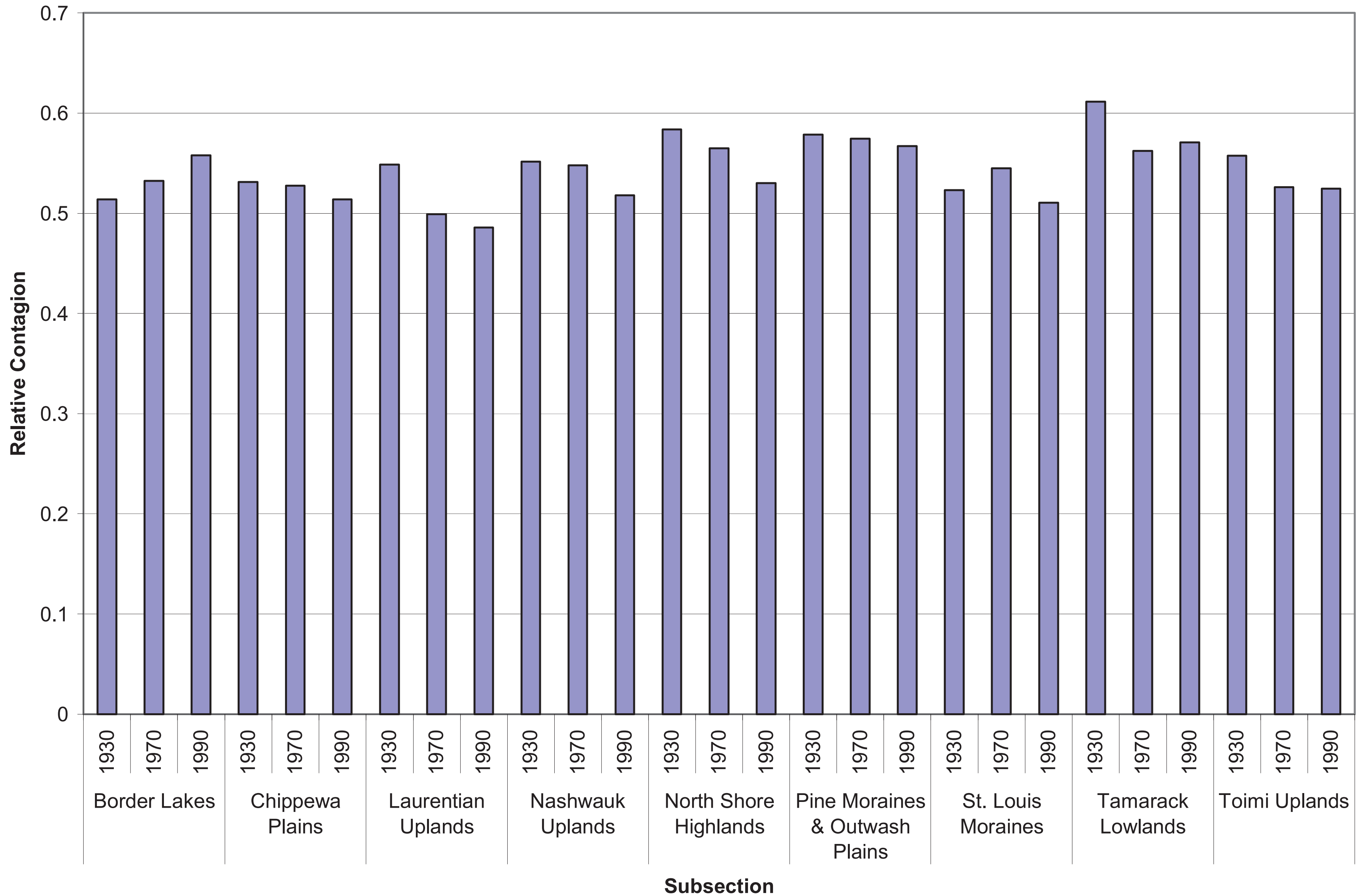


Figure 11 Mean relative contagion for ecological subsections of northern Minnesota from 1930 to 1990.

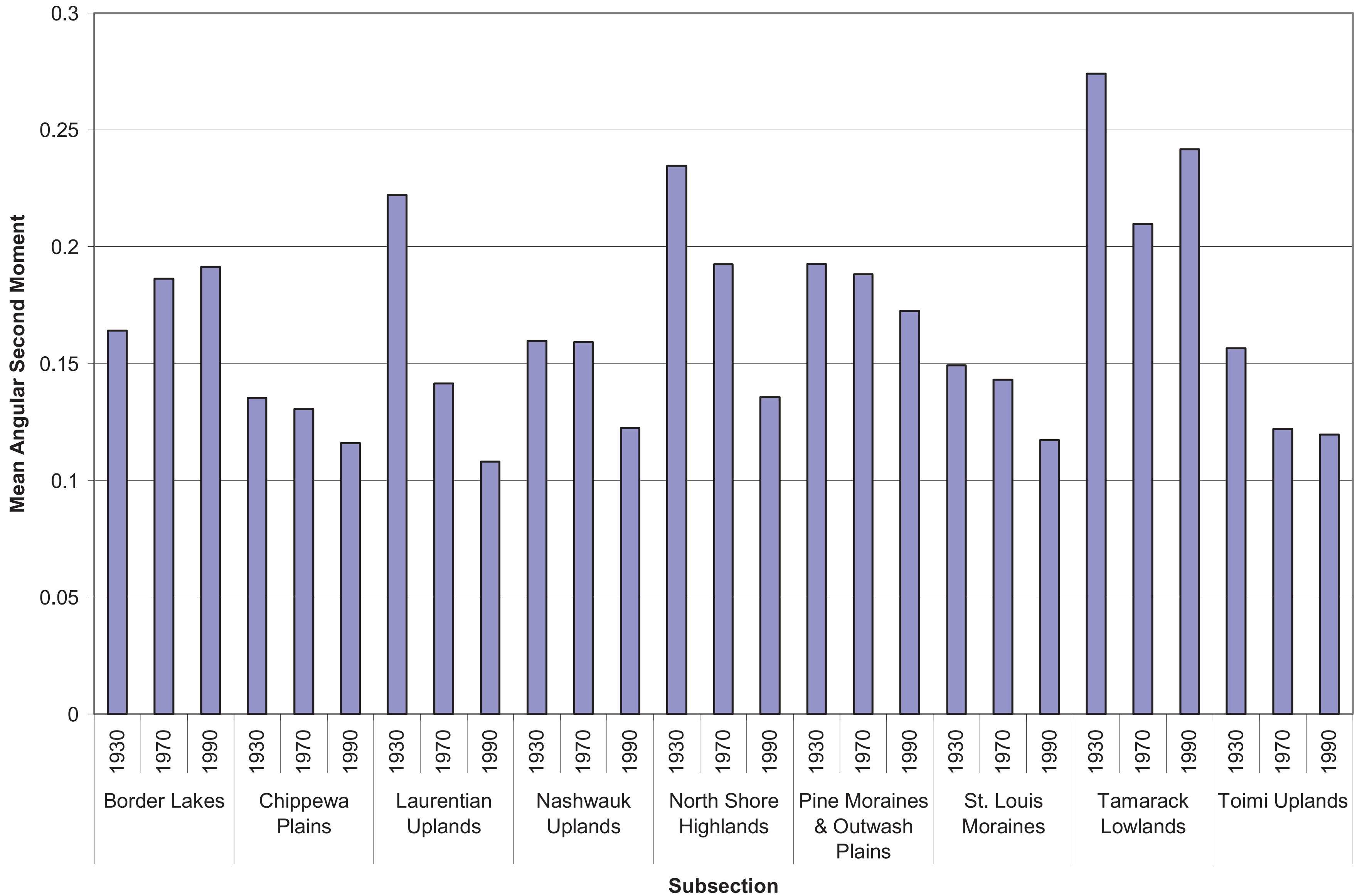


Figure 12   Mean angular second moment for ecological subsections of northern Minnesota from 1930 to 1990.

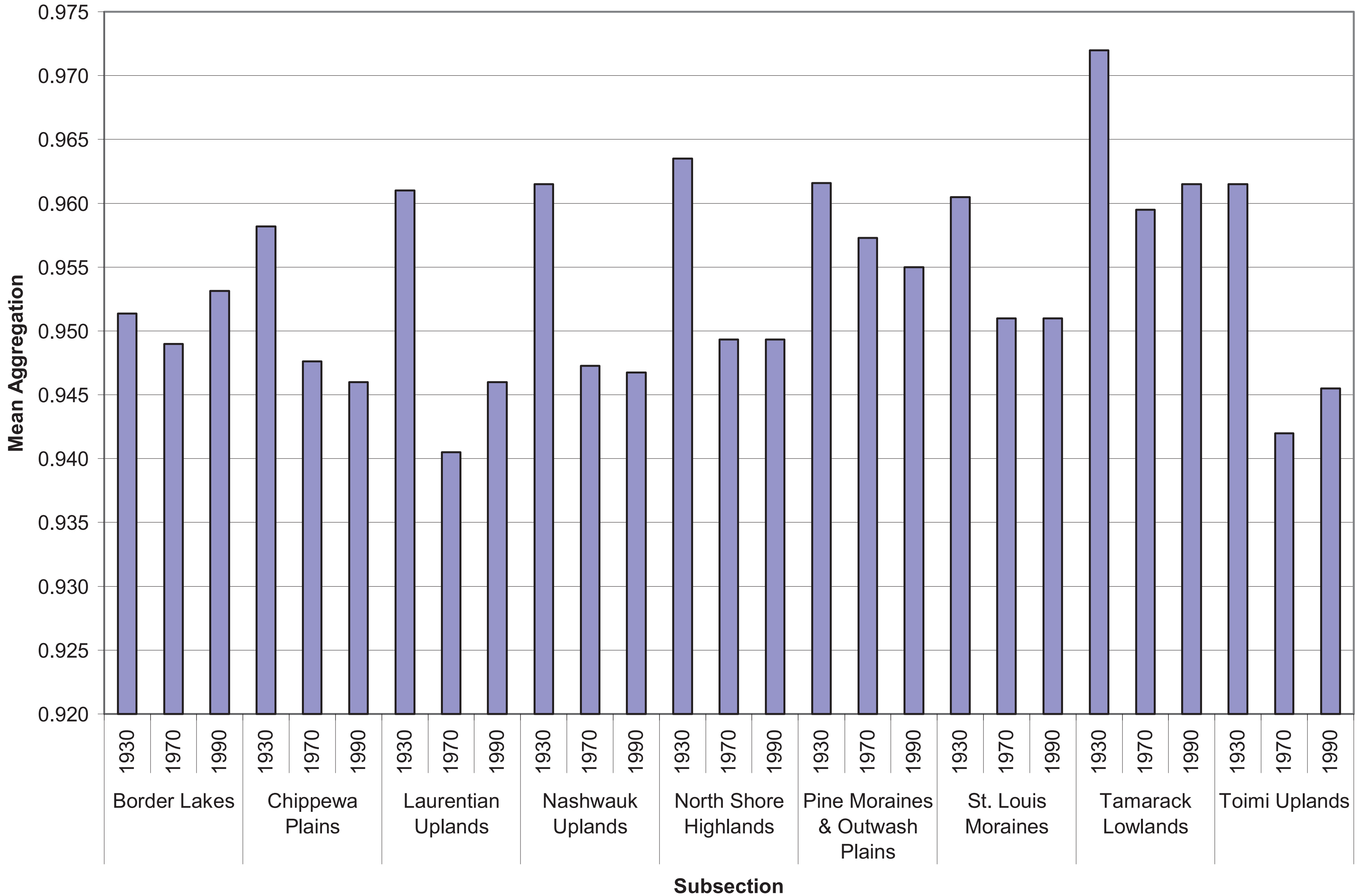
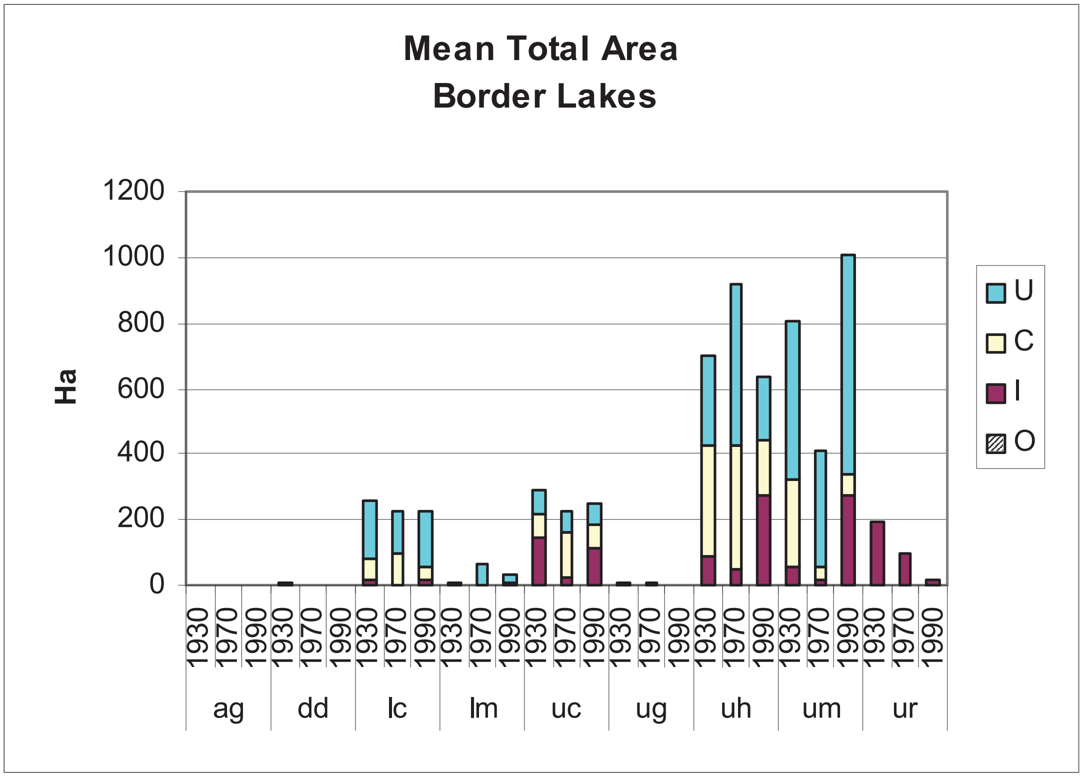
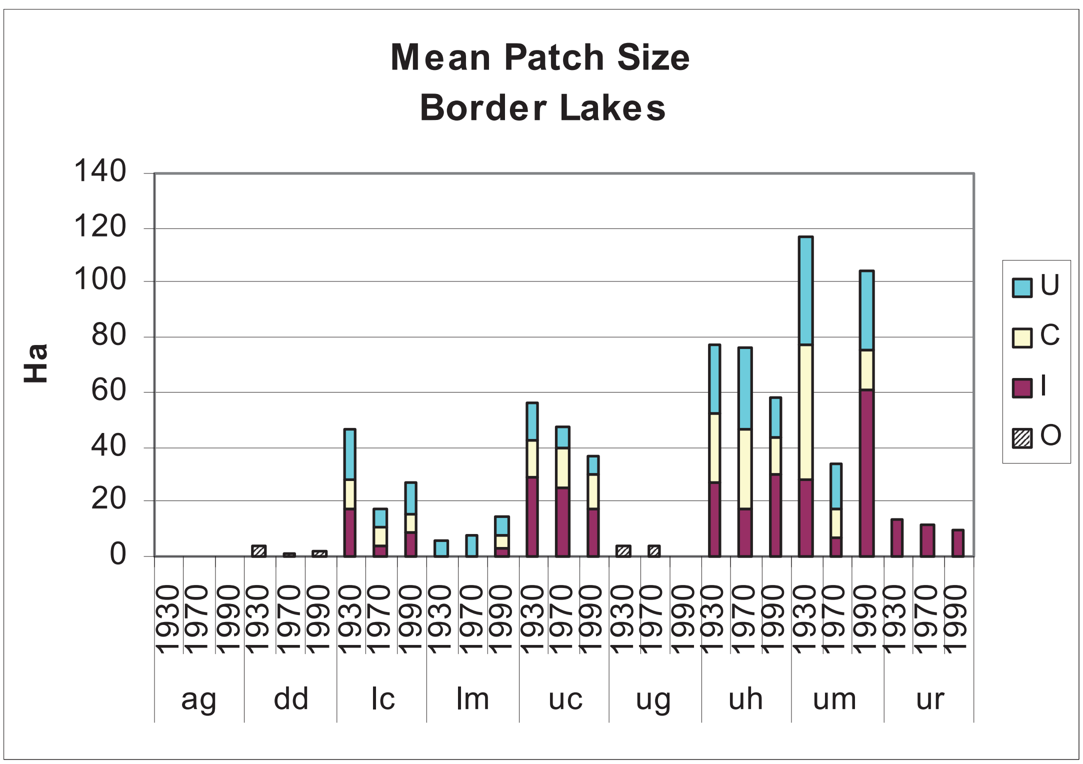
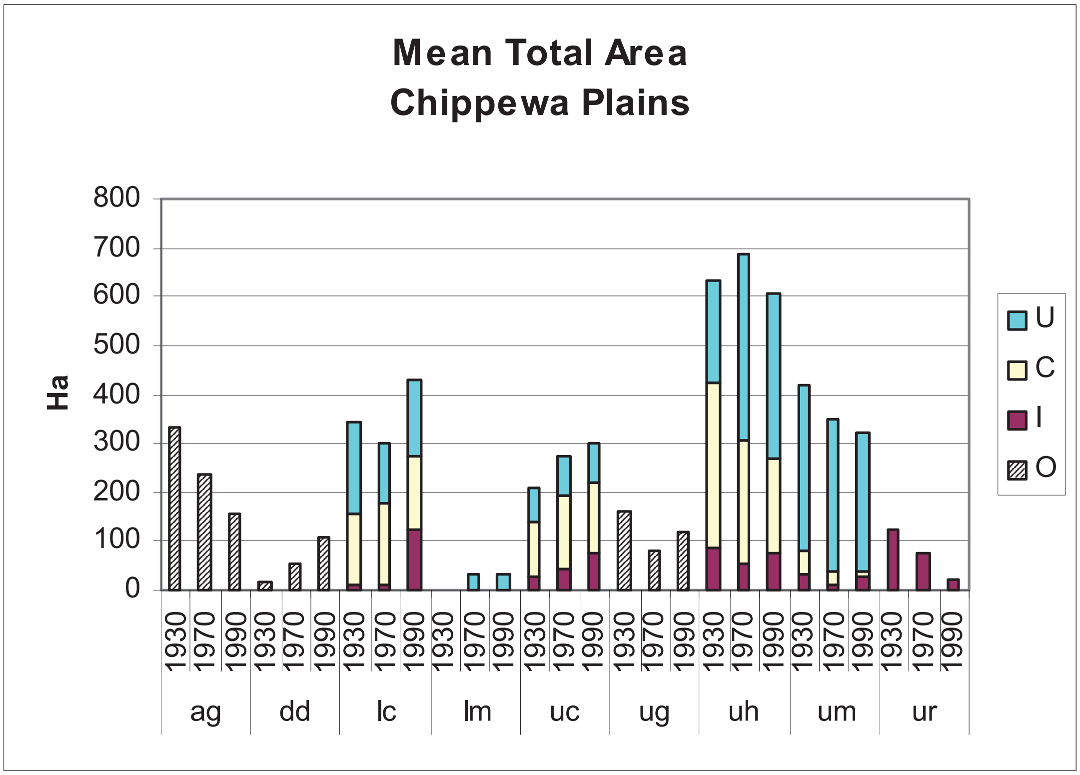


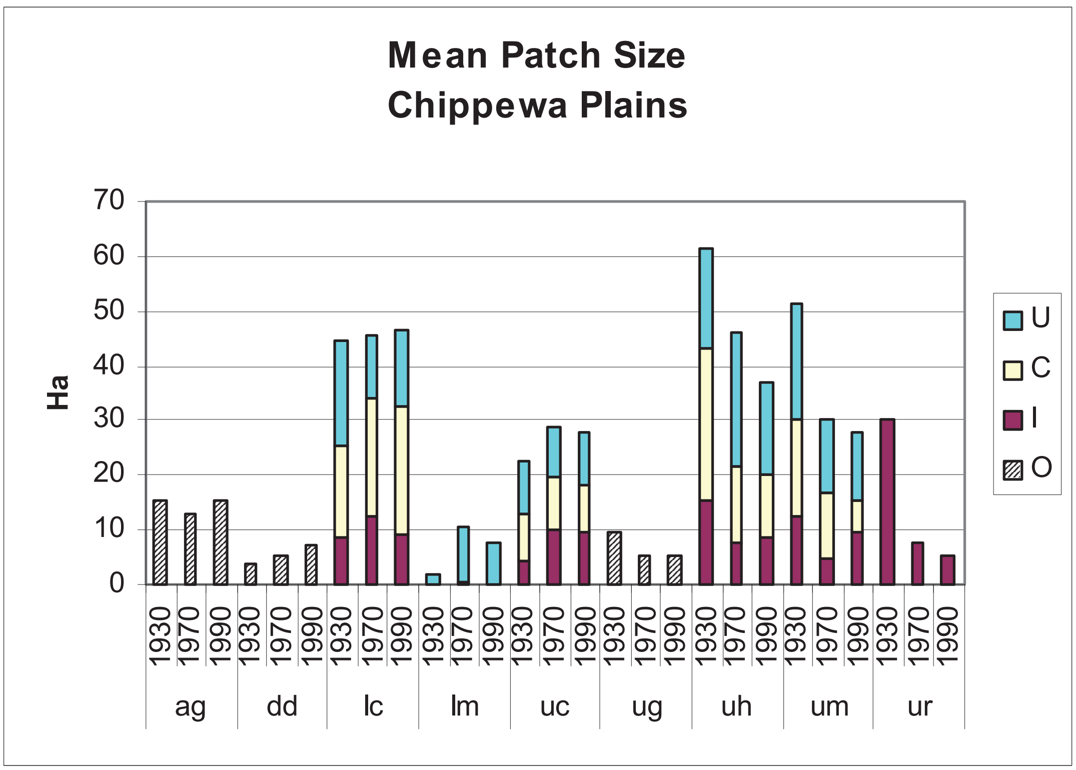
Figure 13 Mean aggregation for ecological subsections of northern Minnesota from 1930 to 1990.



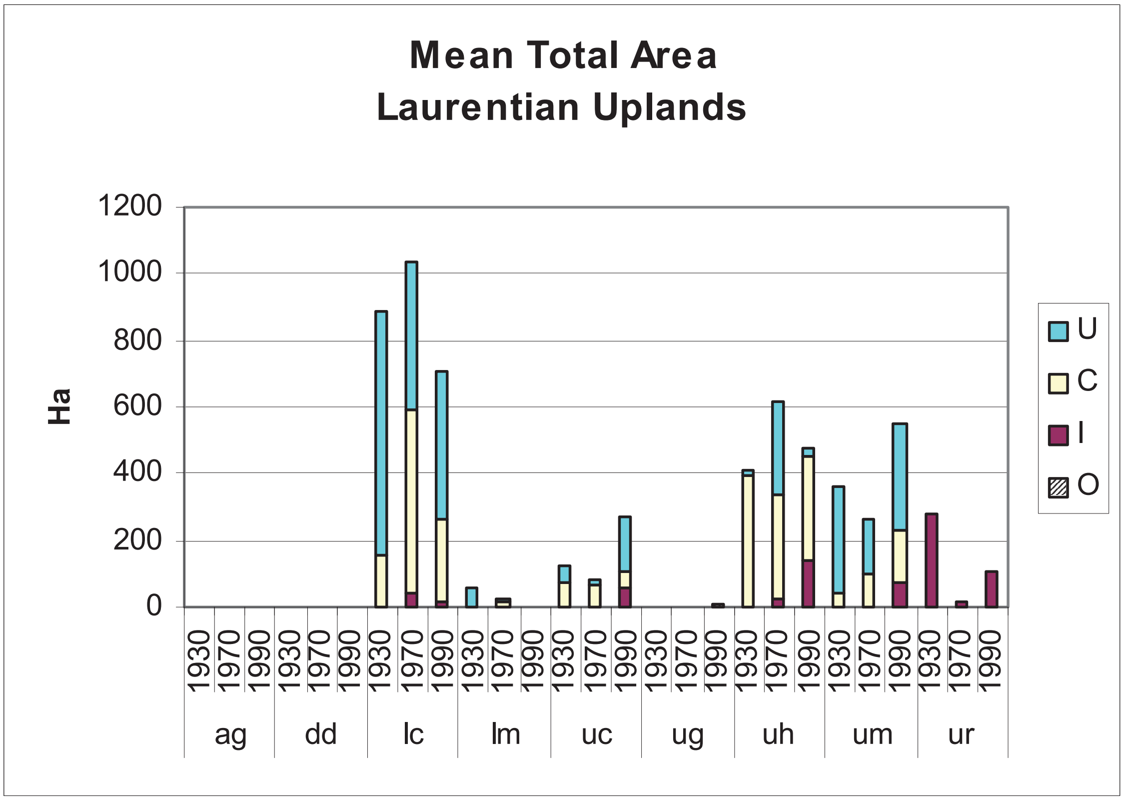


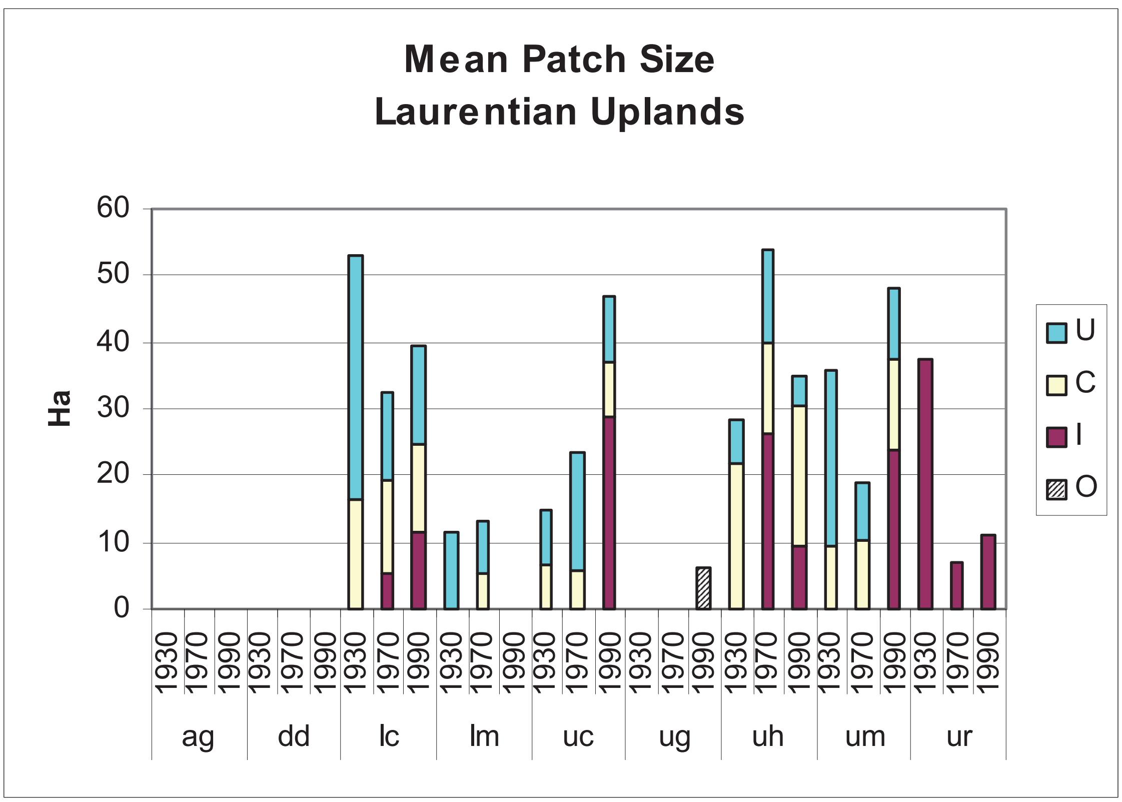
U - Multi-stage Canopy
C - Continuous Canopy
I - Initiation Phase
O - Growth Stage not applicable



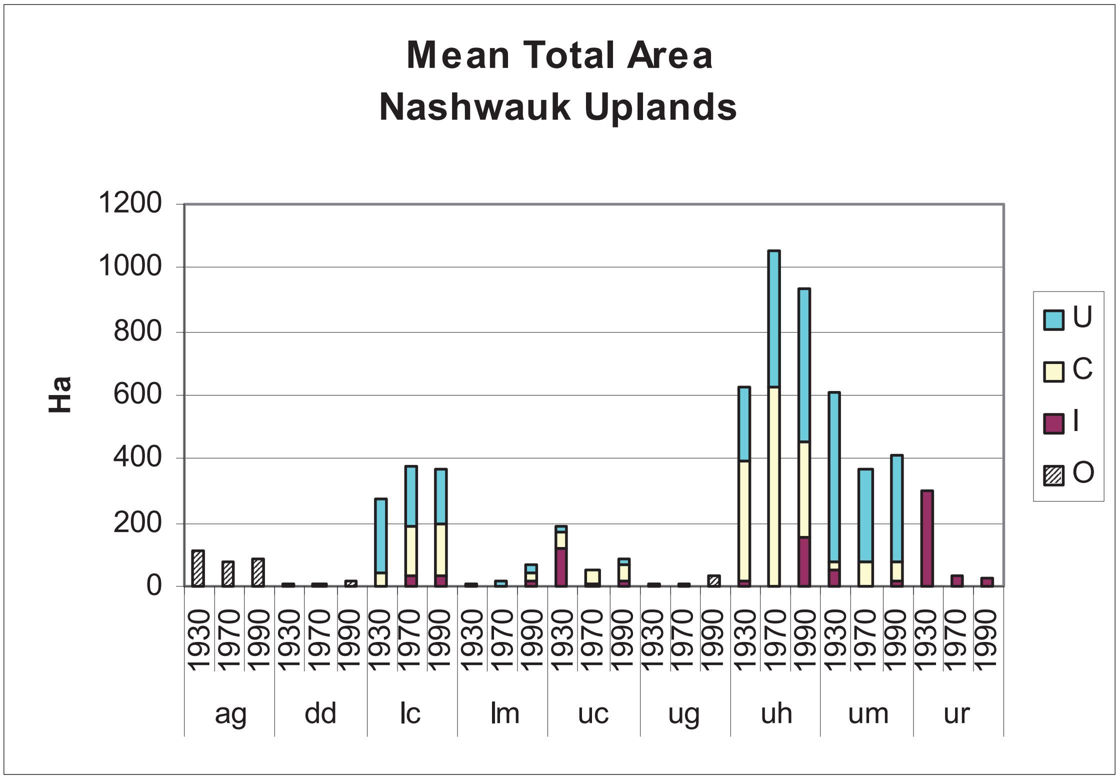


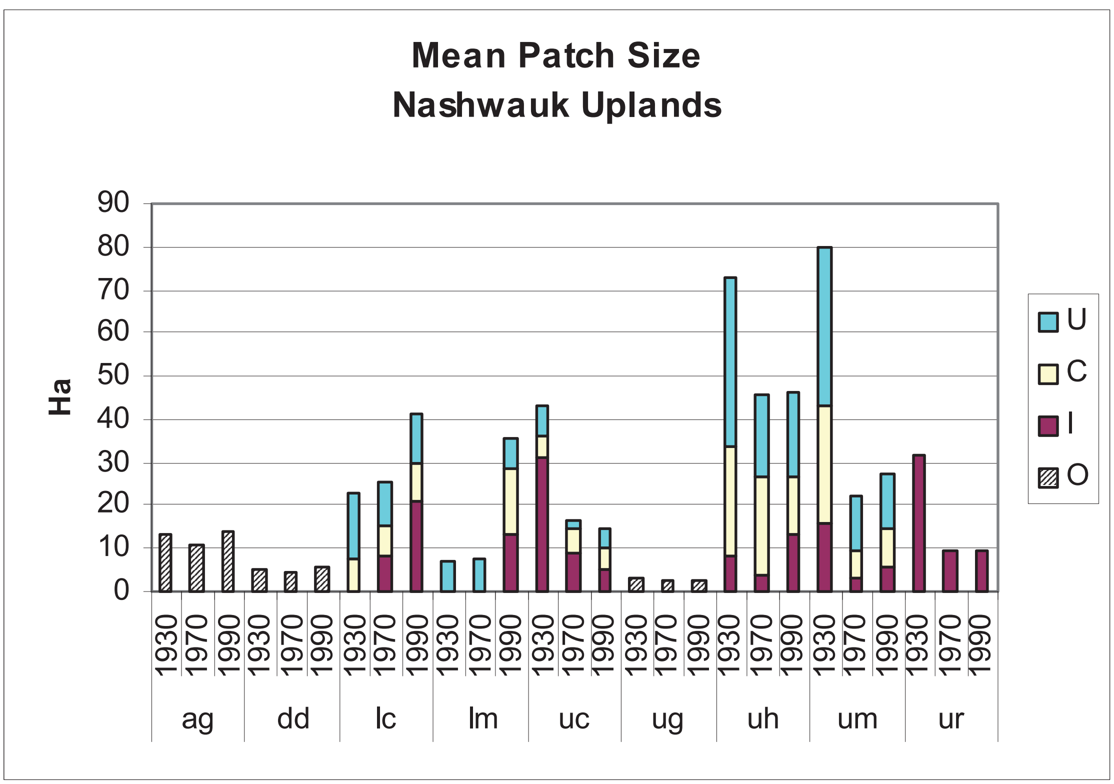
U - Multi-stage Canopy
C - Continuous Canopy
I - Initiation Phase
O - Growth Stage not applicable



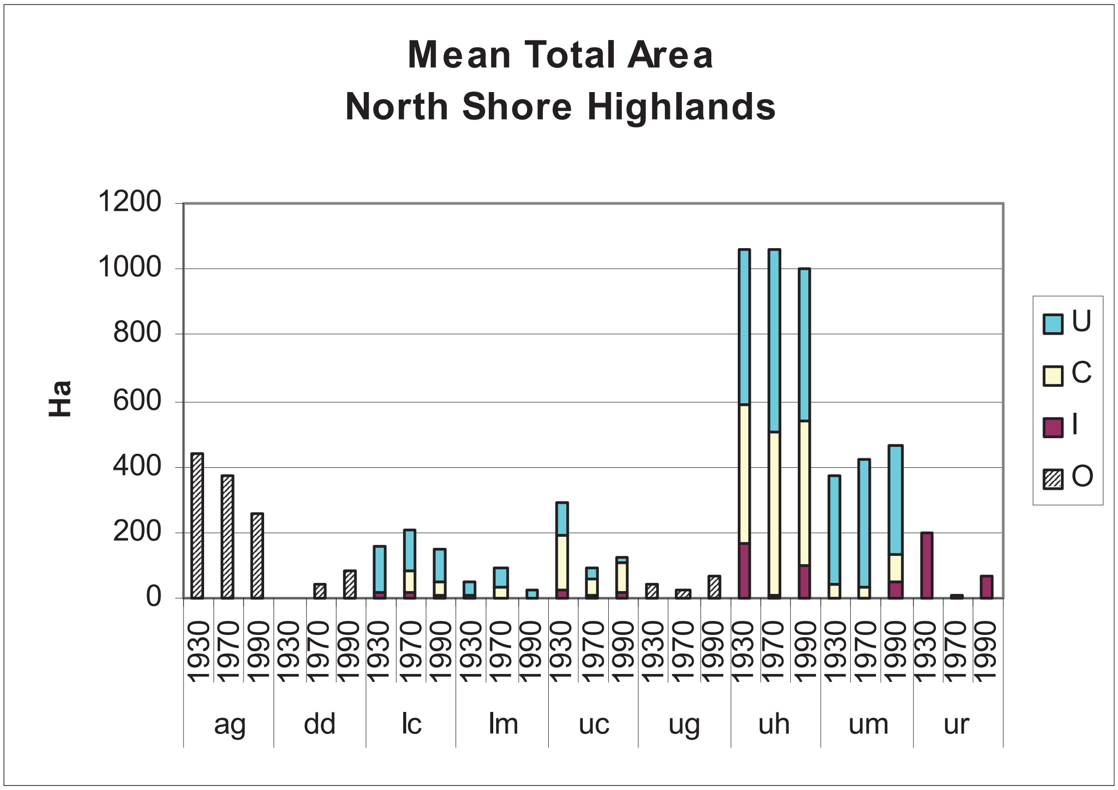


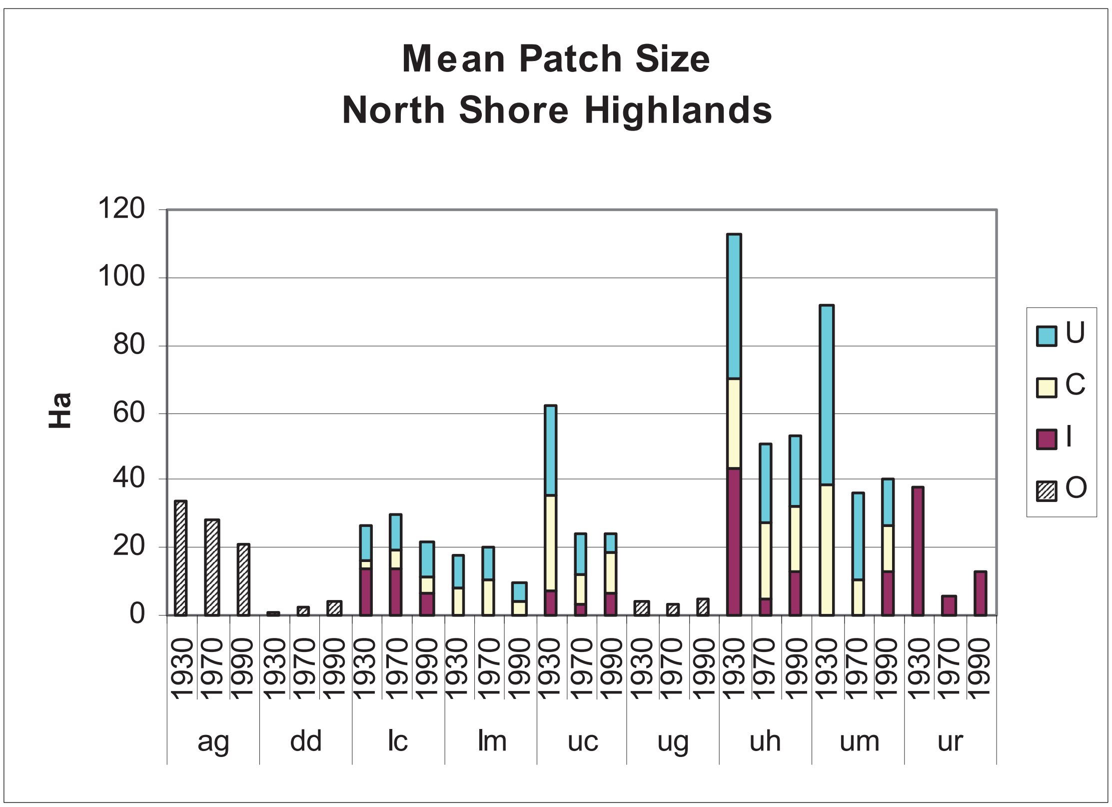
U - Multi-stage Canopy
C - Continuous Canopy
I - Initiation Phase
O - Growth Stage not applicable



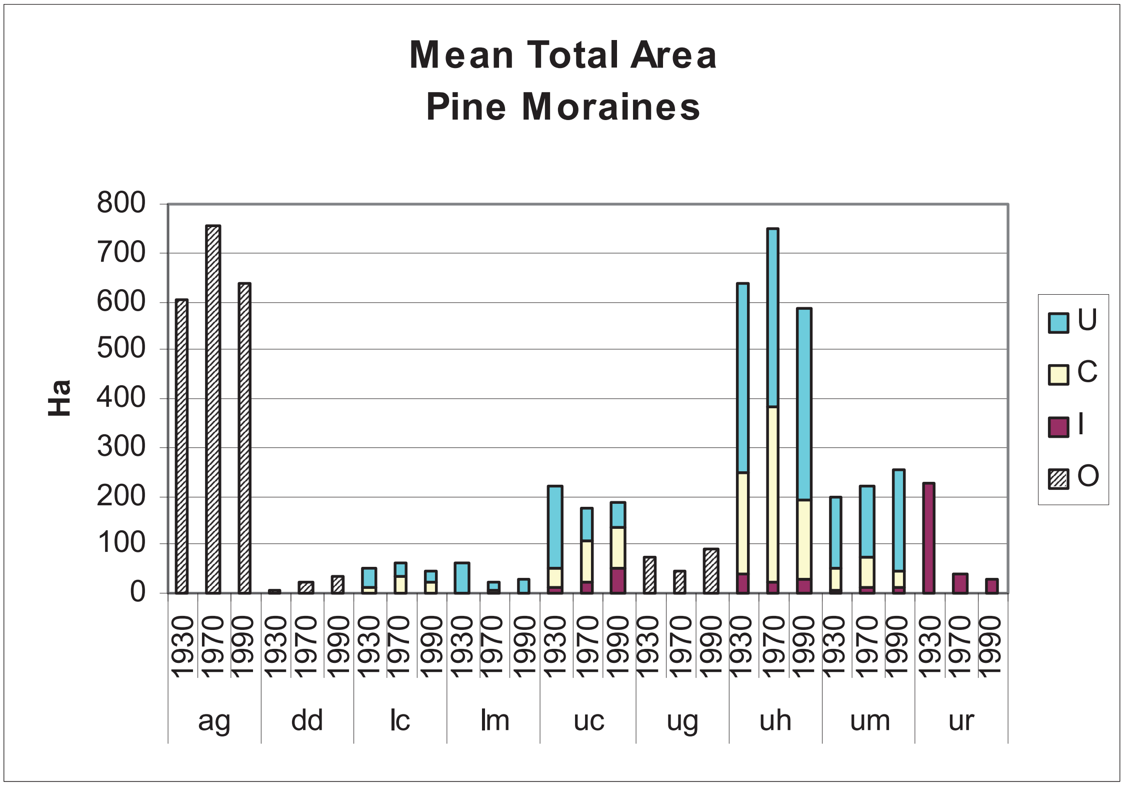


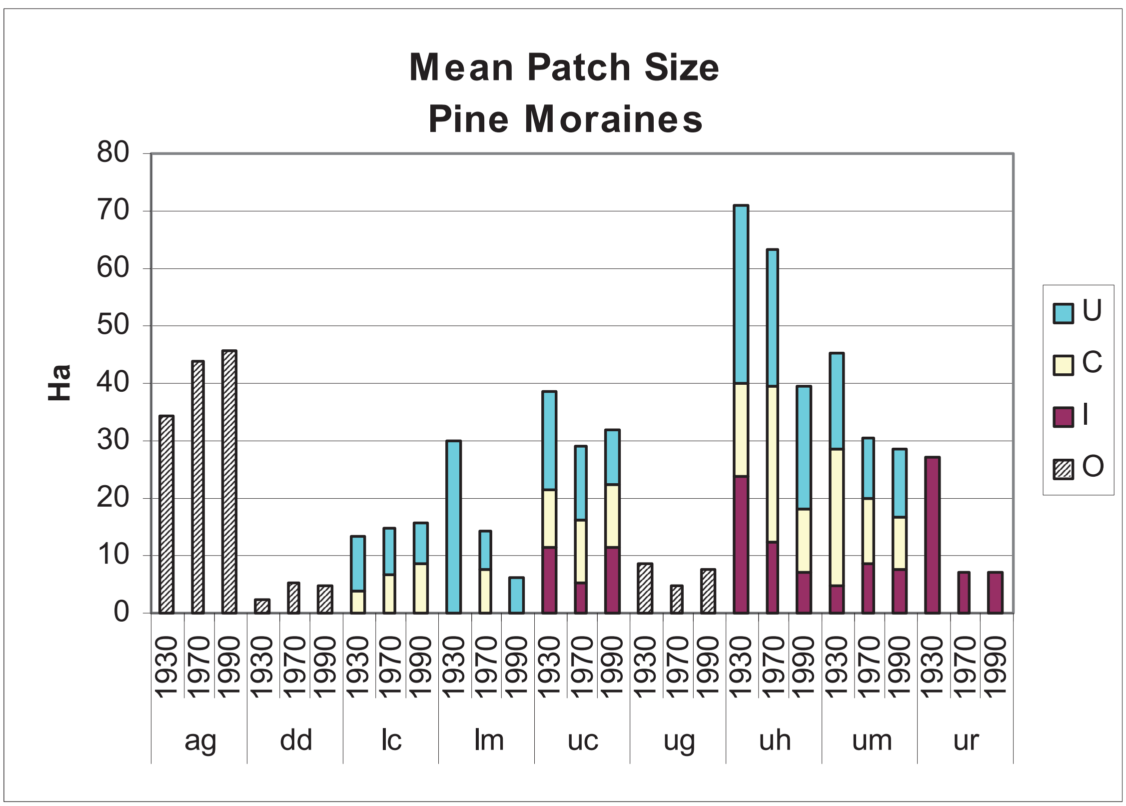
U - Multi-stage Canopy
C - Continuous Canopy
I - Initiation Phase
O - Growth Stage not applicable



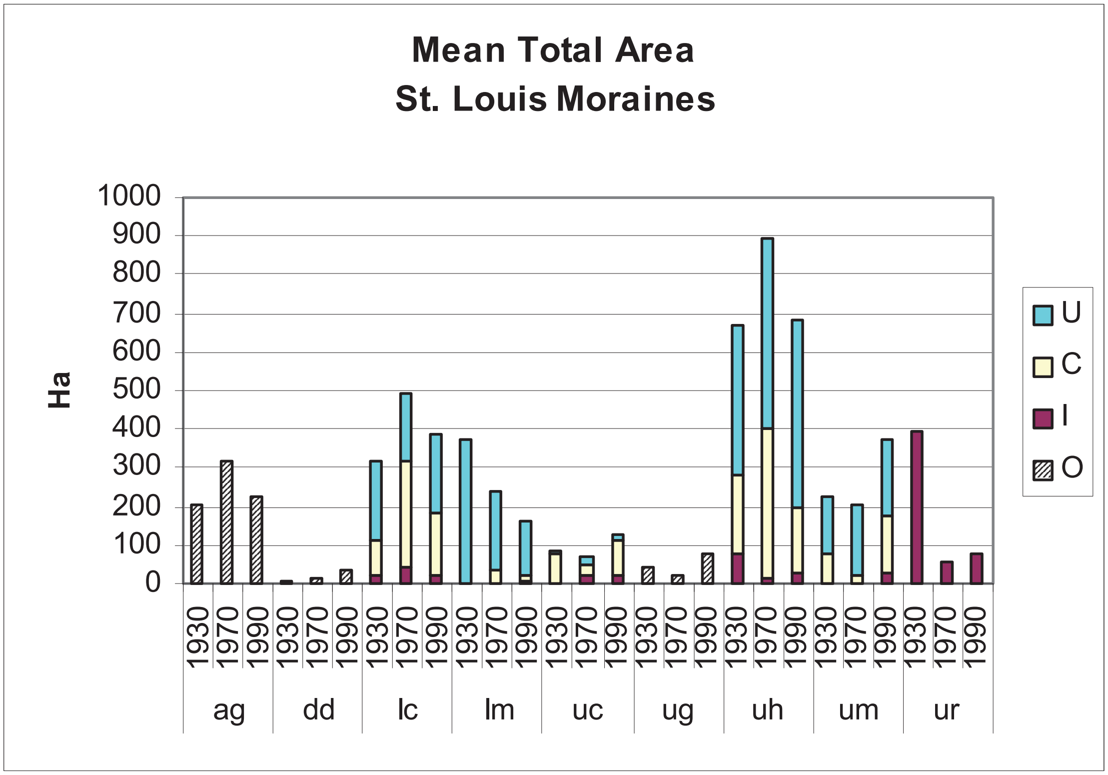


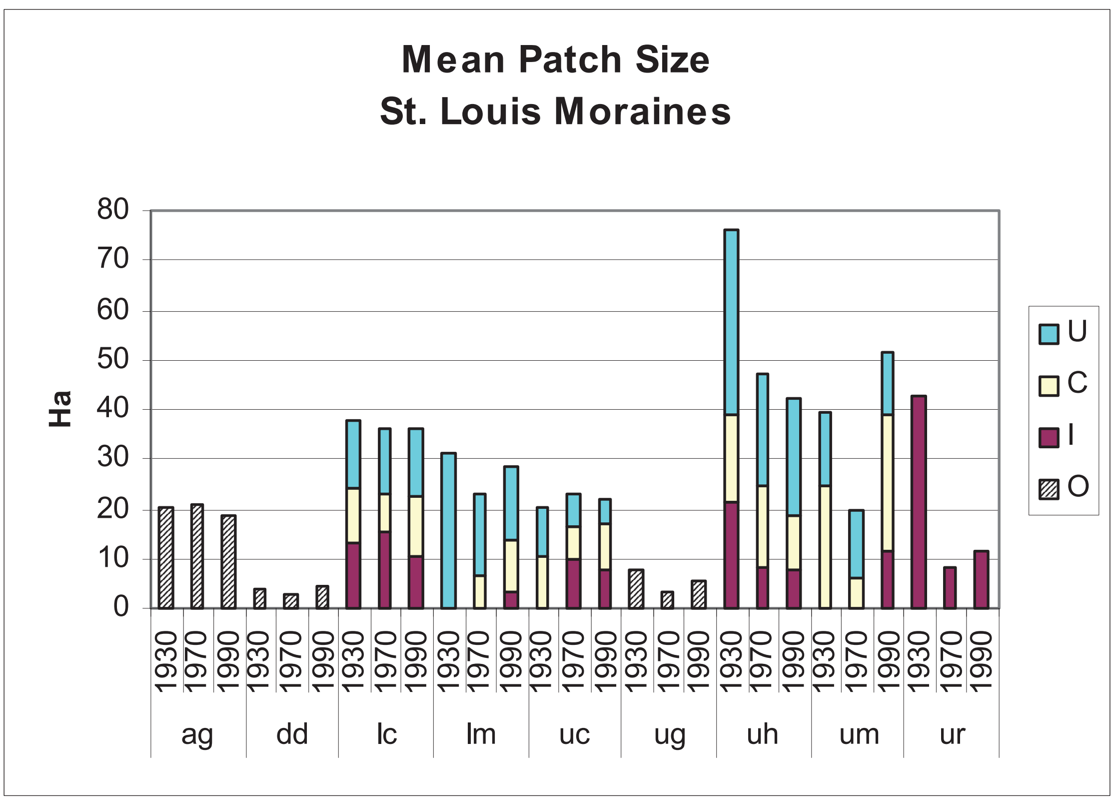
U - Multi-stage Canopy
C - Continuous Canopy
I - Initiation Phase
O - Growth Stage not applicable



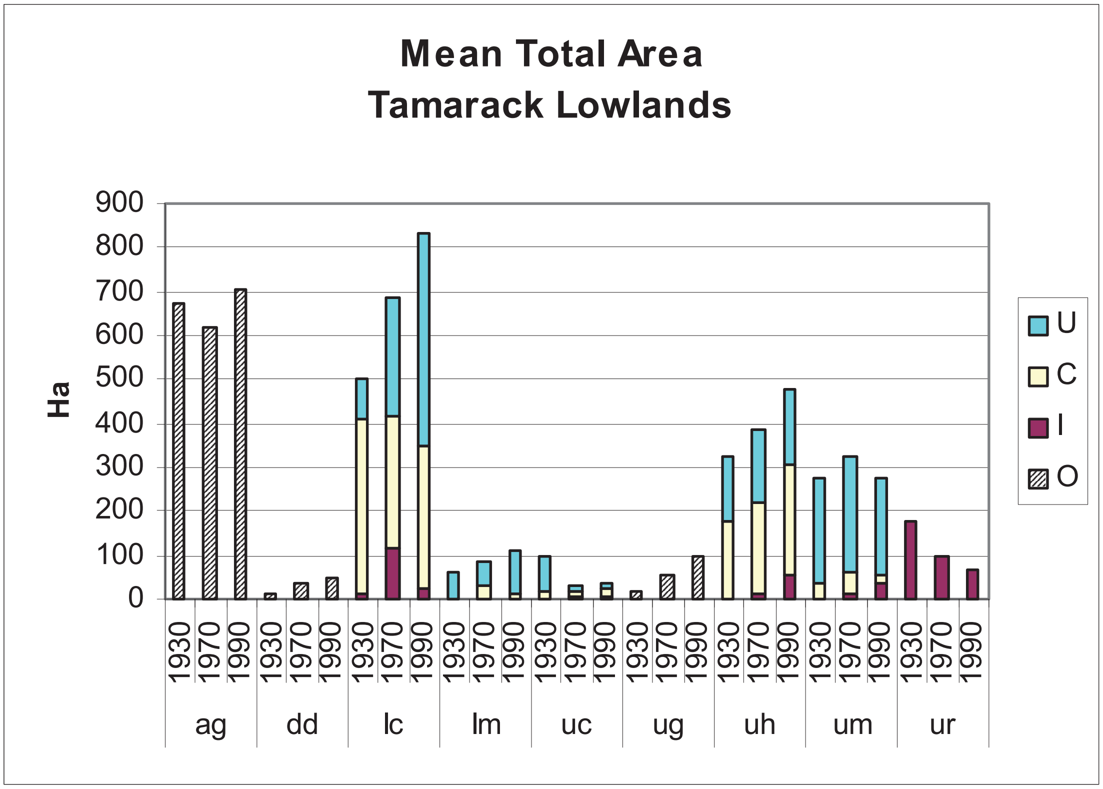


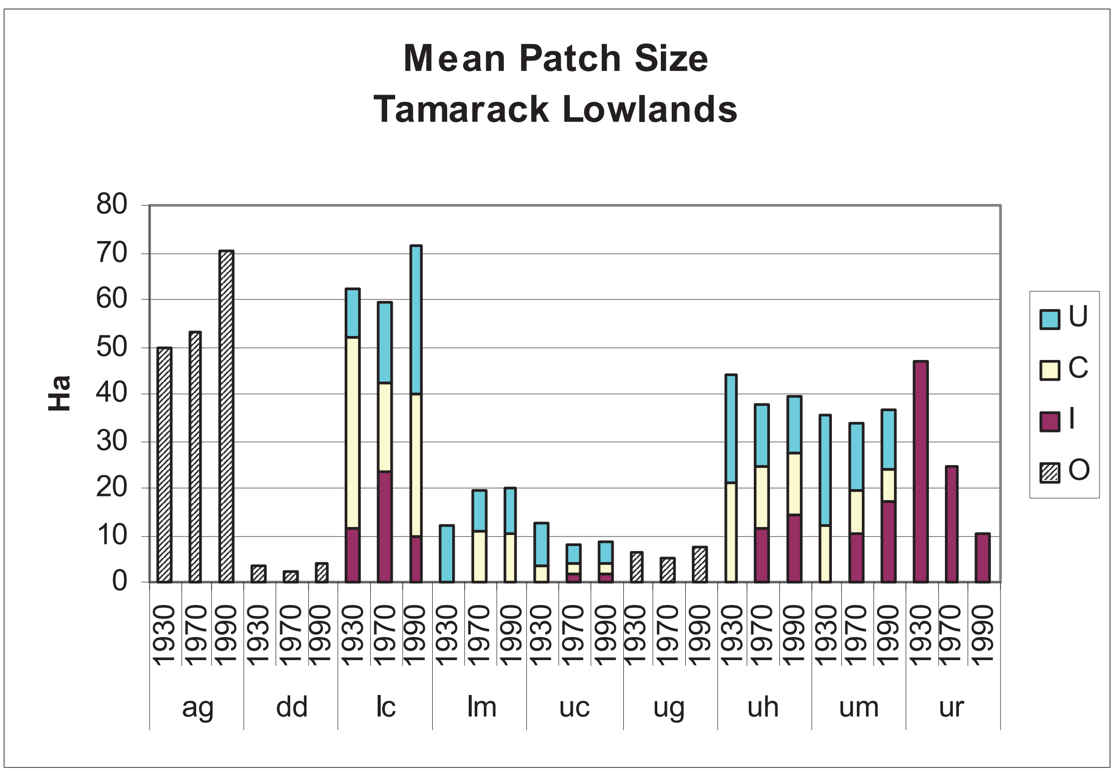
U - Multi-stage Canopy
C - Continuous Canopy
I - Initiation Phase
O - Growth Stage not applicable



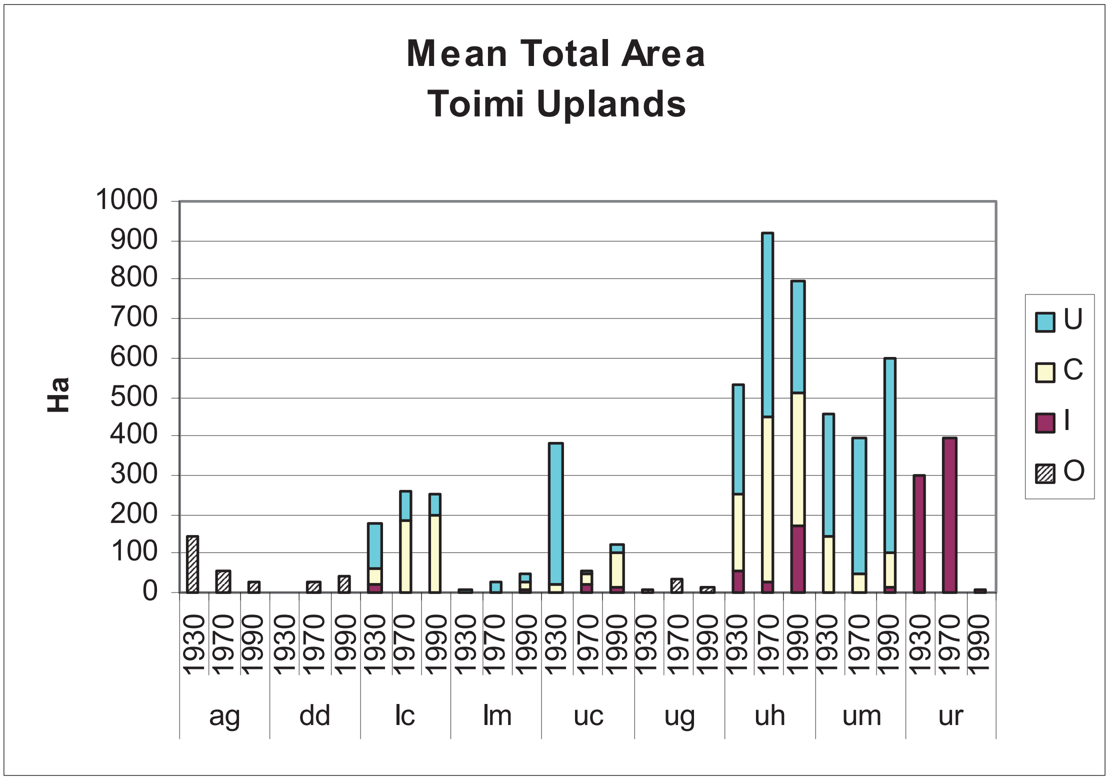


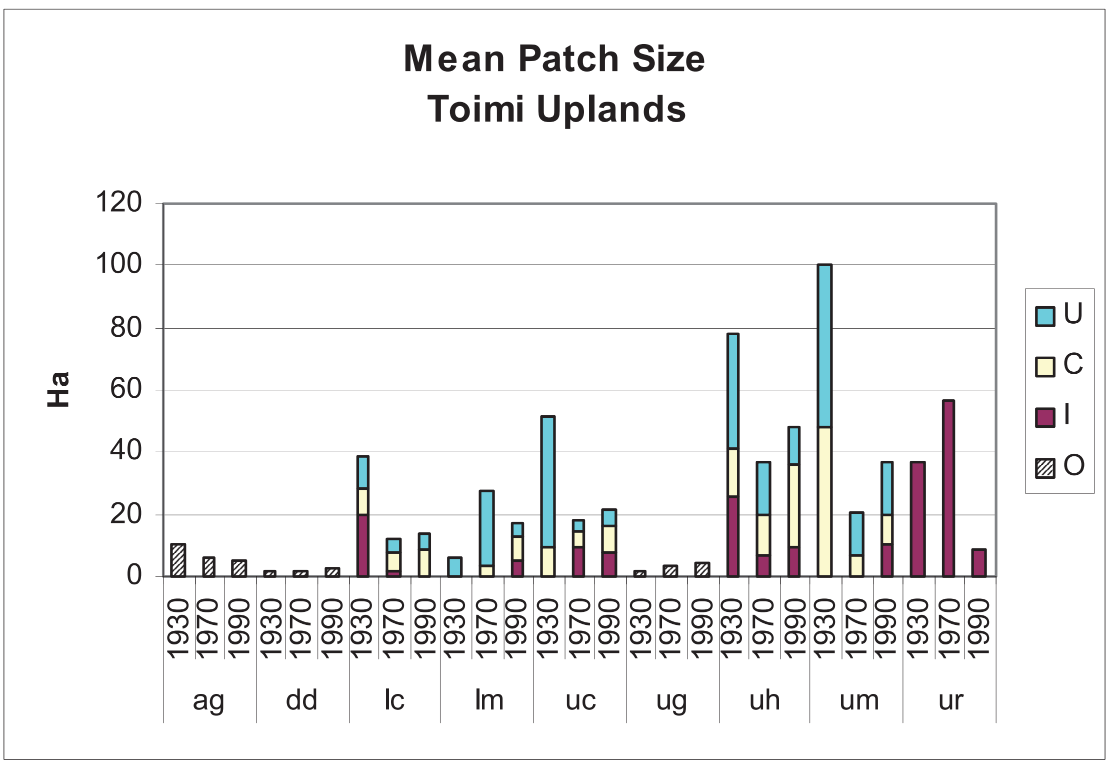
U - Multi-stage Canopy
C - Continuous Canopy
I - Initiation Phase
O - Growth Stage not applicable





U - Multi-stage Canopy
C - Continuous Canopy
I - Initiation Phase
O - Growth Stage not applicable





U - Multi-stage Canopy
C - Continuous Canopy
I - Initiation Phase
O - Growth Stage not applicable

Appendix B

			Year		
SubsecName	CoverName	Data	1930	1970	1990
Border Lakes	Developed	Total Hectares	8.17	0.68	2.03
		Mean Patch Size (ha)	4.08	0.68	2.03
		SD Patch Size (ha)	2.19	--	--
		Number of Patches	2.00	1.00	1.00
	Lowland conifer	Total Hectares	1948.49	1760.05	1742.41
		Mean Patch Size (ha)	15.59	6.74	10.19
		SD Patch Size (ha)	28.13	11.88	21.97
		Number of Patches	125.00	261.00	171.00
	Lowland grass	Total Hectares	1374.41	1569.67	1671.38
		Mean Patch Size (ha)	5.95	4.32	5.70
		SD Patch Size (ha)	17.48	15.54	15.63
		Number of Patches	231.00	363.00	293.00
	Lowland mixed	Total Hectares	23.25	197.93	140.95
		Mean Patch Size (ha)	5.81	7.92	6.13
		SD Patch Size (ha)	1.86	8.27	6.51
		Number of Patches	4.00	25.00	23.00
	Other	Total Hectares	46.26	88.00	111.84
		Mean Patch Size (ha)	2.72	2.84	2.80
		SD Patch Size (ha)	2.83	3.14	2.40
		Number of Patches	17.00	31.00	40.00
	Unknown regen.	Total Hectares	762.93	281.44	48.11
		Mean Patch Size (ha)	13.38	11.26	9.62
		SD Patch Size (ha)	19.25	13.88	4.63
		Number of Patches	57.00	25.00	5.00
	Upland conifer	Total Hectares	1110.88	1284.08	1180.99
		Mean Patch Size (ha)	14.24	11.07	10.18
		SD Patch Size (ha)	21.28	21.43	21.80
		Number of Patches	78.00	116.00	116.00
	Upland grass	Total Hectares	8.18	13.78	
		Mean Patch Size (ha)	4.09	3.44	
		SD Patch Size (ha)	1.56	5.43	
		Number of Patches	2.00	4.00	
	Upland hardwood	Total Hectares	4881.75	7117.45	4241.94
		Mean Patch Size (ha)	25.56	29.41	16.90
		SD Patch Size (ha)	48.52	81.95	29.14
		Number of Patches	191.00	242.00	251.00
	Upland mixed	Total Hectares	5546.74	3122.73	6337.77
		Mean Patch Size (ha)	41.70	15.46	28.04
		SD Patch Size (ha)	103.06	35.49	88.71
		Number of Patches	133.00	202.00	226.00
	Water	Total Hectares	2936.60	3211.87	3170.25
		Mean Patch Size (ha)	25.76	15.15	20.59
		SD Patch Size (ha)	100.47	78.63	91.37
		Number of Patches	114.00	212.00	154.00

Appendix B

SubsecName	CoverName	Data	Year 1930	1970	1990
Chippewa Plains	Agriculture	Total Hectares	1327.59	949.06	630.49
		Mean Patch Size (ha)	15.44	13.18	15.38
		SD Patch Size (ha)	34.52	28.46	21.14
		Number of Patches	86.00	72.00	41.00
	Developed	Total Hectares	34.44	220.53	431.74
		Mean Patch Size (ha)	3.83	5.51	7.08
		SD Patch Size (ha)	6.29	10.58	10.64
		Number of Patches	9.00	40.00	61.00
	Lowland conifer	Total Hectares	1686.95	1478.34	1635.24
		Mean Patch Size (ha)	17.95	15.40	16.03
		SD Patch Size (ha)	36.53	33.59	34.11
		Number of Patches	94.00	96.00	102.00
	Lowland grass	Total Hectares	1171.83	1477.99	1473.98
		Mean Patch Size (ha)	10.56	7.21	10.45
		SD Patch Size (ha)	31.04	18.47	21.47
		Number of Patches	111.00	205.00	141.00
	Lowland mixed	Total Hectares	1.86	122.28	89.48
		Mean Patch Size (ha)	1.86	9.41	7.46
		SD Patch Size (ha)	--	10.04	5.28
		Number of Patches	1.00	13.00	12.00
	Other	Total Hectares	27.25	155.08	335.31
		Mean Patch Size (ha)	6.81	10.34	10.16
		SD Patch Size (ha)	6.64	12.68	27.19
		Number of Patches	4.00	15.00	33.00
	Unknown regen.	Total Hectares	630.74	369.09	96.20
		Mean Patch Size (ha)	30.04	7.53	5.06
		SD Patch Size (ha)	68.30	7.58	3.26
		Number of Patches	21.00	49.00	19.00
	Upland conifer	Total Hectares	823.50	1217.61	1416.58
		Mean Patch Size (ha)	8.85	9.44	9.08
		SD Patch Size (ha)	9.67	13.35	13.29
		Number of Patches	93.00	129.00	156.00
	Upland grass	Total Hectares	798.84	390.61	581.98
		Mean Patch Size (ha)	9.51	5.21	5.29
		SD Patch Size (ha)	29.68	12.12	9.25
		Number of Patches	84.00	75.00	110.00
	Upland hardwood	Total Hectares	3077.30	3332.88	3033.02
		Mean Patch Size (ha)	21.98	17.45	13.30
		SD Patch Size (ha)	43.33	39.33	38.20
		Number of Patches	140.00	191.00	228.00
	Upland mixed	Total Hectares	1940.87	1663.03	1586.78
		Mean Patch Size (ha)	20.01	12.99	11.84
		SD Patch Size (ha)	26.85	15.36	13.81
		Number of Patches	97.00	128.00	134.00
	Water	Total Hectares	133.62	278.32	343.99
		Mean Patch Size (ha)	11.13	3.98	7.48
		SD Patch Size (ha)	13.73	12.46	15.57
		Number of Patches	12.00	70.00	46.00

Appendix B

SubsecName	CoverName	Data	Year 1930	1970	1990
Laurentian Uplands	Lowland conifer	Total Hectares	1780.82	2027.71	1420.79
		Mean Patch Size (ha)	30.18	13.25	14.21
		SD Patch Size (ha)	89.78	21.42	18.09
		Number of Patches	59.00	153.00	100.00
	Lowland grass	Total Hectares	711.26	603.08	624.96
		Mean Patch Size (ha)	15.13	7.73	9.77
		SD Patch Size (ha)	30.44	24.73	31.84
		Number of Patches	47.00	78.00	64.00
	Lowland mixed	Total Hectares	57.66	24.24	
		Mean Patch Size (ha)	11.53	6.06	
		SD Patch Size (ha)	6.87	2.67	
		Number of Patches	5.00	4.00	
	Other	Total Hectares		34.87	36.60
		Mean Patch Size (ha)		34.87	9.15
		SD Patch Size (ha)		--	8.83
		Number of Patches		1.00	4.00
	Unknown regen.	Total Hectares	561.73	34.38	210.86
		Mean Patch Size (ha)	37.45	6.88	11.10
		SD Patch Size (ha)	100.43	3.46	8.78
		Number of Patches	15.00	5.00	19.00
	Upland conifer	Total Hectares	168.51	85.01	379.73
		Mean Patch Size (ha)	7.33	6.54	11.51
		SD Patch Size (ha)	9.53	5.69	13.74
		Number of Patches	23.00	13.00	33.00
	Upland grass	Total Hectares			6.18
		Mean Patch Size (ha)			6.18
		SD Patch Size (ha)			--
		Number of Patches			1.00
	Upland hardwood	Total Hectares	411.45	1205.88	818.94
		Mean Patch Size (ha)	19.59	13.86	14.62
		SD Patch Size (ha)	15.08	20.68	22.87
		Number of Patches	21.00	87.00	56.00
	Upland mixed	Total Hectares	687.41	360.20	875.17
		Mean Patch Size (ha)	23.70	9.48	11.52
		SD Patch Size (ha)	24.86	6.97	13.69
		Number of Patches	29.00	38.00	76.00
	Water	Total Hectares	283.07	286.55	288.68
		Mean Patch Size (ha)	70.77	35.82	36.09
		SD Patch Size (ha)	137.26	97.46	98.36
		Number of Patches	4.00	8.00	8.00

Appendix B

SubsecName	CoverName	Data	Year 1930	1970	1990
Nashwauk Uplands	Agriculture	Total Hectares	324.12	242.13	164.55
		Mean Patch Size (ha)	13.51	10.53	13.71
		SD Patch Size (ha)	17.41	14.53	14.08
		Number of Patches	24.00	23.00	12.00
	Developed	Total Hectares	14.44	23.13	65.54
		Mean Patch Size (ha)	4.81	4.63	5.46
		SD Patch Size (ha)	6.10	6.36	6.83
		Number of Patches	3.00	5.00	12.00
	Lowland conifer	Total Hectares	1114.27	1428.20	1413.91
		Mean Patch Size (ha)	13.11	8.66	10.47
		SD Patch Size (ha)	23.68	17.18	20.24
		Number of Patches	85.00	165.00	135.00
	Lowland grass	Total Hectares	1532.27	1400.70	1301.94
		Mean Patch Size (ha)	18.24	8.29	9.64
		SD Patch Size (ha)	44.22	30.37	35.56
		Number of Patches	84.00	169.00	135.00
	Lowland mixed	Total Hectares	21.23	31.11	152.96
		Mean Patch Size (ha)	7.08	7.78	7.65
		SD Patch Size (ha)	2.70	1.38	6.54
		Number of Patches	3.00	4.00	20.00
	Other	Total Hectares	1.43	62.96	267.47
		Mean Patch Size (ha)	1.43	10.49	4.61
		SD Patch Size (ha)	--	7.72	4.37
		Number of Patches	1.00	6.00	58.00
	Unknown regen.	Total Hectares	1215.50	107.93	76.89
		Mean Patch Size (ha)	31.99	9.81	9.61
		SD Patch Size (ha)	51.92	15.88	8.70
		Number of Patches	38.00	11.00	8.00
	Upland conifer	Total Hectares	200.42	148.42	238.03
		Mean Patch Size (ha)	11.79	4.95	5.06
		SD Patch Size (ha)	18.37	7.85	3.78
		Number of Patches	17.00	30.00	47.00
	Upland grass	Total Hectares	29.20	50.20	62.47
		Mean Patch Size (ha)	2.92	2.39	2.72
		SD Patch Size (ha)	2.24	2.37	2.73
		Number of Patches	10.00	21.00	23.00
	Upland hardwood	Total Hectares	2471.09	4220.42	3726.35
		Mean Patch Size (ha)	28.08	21.10	15.99
		SD Patch Size (ha)	50.35	41.75	29.92
		Number of Patches	88.00	200.00	233.00
	Upland mixed	Total Hectares	2270.03	1465.43	1603.17
		Mean Patch Size (ha)	35.47	10.39	11.53
		SD Patch Size (ha)	76.72	13.49	13.90
		Number of Patches	64.00	141.00	139.00
	Water	Total Hectares	129.83	143.20	250.55
		Mean Patch Size (ha)	6.18	6.23	4.56
		SD Patch Size (ha)	11.36	11.73	8.81
		Number of Patches	21.00	23.00	55.00

Appendix B

SubsecName	CoverName	Data	Year 1930	1970	1990
North Shore Highlands	Agriculture	Total Hectares	1762.58	1124.21	769.30
		Mean Patch Size (ha)	33.90	28.11	20.79
		SD Patch Size (ha)	164.82	108.66	43.87
		Number of Patches	52.00	40.00	37.00
	Developed	Total Hectares	3.51	111.89	337.25
		Mean Patch Size (ha)	0.88	2.33	4.16
		SD Patch Size (ha)	0.55	1.84	4.98
		Number of Patches	4.00	48.00	81.00
	Lowland conifer	Total Hectares	707.45	1166.77	893.58
		Mean Patch Size (ha)	10.56	8.39	7.77
		SD Patch Size (ha)	19.81	19.45	13.13
		Number of Patches	67.00	139.00	115.00
	Lowland grass	Total Hectares	1798.14	1760.64	1656.09
		Mean Patch Size (ha)	10.58	7.56	9.86
		SD Patch Size (ha)	27.26	16.36	18.55
		Number of Patches	170.00	233.00	168.00
	Lowland mixed	Total Hectares	144.53	229.90	80.10
		Mean Patch Size (ha)	9.64	10.00	5.34
		SD Patch Size (ha)	7.76	5.82	3.87
		Number of Patches	15.00	23.00	15.00
	Other	Total Hectares	1.52	91.64	306.75
		Mean Patch Size (ha)	1.52	7.64	5.68
		SD Patch Size (ha)	--	15.05	10.80
		Number of Patches	1.00	12.00	54.00
	Unknown regen.	Total Hectares	980.09	27.15	271.86
		Mean Patch Size (ha)	37.70	5.43	12.95
		SD Patch Size (ha)	86.48	2.44	15.55
		Number of Patches	26.00	5.00	21.00
	Upland conifer	Total Hectares	688.84	258.07	622.54
		Mean Patch Size (ha)	24.60	9.22	9.58
		SD Patch Size (ha)	32.59	9.55	15.95
		Number of Patches	28.00	28.00	65.00
	Upland grass	Total Hectares	167.21	147.25	188.24
		Mean Patch Size (ha)	4.08	2.83	4.83
		SD Patch Size (ha)	5.04	5.83	5.55
		Number of Patches	41.00	52.00	39.00
	Upland hardwood	Total Hectares	5571.45	6344.71	6012.64
		Mean Patch Size (ha)	33.16	22.58	19.09
		SD Patch Size (ha)	89.59	49.99	42.84
		Number of Patches	168.00	281.00	315.00
	Upland mixed	Total Hectares	2045.84	2541.63	2656.10
		Mean Patch Size (ha)	52.46	23.11	13.69
		SD Patch Size (ha)	130.17	52.26	17.10
		Number of Patches	39.00	110.00	194.00
	Water	Total Hectares	114.60	181.89	191.30
		Mean Patch Size (ha)	4.09	2.09	2.90
		SD Patch Size (ha)	7.29	4.60	5.19
		Number of Patches	28.00	87.00	66.00

Appendix B

SubsecName	CoverName	Data	Year 1930	1970	1990
Pine Moraines & Outwash Plains	Agriculture	Total Hectares	4230.09	4521.52	4439.21
		Mean Patch Size (ha)	34.39	43.90	45.77
		SD Patch Size (ha)	88.32	107.49	128.74
		Number of Patches	123.00	103.00	97.00
	Developed	Total Hectares	32.44	177.18	218.49
		Mean Patch Size (ha)	2.16	5.21	4.65
		SD Patch Size (ha)	2.26	7.09	6.73
		Number of Patches	15.00	34.00	47.00
	Lowland conifer	Total Hectares	259.56	212.88	280.92
		Mean Patch Size (ha)	7.02	7.34	7.80
		SD Patch Size (ha)	13.55	8.17	8.08
		Number of Patches	37.00	29.00	36.00
	Lowland grass	Total Hectares	3212.43	2947.88	2609.87
		Mean Patch Size (ha)	10.60	9.01	9.03
		SD Patch Size (ha)	37.21	35.54	25.20
		Number of Patches	303.00	327.00	289.00
	Lowland mixed	Total Hectares	179.76	59.36	127.21
		Mean Patch Size (ha)	29.96	6.60	6.36
		SD Patch Size (ha)	44.22	6.42	4.52
		Number of Patches	6.00	9.00	20.00
	Other	Total Hectares		65.79	120.15
		Mean Patch Size (ha)		6.58	6.01
		SD Patch Size (ha)		11.13	10.18
		Number of Patches		10.00	20.00
	Unknown regen.	Total Hectares	1338.20	148.62	181.45
		Mean Patch Size (ha)	27.31	7.08	7.26
		SD Patch Size (ha)	55.13	7.08	5.24
		Number of Patches	49.00	21.00	25.00
	Upland conifer	Total Hectares	1275.85	1025.24	1226.50
		Mean Patch Size (ha)	14.84	10.46	10.57
		SD Patch Size (ha)	19.86	16.39	14.93
		Number of Patches	86.00	98.00	116.00
	Upland grass	Total Hectares	501.26	325.80	618.71
		Mean Patch Size (ha)	8.64	4.79	7.83
		SD Patch Size (ha)	18.42	8.72	10.31
		Number of Patches	58.00	68.00	79.00
	Upland hardwood	Total Hectares	3711.60	4853.84	4080.43
		Mean Patch Size (ha)	23.49	23.56	15.88
		SD Patch Size (ha)	73.45	39.34	29.33
		Number of Patches	158.00	206.00	257.00
	Upland mixed	Total Hectares	1077.48	1288.33	1695.75
		Mean Patch Size (ha)	16.84	10.47	11.38
		SD Patch Size (ha)	32.71	12.70	13.60
		Number of Patches	64.00	123.00	149.00
	Water	Total Hectares	498.04	690.27	718.01
		Mean Patch Size (ha)	9.06	6.05	6.77
		SD Patch Size (ha)	28.60	20.72	21.69
		Number of Patches	55.00	114.00	106.00

Appendix B

SubsecName	CoverName	Data	Year 1930	1970	1990
St. Louis Moraines	Agriculture	Total Hectares	622.48	630.35	452.83
		Mean Patch Size (ha)	20.08	21.01	18.87
		SD Patch Size (ha)	25.28	24.96	18.19
		Number of Patches	31.00	30.00	24.00
	Developed	Total Hectares	27.84	28.39	100.84
		Mean Patch Size (ha)	3.98	2.84	4.38
		SD Patch Size (ha)	4.96	1.82	4.15
		Number of Patches	7.00	10.00	23.00
	Lowland conifer	Total Hectares	1224.61	1372.09	1510.86
		Mean Patch Size (ha)	12.76	10.47	13.02
		SD Patch Size (ha)	19.29	20.92	21.50
		Number of Patches	96.00	131.00	116.00
	Lowland grass	Total Hectares	1275.45	1457.02	1336.36
		Mean Patch Size (ha)	11.19	8.94	10.95
		SD Patch Size (ha)	21.40	17.85	18.91
		Number of Patches	114.00	163.00	122.00
	Lowland mixed	Total Hectares	746.44	694.53	600.61
		Mean Patch Size (ha)	31.10	14.17	14.30
		SD Patch Size (ha)	69.13	26.70	25.14
		Number of Patches	24.00	49.00	42.00
	Other	Total Hectares	1.93	47.73	169.66
		Mean Patch Size (ha)	0.96	5.97	4.85
		SD Patch Size (ha)	0.34	11.63	7.11
		Number of Patches	2.00	8.00	35.00
	Unknown regen.	Total Hectares	1586.46	118.59	235.61
		Mean Patch Size (ha)	42.88	8.47	11.78
		SD Patch Size (ha)	126.96	8.44	14.00
		Number of Patches	37.00	14.00	20.00
	Upland conifer	Total Hectares	99.35	184.55	375.57
		Mean Patch Size (ha)	9.93	7.38	7.99
		SD Patch Size (ha)	4.81	8.84	8.08
		Number of Patches	10.00	25.00	47.00
	Upland grass	Total Hectares	85.54	80.38	158.33
		Mean Patch Size (ha)	7.78	3.35	5.28
		SD Patch Size (ha)	7.83	2.94	5.06
		Number of Patches	11.00	24.00	30.00
	Upland hardwood	Total Hectares	2590.49	3568.26	2721.94
		Mean Patch Size (ha)	26.43	18.98	17.23
		SD Patch Size (ha)	54.84	46.09	35.91
		Number of Patches	98.00	188.00	158.00
	Upland mixed	Total Hectares	761.09	827.79	1282.58
		Mean Patch Size (ha)	15.86	12.17	15.27
		SD Patch Size (ha)	16.68	20.49	26.43
		Number of Patches	48.00	68.00	84.00
	Water	Total Hectares	302.16	314.15	378.64
		Mean Patch Size (ha)	23.24	18.48	9.47
		SD Patch Size (ha)	39.32	36.11	24.68
		Number of Patches	13.00	17.00	40.00

Appendix B

SubsecName	CoverName	Data	Year 1930	1970	1990
Tamarack Lowlands	Agriculture	Total Hectares	2026.80	1852.31	2106.57
		Mean Patch Size (ha)	49.43	52.92	70.22
		SD Patch Size (ha)	206.18	168.96	205.27
		Number of Patches	41.00	35.00	30.00
	Developed	Total Hectares	12.94	68.70	154.37
		Mean Patch Size (ha)	3.23	2.45	4.17
		SD Patch Size (ha)	3.04	2.13	6.55
		Number of Patches	4.00	28.00	37.00
	Lowland conifer	Total Hectares	1594.28	2088.04	2468.68
		Mean Patch Size (ha)	23.11	18.16	29.74
		SD Patch Size (ha)	67.93	32.72	82.46
		Number of Patches	69.00	115.00	83.00
	Lowland grass	Total Hectares	2299.91	2162.77	1433.09
		Mean Patch Size (ha)	41.07	23.26	20.18
		SD Patch Size (ha)	161.79	80.87	47.44
		Number of Patches	56.00	93.00	71.00
	Lowland mixed	Total Hectares	181.67	230.39	331.79
		Mean Patch Size (ha)	12.11	8.86	9.76
		SD Patch Size (ha)	8.64	6.59	9.61
		Number of Patches	15.00	26.00	34.00
	Other	Total Hectares	27.61	67.87	132.30
		Mean Patch Size (ha)	9.20	5.22	4.72
		SD Patch Size (ha)	6.09	3.77	5.28
		Number of Patches	3.00	13.00	28.00
	Unknown regen.	Total Hectares	702.29	195.59	70.25
		Mean Patch Size (ha)	46.82	24.45	10.04
		SD Patch Size (ha)	77.61	26.84	7.71
		Number of Patches	15.00	8.00	7.00
	Upland conifer	Total Hectares	100.72	42.10	50.45
		Mean Patch Size (ha)	7.19	2.48	2.66
		SD Patch Size (ha)	6.60	1.97	2.03
		Number of Patches	14.00	17.00	19.00
	Upland grass	Total Hectares	63.39	159.47	298.98
		Mean Patch Size (ha)	6.34	5.14	7.67
		SD Patch Size (ha)	12.72	10.69	8.70
		Number of Patches	10.00	31.00	39.00
	Upland hardwood	Total Hectares	1124.20	1300.21	1287.10
		Mean Patch Size (ha)	22.04	13.00	12.62
		SD Patch Size (ha)	30.25	16.03	14.63
		Number of Patches	51.00	100.00	102.00
	Upland mixed	Total Hectares	990.84	948.48	766.76
		Mean Patch Size (ha)	22.52	13.17	12.37
		SD Patch Size (ha)	37.89	18.68	16.71
		Number of Patches	44.00	72.00	62.00
	Water	Total Hectares	199.18	207.90	223.49
		Mean Patch Size (ha)	22.13	12.23	11.76
		SD Patch Size (ha)	33.58	21.74	21.85
		Number of Patches	9.00	17.00	19.00

Appendix B

SubsecName	CoverName	Data	Year 1930	1970	1990
Toimi Uplands	Agriculture	Total Hectares	141.86	55.73	27.34
		Mean Patch Size (ha)	10.13	6.19	5.47
		SD Patch Size (ha)	9.36	4.25	3.21
		Number of Patches	14.00	9.00	5.00
	Developed	Total Hectares	2.91	30.20	42.95
		Mean Patch Size (ha)	1.46	1.59	2.39
		SD Patch Size (ha)	0.04	0.86	3.30
		Number of Patches	2.00	19.00	18.00
	Lowland conifer	Total Hectares	340.81	508.52	499.40
		Mean Patch Size (ha)	10.33	5.47	7.34
		SD Patch Size (ha)	10.17	7.74	12.06
		Number of Patches	33.00	93.00	68.00
	Lowland grass	Total Hectares	859.12	774.49	780.76
		Mean Patch Size (ha)	17.90	9.68	12.80
		SD Patch Size (ha)	39.78	18.05	23.66
		Number of Patches	48.00	80.00	61.00
	Lowland mixed	Total Hectares	6.13	27.49	63.39
		Mean Patch Size (ha)	6.13	13.74	5.28
		SD Patch Size (ha)	--	15.01	3.17
		Number of Patches	1.00	2.00	12.00
	Other	Total Hectares	3.70	37.82	154.33
		Mean Patch Size (ha)	3.70	5.40	11.87
		SD Patch Size (ha)	--	5.97	21.41
		Number of Patches	1.00	7.00	13.00
	Unknown regen.	Total Hectares	595.68	394.79	16.65
		Mean Patch Size (ha)	37.23	56.40	8.32
		SD Patch Size (ha)	44.91	81.14	2.11
		Number of Patches	16.00	7.00	2.00
	Upland conifer	Total Hectares	736.33	113.08	221.34
		Mean Patch Size (ha)	38.75	5.65	7.91
		SD Patch Size (ha)	45.53	4.78	6.30
		Number of Patches	19.00	20.00	28.00
	Upland grass	Total Hectares	9.22	30.94	12.85
		Mean Patch Size (ha)	1.54	3.09	4.28
		SD Patch Size (ha)	0.71	1.92	3.70
		Number of Patches	6.00	10.00	3.00
	Upland hardwood	Total Hectares	1010.27	1831.01	1587.45
		Mean Patch Size (ha)	22.96	14.42	14.56
		SD Patch Size (ha)	44.21	18.85	25.05
		Number of Patches	44.00	127.00	109.00
	Upland mixed	Total Hectares	912.00	792.05	1201.25
		Mean Patch Size (ha)	50.67	12.00	15.21
		SD Patch Size (ha)	59.26	13.22	19.21
		Number of Patches	18.00	66.00	79.00
	Water	Total Hectares	43.89	65.80	54.20
		Mean Patch Size (ha)	3.99	2.86	6.78
		SD Patch Size (ha)	7.34	5.59	8.51
		Number of Patches	11.00	23.00	8.00