CONTEMPORARY FOREST COMPOSITION AND SPATIAL PATTERNS OF NORTH CENTRAL AND NORTHEASTERN MINNESOTA: AN ASSESSMENT USING 1990s LANDSAT DATA

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Introduction

The spatial pattern of forested landscapes, and in particular the size and arrangement of forest patches, the amount of edge in a landscape, and the adjacency relationships of cover types, has been a key issue in managing forests across landscape and larger spatial scales. There have been numerous approaches to quantifying landscape patterns, generally based on synoptic coverages of the landscape, such as those derived from air photo or satellite imagery. Satellite imagery has the ability to cover broad spatial scales with a fine degree of spatial and classification resolutions.

In this study, 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. The metrics were calculated at the scale of ecological subsections, which are defined primarily in terms of landform or glacial geology, and thus provide some information on the underlying spatial structure of the landscape as imposed by differences in physiographic and soil conditions. Metrics were selected to represent the range of descriptors commonly used in landscape analyses (Crow et al. 1999, Gustafson et al 1998, Liu and Cameron 2001), that cover the various aspects of spatial pattern (Fuller, 2001, Ritters et al. 1995), and that have been shown in the literature to relate to viability of plant and animal communities (e.g., McIntyre 1995, Trzcinski et al. 1999). These 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 included 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.

The source data were two LANDSAT classifications of the landscape, the GAP classification developed by the Minnesota DNR as part of the national GAP analysis program, and a more detailed classification developed at the Natural Resources Research Institute (NRRI) (Wolter et al. 1995). This latter classification involved extensive use of multitemporal imagery to discriminate among spectrally similar forest cover types, but is less extensive than the GAP coverage, which is available on a statewide basis. Our overall objective was to develop basic descriptions of the ecological subsections in the study area for input into the more detailed historic spatial analysis project being conducted by the Minnesota Forest Resources Council. A secondary objective was to assess the degree of difference or similarity in forest composition and spatial structure given these two LANDSAT classifications of northern Minnesota forests.

Methods

The GAP and NRRI Landsat classifications were clipped to the boundaries of subsections within the Northern Superior Uplands and Drift and Lake Plains sections. To generate comparable results, the two Landsat classifications were recoded into a common classification system (Table 1). This resulted in a substantial reduction in the number of classes: 48 for the NRRI classification and 45 for the GAP classification were reduced to 22 common classes. These common classes were identified by the technical team of the spatial analysis project based on what could reasonably be interpreted from historic (1930s, 1970s, and 1990s) air photos.

The two classifications were also placed in a comparable spatial framework. Unfiltered Landsat classifications commonly contain large numbers of small patches (<4 pixels) including individual pixel patches. In the classifications analyzed here, the pixel dimensions are 28.5 m on a side. These small patches can have a strong influence on landscape pattern measures and are much smaller than patches typically used in forest management. In order to make the analysis more meaningful to forest managers and ecologists, a smoothing algorithm was applied to both classifications. We used the GAP Analysis Program smoothing protocol as applied by Minnesota DNR Resource Assessment for the Minnesota GAP classification. In this filtering procedure, patches less than 4 pixels in area are recoded to a new class based on the majority of surrounding pixels. Initially, each classification was separated into upland and lowland based on National Wetland Inventory data. Each stratum was smoothed twice; multiple iterations of the smoothing process are required to eliminate stray pixels. Open water classes and transportation were not smoothed. The upland and lowland strata were then mosaiced back together. The smoothing process was applied a final time to the new image. All classes were included in the smoothing.

Landscape metrics were calculated using two publicly available programs: APACK and FRAGSTATS. APACK (Boeder et al.1995; Mladenoff and DeZonia 2000) was originally developed to process output from LANDIS, a model 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 patch size and edge density statistics, patch complexity indices, and patch connectivity. Instruction sequences describing the desired metrics and outputs were coded into a batch file and run for all subsections. Outputs from APACK were summarized in Excel in graphic and tabular form. Data were summarized at several scales, including the whole landscape, which describes aggregate patch behavior, and by individual or aggregate cover types. Several analyses, such as lacunarity and core area, required aggregating types into coniferous or deciduous forest. FRAGSTATS (McGarigal et al. 2002), was used to calculate core area indices.

Results

Whole Landscape Descriptors

The broadest level assessment of spatial pattern consists of metrics calculated for a landscape as a whole, and allows comparisons of the individual subsections. These metrics include average patch area, edge density, and fractal dimension. A finer scale of assessment is described by metrics at the level of individual cover types, such as the average area of Jack pine patches. Area metrics can be further broken down into analysis of the distribution of patch sizes within an individual cover type, *sensu* Crow, Host and Mladenoff (1999). This report will begin with broad level descriptors, and move to progressively finer levels of description. Results will be summarized and compared across ecological subsections.

Absolute Area

The total area for the two sections was approximately 460 km^2. Chippewa Plains and Border Lakes occupy 80 and 90 km^2, respectively, or roughly 20% of the total area (Figure 1). Toimi Uplands and Laurentian Highlands (which were originally mapped as a single subsection) are the smallest subsections, covering 14 and 23 km^2, respectively (3 and 5% of landscape). There is thus a sixfold range in sizes among the subsections - these size differences need to be considered in interpreting landscape metrics, as there will be a large difference in the numbers of patches being analyzed in a particular landscape.

Average Patch Area

Average patch areas are influenced both by the classification resolution and the methods used to smooth and filter the data. Average patch areas ranged from 3.1 ha in the Nashwauk Uplands to 5.7 ha in the North Shore Highlands (Figure 2). In general, patches were on average 0.44 ha smaller in the GAP classification, although in the Toimi Uplands, Nashwauk Uplands and Tamarack Lowlands the difference in mean patch size exceeded 1 ha.

Averages also need to be considered in light of the distribution of the data being averaged. The standard deviation and associated coefficients of variation describe the variation around the mean - large values for these statistics mean that there is a broad range in patch sizes contributing to the mean. A large coefficient of variation (CV) can be interpreted as a diversity of patch sizes in the landscape, whereas a small standard deviation indicates that most patches are of similar size. In all cases, CVs of patch size were quite high, ranging from 10 in the Tamarack Lowlands to 96 in the North Shore Highlands; CVs of most subsections ranged from 20 to 40 (Appendix A). Given the large variance in patch size, the patch size class statistics presented for individual subsections will provide better descriptors than average patch size alone.

Patch Size Class

Patch size class plots show the area or proportions of patches in different patch size classes, and provide one index of landscape fragmentation. Strong representation in lower size classes (e.g., 1-10 ha) indicate a fine-grained landscape, whereas significant areas in the 100-500 or 500+ size categories represent a more coarse-grained or spatially diverse landscape.

Even though average patch areas show a relatively small range of variation across subsections, there were strong differences in patch size classes among subsections. The North Shore Highlands, Pine Moraines, and Border Lakes subsections had significant amounts of land in the 500+ patch size category, and reflect those subsections characterized by large patch sizes (Figure 3). The Tamarack Lowlands, Nashwauk Uplands, and Laurentian Highlands occupy the opposite end of the gradient, with significant acreages in patch the lower patch size classes (Figure 4). The remaining subsections occupy intermediate positions (Figure 5).

Edge Density

Edge density (in meters of edge per hectare of area) is related to both patch size and patch shape complexity. The range in edge densities among subsections was rather small (109 m/ha in the Pine Moraines to 137 m/ha in the Tamarack Lowlands; Figure 6). A broader range of edge densities can be found when edges are summarized by cover types within the subsections, as shown below.

Fractal Dimension

The fractal dimension is a description of patch shape complexity, and scales between 1.0 and 2.0 for two-dimensional objects (e.g., map polygons). The range in fractal dimensions was small: 1.32 to 1.36 for the NRRI classification and 1.28 to 1.33 for the GAP classification (Figure 7). This relatively narrow range implies that across subsections, map polygons are relatively similar in terms of their shape. Polygon complexity is determined by a number of factors, including the innate pattern of the landscape (e.g., patterns imposed by drainage systems), natural disturbance, and anthropogenic patterns of land use. The fractal analysis shows that factors that affect patch shape do not vary significantly across subsections. A second consideration, though, is that the smoothing process used in the initial processing of the imagery does tend to simplify polygon complexity, potentially reducing the complexity of the raw imagery. The GAP fractal dimensions were generally less than the NRRI dimensions, indicating that the GAP classification identifies simpler polygons than the NRRI classification. Differences were strongest in the Pine Moraines and Chippewa Plains.

Shannon-Weaver Index

The Shannon-Weaver Index considers both the number and relative proportion of patch types in an area. Because the total possible number of patch types in the common classification is rather limited, the SW Index varies within a relatively narrow range (.66 to .80 in the NRRI classification), with little differences between the NRRI and GAP classifications (Figure 8).

Lacunarity

Lacunarity is a multiscale metric describing the texture of spatial patterns. It is applied to a binary description of the landscape, such as forest/non-forest or conifer/non-conifer. In terms of ecological significance, lacunarity relates strongly to dispersal processes, in which the ability to move among habitats is related to the distribution and size of habitat and non-habitat patches. It is also important for describing the availability of 'interior' habitat across spatial scales.

The lacunarity metric essentially describes the distribution of gap sizes, with a landscape being more lacunar if gap sizes are distributed over a broad range (e.g., containing both large

and small gaps). Lacunarity is low when gaps are distributed over a narrow range of values - i.e. gaps are of similar size. It thus measures the 'gappiness' or 'hole-iness' of a geometric structure (Plotkin et al. 1993). Gaps are assessed by using a 'moving window' that quantifies the relative amount of habitat within a window of fixed size moved systematically across the map.

It is useful, however, to assess lacunarity across a range of scales, by using analyzing the landscape with a series of windows of progressively larger sizes. The shape of lacunarity curves across a range of scales provides insight as to whether a landscape is more heterogeneous at fine scales, coarse scales, or if the landscape structure is independent of scale. Plotkin et al. (1993) point out that the shape of lacunarity curves are relatively insensitive to the number or density of gaps in the landscape; given the same basic size distribution of gaps, sparsely occupied landscapes will have similar curves to densely occupied ones.

In our analysis, we assessed lacunarity in three categories: forest/non-forest, conifer/non-conifer, and deciduous/non-deciduous. Window sizes began at 2x2 pixels (30 m pixels from Landsat classification), and were increased across 9 powers of 2 (4x4, 8x8, 16x16…) to a maximum of 512x512 (29) pixels. In terms of hectares, box sizes ranged from 0.3 ha to approximately 21,300 ha. Lacunarity was assessed for each of the 9 subsections. Because of the wide range of sizes used in lacunarity analyses, results are typically presented as logrithmic graphs, specifically ln lacunarity vs ln box size. This simply makes the curves more linear, and aids in visual interpretation of the graph.

The relationships between forest and deciduous lacunarity were very similar across all subsections; they differed in that deciduous lacunarity values were slightly higher than those for forest (Figure 9). Both were significantly lower than lacunarity based on conifer/non-conifer comparisons. In both forest and deciduous, the North Shore Highlands and the Pine Moraines had consistently high scores across all box sizes. The Chippewa Plains generally had the lowest. In terms of deciduous/non-deciduous lacunarity, the North Shore Highlands were particularly high, and the distinction between them and other subsections increased with increasing box size. This can be interpreted as a high degree of clumping of deciduous habitat on the North Shore, particularly at large spatial scales.

The conifer/non-conifer analysis had the highest levels of lacunarity and more complex slope shapes than the other two analyses. Pine Moraines had the highest lacunarity at smaller box sizes (83 ha and less); the North Shore Highlands showed greater lacunarity at box sizes of 330 ha or higher. The St. Louis Moraines also showed high conifer lacunarity across all scales. The Border Lakes and Laurentian Highlands showed the lowest levels of conifer lacunarity, particularly at fine spatial scales (0.3 - 83 ha); this implies that conifers in these landscape show a relatively low degree of aggregation, particularly at the scale of small patches.

Core Area

Core area, also known as interior forest, is calculated by removing a fixed-distance interior buffer from all patches. The resulting numbers are the effective interior area for each patch,

and can be aggregated by individual or aggregate cover type. For this analysis, we grouped the cover types into four categories: Lowland hardwood, Lowland conifer, Upland hardwood, and Upland conifer. The analysis was based on a 100 m interior buffer distance.

Three to six percent of each subsection was in effective core area. Tamarack Lowlands and Border Lakes subsections had the least amounts of effective core area (~3%), although it is important to point out that the Border Lakes subsection was the only subsection that had a significant amount of Upland conifers core area (Figure10). Upland hardwoods made up the majority (3-4%) of core area space in all subsections except for the Tamarack Lowlands, which were evenly divided between Upland hardwoods and Lowland conifers. Lowland conifers were also a significant component of core area in the Laurentian Highlands, where they occur in relatively large patches in the drumlin field.

Landscape Summaries by Subsection and Cover Type

This section provides detailed breakdowns of key spatial metrics by subsection and cover type. Results are presented as overall tables (all subsections, followed by more detailed descriptions for individual subsections. The physiographic and soil descriptions for the subsections given below were taken largely from the Minnesota DNR's ECS program and are presented on the Minnesota DNR web site. Spatial data are from APACK or FRAGSTATS-based summaries.

Table 2. Area by subsection and cover type.

Table 3. Average patch area by subsection and cover type.

Table 4. Edge density by subsection and cover type.

Northern Superior Uplands

Toimi Uplands Subsection

Toimi Uplands (Plate 1) is the smallest of the subsections at 137,269 ha area. The dominant feature of this subsection is Toimi drumlin field, a series of SW-NE oriented ridges composed of gravelly sandy loams, with poorly to very poorly drained conifer swamps or bogs between the drumlins.

Aspen-birch is the dominant cover type (~70,000 ha) of the Toimi Uplands, followed by Lowland conifers and Lowland brush (Figure 11). The overall mean patch size is 5 ha. The largest average patches are found in the Aspen-birch (27 ha), Lowland conifer, and Northern hardwood types (Figure 12); although the variance statistics (Appendix A) indicate that Aspen-birch occurs in a wide range of sizes. These same three types have the greatest edge density, Aspen-birch at 70 m/ha, and Lowland conifers at 30 m/ha (Figure 13).

Border Lakes Subsection

Border Lakes (Plate 2) is a bedrock-controlled landscape in northeastern Minnesota that contains the Boundary Waters Canoe Area. It is characterized by rolling topography with irregular slopes and craggy bedrock outcrops.Border Lakes differs from the other subsections

in that Jack pine and spruce fir are important codominants, occupying 14% and 11% of the total area (Figure 14). Aspen-birch, the main dominant, occupies 32%. Lakes occupy 20% of the subsection; the Border Lakes differ from the other water-dominated subsection, the Pine Moraines, in that the Border Lakes consist of many small to medium-sized irregularly-shaped lakes. The Pine Moraines, in contrast, is dominated by a few, very large lakes (Winnibigoshish, Leech, Cass, and others). Thus, lakes are an integral part of the fine-scale spatial structure of the Border Lakes. Aspen-birch has the largest patch size, ~15 ha, followed by Jack pine at 5 ha (Figure 15). Aspen-birch, Spruce-fir, and Jack pine have the greatest edge densities (Figure 16).

Nashwauk Uplands Subsection

Nashwauk Uplands (Plate 3) comprises end moraines, outwash plains and lake plains, with medium to coarse textured soils.

Forty percent of Nashwauk Uplands is in the Aspen-birch cover type; Developed land, Upland grasses and Lowland conifers are the other dominant types (Figure 17). Mean patch sizes for Aspen-birch is 16 ha, and variability in patch size is relatively low (CV=9; Figure 18). Along with Aspen-birch, Lowland conifers and the Upland brush and grass categories are the dominant classes of edge (Figure 19).

Laurentian Highlands Subsection

Laurentian Highlands (Plate 4) consists predominately of mixed outwash and till plain as well as the Giants Range, the bedrock controlled ridge important to Minnesota's iron mining economy. The subsection also includes a drumlin field, a series of SW-NE oriented ridges. The drumlins generally consist of gravelly sandy loams, with interspersed poorly to very poorly drained swamps or bogs.

Twenty-eight percent of Laurentian Highlands is dominated by Aspen-birch; the Lowland conifers which occur in the inter-drumlin areas occupy 15% of the landscape and open water accounts for 13% (Figure 20). Aspen-birch and the Lowland conifers have the largest mean patch sizes (16 and 8 ha respectively; Figure 21), as well as the greatest edge density (59 and 43 m/ha, respectively; Figure 22).

North Shore Highlands Subsection

North Shore Highlands (Plate 5) parallels the Lake Superior shoreline and extends 20-25 miles inland. Topography is gently rolling to steep, and Lake Superior exerts a strong moderating influence on the climate of this subsection.

Aspen-birch comprises 53% of North Shore Highlands, with Northern hardwoods and Lowland conifers forming an additional 15% (Figure 23). The Aspen-birch and Northern hardwood types have the largest mean patch sizes - 30 and 9 ha respectively (Figure 24), but the aspen systems are highly variable (CV=57), whereas the Northern hardwoods have a relatively narrow range of patch sizes (CV=5). Aspen-birch is the greatest contributor to edge density, with Lowland hardwoods and brush also important (Figure 25).

Drift and Lake Plains

Tamarack Lowlands Subsection

Tamarack Lowlands (Plate 6) consists of the old lake plain of glacial Lake Upham and the adjacent Aurora Till Plain. Topography is level to gently rolling, and poorly-drained peat soils are extensive. Due to its low-lying landscape position, this subsection has a short growing season.

Aspen-birch, Lowland conifers, Lowland brush, and Upland grasses are the dominant cover types of Tamarack Lowlands. (Figure 26) Lowland conifers have the largest patches (9 ha) followed by Aspen-birch (8 ha)(Figure 27). The greatest amount of edge occurs in the Aspen-birch and lowland brush types; 58 and 48 m/ha respectively (Figure 28).

Chippewa Plains Subsection

Chippewa Plains (Plate 7) consists of level to gently rolling lake plains and till plains, with loamy, moderately well drained soils on morainal landforms and sandy, excessively well-drained soils on outwash materials.

Aspen-birch comprises 30% of Chippewa Plains, with upland grass or agriculture, lowland brush and water being other dominant land cover classes (12-14%; Figure 29). NRRI and GAP classifications appear to be mutually exclusive with respect to classifying a land use as upland grass or agriculture. Mean patch size for Aspen-birch is 11 ha, CV = 10. Lowland conifers and the grass/agriculture categories also have high mean patch sizes (Figure 30). Aspen-birch, Lowland conifers, and grasses are the main contributors to edge (Figure 31).

St. Louis Moraines Subsection

St. Louis Moraines (Plate 8) consists predominately of end moraines with rolling to steep slopes; loamy calcareous soils make up about 75% of the subsection, with excessively well drained outwash sands accounting for 10-15% (Soil Science, University of Minnesota, in DNR ECS web site).

Aspen-birch is the sole dominant of St. Louis Moraines, occupying 213,651 ha or 41% of the subsection (Figure 32). Northern hardwoods, Upland grasses, and Lowland conifers and brush are other key types, but each occupying less than 10% of the landscape. Aspen-birch has both the largest mean and absolute patch sizes, as well as a large variation in patch size (CV=30; Figure 33). It also has the largest edge density ~58 m/ha, although Aspen-birch edge density is low compared to other subsections (Figure 34).

Pine Moraines Subsection

Pine Moraines (Plate 9) is a mix of end moraines, outwash plains, till plains and drumlin fields. Soils are therefore quite variable, ranging from excessively drained sands to calcareous loams. Over 10% of the soils are organic.

Like St. Louis Moraines, Pine Moraines are dominated by Aspen-birch (33% of total area), with upland grass or agriculture being dominant secondary types (Figure 35). Aspen-birch has the largest mean patch size (14 ha) of forested types; the presence of several large lakes makes water a significant fraction of the subsection (Figure 36). Aspen-birch, upland grass and Northern hardwoods are the main contributors to edge in this subsection (Figure 37).

Discussion

This study provides a comprehensive description of contemporary landscape patterns for subsections of northeastern and north central Minnesota. It is more detailed than our broader 1997 assessment of Lake States forests (Host et al. 1997), and complements the ongoing work of the Spatial Assessment of the Forest Resources Council and other related research (e.g., Friedman et al. 2001) and forest planning efforts. Given the relatively fine (30 m) resolution of the source data, the extent of the study is large, covering nine subsections distributed across two of the three ecological sections that cover the forested region of Minnesota. As managers begin to develop subsection-scale forest plans, this analysis and the associated data provides basic information on the current spatial patterns, including information on patch size, regions with high edge density, on the location of the largest continuous patches of forests lands.

There are several key results from this analysis that need to be considered in drawing conclusions on the overall spatial structure for these two sections. First, the Aspen-birch type dominates all nine subsections, ranging from 27% in the Tamarack Lowlands to 53% of the North Shore highlands. Consequently, patches in the Aspen-birch type tend to dominate most spatial metrics, such as average patch size, patch size distributions and edge densities. But, given that Aspen-birch is the major cover type across both sections and the primary focus of forest management in Minnesota, it is clear that the strategies used to manage the Aspen-birch type, both compositionally and spatially, will have the most influence on future habitats of Minnesota forests.

Landscape physiognomy, particularly aspects that relate to hydrology or soil drainage, exerts significant constraints over both composition and spatial pattern. Subsections characterized by level topography in low-lying areas tend to have extensive patches of Lowland conifers, a native plant community for these landforms (White and Host 2000). Historic land use patterns interact with physiography - slight upland conditions in flat landscapes were often placed into or are currently in agricultural use, resulting in the presence of interspersed agriculture or upland grasslands in these areas that alters the patch structure. Similarly, more topographically complex landforms such as end moraines impart a physiographically-based spatial structure to the landscape, which in turn selects for different cover types as well as different management strategies.

The patch size distribution and lacunarity analysis show that there are strong differences among subsections in terms of the 'grain' of the landscape. “Grain’ of course, is quite species specific - what is fine-grained to one species might be quite coarse-grained to another. Furthermore, grain as reported in this study is closely related to the source data - the minimum mapping resolution of Landsat data is 30 m, and these pixels were aggregated during the smoothing operations - there are likely very few polygons smaller than 1 ha. Conclusions on landscape grain or texture need to be considered in light of these qualifications. Given these caveats, the study revealed differences in spatial structure among subsections. The Tamarack Lowlands and Nashwauk Uplands, exhibited a relatively fine-grained spatial structure - i.e., they were characterized by numerous small patches.

Subsections such as the North Shore Highlands have extensive areas in 500+ ha patch sizes, indicating a more coarse-grained landscape structure.

Interior forest is often cited as an important habitat component for a number of species, and particularly migratory birds. Across all subsections, most core area was in upland hardwoods, and most of this occurs in the Aspen-birch type. Lowland conifers had significant core areas in the Laurentian Highlands and Tamarack Lowlands, and to a lesser degree in the Nashwauk and Toimi Uplands. The only significant Upland conifer areas core areas occurred in the Border Lakes subsection. Identification and mapping of key core areas by ownership would be an important data layer for strategic forest planning, as it is easier to retain contiguous areas than to restore fragmented areas.

There are several caveats to consider in the interpretation of this data. First, these Landsat classifications provide information only on forest cover type. The only age information is that the classifications identify regenerating lands, which can be interpreted as forests in the 0-15 year age class. Beyond that, there is no discrimination among ages. For many species, both the type and the age of forests will need to be considered in assessing their response to edge density, patch size, etc. In addition, all Landsat classification have some degree of classification error, in which spectrally-similar tree species are confused. The accuracy of the NRRI classification prior to the smoothing process was approximately 75% (Wolter and White, 2002). Accuracy of the GAP classification is assessed by fractional subsections - at an analogous classification resolution (GAP Level 4), overall accuracies ranged from 45 to 60%. However, because the classification units were highly aggregated (Table 1), errors in assessing spatial pattern due to misclassification are probably quite low.

At the scale of aggregated classifications and spatial smoothings conducted in this study, the NRRI and GAP classification produced similar results; in most cases there was a <10% difference between the two data sets. However, there were several instances in which results from the analyses diverged. One discrepancy appeared in Toimi and Nashwauk Uplands: the NRRI classification would classify polygons as Aspen-birch whereas GAP would classify these as upland brush. In terms of mean patch size, there was somewhat more variability across the subsections in the GAP classification. The fractal dimensions for Pine Moraines and Chippewa Plains were higher in the NRRI classification compared with the GAP analysis. Beyond these few examples, however, the majority of metrics calculated were quite similar. It is important to note, however, that this is not a strict comparison of the classifications, as the aggregation of units and spatial smoothings altered both data sets to a significant degree. Nonetheless, if managers are to use these aggregated and smoothed data to aid in making forest management decisions, there appear to be no strong differences in selecting one classification over the other.
These initial descriptions of spatial patterns for subsections provide important background information for the more detailed air photo analysis to follow as part of the FRC spatial analysis project. In particular, it will provide a basis for understanding how the results from the detailed analysis within subsections compare with the subsection as a whole. It also provides a baseline to assess future changes in landscape structure due to forest management strategies and natural disturbances.

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Table 1. Assignment of cover types from the MN GAP and NRRI (PTW) Landsat classifications into a common cover type classification.

PTW Landsat Classification	MN GAP Classification	Common Classification
Jack Pine Jack Pine - Hardwood Jack Pine - Oak	Jack pine Jack pine - deciduous mix	Jack Pine
Red Pine Red Pine - Hardwood	Red / White Pine Red Pine White Pine mix Red/White pine - Deciduous mix	Red-White Pine
Spruce-Fir Spruce-Fir - Hardwood Conifer, Misc. (low density) Conifer, Regeneration	Balsam Fir mix White Spruce Spruce/Fir - Deciduous mix Upland Coniferous mix Upland Black Spruce	Spruce-Fir
Aspen-Birch Aspen-Birch -Spruce-Fir Aspen-Birch, Conifer Under. Hardwood, Regeneration Hardwood, Transitional	Aspen/White Birch mix Upland Deciduous mix	Aspen-Birch
		Aspen-Birch-Spruce-Fir
Norhtern Hardwoods Northern Hardwoods - Conifer Northern Hwd - Conifer Under. Red Oak	Maple/Basswood mix Red Oak Oak Bur/White Oak mix	Northern Hardwood
Cedar Tamarack Black Spruce Acid Bog Conifer, Stagnant	Black Spruce Tamarack Northern White Cedar Stagnant Black Spruce Stagnant Tamarack Stagnant Northern White Cedar Stagnant Coniferous mix	Lowland Conifer
Black Ash Black Ash - Conifer Under. Hardwoods, Misc. (lowland)	Black Ash Silver Maple Cottonwood Lowland Deciduous mix	Lowland Hardwood
	Upland Coniferous / Deciduous mix	Upland mixed hwd/con
Cedar - Hardwood Black Ash - Conifer	Lowland Deciduous / Coniferous mix	Lowland Mixed Hwd/Con
Cedar (North Shore)	Upland Northern White Cedar	Upland Cedar
		White pine (sup. Canopy)
		Unknown regen.
Grass, Native Grass, Cool Season Grass, Domestic	Grassland	Upland grass
Brush, Alder Brush, Willow Brush, Misc. Hardwood Regeneration, low	Upland broadleaf dec shrub	Upland brush
Brush, Alder (lowland) Brush, Willow (lowland) Brush, Misc. (lowland) Brush, Ericacious	Lowland broad-leaf dec shr Lowland broad-leaf evg shr	Lowland brush
Grass, Native (lowland) Emergent Sphagnum, Spp.	Sedge Meadow Cattails	Lowland grass Spaghnum (emergent)
Agriculture	Herbaceous/field crops	Agriculture
Developed Roads	Developed High intensity urban Low intensity urban Transportation	High, low den. Developed
Water Emergent, Aquatic	Open Water Floating aquatic	Water
Bare Ground, Bare Upland	Mixed Barren	Bare ground (barren)

Table 2. Overall area (ha) by cover type.

Northern Superior Uplands

	Toimi Uplands		Border Lakes		Nashwauk Uplands		Laurentian Highlands		North Shore Highlands	
COVER TYPE	NRRI	GAP	NRRI	GAP	NRRI	GAP	NRRI	GAP	NRRI	GAP
Jack pine	3621	4255	125174	125188	4916	5815	12051	14151	3747	2836
Red/white pine	1343	4929	20618	52758	2782	8284	10334	16824	4879	11926
Spruce-fir	5523	4109	101089	45947	12034	15824	12314	8843	18920	32543
Aspen-birch	70012	52186	287277	338415	128558	94491	86707	80507	278946	277022
Northern hardwood	3550	3843	1263	255	4982	4907	579	620	42357	26191
Lowland conifer	21619	21002	69057	81373	29879	34440	50455	58031	34418	43117
Lowland hardwood	1519	1995	2326	4000	3955	5247	808	701	7141	4132
Upland mixed hwd/con	0	0	0	0	0	119	0	528	0	109
Lowland mixed hwd/con	1769	534	2176	0	2503	0	1708	0	7040	0
Upland grass	3905	2711	30148	2831	27247	15331	8804	1098	34445	7804
Upland brush	3271	10640	20923	46047	11577	58333	4881	10832	9280	24771
Lowland brush	9775	24410	25382	29605	21831	31127	13463	21331	31849	51721
Lowland herbaceous	3460	1303	21257	11070	10518	2035	7681	2356	8294	2046
Upland cedar	0	0	0	0	0	0	0	0	469	0
Agriculture	0	29	0	588	1	3745	0	4	0	4257
Developed	1928	962	6240	1156	31310	18213	5846	3802	19195	20613
Water	5257	4394	183967	160202	18201	20196	11789	9947	21887	19487
Barren	717	9	4728	2486	8835	1021	2110	3	5097	639

Drift and Lake Plains

	Tamarack Lowlands		Chippewa Plains		St. Louis Moraines		Pine Moraines	
COVER TYPE								
Jack pine	NRRI	GAP	NRRI	GAP	NRRI	GAP	NRRI	GAP
Red/white pine	3955	16527	11629	24533	1494	6951	7451	24218
Spruce-fir	2976	8851	19177	28150	4950	10163	8043	18447
Aspen-birch	10049	3786	8551	20245	7553	8880	4120	1843
Northern hardwood	162896	114159	242692	276954	213651	203336	184239	212955
Lowland conifer	10999	10101	38904	28343	55635	45308	42890	36383
Lowland hardwood	90834	125773	47697	48152	38208	49880	8381	14001
Upland mixed hwd/con	14681	28998	9754	28046	13094	19755	1734	7407
Lowland mixed hwd/con	0	0	0	0	0	356	0	0
Upland grass	4559	3533	623	16029	3544	79	367	55
Upland brush	75700	86870	112402	2376	42578	31886	63202	23539
Lowland brush	18550	18817	36568	19256	10408	28878	24117	19837
Lowland herbaceous	102347	113087	89596	77665	35374	43763	30646	16625
Upland cedar	65627	29359	46132	46035	21002	10922	22261	30425
Agriculture	0	0	0	0	0	0	0	0
Developed	5037	31113	1569	96845	970	6311	589	53670
Water	16296	1950	17008	7990	11183	2179	11310	927
Barren	16180	14590	100017	87122	54353	50301	105174	95124

Table 3. Average Patch Area (ha) by Cover Type.

Northern Superior Uplands

	Toimi Uplands		Border Lakes		Nashwauk Uplands		Laurentian Highlands		North Shore	
COVER TYPE	NRRI	GAP	NRRI	GAP	NRRI	GAP	NRRI	GAP	NRRI	GAP
Jack pine	1.85	1.81	5.18	4.39	1.63	1.24	2.30	2.50	1.55	1.58
Red/white pine	2.89	1.96	2.31	2.52	2.61	1.96	2.67	2.47	1.69	1.67
Spruce-fir	1.26	1.30	2.25	1.42	1.40	1.49	1.31	1.18	1.62	2.23
Aspen-birch	27.64	12.57	13.40	16.85	15.87	6.15	16.30	13.68	30.16	27.31
Northern hardwood	5.41	1.69	1.43	1.22	3.03	1.83	1.42	0.89	9.24	4.57
Lowland conifer	7.07	7.12	2.48	3.59	5.44	4.19	8.74	11.25	4.27	4.97
Lowland hardwood	1.99	1.50	1.19	1.14	2.40	1.74	1.02	1.29	1.55	1.30
Upland mixed hwd/con	0.00	0.00	0.00	0.00	0.00	0.81	0.00	1.18	0.00	1.00
Lowland mixed hwd/con	1.64	0.96	1.16	0.00	1.57	0.00	1.30	0.00	1.80	0.00
Upland grass	2.05	1.77	3.13	1.25	2.95	2.92	3.02	1.18	3.49	1.75
Upland brush	1.25	2.46	1.43	2.29	1.30	3.32	1.37	2.11	1.09	2.24
Lowland brush	2.58	3.38	1.72	2.01	2.82	2.78	2.46	3.17	2.50	3.47
Lowland herbaceous	1.91	1.55	2.11	1.58	1.71	1.03	2.32	1.50	1.59	1.28
Upland cedar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.24	0.00
Agriculture	0.00	0.68	0.00	2.67	0.11	1.62	0.00	0.55	0.00	2.17
Developed	1.61	1.69	1.97	3.96	9.85	4.47	3.49	4.84	3.86	4.74
Water	6.84	6.56	22.47	27.93	7.84	1.99	7.68	7.62	8.34	7.49
Barren	1.89	0.52	1.80	1.45	2.20	1.85	2.10	0.65	1.63	0.95

Drift and Lake Plains

	Tamarack Lowlands		Chippewa Plains		St. Louis Moraines		Pine Moraines	
COVER TYPE	NRRI	GAP	NRRI	GAP	NRRI	GAP	NRRI	GAP
Jack pine	1.46	1.44	4.26	2.58	1.27	1.32	3.51	3.50
Red/white pine	1.65	1.40	3.65	2.31	1.88	1.70	2.30	2.53
Spruce-fir	1.16	0.62	0.97	1.16	1.20	1.25	1.01	0.89
Aspen-birch	7.98	4.43	10.69	11.88	13.29	11.69	14.53	20.99
Northern hardwood	2.78	1.40	2.01	1.51	5.05	2.51	2.22	1.44
Lowland conifer	9.36	8.71	5.98	4.75	4.90	4.05	3.04	3.87
Lowland hardwood	2.39	1.97	1.38	1.27	1.83	1.95	1.17	1.51
Upland mixed hwd/con	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00
Lowland mixed hwd/con	1.37	0.69	0.93	1.45	1.03	0.75	0.94	0.68
Upland grass	5.83	3.72	5.23	0.64	3.55	2.74	3.70	2.17
Upland brush	1.38	0.98	1.27	0.92	1.13	1.95	1.23	1.84
Lowland brush	4.63	4.36	3.38	2.71	2.35	2.71	1.90	2.11
Lowland herbaceous	4.39	3.23	2.65	1.92	2.12	2.26	2.05	2.34
Upland cedar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture	2.60	2.95	1.65	8.48	1.24	1.75	2.39	11.01
Developed	4.32	2.60	2.57	0.41	2.39	1.76	2.29	1.23
Water	6.03	2.01	25.21	9.86	15.73	8.57	23.83	19.09
Barren	1.74	0.96	2.19	0.53	1.70	1.06	5.32	0.88

Table 4. Edge Density (m/ha) by cover type.

Northern Superior Uplands

	Toimi Uplands		Border Lakes		Nashwauk Uplands		Laurentian Highlands		North Shore	
COVER TYPE	NRRI	GAP	NRRI	GAP	NRRI	GAP	NRRI	GAP	NRRI	GAP
Jack pine	10.37	11.98	35.92	39.21	6.41	7.99	19.47	21.56	2.93	2.20
Red/white pine	2.90	12.75	7.82	19.15	2.77	9.06	14.49	24.27	3.59	8.63
Spruce-fir	19.12	13.26	42.24	22.45	17.04	21.30	24.89	18.22	14.74	21.21
Aspen-birch	72.85	74.64	57.11	62.76	67.78	67.99	59.93	62.32	73.05	73.76
Northern hardwood	5.32	11.01	0.53	0.12	4.45	5.91	0.97	1.46	13.18	12.05
Lowland conifer	33.53	29.63	26.57	25.49	21.38	23.38	42.78	42.27	17.53	19.14
Lowland hardwood	4.24	6.09	1.20	2.09	4.31	6.24	1.82	1.31	5.72	3.57
Upland mixed hwd/con	0.00	0.00	0.00	0.00	0.00	0.19	0.00	1.08	0.00	0.10
Lowland mixed hwd/con	5.49	1.91	1.19	0.00	3.36	0.00	3.46	0.00	5.55	0.00
Upland grass	10.51	7.80	9.73	1.44	27.34	15.48	11.65	2.29	18.18	5.93
Upland brush	11.22	26.57	10.34	18.01	16.80	61.45	9.59	16.97	8.70	16.60
Lowland brush	25.50	57.49	12.08	12.96	23.16	31.76	21.36	30.57	22.16	31.97
Lowland herbaceous	9.90	3.96	9.18	5.30	13.60	2.91	12.00	4.23	6.69	1.78
Upland cedar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00
Agriculture	0.00	0.13	0.00	0.22	0.00	4.71	0.00	0.01	0.00	2.91
Developed	7.96	2.83	3.39	0.19	23.68	8.97	6.86	2.78	13.69	9.36
Water	6.02	4.60	19.21	15.74	8.44	12.85	7.94	5.93	5.37	4.15
Barren	1.87	0.04	2.00	1.20	10.03	1.19	3.33	0.01	3.94	0.65

Drift and Lake Plains

	Tamarack Lowlands		Chippewa Plains		St. Louis Moraines		Pine Moraines	
COVER TYPE	NRRI	GAP	NRRI	GAP	NRRI	GAP	NRRI	GAP
Jack pine	1.46	1.44	3.66	8.30	1.27	1.32	3.51	3.50
Red/white pine	1.65	1.40	6.68	10.41	1.88	1.70	2.30	2.53
Spruce-fir	1.16	0.62	5.64	10.74	1.20	1.25	1.01	0.89
Aspen-birch	7.98	4.43	63.92	62.59	13.29	11.69	14.53	20.99
Northern hardwood	2.78	1.40	18.89	14.60	5.05	2.51	2.22	1.44
Lowland conifer	9.36	8.71	12.95	12.20	4.90	4.05	3.04	3.87
Lowland hardwood	2.39	1.97	5.49	15.69	1.83	1.95	1.17	1.51
Upland mixed hwd/con	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00
Lowland mixed hwd/con	1.37	0.69	0.41	8.30	1.03	0.75	0.94	0.68
Upland grass	5.83	3.72	38.22	1.70	3.55	2.74	3.70	2.17
Upland brush	1.38	0.98	21.78	12.38	1.13	1.95	1.23	1.84
Lowland brush	4.63	4.36	36.42	30.85	2.35	2.71	1.90	2.11
Lowland herbaceous	4.39	3.23	17.43	17.41	2.12	2.26	2.05	2.34
Upland cedar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture	2.60	2.95	0.77	21.58	1.24	1.75	2.39	11.01
Developed	4.32	2.60	12.71	6.01	2.39	1.76	2.29	1.23
Water	6.03	2.01	7.19	6.79	15.73	8.57	23.83	19.09
Barren	1.74	0.96	10.77	0.01	1.70	1.06	5.32	0.88

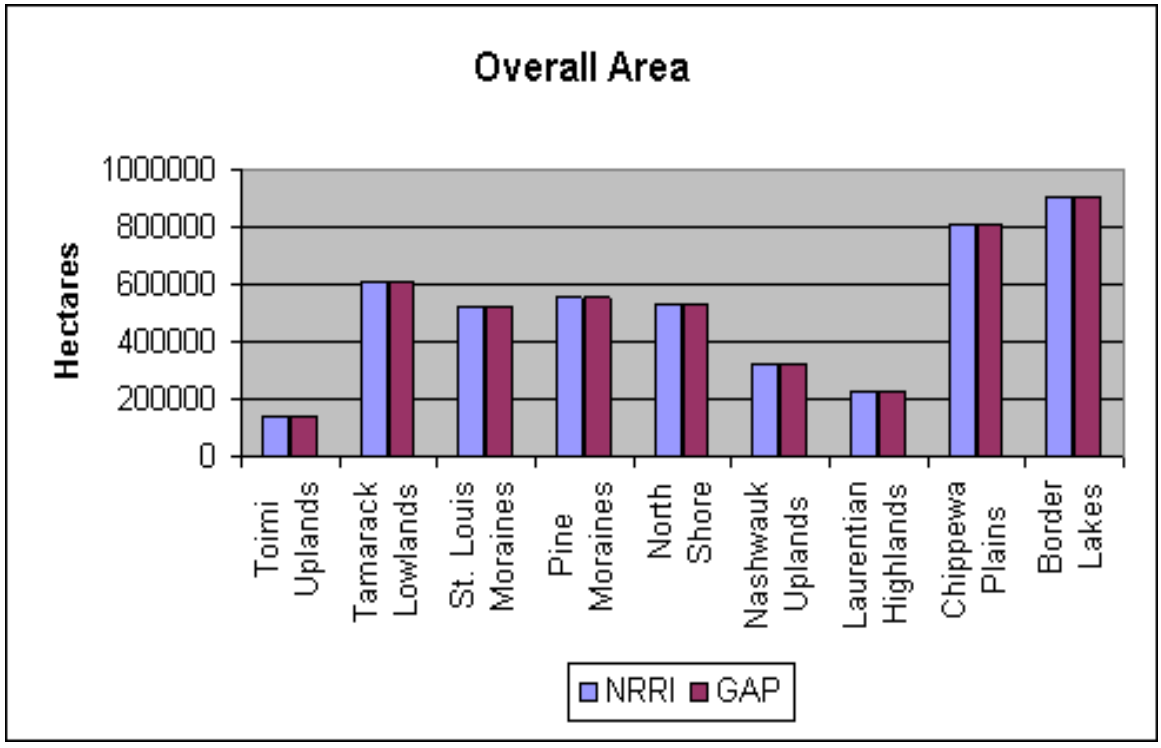


Figure 1. Overall area for ecological subsections of northern Minnesota.

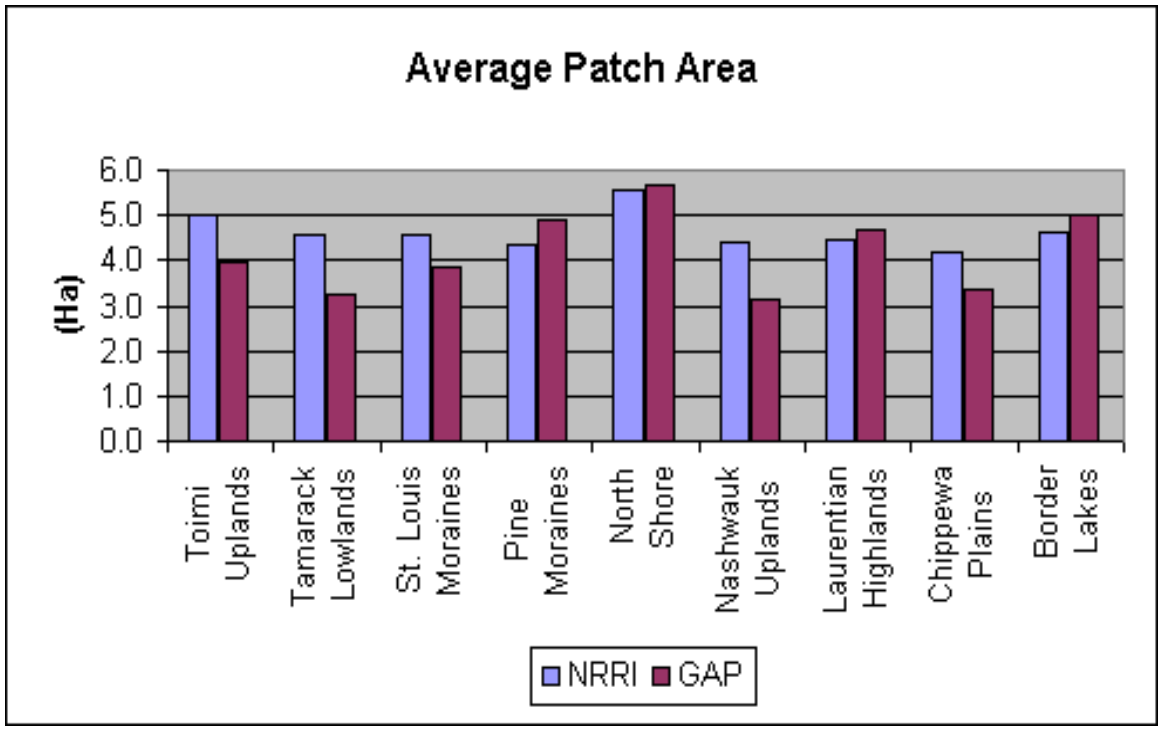


Figure 2. Average patch area for ecological subsections of northern Minnesota.

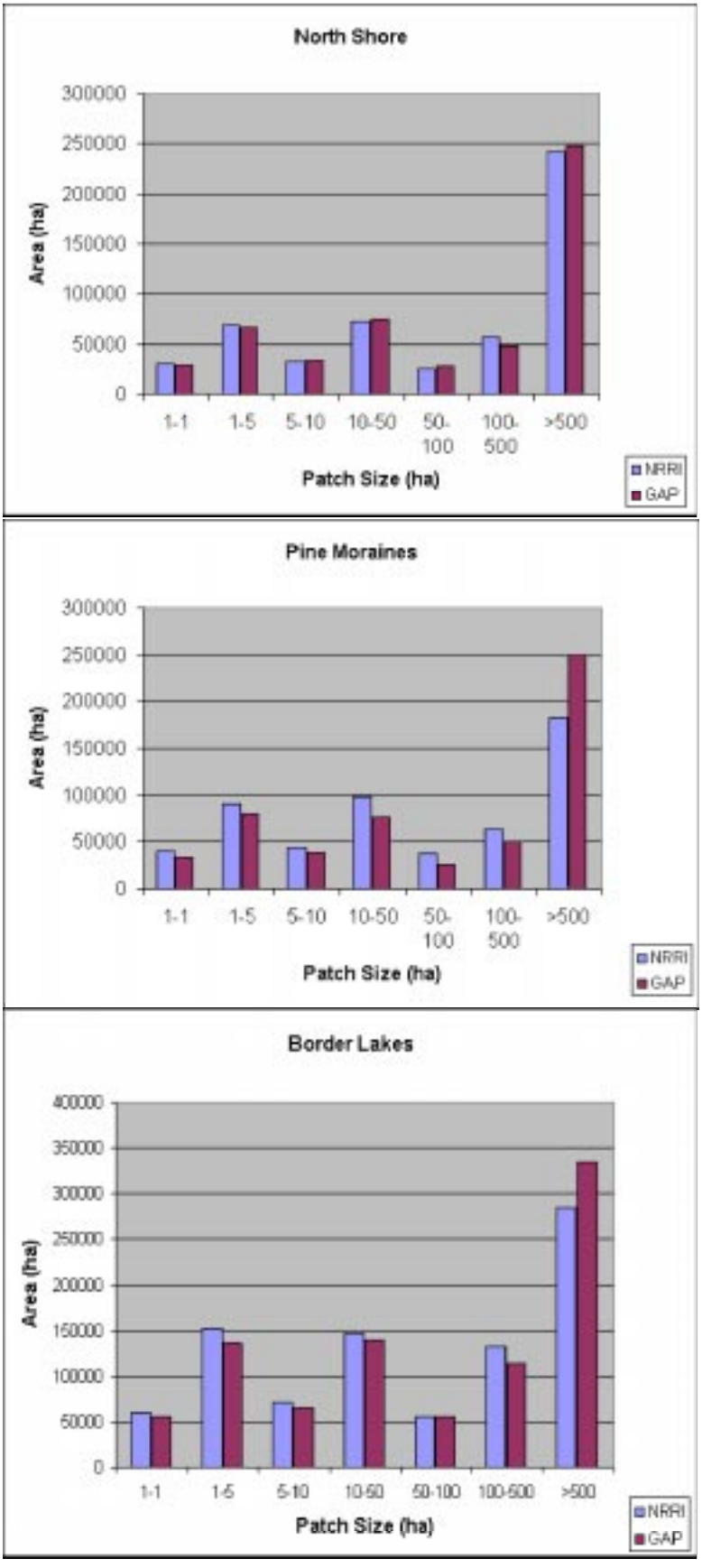


Figure 3. Total area in patch size classes.

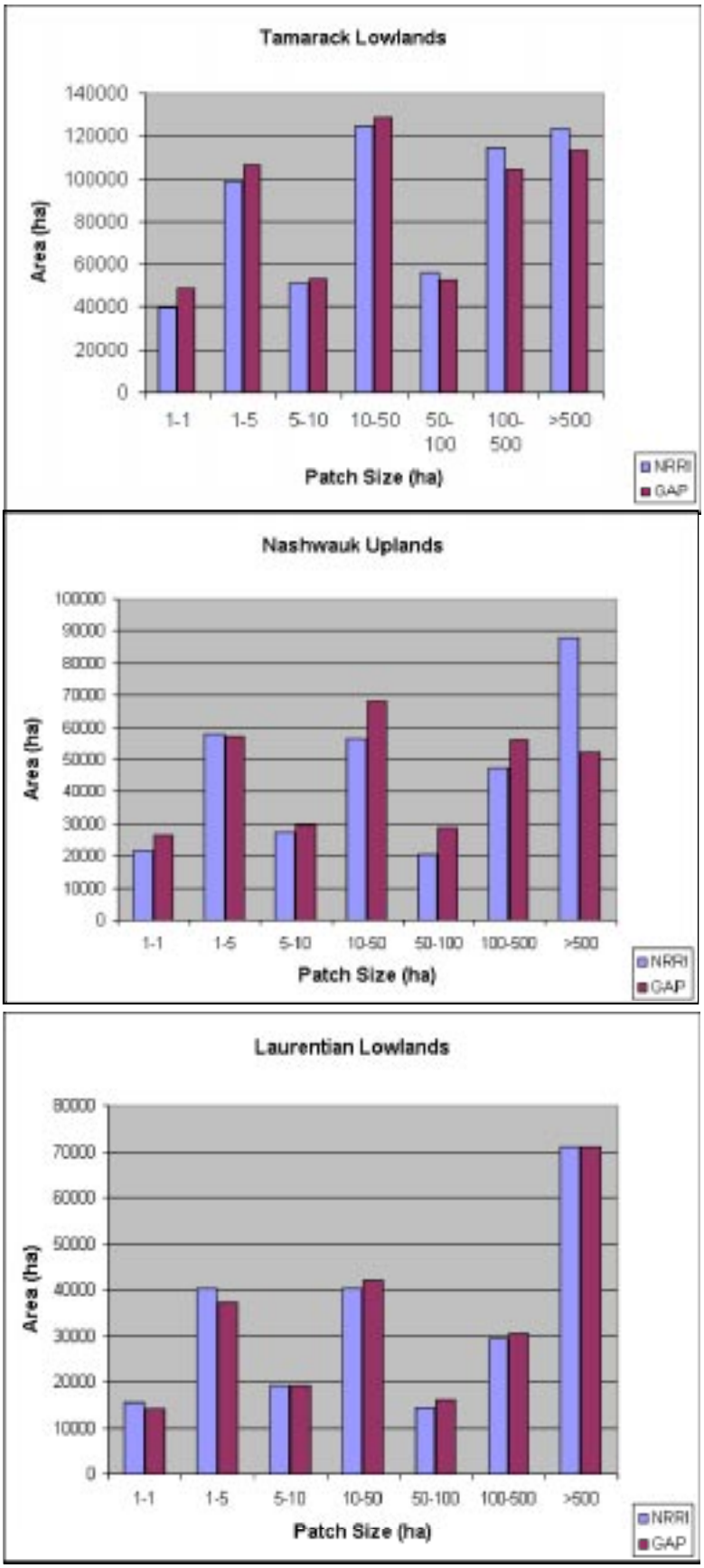


Figure 4. Total area in patch size classes.

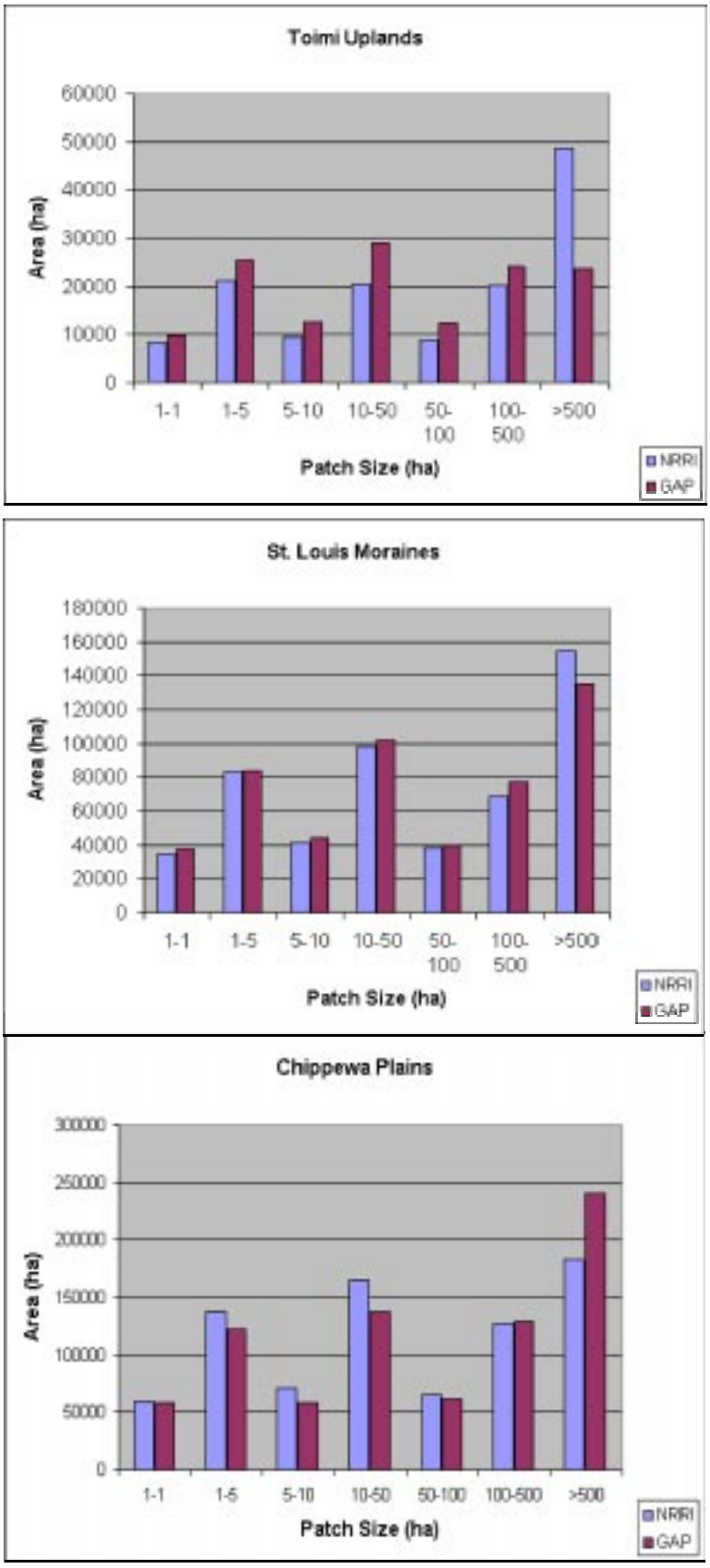


Figure 5. Total area in patch size classes.

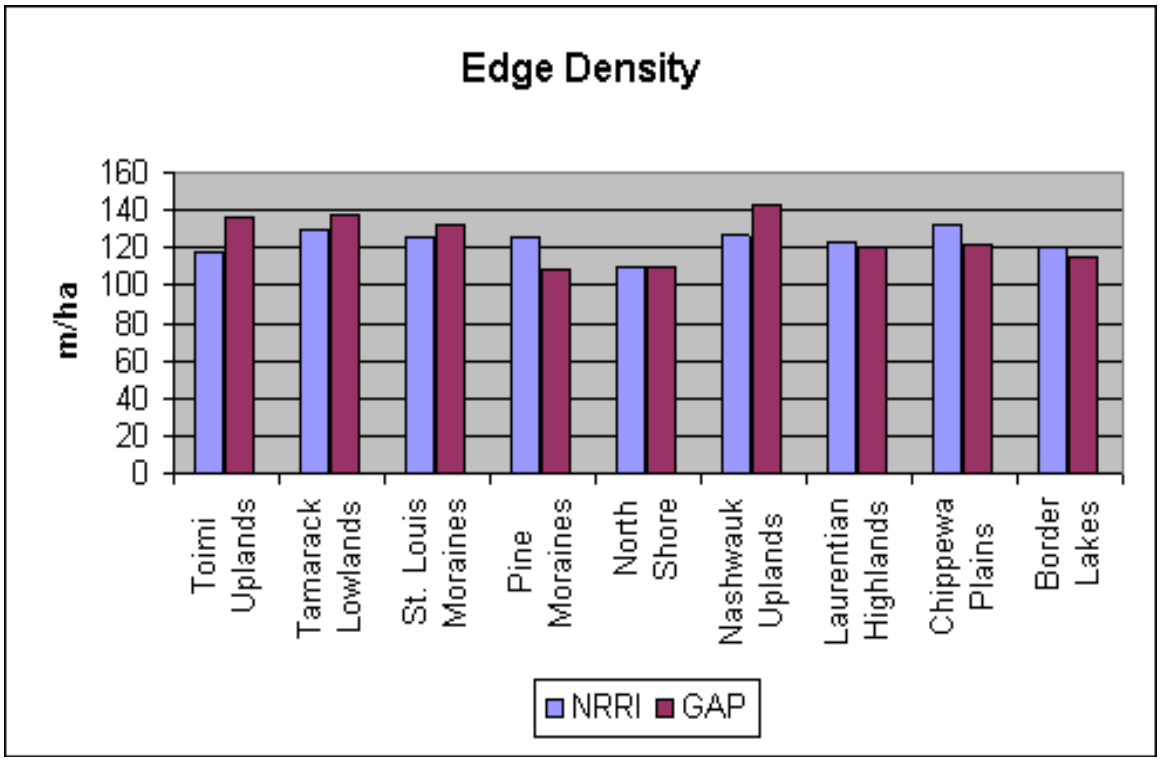


Figure 6. Edge density for ecological subsections of northern Minnesota.

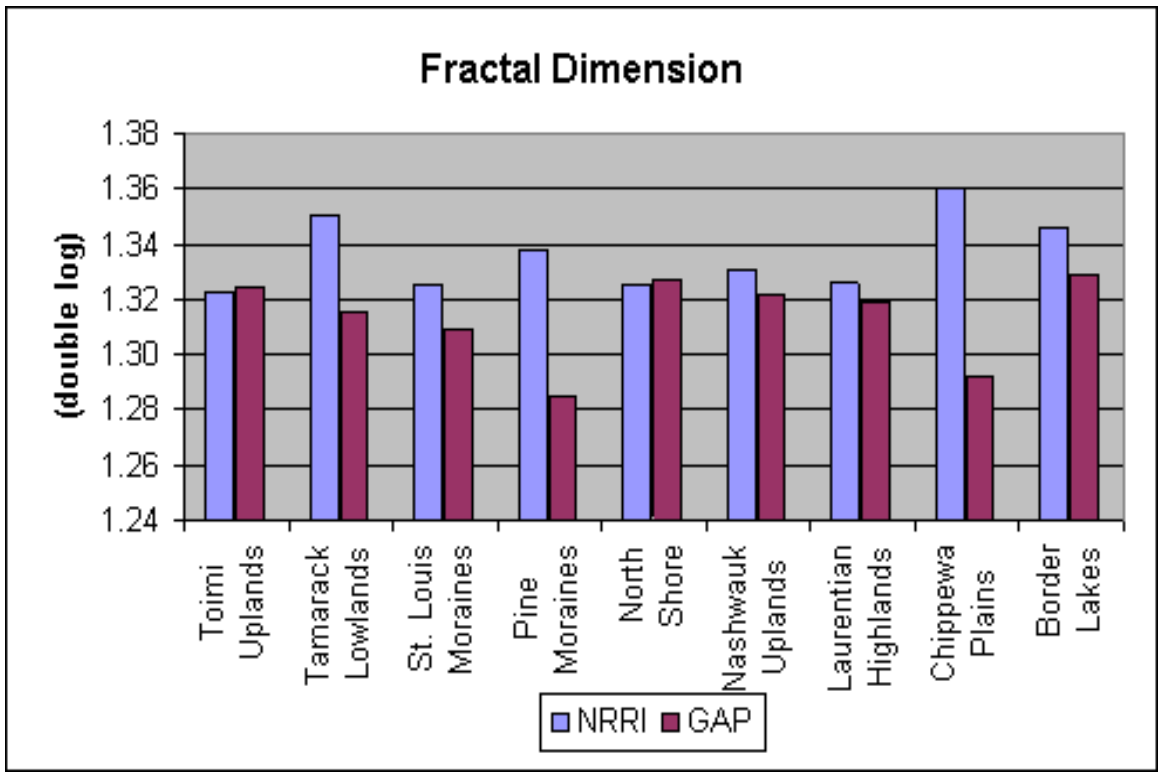


Figure 7. Fractal dimension for ecological subsections of northern Minnesota.

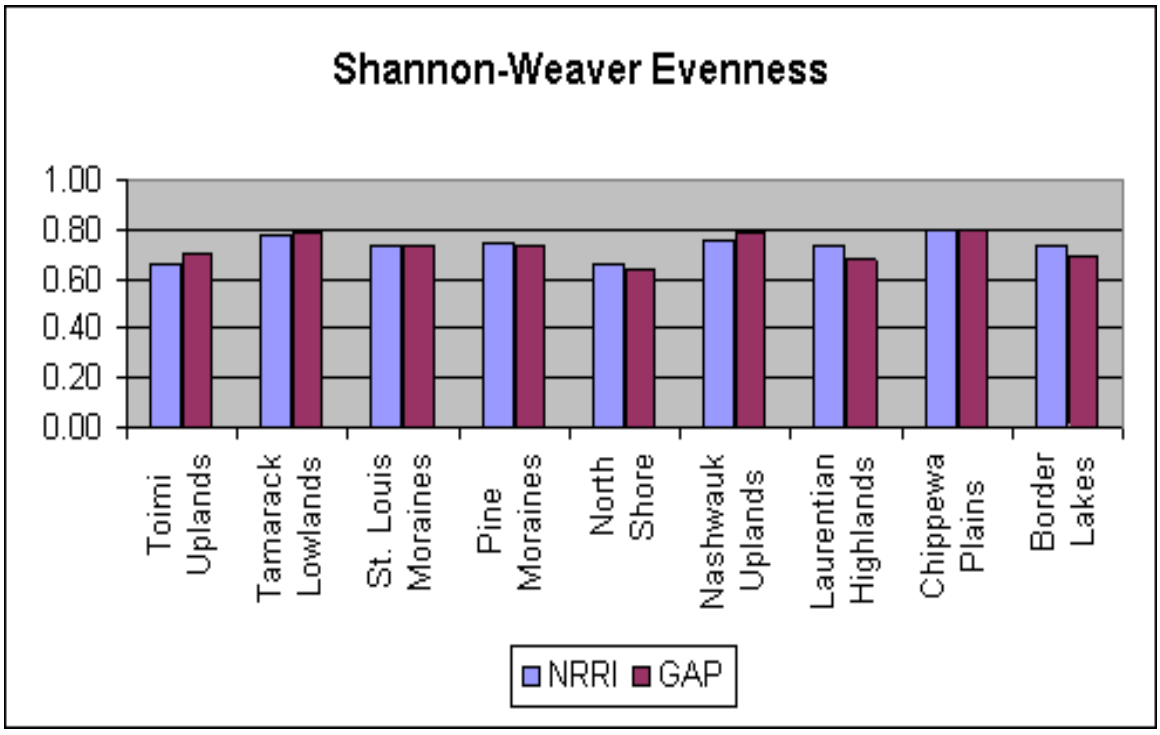
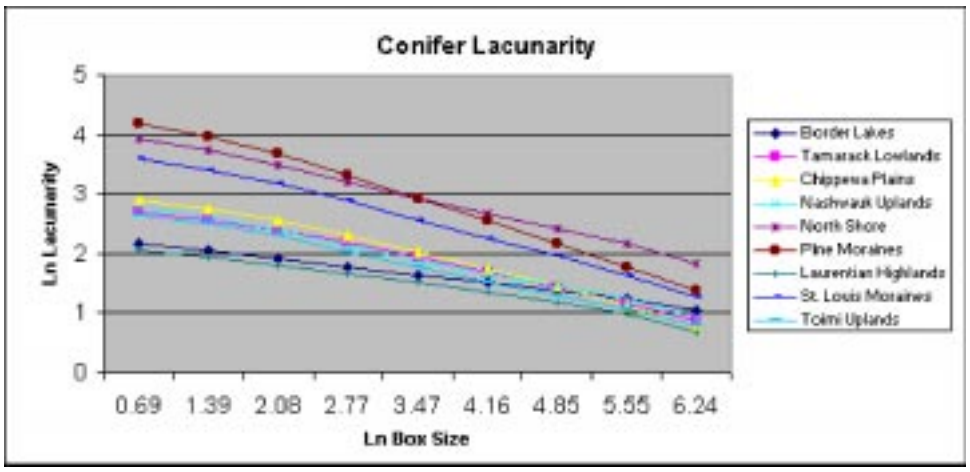
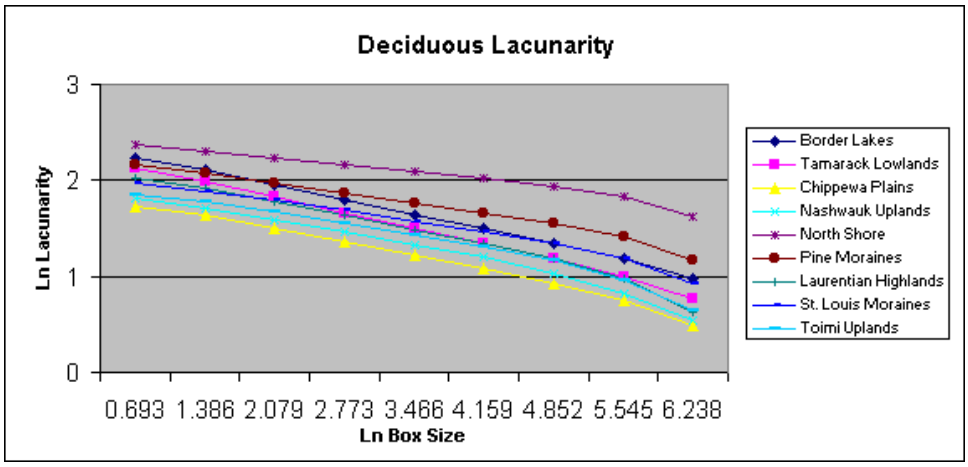


Figure 8. Shannon-Weaver evenness for ecological subsections of northern Minnesota.





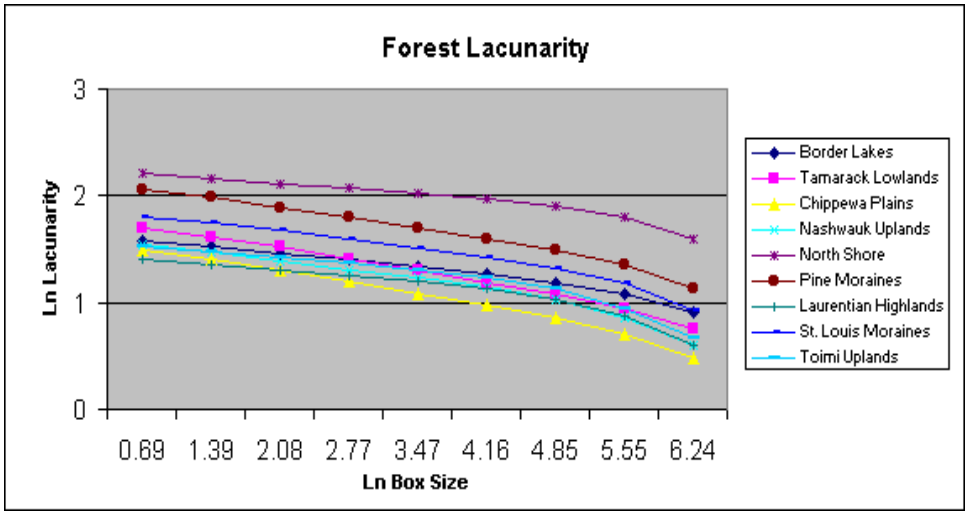


Figure 9. Coniferous, deciduous, and forest lacunarity.

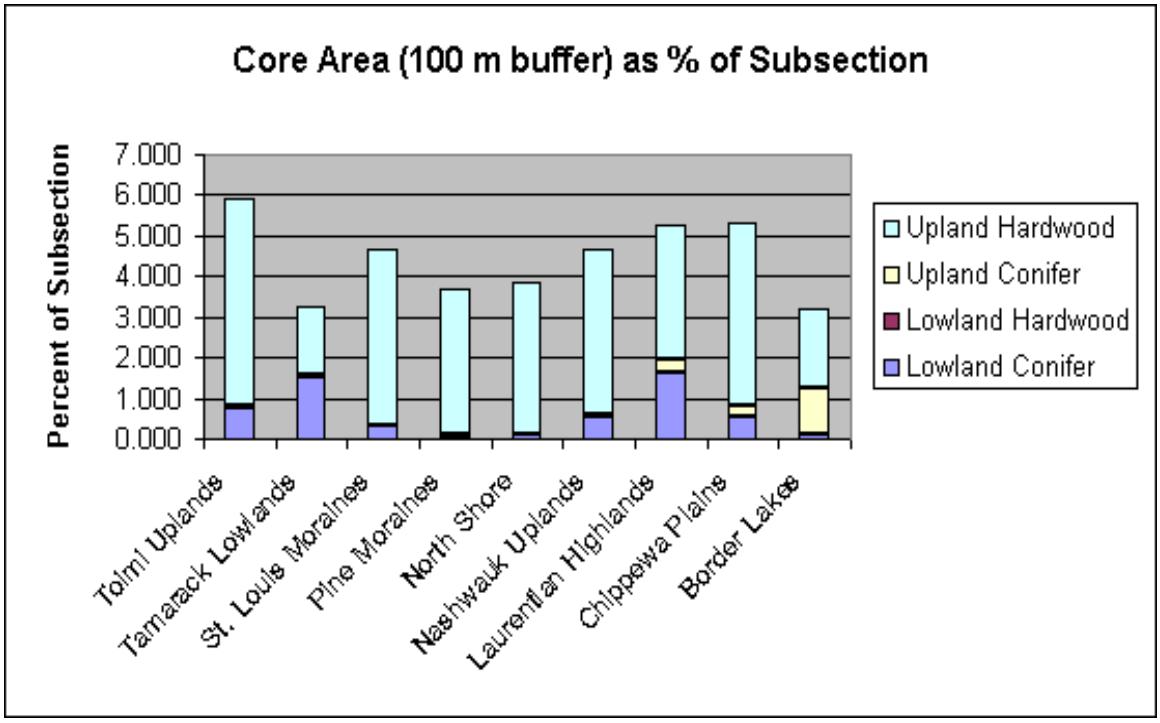


Figure 10. Core area for ecological subsections of northern Minnesota.

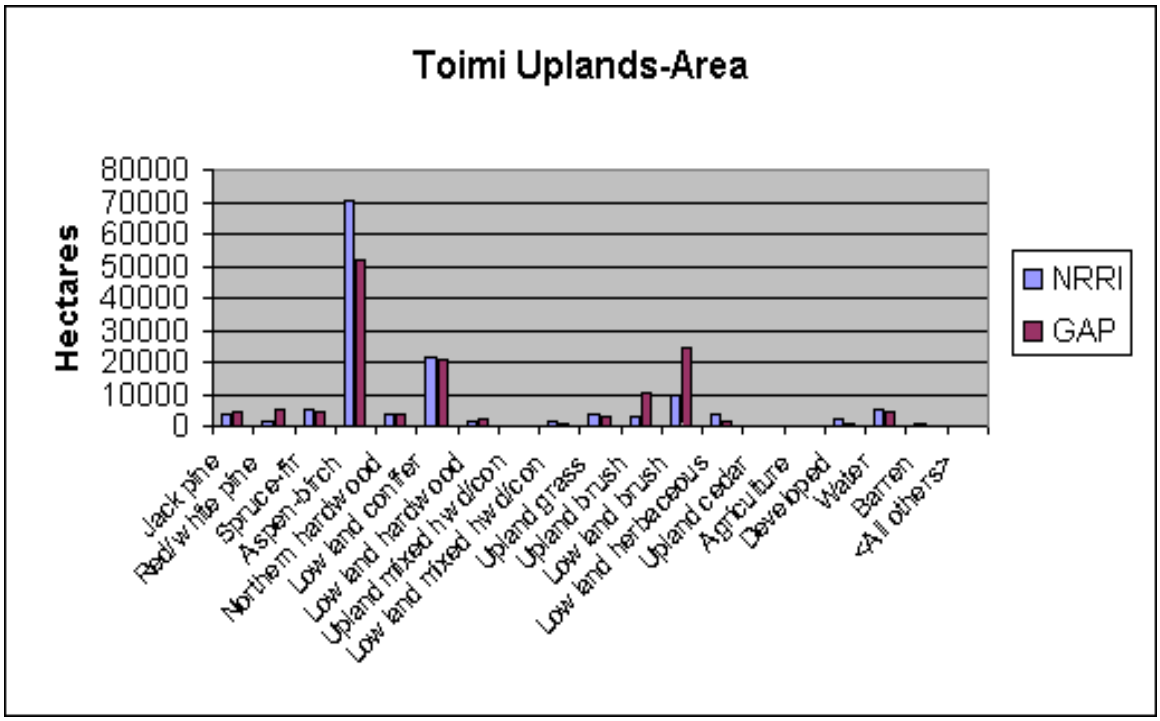


Figure 11. Overall area for Toimi Uplands subsection.

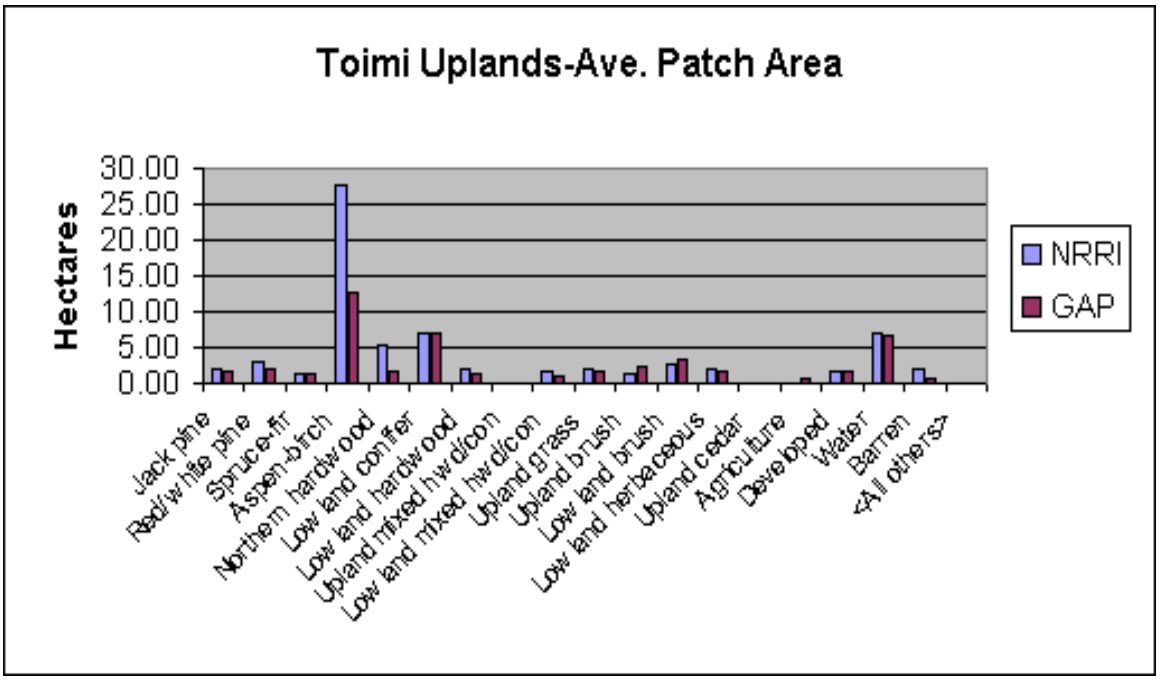


Figure 12. Patch area for the Toimi Uplands of northern Minnesota.

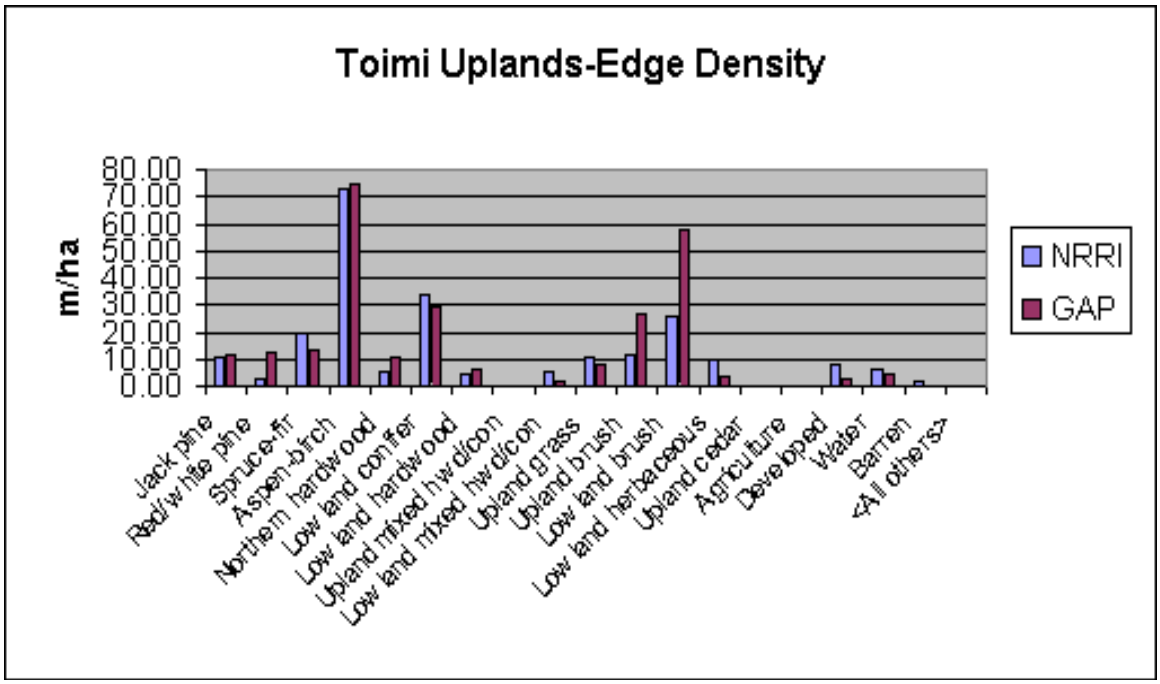


Figure 13. Edge density for the Toimi Uplands of northern Minnesota.

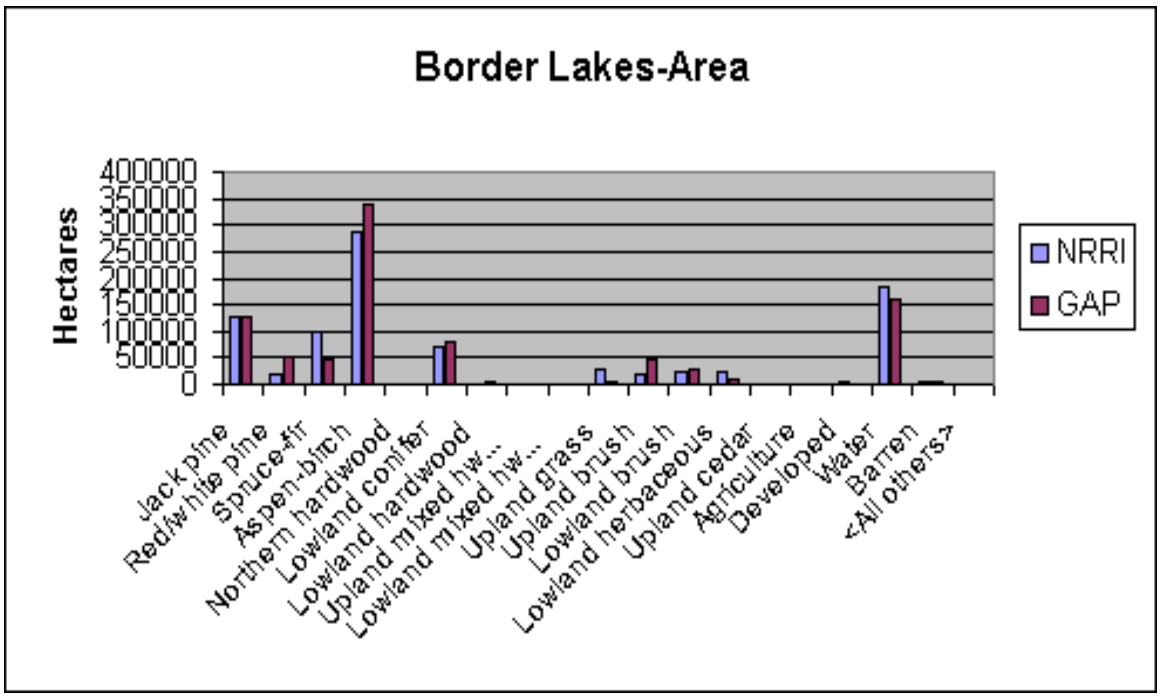


Figure 14. Overall area for the Border Lakes subsection.

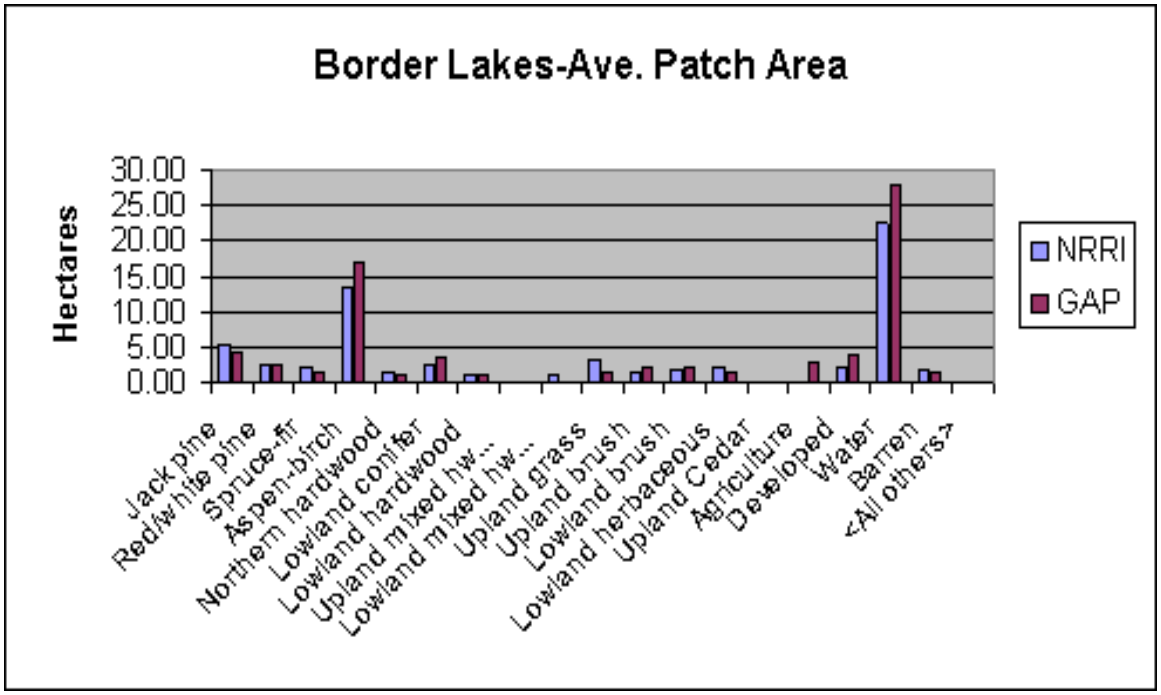


Figure 15. Patch area for the Border Lakes subsection.

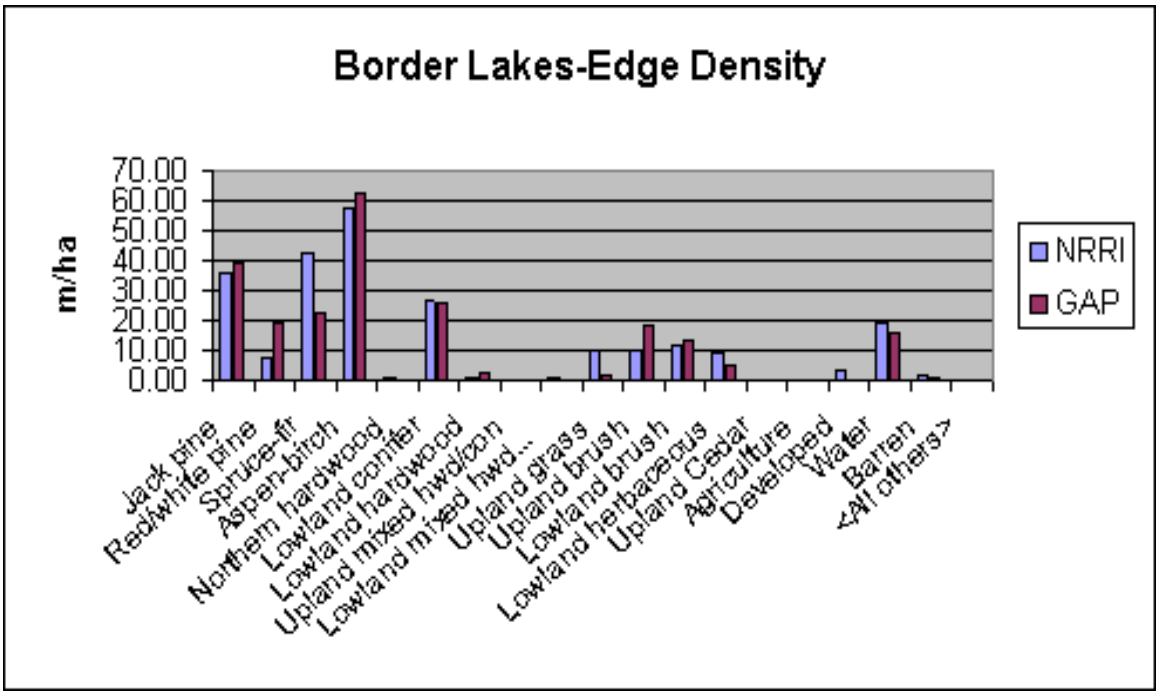


Figure 16. Edge density for the Border Lakes subsection.

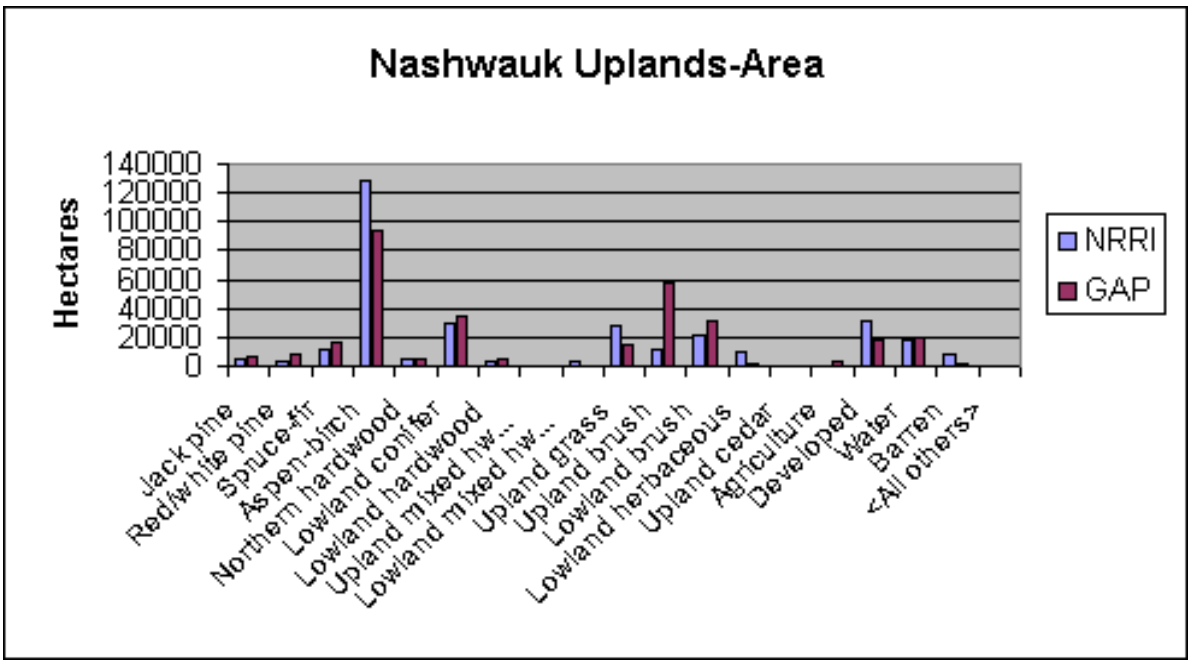


Figure 17. Overall area for the Nashwauk Uplands subsection.

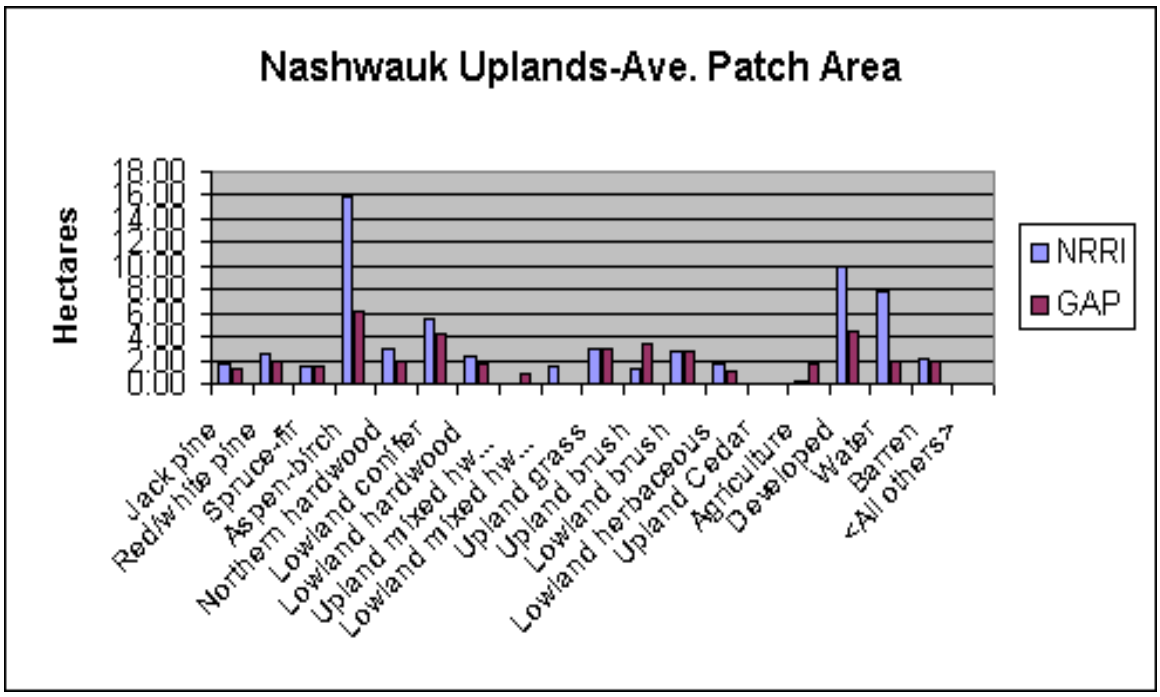


Figure 18. Patch area for the Nashwauk Uplands subsection.

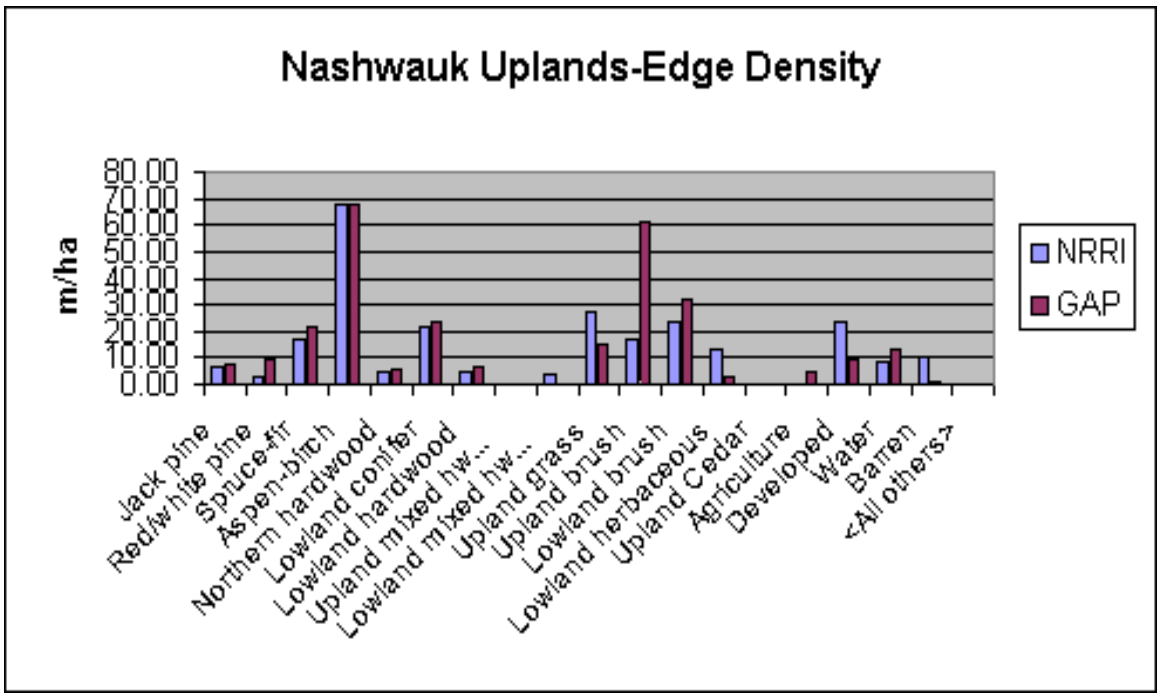


Figure 19. Edge density for the Nashwauk Uplands subsection.

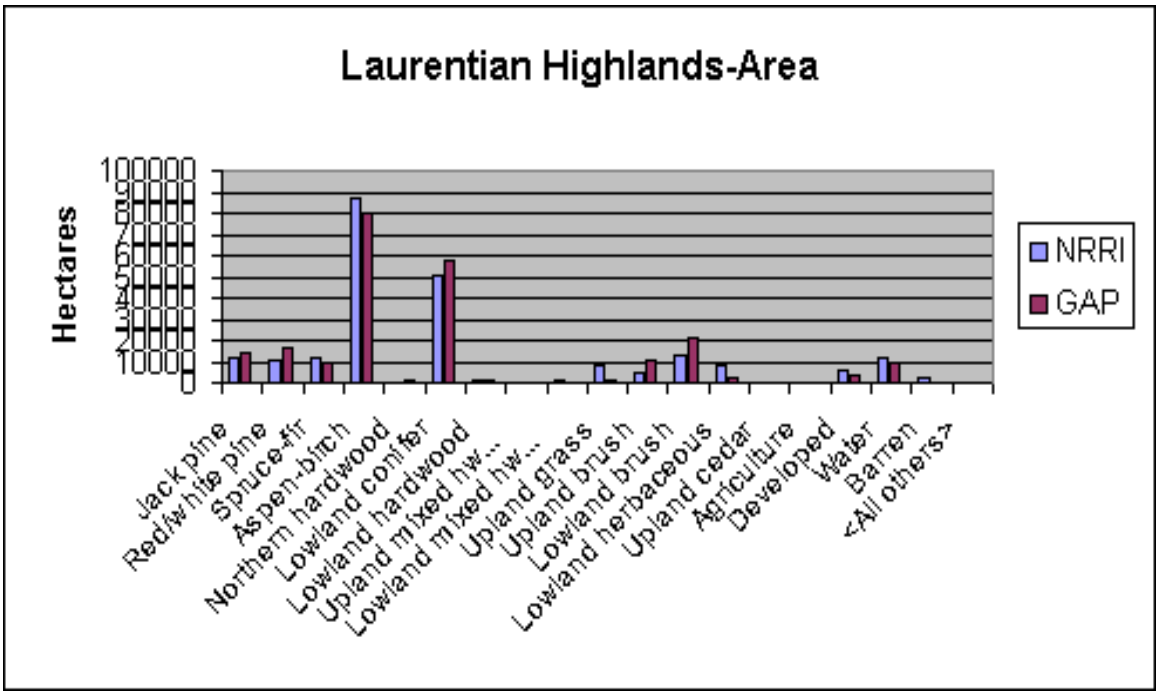


Figure 20. Overall area for the Laurentian Highlands subsection.

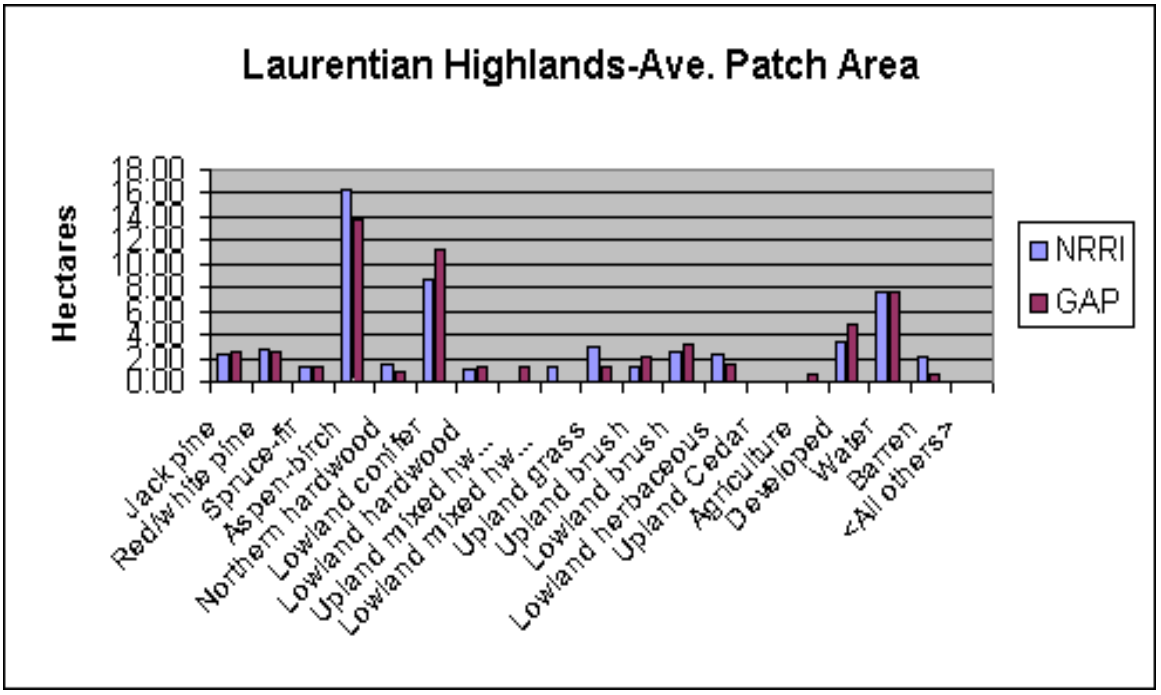


Figure 21. Patch area for the Laurentian Highlands subsection.

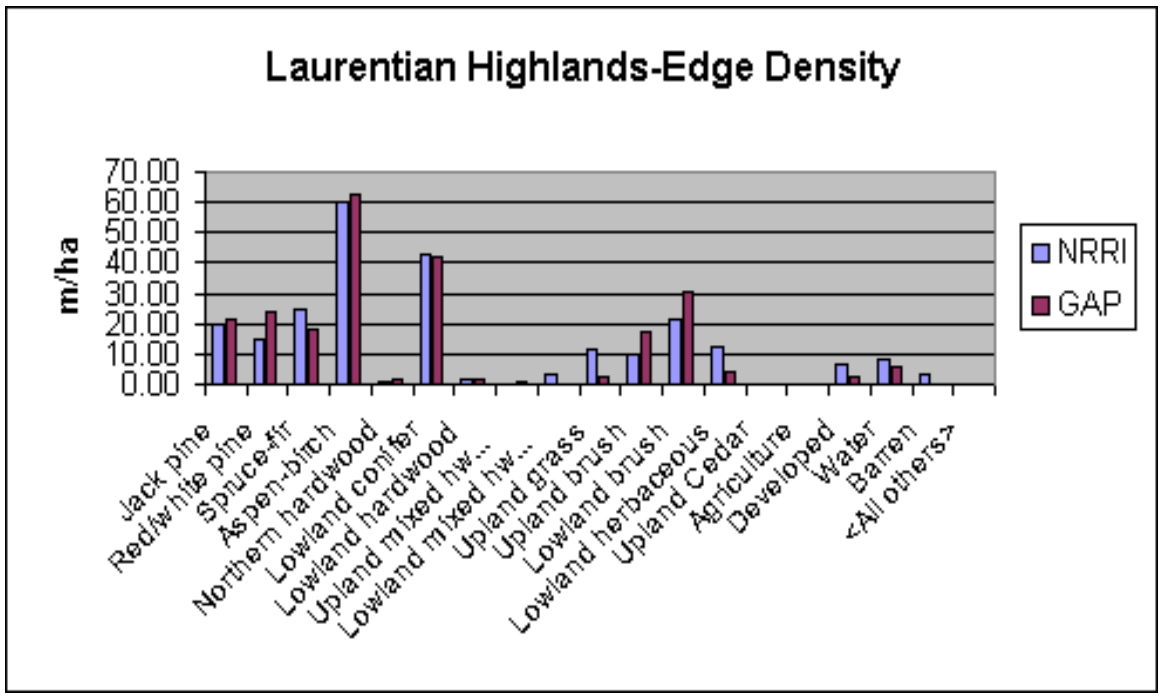


Figure 22. Edge density for the Laurentian Highlands subsection.

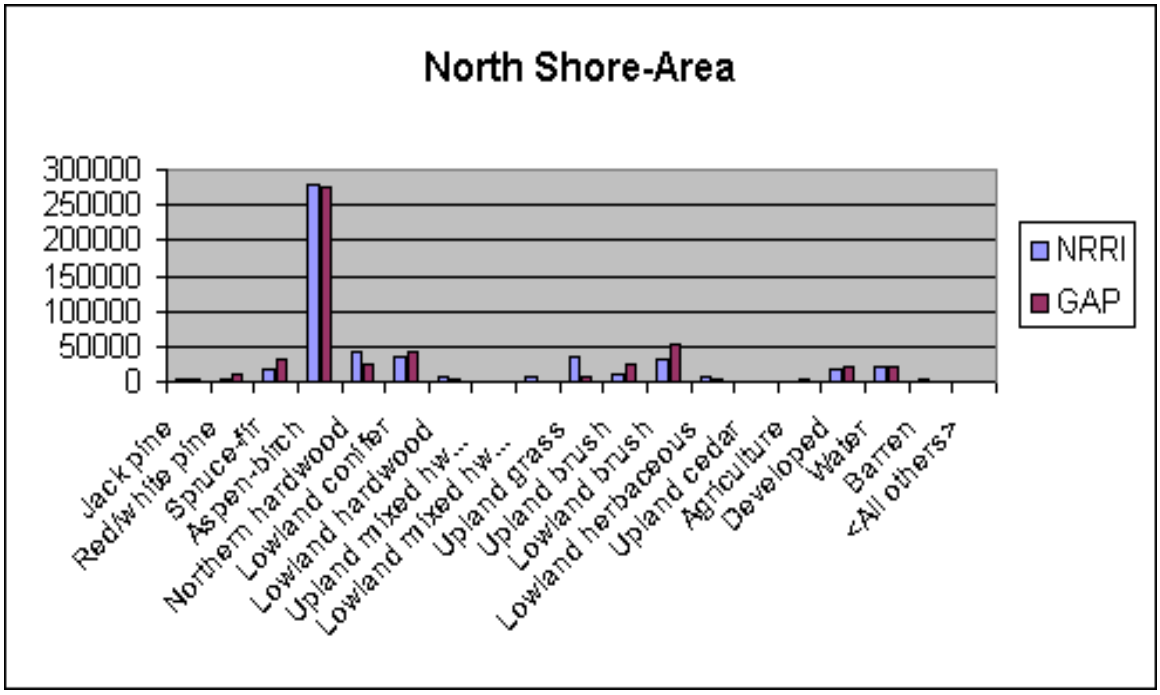


Figure 23 Overall area for the North Shore subsection.

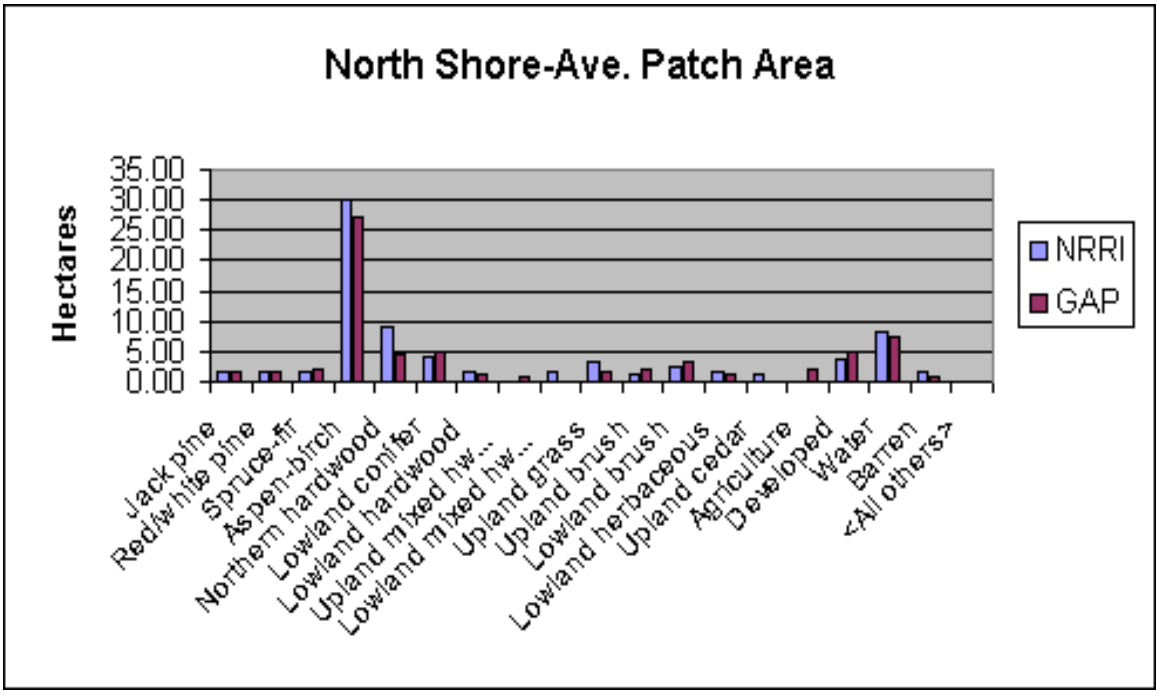


Figure 24. Patch area for the North Shore subsection.

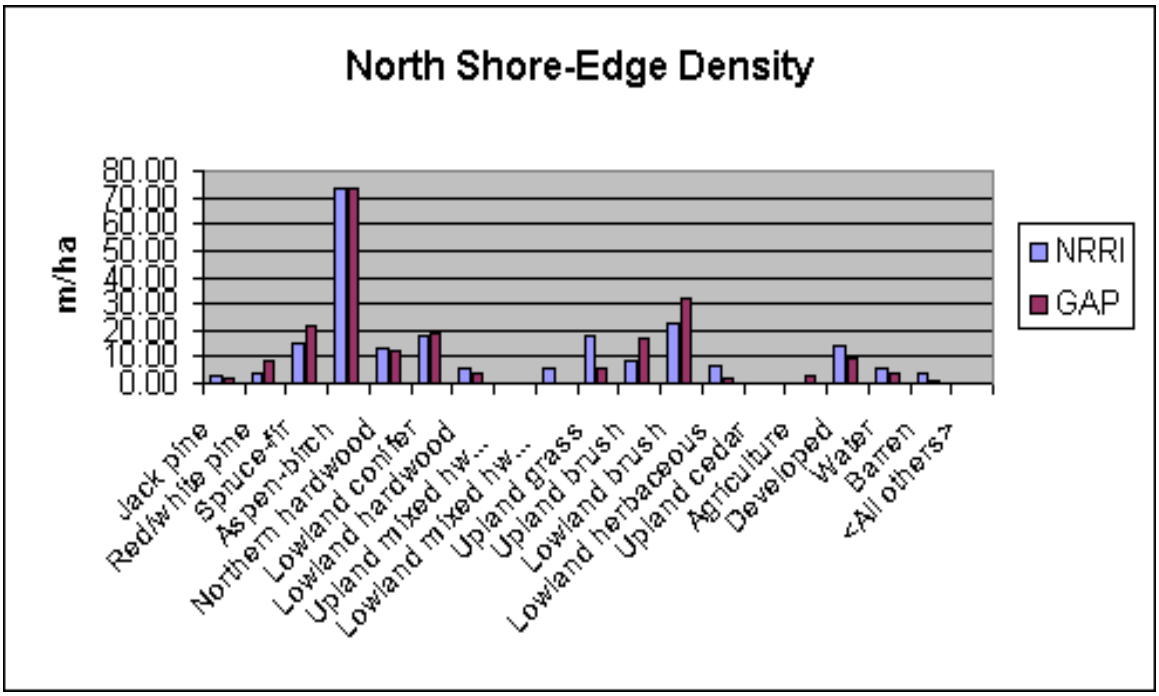


Figure 25. Edge density for the North Shore subsection.

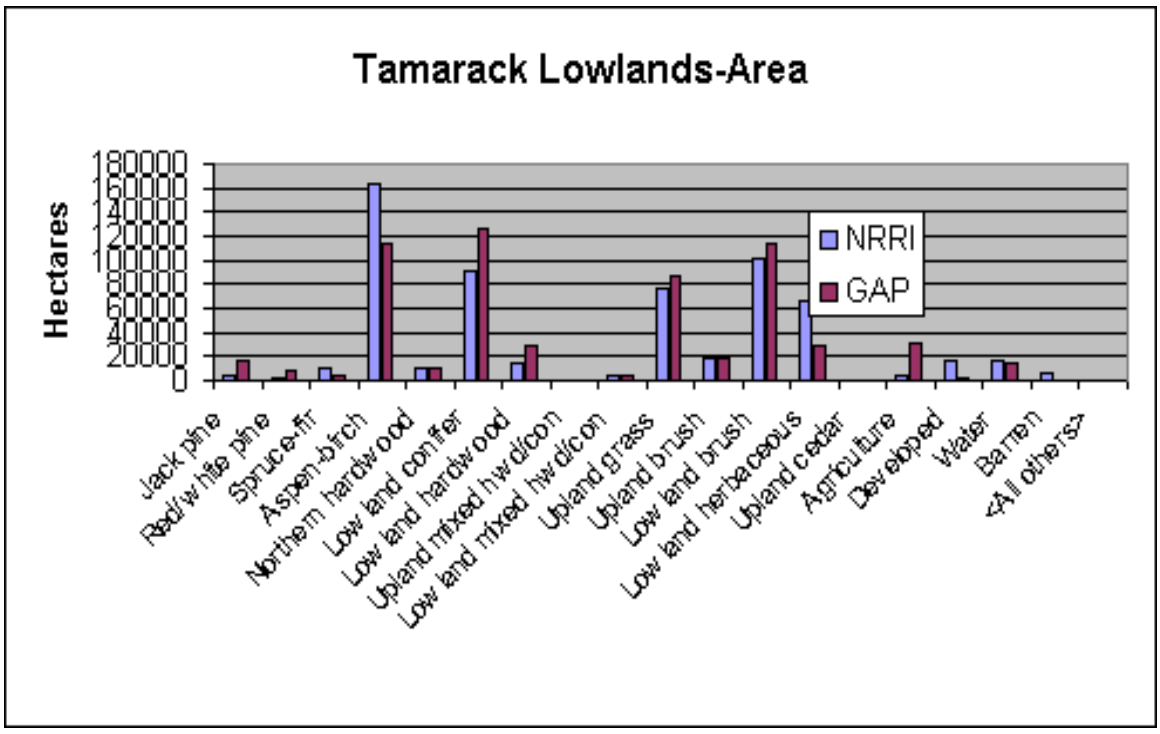


Figure 26. Overall area for the Tamarack Lowlands.

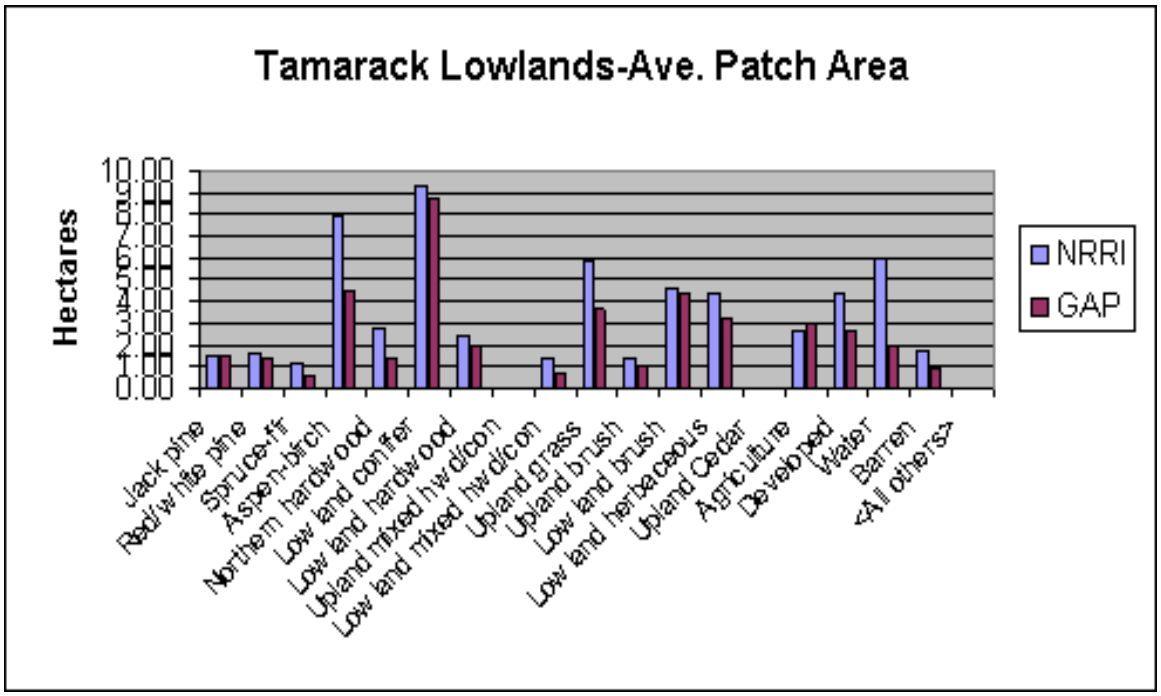


Figure 27. Patch area for the Tamarack Lowlands.

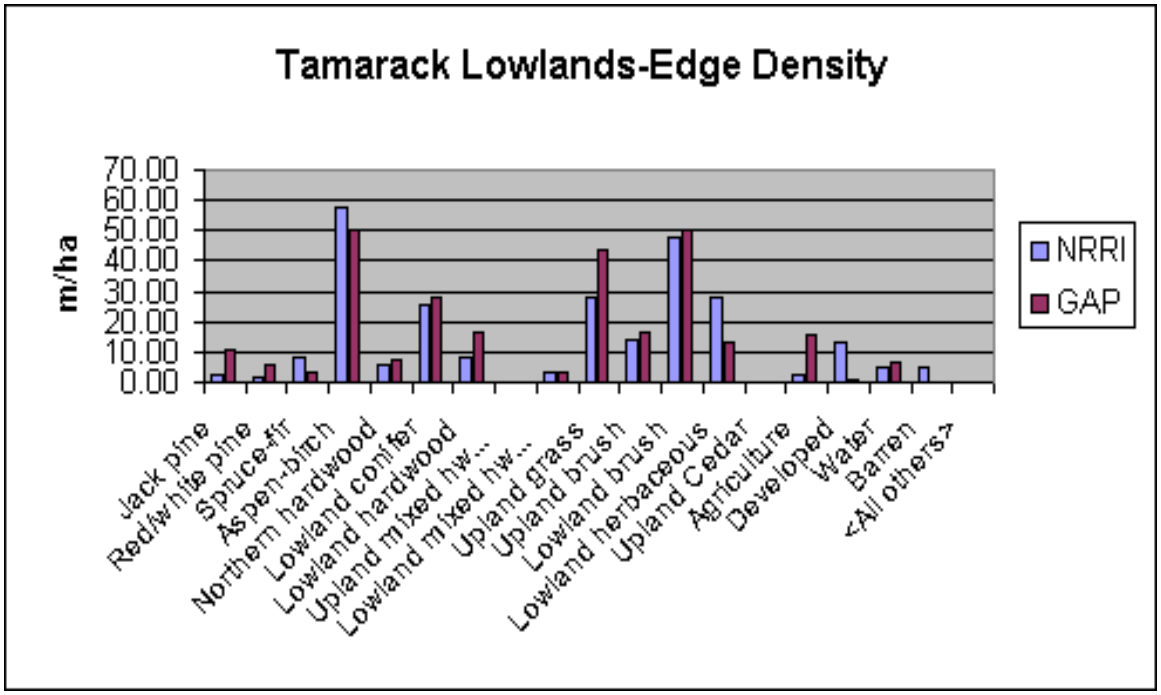


Figure 28. Edge density for the Tamarack Lowlands of northern Minnesota.

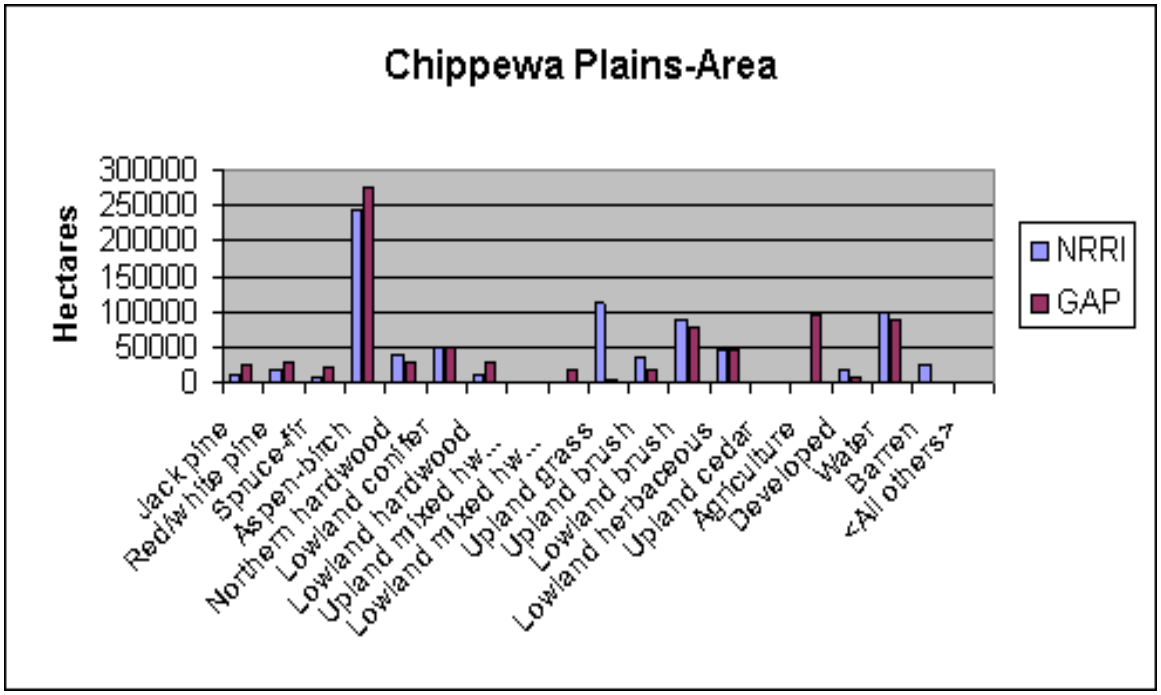


Figure 29. Overall area for the Chippewa Plains subsection.

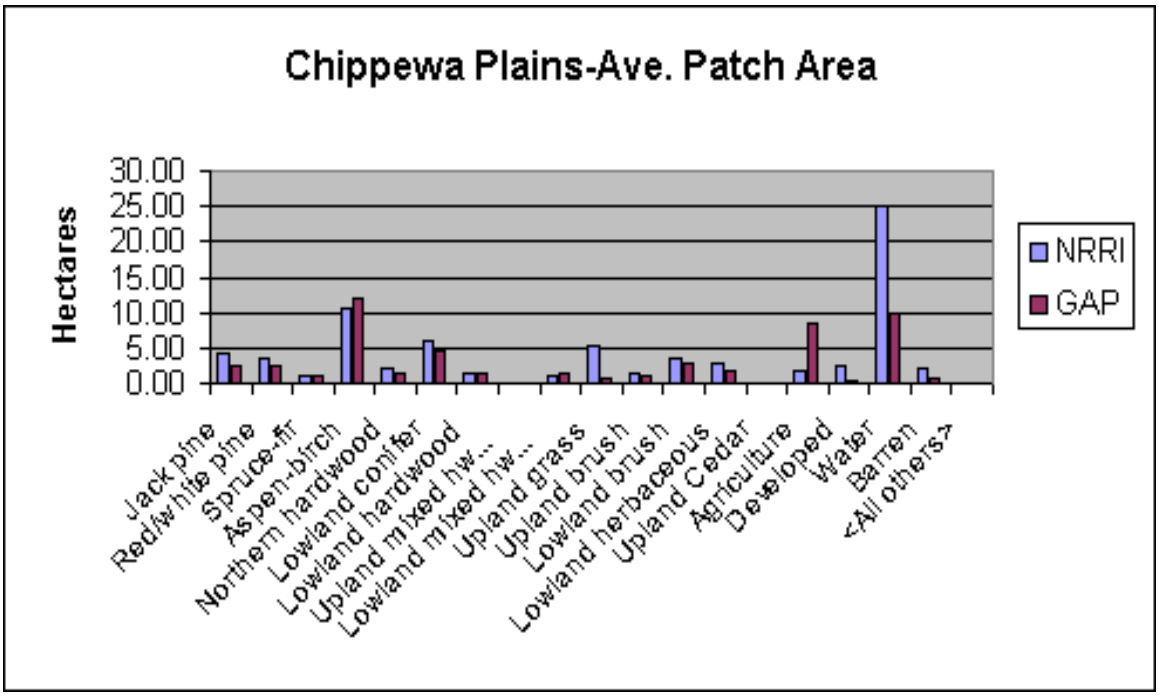


Figure 30. Patch area for the Chippewa Plains subsection.

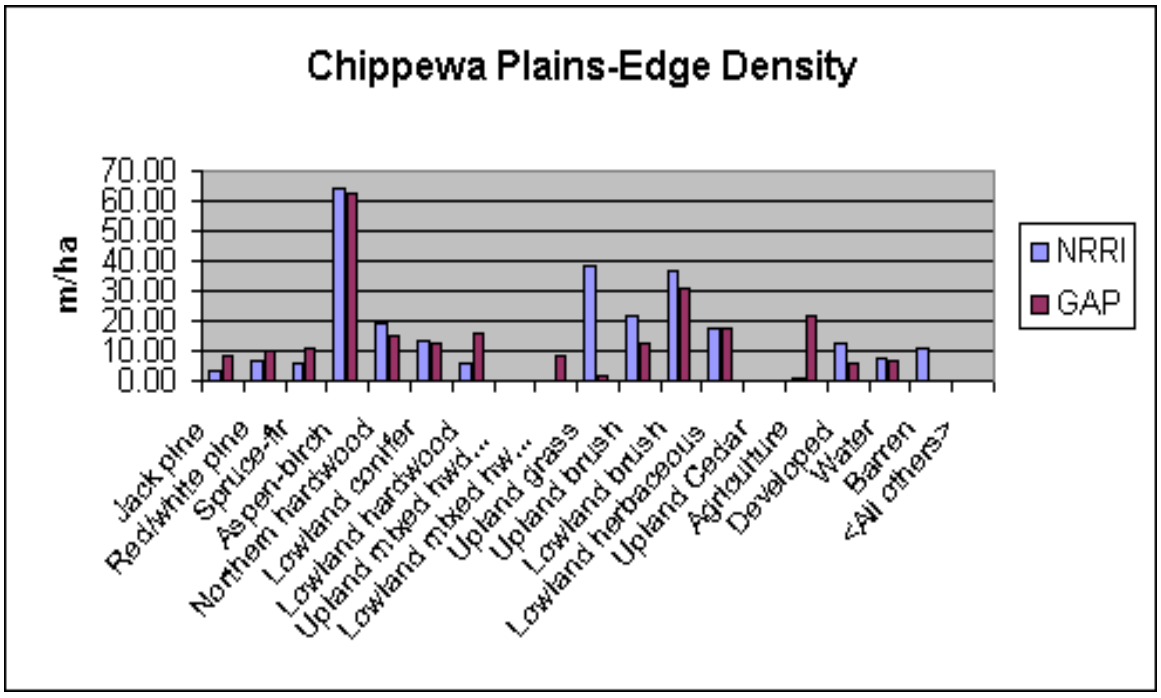


Figure 31. Edge density for the Chippewa Plains subsection.

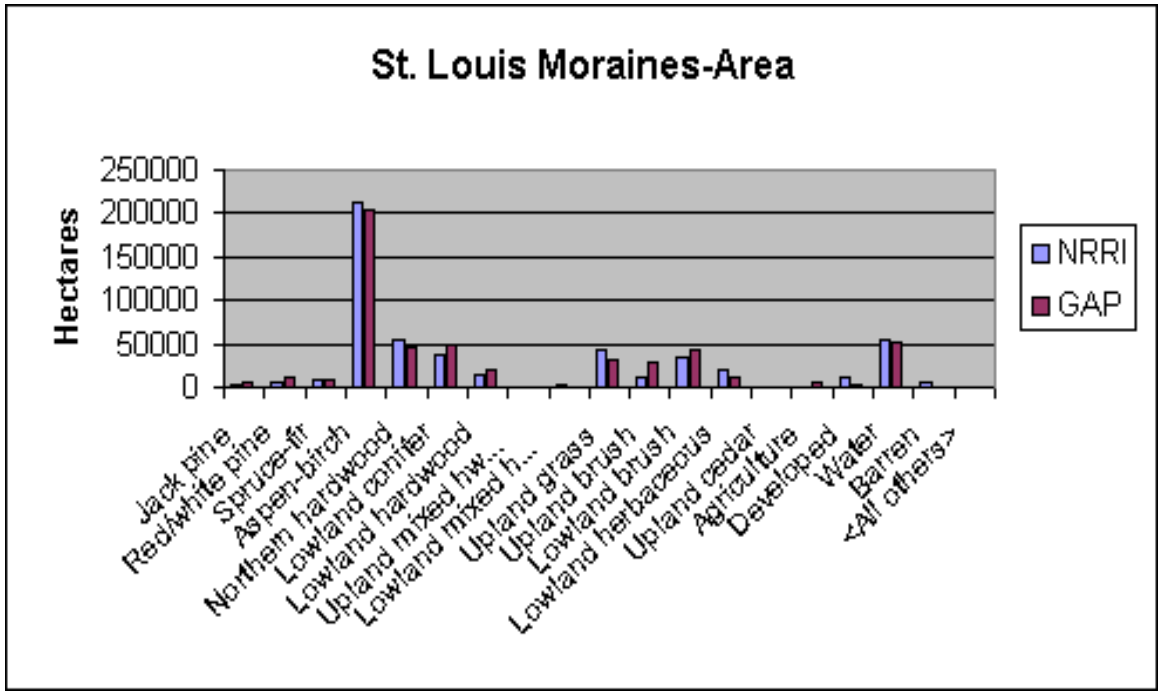


Figure 32. Overall area for the St. Louis Moraines subsection.

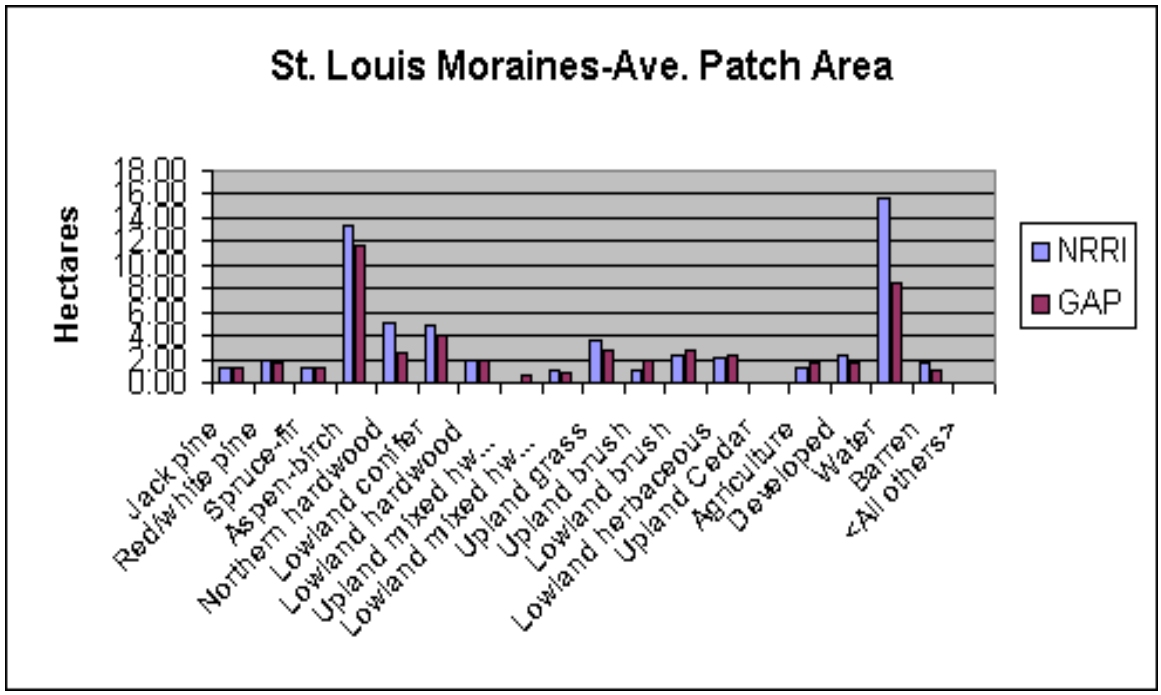


Figure 33. Patch area for the St. Louis Moraines subsection.

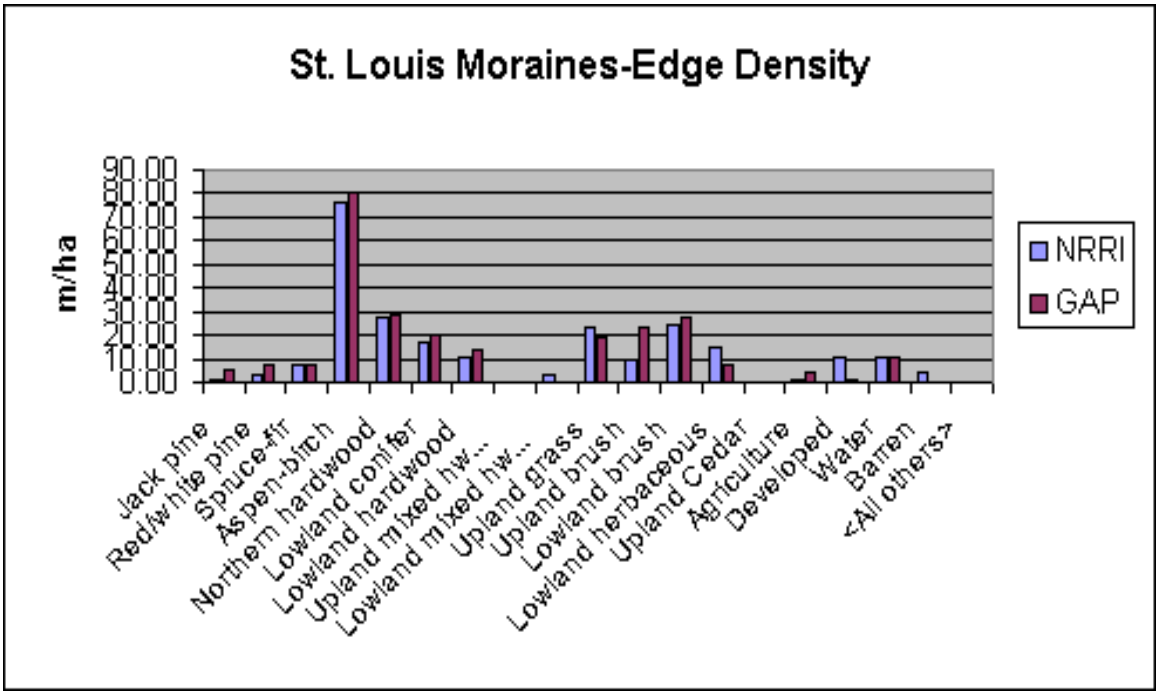


Figure 34. Edge density for the St. Louis Moraines subsection.

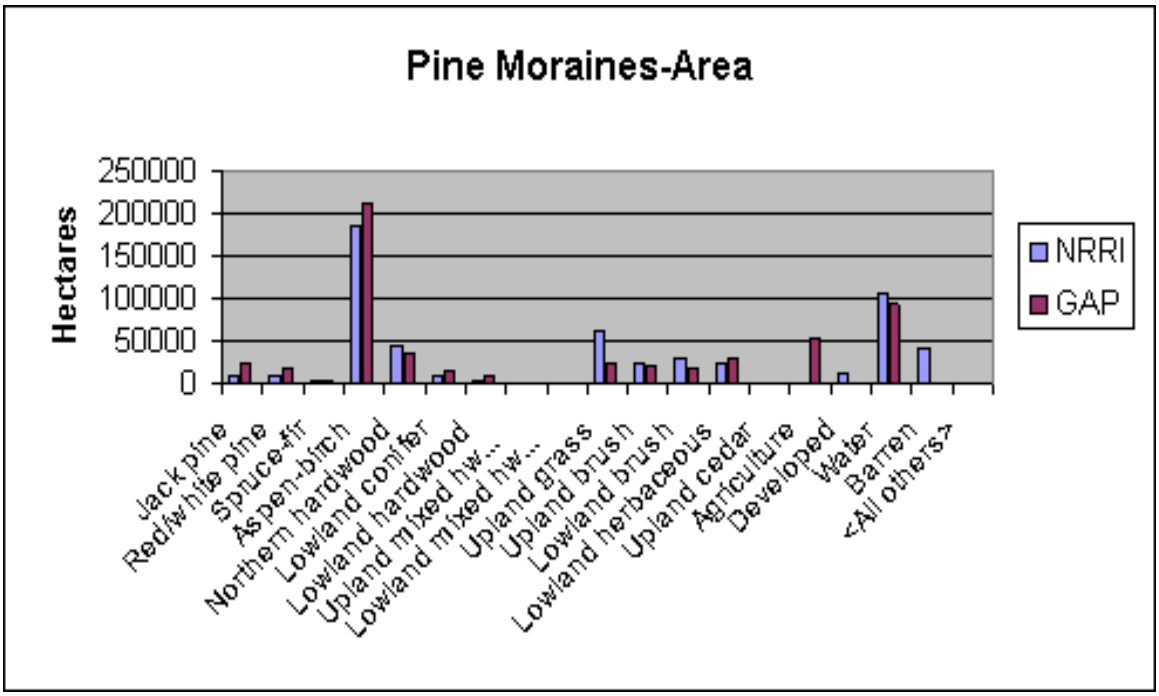


Figure 35. Overall area for the Pine Moraines subsection.

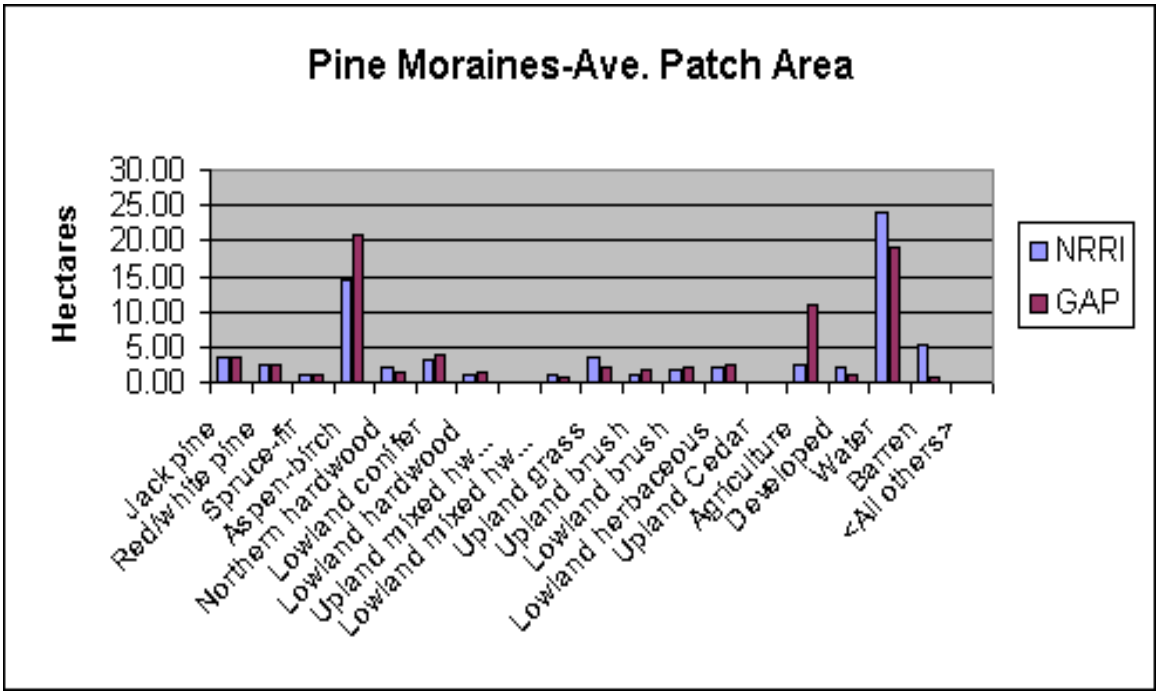


Figure 36. Patch area for the Pine Moraines subsection.

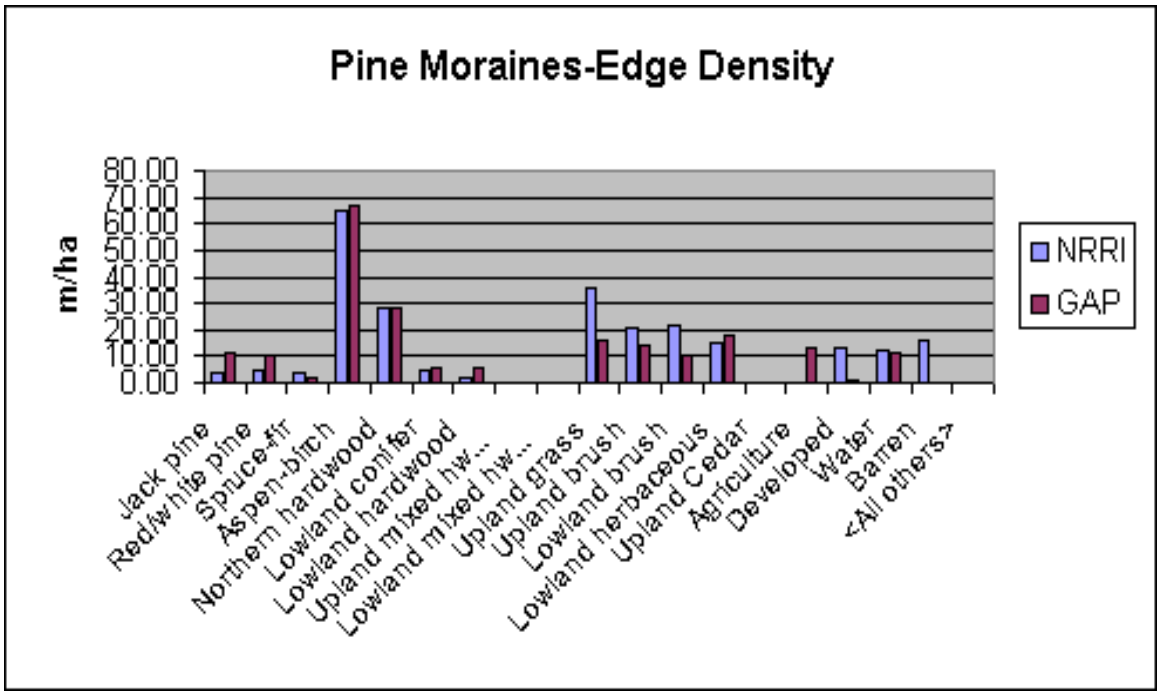


Figure 37. Edge density for the Pine Moraines subsection.

Appendix 1—Mean and variance statistics by covertype

Toimi Uplands	Mean (ha)		Standard Deviation (ha)		CV		Largest Patch (ha)	
	PTW	GAP	PTW	GAP	PTW	GAP	PTW	GAP
Overall	5.01	3.98	135.15	37.21	26.98	9.36	20913.33	2617.56
Jack pine	1.85	1.81	4.12	3.44	2.23	1.91	131.50	70.91
Red/white pine	2.89	1.96	6.62	6.04	2.29	3.08	78.79	190.15
Spruce-fir	1.26	1.30	1.56	1.86	1.24	1.43	22.99	32.41
Aspen-birch	27.64	12.57	441.10	90.46	15.96	7.20	20913.33	2617.56
Northern hardwood	5.41	1.69	13.75	4.98	2.54	2.94	204.61	127.44
Lowland conifer	7.07	7.12	23.21	26.67	3.28	3.74	446.66	857.17
Lowland hardwood	1.99	1.50	2.76	2.48	1.39	1.66	27.37	31.19
Lowland mixed hwd/con	1.64	0.00	2.20	0.00	1.35	0.00	26.56	0.00
Upland mixed hwd/con	0.00	0.96	0.00	0.95	0.00	1.00	0.00	9.83
Upland grass	2.05	1.77	3.44	3.04	1.68	1.72	44.67	36.23
Upland brush	1.25	2.46	1.68	5.54	1.35	2.26	32.41	117.61
Lowland brush	2.58	3.38	5.36	31.68	2.08	9.38	131.50	2582.47
Lowland herbaceous	1.91	1.55	3.49	1.98	1.83	1.28	56.86	20.47
Agriculture	0.00	0.68	0.00	0.55	0.00	0.80	0.00	2.44
Developed	1.61	1.69	6.38	3.42	3.97	2.03	192.67	40.53
Water	6.84	6.56	73.02	74.13	10.68	11.30	1973.61	1876.87
Barren	1.89	0.52	3.81	0.51	2.01	0.98	55.15	1.87
<All others>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Tamarack Lowlands	Mean (ha)		Standard Deviation (ha)		CV		Largest Patch (ha)	
	PTW	GAP	PTW	GAP	PTW	GAP	PTW	GAP
Overall	4.58	3.24	48.28	38.28	10.54	11.81	6500.84	9573.42
Jack pine	1.46	1.44	2.61	4.07	1.80	2.82	62.14	152.95
Red/white pine	1.65	1.40	3.12	3.15	1.89	2.24	42.48	81.55
Spruce-fir	1.16	0.62	1.49	1.17	1.28	1.88	39.15	53.85
Aspen-birch	7.98	4.43	82.20	24.73	10.31	5.58	6500.84	1863.22
Northern hardwood	2.78	1.40	6.38	3.53	2.29	2.52	113.80	135.81
Lowland conifer	9.36	8.71	55.80	111.99	5.96	12.85	2093.25	9573.42
Lowland hardwood	2.39	1.97	7.34	10.43	3.07	5.29	273.24	973.73
Lowland mixed hwd/con	1.37	0.00	2.44	0.00	1.78	0.00	66.77	0.00
Upland mixed hwd/con	0.00	0.69	0.00	0.83	0.00	1.19	0.00	11.29
Upland grass	5.83	3.72	75.24	24.73	12.90	6.64	5570.25	1571.38
Upland brush	1.38	0.98	2.10	1.51	1.53	1.54	57.02	44.84
Lowland brush	4.63	4.36	30.59	43.50	6.61	9.97	1765.75	3266.95
Lowland herbaceous	4.39	3.23	49.79	26.82	11.34	8.30	2786.02	1757.55
Agriculture	2.60	2.95	15.31	19.02	5.89	6.46	410.67	1181.17
Developed	4.32	2.60	32.01	17.67	7.42	6.79	1286.93	340.58
Water	6.03	2.01	38.70	12.80	6.42	6.38	1685.09	513.42
Barren	1.74	0.96	3.21	2.72	1.84	2.83	64.09	23.31
<All others>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

St Louis Moraines	Mean (ha)		Standard Deviation (ha)		CV		Largest Patch (ha)	
	PTW	GAP	PTW	GAP	PTW	GAP	PTW	GAP
Overall	4.57	3.83	152.78	110.68	33.47	28.87	38324.88	31252.13
Jack pine	1.27	1.32	2.12	4.30	1.67	3.25	38.83	159.77
Red/white pine	1.88	1.70	4.23	6.29	2.25	3.70	104.13	362.43
Spruce-fir	1.20	1.25	1.73	4.20	1.44	3.36	47.27	203.23
Aspen-birch	13.29	11.69	402.24	303.59	30.27	25.97	38324.88	31252.13
Northern hardwood	5.05	2.51	24.08	13.32	4.77	5.31	1149.42	630.31
Lowland conifer	4.90	4.05	35.26	37.17	7.20	9.18	2299.16	2687.90
Lowland hardwood	1.83	1.95	4.78	5.47	2.61	2.80	219.47	218.66
Lowland mixed hwd/con	1.03	0.75	1.19	0.70	1.16	0.93	23.15	5.61
Upland mixed hwd/con	0.00	0.60	0.00	0.69	0.00	1.14	0.00	6.01
Upland grass	3.55	2.74	11.41	13.75	3.22	5.01	536.82	1040.98
Upland brush	1.13	1.95	1.56	5.05	1.38	2.60	35.90	198.35
Lowland brush	2.35	2.71	6.87	16.58	2.93	6.11	218.90	1525.49
Lowland herbaceous	2.12	2.26	8.16	10.12	3.84	4.47	427.33	325.39
Agriculture	1.24	1.75	1.65	4.77	1.34	2.73	19.58	147.59
Developed	2.39	1.76	16.88	14.79	7.06	8.41	808.60	419.37
Water	15.73	8.57	97.65	67.91	6.21	7.92	3506.08	2790.40
Barren	1.70	1.06	3.24	1.65	1.90	1.55	73.10	13.16
<All others>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Pine Moraines	Mean (ha)		Standard Deviation (ha)		CV		Largest Patch (ha)	
	PTW	GAP	PTW	GAP	PTW	GAP	PTW	GAP
Overall	4.36	4.89	159.64	270.88	36.61	55.35	41972.94	55663.90
Jack pine	3.51	3.50	20.38	24.05	5.81	6.87	842.63	1407.22
Red/white pine	2.30	2.53	3.87	6.19	1.68	2.44	67.90	166.02
Spruce-fir	1.01	0.89	1.96	1.12	1.94	1.27	99.26	14.21
Aspen-birch	14.54	20.99	337.21	796.89	23.20	37.96	26198.96	55663.90
Northern hardwood	2.22	1.44	10.12	3.84	4.56	2.67	756.37	191.61
Lowland conifer	3.04	3.87	10.28	15.30	3.39	3.96	222.88	469.64
Lowland hardwood	1.17	1.51	3.05	3.47	2.60	2.29	96.33	126.06
Lowland mixed hwd/con	0.94	0.68	1.22	1.28	1.30	1.89	16.08	8.53
Upland grass	3.70	2.17	11.60	5.37	3.14	2.47	429.19	182.11
Upland brush	1.23	1.84	1.89	3.05	1.54	1.66	48.90	57.02
Lowland brush	1.90	2.11	8.41	6.29	4.43	2.98	815.91	251.64
Lowland herbaceous	2.05	2.34	7.78	12.20	3.79	5.21	353.33	1115.95
Agriculture	2.39	11.01	6.42	191.71	2.69	17.42	70.67	8349.93
Developed	2.29	1.23	17.70	10.19	7.72	8.29	666.05	219.06
Water	23.83	19.09	637.36	583.87	26.75	30.58	41972.94	40910.84
Barren	5.32	0.88	15.62	1.90	2.94	2.16	223.29	17.87
<All others>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

North Shore	Mean (ha)		Standard Deviation (ha)		CV		Largest Patch (ha)	
	PTW	GAP	PTW	GAP	PTW	GAP	PTW	GAP
Overall	5.57	5.69	535.63	675.86	96.20	118.82	162143.45	205777.86
Jack pine	1.55	1.58	3.25	3.54	2.09	2.23	79.76	58.64
Red/white pine	1.69	1.67	4.13	4.64	2.45	2.79	91.38	172.44
Spruce-fir	1.62	2.23	5.06	12.71	3.12	5.71	229.54	854.00
Aspen-birch	30.16	27.31	1711.46	2043.67	56.75	74.84	162143.45	205777.86
Northern hardwood	9.24	4.57	43.63	20.20	4.72	4.43	793.16	575.56
Lowland conifer	4.27	4.97	15.05	19.40	3.53	3.90	604.31	916.38
Lowland hardwood	1.55	1.30	2.71	2.13	1.75	1.64	57.26	64.01
Lowland mixed hwd/con	1.80	0.00	2.74	0.00	1.53	0.00	38.74	0.00
Upland mixed hwd/con	0.00	1.00	0.00	0.92	0.00	0.92	0.00	4.79
Upland Cedar	1.24	0.00	5.27	0.00	4.26	0.00	99.18	0.00
Upland grass	3.49	1.75	9.41	3.62	2.70	2.06	199.65	105.59
Upland brush	1.09	2.24	1.41	7.53	1.29	3.37	33.06	366.81
Lowland brush	2.50	3.47	7.02	12.53	2.80	3.61	393.13	652.07
Lowland herbaceous	1.59	1.28	3.38	1.36	2.13	1.06	95.03	12.10
Agriculture	0.00	2.17	0.00	3.97	0.00	1.83	0.00	97.71
Developed	3.86	4.74	117.37	147.53	30.37	31.12	8182.93	9703.14
Water	8.34	7.49	89.81	87.54	10.78	11.68	3583.16	3533.94
Barren	1.63	0.95	2.88	1.78	1.77	1.88	42.40	31.19
<All others>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Nashwauk Uplands	Mean (ha)		Standard Deviation (ha)		CV		Largest Patch (ha)	
	PTW	GAP	PTW	GAP	PTW	GAP	PTW	GAP
Overall	4.39	3.13	65.17	33.82	14.84	10.81	8831.92	5356.87
Jack pine	1.63	1.24	2.85	3.85	1.75	3.11	92.03	208.59
Red/white pine	2.61	1.96	5.60	5.72	2.15	2.92	71.97	130.69
Spruce-fir	1.40	1.49	1.99	2.62	1.42	1.75	53.69	52.15
Aspen-birch	15.87	6.15	138.62	63.04	8.73	10.25	6418.32	5356.87
Northern hardwood	3.03	1.83	10.54	6.59	3.48	3.61	187.79	148.48
Lowland conifer	5.44	4.19	21.27	26.01	3.91	6.21	479.31	1154.05
Lowland hardwood	2.40	1.74	4.95	3.94	2.06	2.26	93.00	87.89
Lowland mixed hwd/con	1.57	0.00	3.17	0.00	2.02	0.00	88.37	0.00
Upland mixed hwd/con	0.00	0.81	0.00	0.87	0.00	1.07	0.00	6.42
Upland grass	2.95	2.92	5.96	31.01	2.02	10.61	128.01	1748.94
Upland brush	1.30	3.32	1.70	19.05	1.31	5.74	43.29	1402.59
Lowland brush	2.82	2.78	9.45	11.33	3.35	4.07	451.61	441.95
Lowland herbaceous	1.71	1.03	4.54	2.83	2.65	2.74	197.05	81.23
Agriculture	0.11	1.62	0.07	2.93	0.61	1.81	0.24	42.16
Developed	9.85	4.47	212.66	87.78	21.59	19.62	8831.92	4090.98
Water	7.84	1.99	40.56	22.50	5.18	11.29	1031.72	1201.40
Barren	2.20	1.85	5.85	4.77	2.66	2.57	168.06	53.45
<All others>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Laurentian Highlands	Mean (ha)		Standard Deviation (ha)		CV		Largest Patch (ha)	
	PTW	GAP	PTW	GAP	PTW	GAP	PTW	GAP
Overall	4.45	4.67	102.56	116.19	23.05	24.88	17921.97	18070.05
Jack pine	2.30	2.50	4.14	9.63	1.80	3.85	64.33	502.86
Red/white pine	2.67	2.47	7.18	6.43	2.69	2.60	203.06	140.19
Spruce-fir	1.31	1.18	2.38	1.97	1.82	1.67	86.51	70.83
Aspen-birch	16.30	13.68	295.66	302.40	18.14	22.11	17921.97	18070.05
Northern hardwood	1.42	0.89	2.14	1.16	1.51	1.30	32.65	22.66
Lowland conifer	8.74	11.25	108.48	151.26	12.41	13.45	7449.06	9541.01
Lowland hardwood	1.02	1.29	1.14	2.74	1.12	2.12	16.25	55.40
Lowland mixed hwd/con	1.30	0.00	1.79	0.00	1.38	0.00	23.88	0.00
Upland mixed hwd/con	0.00	1.18	0.00	1.04	0.00	0.89	0.00	8.20
Upland grass	3.02	1.18	6.65	1.82	2.20	1.54	153.60	31.92
Upland brush	1.37	2.11	1.78	5.16	1.30	2.45	38.66	168.30
Lowland brush	2.46	3.17	6.17	10.47	2.51	3.30	219.39	288.27
Lowland herbaceous	2.32	1.50	6.31	3.12	2.72	2.07	154.00	76.43
Agriculture	0.00	0.55	0.00	0.43	0.00	0.78	0.00	1.22
Developed	3.49	4.84	60.42	66.25	17.30	13.69	2271.70	1489.42
Water	7.68	7.62	36.72	37.20	4.78	4.88	797.71	726.72
Barren	2.10	0.65	4.87	0.80	2.31	1.23	72.21	1.95
<All others>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chippewa Plains	Mean (ha)		Standard Deviation (ha)		CV		Largest Patch (ha)	
	PTW	GAP	PTW	GAP	PTW	GAP	PTW	GAP
Overall	4.21	3.34	91.74	73.96	21.79	22.14	34941.94	24469.36
Jack pine	4.26	2.58	13.19	12.32	3.10	4.77	279.41	524.23
Red/white pine	3.65	2.31	25.22	17.32	6.91	7.49	1708.65	1658.21
Spruce-fir	0.97	1.16	1.18	2.63	1.21	2.27	25.99	94.22
Aspen-birch	10.69	11.88	110.23	149.10	10.31	12.56	7747.65	12041.77
Northern hardwood	2.01	1.51	4.77	4.56	2.38	3.02	162.04	242.62
Lowland conifer	5.98	4.75	51.70	49.81	8.65	10.49	3723.92	4430.91
Lowland hardwood	1.38	1.27	2.75	2.68	1.99	2.12	76.92	103.72
Lowland mixed hwd/con	0.93	1.45	1.27	5.27	1.37	3.62	20.06	378.43
Upland grass	5.23	0.64	20.30	0.82	3.88	1.27	1523.70	13.00
Upland brush	1.27	0.92	1.80	1.38	1.41	1.51	47.92	30.22
Lowland brush	3.38	2.71	17.79	13.97	5.26	5.15	1514.03	1191.90
Lowland herbaceous	2.65	1.92	24.37	26.05	9.19	13.60	1787.52	2384.69
Agriculture	1.65	8.48	2.46	70.87	1.49	8.36	33.71	4691.48
Developed	2.57	0.41	29.56	12.53	11.50	30.56	2318.97	1713.60
Water	25.21	9.86	567.52	279.07	22.51	28.31	34941.94	24469.36
Barren	2.19	0.53	4.95	1.31	2.25	2.47	172.77	6.09
<All others>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Border Lakes	Mean (ha)		Standard Deviation (ha)		CV		Largest Patch (ha)	
	PTW	GAP	PTW	GAP	PTW	GAP	PTW	GAP
Overall	4.62	5.00	97.44	244.47	21.09	48.92	18920.80	96204.19
Jack pine	5.18	4.39	104.81	51.32	20.24	11.69	11280.53	6551.85
Red/white pine	2.31	2.52	11.18	11.32	4.84	4.50	539.01	943.51
Spruce-fir	2.25	1.42	15.23	3.34	6.77	2.35	2804.94	176.99
Aspen-birch	13.40	16.85	176.06	703.26	13.14	41.74	17978.75	96204.19
Northern hardwood	1.43	1.22	4.32	2.20	3.03	1.81	80.90	15.76
Lowland conifer	2.48	3.59	7.39	11.84	2.98	3.30	373.55	424.40
Lowland hardwood	1.19	1.14	1.79	1.55	1.50	1.36	29.40	30.95
Lowland mixed hwd/con	1.16	0.00	1.38	0.00	1.20	0.00	18.60	0.00
Upland grass	3.13	1.25	14.26	2.54	4.55	2.03	910.94	49.95
Upland brush	1.43	2.29	2.27	8.20	1.59	3.58	61.98	303.78
Lowland brush	1.72	2.01	3.12	3.80	1.81	1.89	96.50	145.47
Lowland herbaceous	2.11	1.58	4.67	2.10	2.21	1.33	194.45	30.95
Agriculture	0.00	2.67	0.00	3.96	0.00	1.48	0.00	40.13
Developed	1.97	3.96	11.43	33.10	5.80	8.36	498.40	454.29
Water	22.47	27.93	332.34	365.38	14.79	13.08	18920.80	18578.11
Barren	1.80	1.45	3.35	3.04	1.86	2.10	50.28	63.11
<All others>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00