A Natural Resources Analysis for Duluth's Natural Resources Inventory

Introduction

Although a natural resources inventory had been developed for Duluth and its watersheds, this inventory had not yet been integrated with other information to identify ecologically significant areas (ESAs) in Duluth. Identifying ESAs through some sort of natural resource analysis (NRA), is an important step in comprehensive planning. Understanding where ESAs exist, and developing an accepted plan for their long term conservation, furthers both conservation and development efforts, by providing more certainty about the appropriate use for non-developed areas throughout the city. More certainty about the appropriate use of non-developed lands reduces the controversy often associated with newly proposed developments.

The following is an Natural Resources Assessment for Duluth, within a natural areas assessment framework, designed to help identify ESAs in Duluth. We used data from Duluth's Natural Resources Inventory, the Minnesota County Biology Survey, and other existing data sets, to rank existing non-developed patches in Duluth for their ecological significance. The rank is a composite score based on measures of land cover types, patch size and shape, plant composition, and connectivity with other patches. The specific fields and their descriptions are listed in Figure NR-2. These measures were all normalized with scores ranging from 0 to 1. For some categorical measures, relative rarity was used to rank classes, so that rare types are valued more highly (i.e. white cedar versus aspen).

The results of this analysis are expressed in Figure NR-20 showing the NRA scores from which significant ecological areas can be identified. This value representing the ecological significance of specific non-developed areas in Duluth can be considered along with other information contained within the comprehensive plan. This ESA overlay will then provide long term guidance for specific land use considerations

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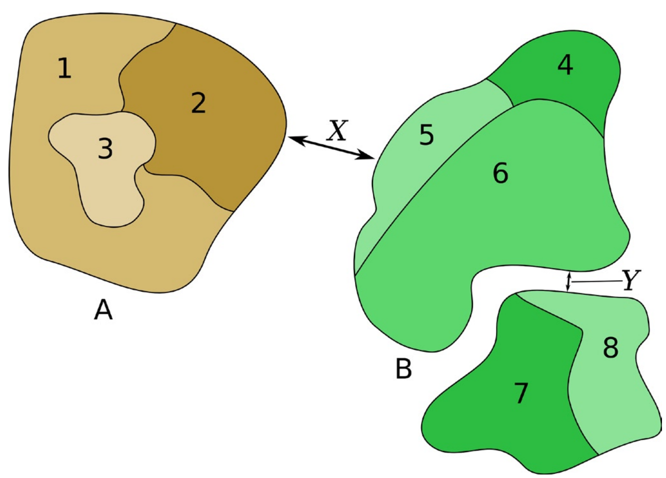
General Approach and Goals

The main components of the Duluth Natural Resource Inventory (NRI) are detailed GIS polygon maps of all forest stands, wetlands, and other undeveloped lands within the city. Combining the forest and wetland polygon maps yields 6,808 polygons. These polygons will be referred as "stands", although they may be non-forested wetland or other treeless natural land cover types. Playing fields and golf courses are also included. These stands can be grouped together into "clusters" based on some threshold distance at which two stands are considered to be close enough to be connected in an ecological sense. The term "patch" is often applied to an uninterrupted area of forest or some other habitat type. While it may be appropriate to describe some clusters as patches, because of the high level of detail in the NRI it is better in general to think of the stands as sub-patch units and the clusters as dense collections of one or more patch like units.

The idea of connectivity between stands forming clusters is highly species dependent. While many bird species may require larger patches of habitat for protection from predators, birds can easily cross large gaps between patches. On the other hand small plants that prefer the interior of more mature forest patches may find it very difficult to propagate across even small breaks in the natural land cover.

Figure NR-1: Stands and Clusters



Two clusters comprised of 7 stands. These clusters are defined for some connectivity threshold Z; X is larger than Z, but Y is smaller than Z.

Specific Methods

Data import and preparation

Figure NR-2: Initial data import and preparation

Data layer	Modifications
forest_final.shp and wetlands_final.shp, polygon coverages	• Acquired from Paul Meysembourg's collection of Duluth NRI files. • Split multi-part polygons (a small number) into single part polygons. Used test-case to confirm that polygons containing holes are not multi-part polygons. • Added ID values, 1 and 3692 inclusive and 10000 and 13423 inclusive for forest and wetland polygons respectively.
forwet2.shp, polygon coverage	• Created by merging forest_final.shp and wetlands_final.shp using Arcview X-Tools extension. • Arcview extension "Add-XY" was used to add X and Y coordinates for each polygon. This extension ensures that the point occurs within the polygon even in those cases where the center of the polygon's bounding box is not part of the polygon. • Added connects field, see the section called Connectivity classification. • Added type field; F, W, or U for Forest, Wetland, or Unnatural.
forwetpnt.shp, point coverage	• Created from forwet.shp X- and Y-coord fields via the "Event theme" mechanism.

Figure NR-3: Connects field assignments in the shapefile forwet.shp.

Type	connects field assignment	Comment
Industrial devel.	N	
Urban devel.	N	
Road	N	
Bare soil	Y	Small forest clearings or stream banks
Recreation devel.	Y or N	Individually assessed and assigned either "N" if they were fenced (baseball diamonds) or predominantly impervious surface (parking lots, buildings), and "Y" otherwise (golf courses, city parks, playing fields).
Permanent water	Y or N	A few large water bodies were assigned "N".
Upland grass	Y	There were too many polygons in this class to assess individually. Most polygons in this type will be passable by many species, although areas maintained in mowed grass are a barrier to plant species dispersion and some smaller animals.
All other types	Y	These are forests, wetlands, upland and lowland brush, and lowland grass.

Connectivity classification

The shapefile forwet2.shp was classified into 58 broad classes (see the table at the end of this chapter). A field was added to the shapefile forwet.shp, "connects." This field was used to distinguish between cover types that act as a break in the natural landscape (connects="N") and those that don't (connects="Y"). Figure NR-3 shows the assignment of values to the cover types. In practice assigning a non-connective status to some recreational developments will have very little impact on overall connectivity as they almost always occur on the edge of an urban development and as such are not disconnecting natural areas.

Data processing

Cluster mapping

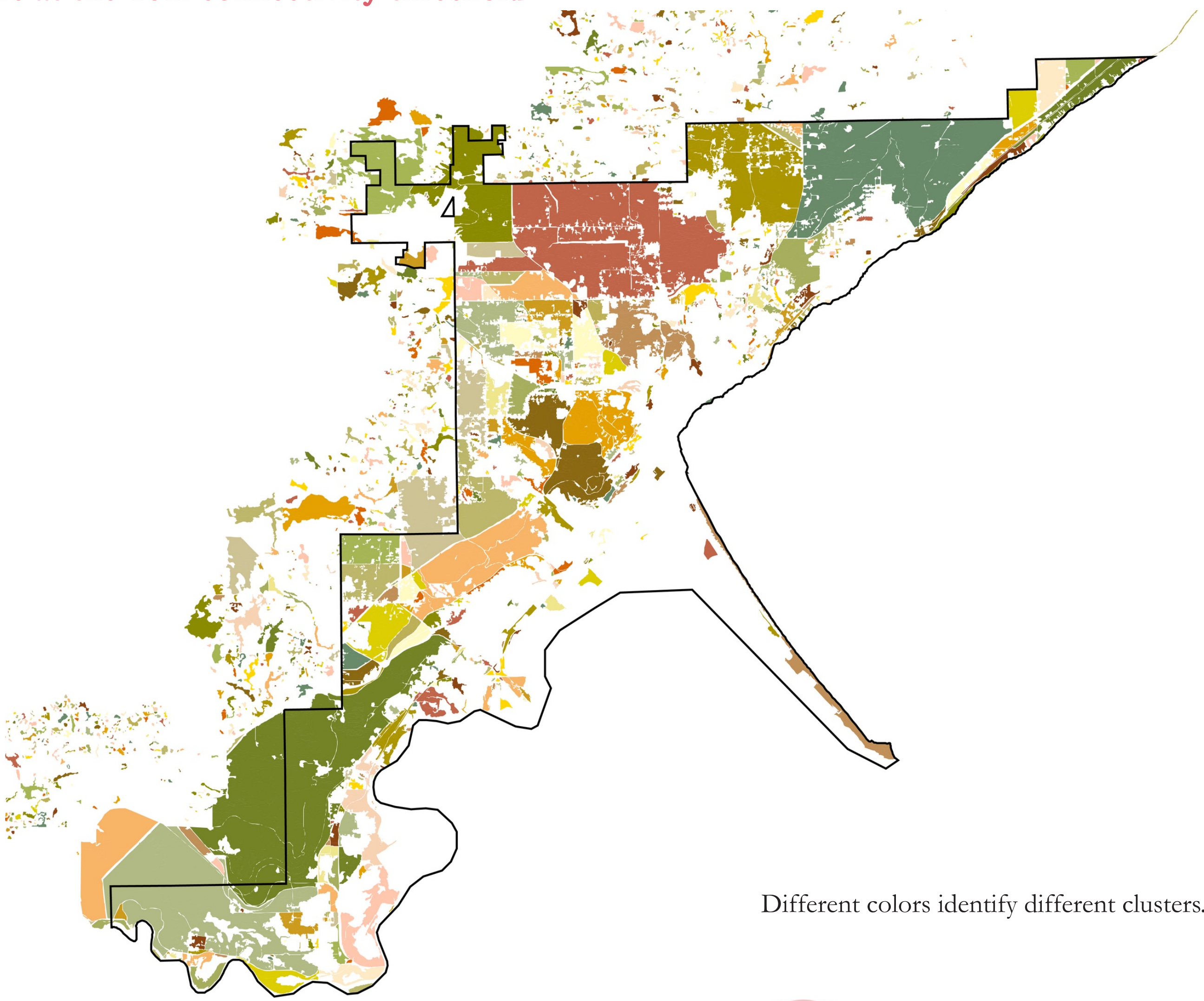
Clusters of connected stands were identified at 1, 10, 25 and 150 meter connectivity thresholds. In each case the base stand coverage (forwet2.shp) was buffered out by the required distance, and the buffered stand polygons were related to the original stand polygons using the ArcView X-Tools extension "Union" function. This process yields a table of paired ID codes for every pair of stand polygons that are within the connectivity threshold distance of each other. Custom ArcView and C++ computer code was then applied to identify connected clusters of stands. The ArcView and C++ code produced the same results, the C++ version was necessary only because ArcView was unacceptably slow for the larger clusters.

Figure NR-4: Components of connectivity analysis

Component	Purpose
ForwetXXm.shp	The base stand coverage buffered out XX m.
ForwetXXmint.shp	The X-Tools "Union" of the base stand coverage and ForwetXXm.shp.
ForwetXXlink.shp	A line coverage showing connections between stands at XX m, used for visualization only.
ClusterXX.shp	Clusters of stands merged together at connectivity threshold XX m.
ClusXXcoreYY.shp	ClusterXX.shp buffered inwards YY m to determine cluster core area.

The clusters identified at the 10 meter threshold were considered to be the most informative in terms of ecological function. At this threshold trails and other small breaks in natural stand cover would not separate clusters, but sealed roads and larger breaks would. Figure NR-5 shows the distribution of clusters at the 10 meter threshold.

Figure NR-5: Clusters at the 10m connectivity threshold



Different colors identify different clusters.

Scoring analysis

Each stand was scored according to several attributes. These attributes are listed in Figure NR-6 and then covered in more detail in following subsections. For each attribute there is an input value which is an actual measure of some characteristic of the stand, and a corresponding score, which is a number between zero and one. This allows the scores to be averaged together to form an aggregate score of ecological value for each stand.

With one exception (the ftype attribute) scoring is based on the stand's position within the range of values for each attribute. For example the tree size attribute ranges from 2 to 6. A stand with a tree size of 2 would score zero, and a stand with a tree size of 6 would score 1. A stand with a tree size of 4, half way between the minimum and maximum for that attribute, would score 0.5. So no matter what the range of the attribute, 2 to 6 or -1.8 to -1.2, the score always ranges from zero to one. In general terms the score is:

$$S = \frac{A\text{-}Min}{Max\text{-}Min}$$

where

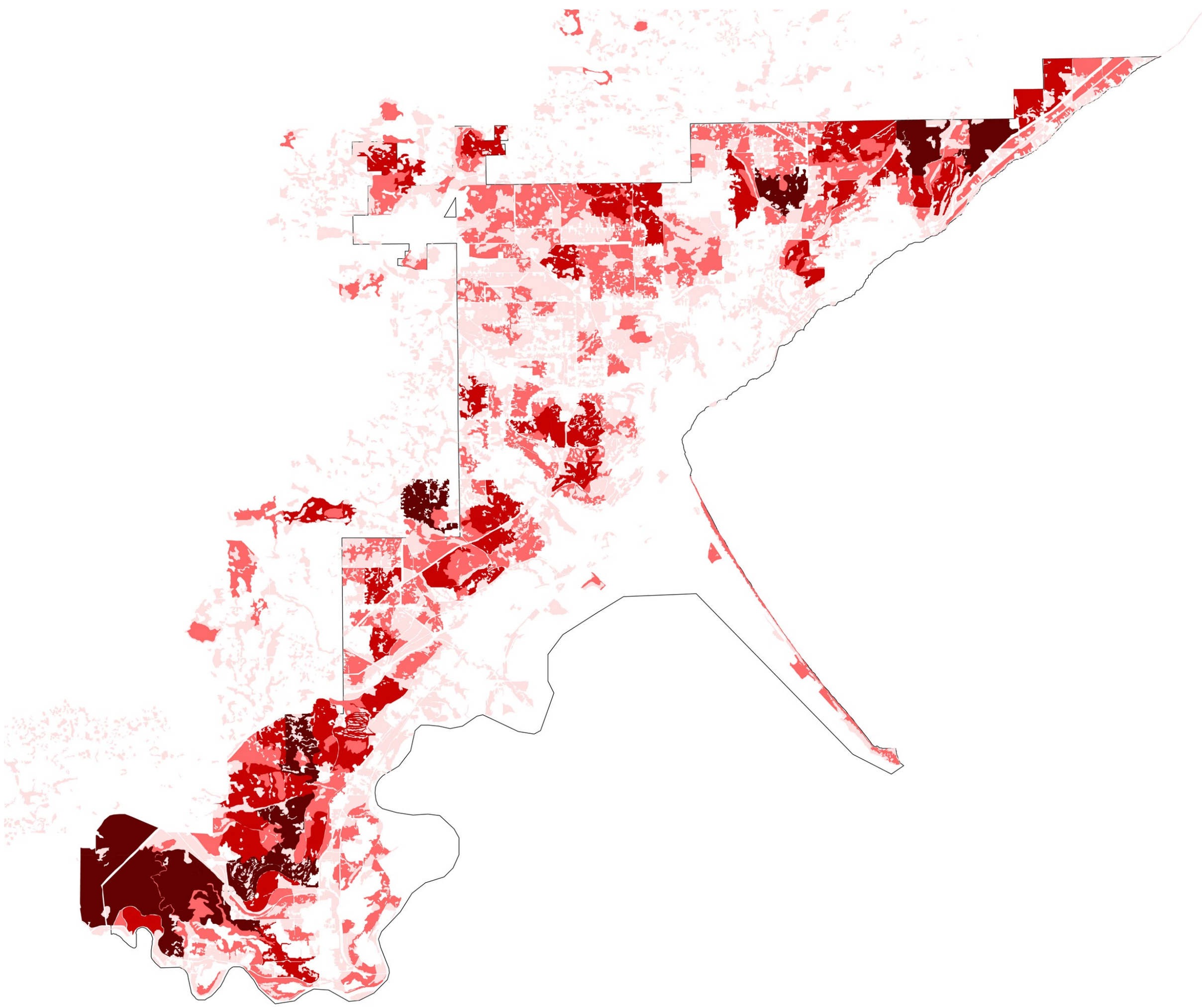
Min	= the minimum value in the attribute's range (closest to negative infinity).
Max	= the maximum value in the attribute's range (closest to positive infinity).
A	= the stands value for the attribute in question.
S	= the stands score for the attribute in question.

Figure NR-6: Stand attribute scoring

Attribute name	Source	Interpretation
size	Area of stand in meters, from forwet2.shp.	Generally large stands are have greater ecological value than small stands, particularly in a landscape where the number of larger stands has been significantly reduced.
treesz	Tree size class recorded in forwet2.shp. Ranges from 2-6.	While healthy ecosystems contain trees of all sizes, stands with larger trees are unnaturally rare in northern Minnesota, and consequently more ecologically valuable.
shape	-2*ln(perimeter)/ln(area) where perimeter and area are calculated from forwet2.shp.	Generally the closer to circular a stand is the less edge habitat it contains and the more protection it offers to plants and animals from predators and physical stresses that enter the stand from the edge.
wsbo	Mean impervious land cover in the stand. 0-100 percent.	The higher the proportion of impervious surface in the watershed or immediate catchment of a stand, the more valuable the stand is in terms of its ability to slow runoff.
mcbs	Number of Minnesota County Biological Survey records intersecting the stand. 0-32.	MCBS survey records indicate the presence of an endangered, rare, or threatened species or community.
conn	Index of the impact of removing this stand on cluster connectivity.	Stands whose removal would break large clusters into smaller clusters are valuable for their role as connectors.
pcarea10	Core area (more than 150 m from edge) of the stands cluster.	Stands that form clusters that have significant core area are valuable because such core area habitat is rare.
water	A zero or one score, is the stand within XX feet of a stream, YY feet of a trout stream, or ZZ feet of the St. Louis River Estuary or Lake Superior.	Stands of natural land cover close to water bodies are valuable as buffers to those water bodies.
ftype	Relative rarity of a forest type, between zero and one (but not zero or one).	Generally the less common a forest type is the more valuable it is ecologically. In order for this to be true the distribution of forest types in Duluth needs to match that in the region, which it does.

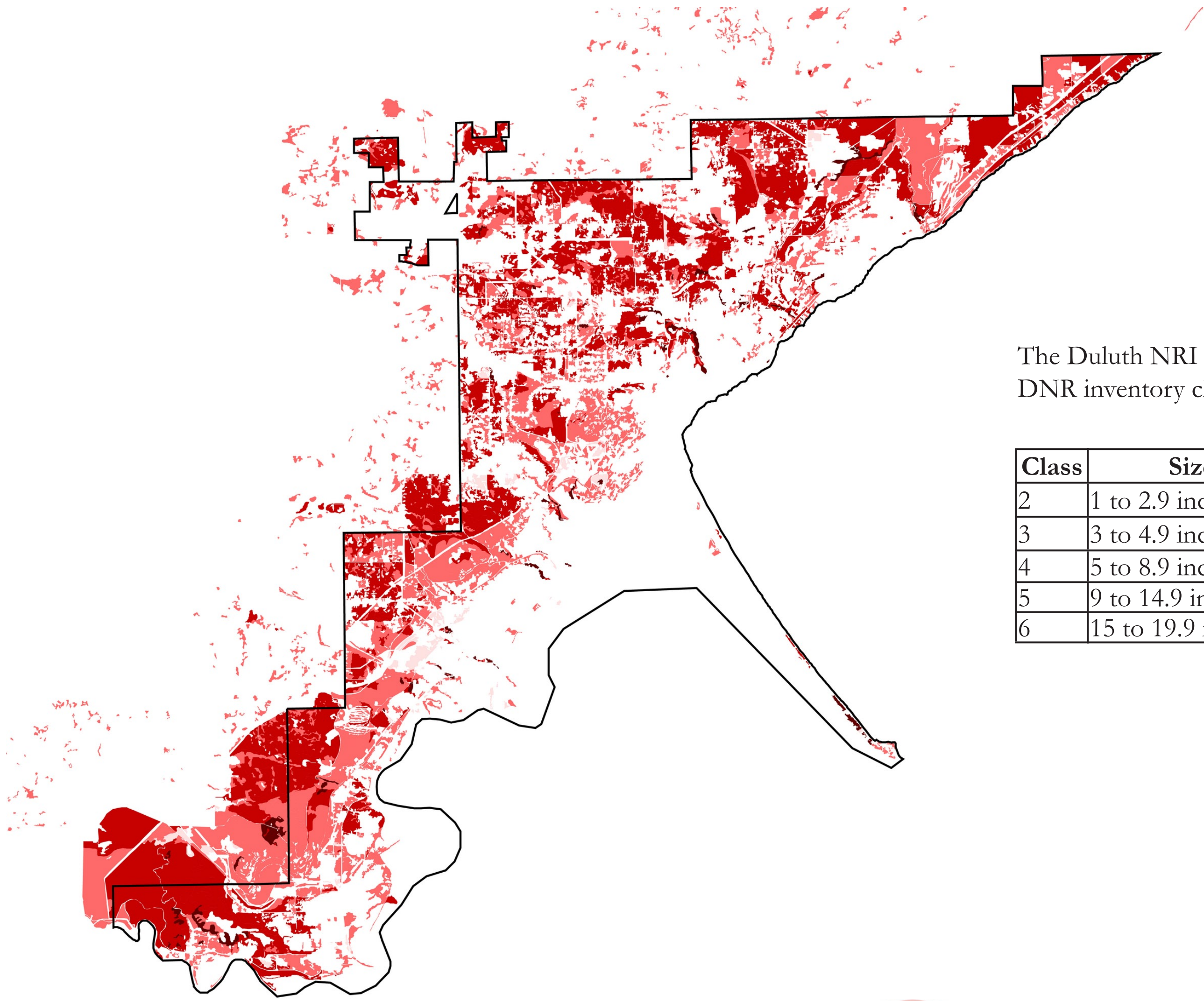
Input for scoring the stand area attribute is simply the area of the stand in square meters. The six largest areas are 2,701,440, 1,450,338, 1450197, 1,393,860, 1,371,585, 1,270,889. The largest stand, at almost twice the size of the next largest stand, is clearly an outlier, which would compress the scoring for the remaining stands into an approximately 0-0.5 range. To avoid this the largest stand was considered to have an area equal to that of the second largest stand for the scoring of this attribute.

Figure NR-7: Stand area (4-level, darker colors are higher scores)



Examining the distribution of tree sizes in the NRI data, it appears that the smaller classes are under represented and should be valued for their rarity. This is, however, misleading as no size class values were recorded for the common "Upland Brush" category, and in fact smaller size classes are not rare. Figure NR-8 shows the distribution of tree size class scores.

Figure NR-8: Tree size class (4-level, darker colors are higher scores)



The Duluth NRI estimated tree sizes in DNR inventory classes:

Class	Size
2	1 to 2.9 inches
3	3 to 4.9 inches
4	5 to 8.9 inches
5	9 to 14.9 inches
6	15 to 19.9 inches

In general habitat patches are considered more closely their shape approaches that of a circle. This is because a circle has the lowest possible perimeter to area ratio, so patches that are roughly circular have less "edge" than patches that have more complex shapes. Plants and animals are subject to stresses (predator, parasite, and micro-climate) which are often associated with edges. Three shape indices were evaluated and scored, as shown in Figure NR-9.

Figure NR-9: Stand shape (4-level, darker colors are higher scores)

perimeter/area. This indice is highly area dependent, large polygons will always score well, even if they have highly convoluted shapes which expose their occupants to a lot of edge stress. This indice was not used.

perimeter/circle_perimeter. By dividing the perimeter of a stand by the perimeter of a circle with equivalent area a pure shape indice which is completely area independent is obtained. This indice will rate very small roughly circular patches very highly even though they are prone to edge based stresses. This indice was not used.

-2*ln(perimeter)/ln(area). By taking the natural log (log base e) of perimeter and area their ranges are condensed so that an indice that is only moderately area dependent is obtained. This is the indice that was used in this analysis. The value is multiplied by two for consistency with other applications of this indice, and negated to provide the "higher is better" ordering required for the scoring used in this analysis.

Watersheds play a critical function in determining natural resource value of many attributes. Watersheds (distinct colors) and sub-catchments (smaller polygons with the same watershed color) in Duluth are shown in Figure NR-10. Streams are shown as blue lines.

Figure NR-10: Watersheds and sub-catchments

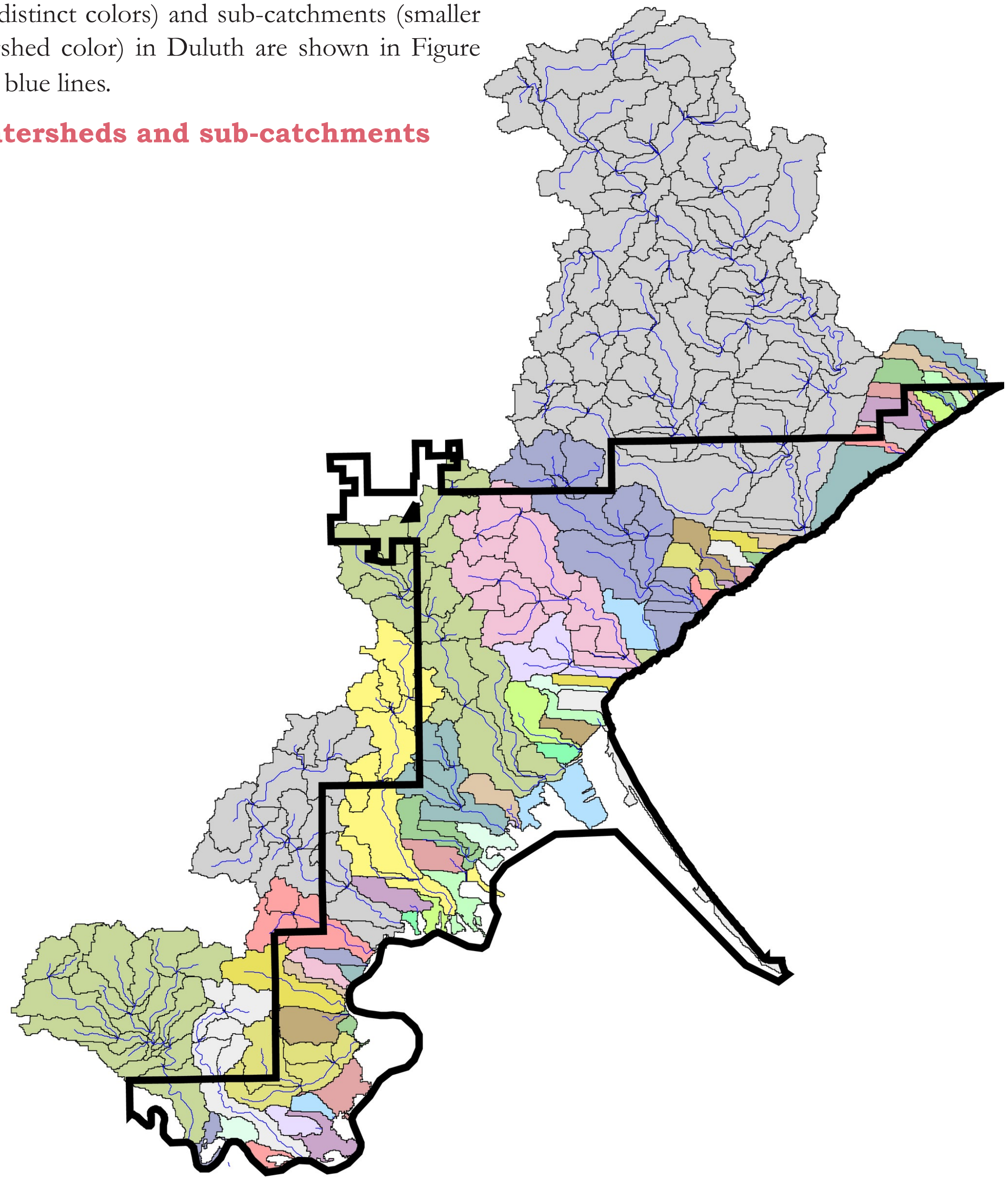
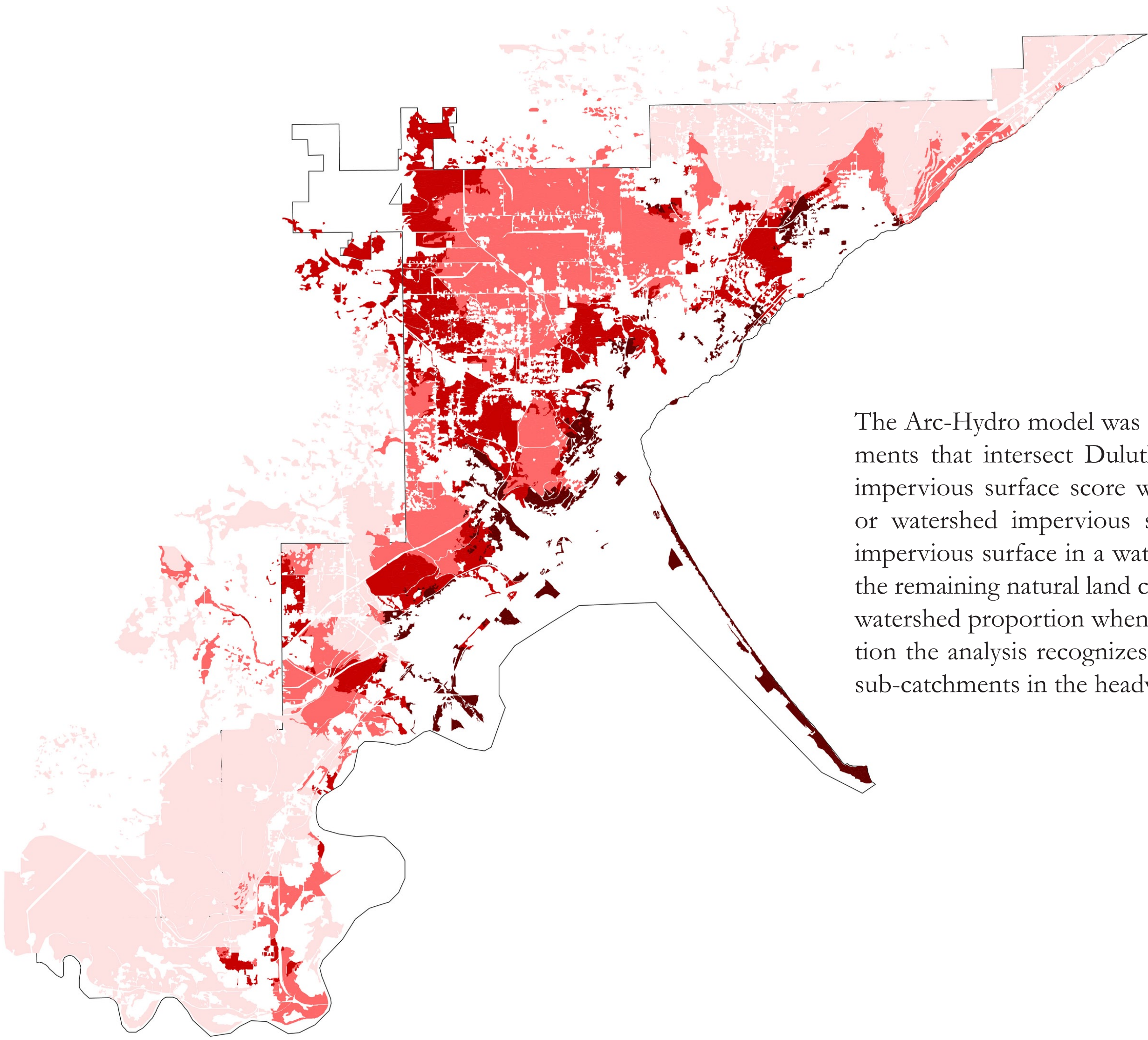


Figure NR-11: Stand watershed impervious cover (4-level, darker colors are higher scores).



The Arc-Hydro model was used to delineate watersheds and sub-catchments that intersect Duluth (see Figure NR-11). The input for the impervious surface score was the higher of either the sub-catchment or watershed impervious surface proportion. In general the more impervious surface in a watershed or sub-catchment the more valuable the remaining natural land cover for watershed protection. By using the watershed proportion when it is higher than the sub-catchment proportion the analysis recognizes the special value of relatively undeveloped sub-catchments in the headwaters of some watersheds.

Minnesota County Biological Survey data was considered as a collection of mostly circular polygons with areas ranging from 0.5 to 1,700 acres (see Figure NR-12). MCBS staff advise against using the centers of these polygons, as polygon area reflects site size. Relating the individual MCBS polygons to the Duluth NRI forest and wetland polygons is problematic. A large MCBS polygon near Fon du Lac representing reed canary grass could be considered to apply only to the NRI wetland polygons in the St. Louis River in that vicinity. It might also be argued that the MCBS record should also be applied to the NRI upland forest polygons in the area as they represent the immediate watershed of the reed canary grass site. A nearby MCBS polygon representing a bald eagle nesting area should more obviously apply to all the wetland and forest NRI polygons it overlaps, as all these cover types are utilized by the bald eagle or its prey. MCBS sampling patterns and the rarity of some community types cause hot spots of overlapping observations. MCBS records are also graded according to level of rarity and state and federal status.

Figure NR-12: Density of overlapping Minnesota County Biological Survey observations.

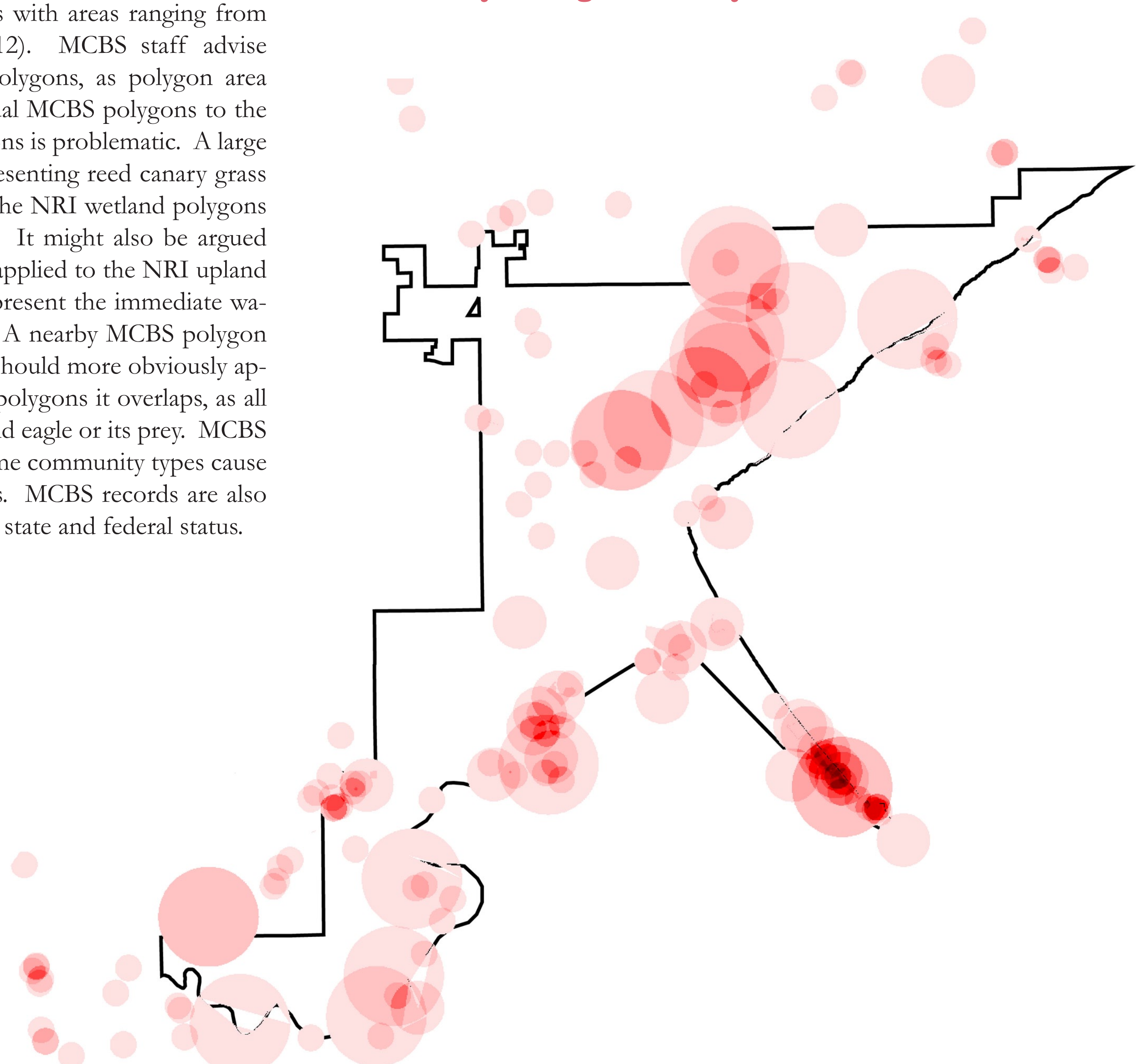
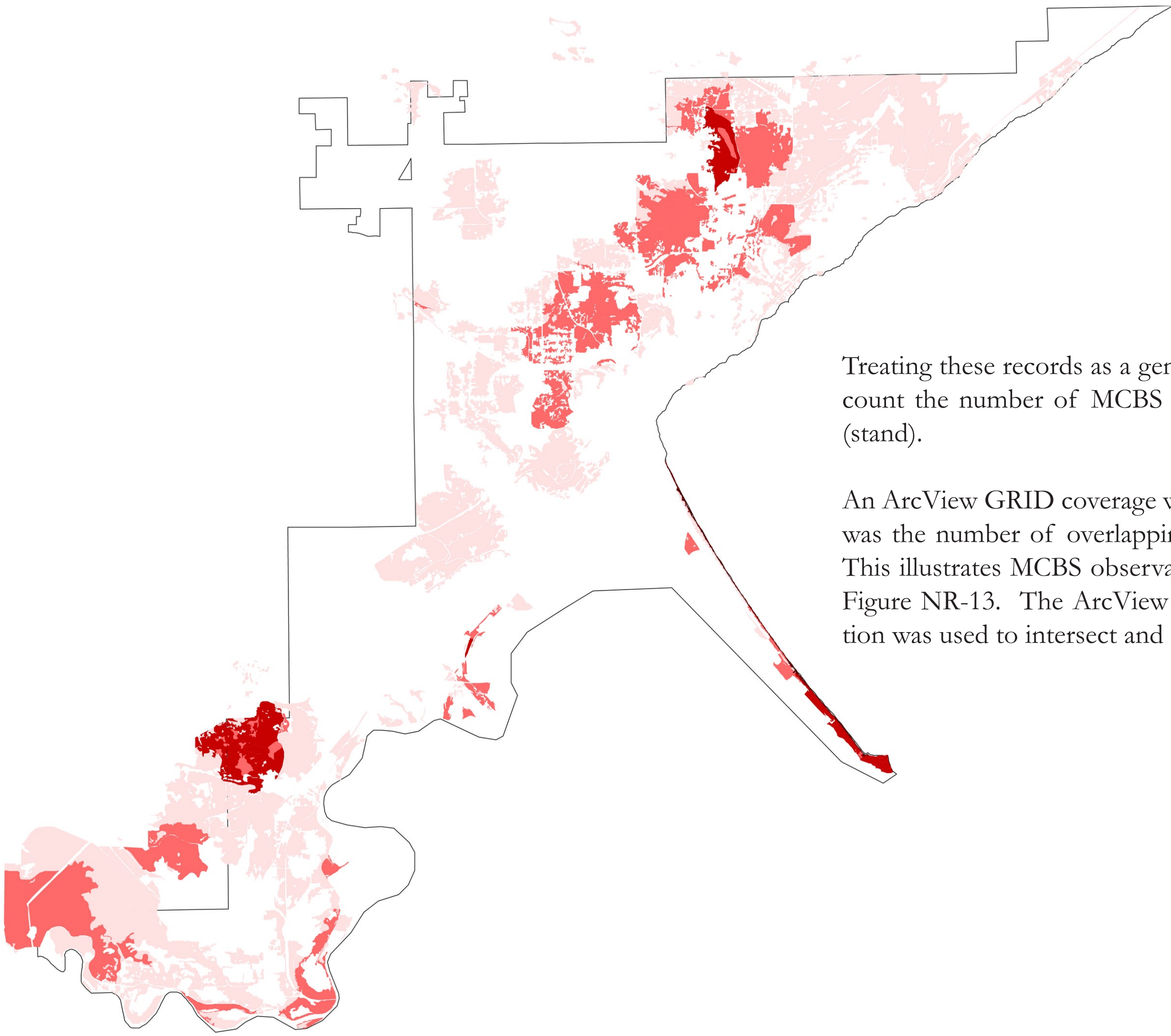


Figure NR-13: Minnesota County Biological Survey records (4-level, darker colors are higher scores)



Treating these records as a general indicator of valuable habitat, we simply count the number of MCBS polygons intersected by each NRI polygon (stand).

An ArcView GRID coverage was constructed such that each grid cell value was the number of overlapping MCBS polygons occurring at that point. This illustrates MCBS observation overlap and hot spots, as portrayed on Figure NR-13. The ArcView extension X-Tools Union shapefiles operation was used to intersect and associate the MCBS and NRI polygons.

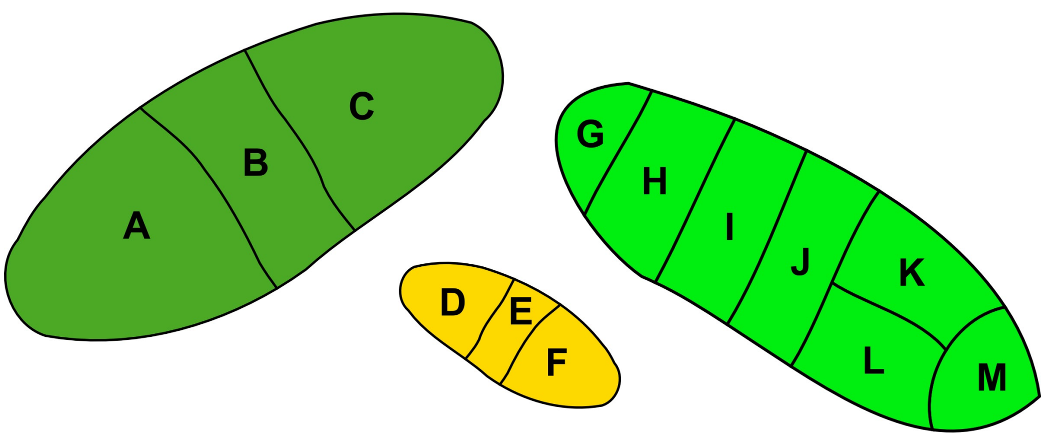
To calculate the impact on cluster connectivity of removing any one stand, the C++ computer code described previously was modified to compare the total number of clusters present at a given connectivity threshold with and without the stand in question. Stands that do not break their cluster into two or more smaller clusters when they are removed returned an intermediate value "I" of zero. Stands that do break their cluster into two or more smaller clusters when they are removed returned a value I calculated in the following manner:

$$I = \frac{\text{Area of unbroken cluster}}{\left(\frac{\text{Area of largest new cluster}}{\text{Area of second largest new cluster}} \right)}$$

The above process gives a higher value to stands whose removal breaks a cluster approximately in half than those whose removal isolates only a small part of the cluster. Also, the value of I is proportional to the size of the original cluster, so stands whose removal would break larger cluster score more highly. Figure NR-14 illustrates various possible scoring scenarios.

Figure NR-14 shows an example with three separate clusters. Removing stands A, C, D, F, G, or M would not increase the number of clusters, so these stands score zero for connectivity. Likewise removing stands K or L would not increase the number of clusters, as in each case there is an alternate route from J to M, so these stands also score zero for connectivity. Removing B would break a large cluster almost exactly in half, so B scores very highly for connectivity. Likewise removing J would break a large cluster almost exactly in half, so J scores very highly for connectivity. I scores a little lower than J, because its removal would break and cluster more unevenly than the removal of J. H scores even lower than I, because its removal would cause a very uneven break. Finally E gets a low score because while its removal breaks its cluster roughly in half, it was a small cluster to start with.

Figure NR-14: Explanation of connectivity scoring



Stands were scored according to the amount of "core area" (area more than 150 meters from an edge) in the stand's cluster. 150 meter is a distance commonly given as the upper bound for edge derived stresses. The results of the stand connectivity analysis is shown in Figure

Figure NR-15: Stand connectivity (4-level, darker colors are higher scores).

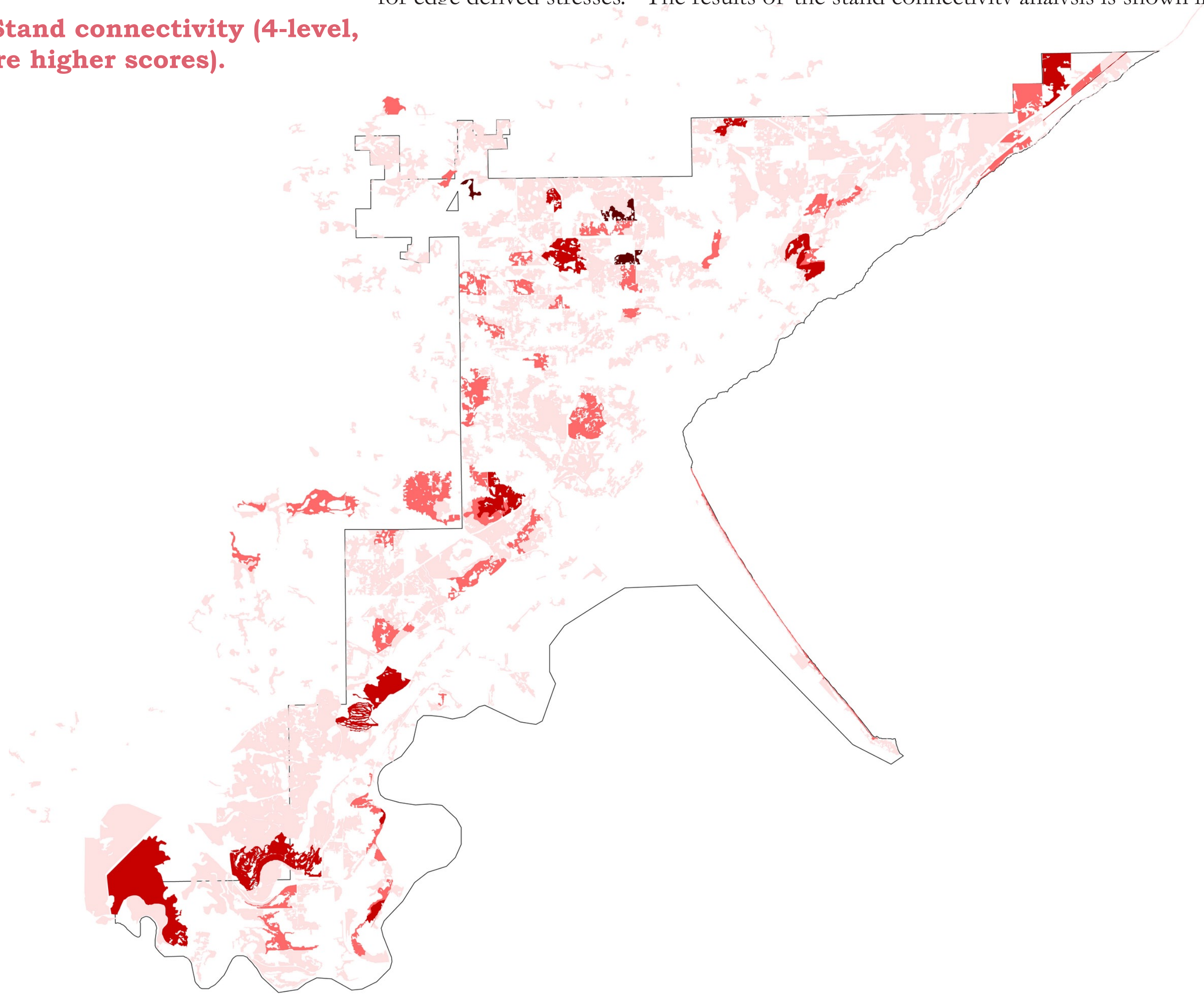
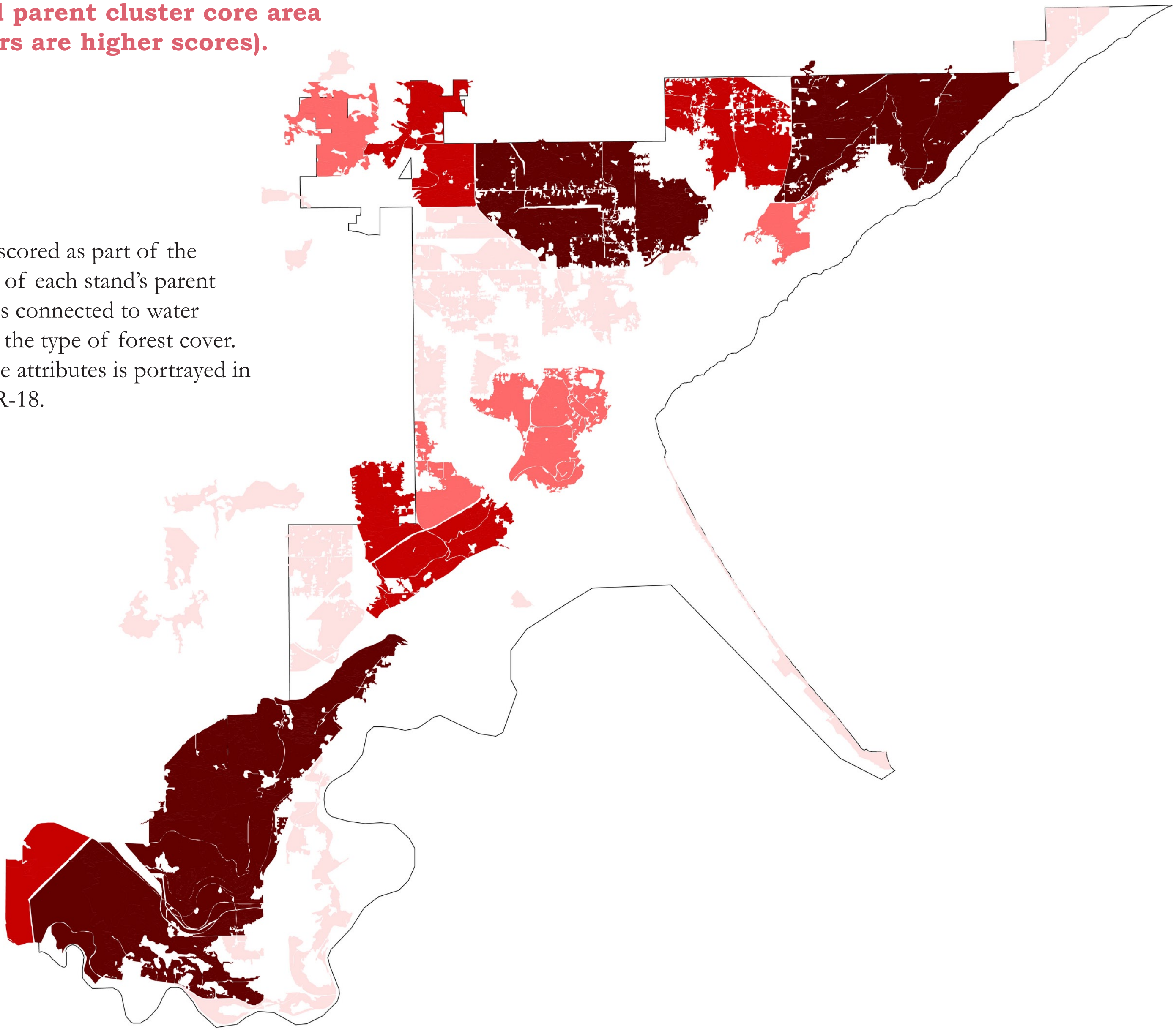


Figure NR-16: Stand parent cluster core area (4-level, darker colors are higher scores).



Additional attributes were scored as part of the analysis, including the size of each stand's parent cluster, whether the stand is connected to water (stream, river, or lake), and the type of forest cover. The results of scoring these attributes is portrayed in Figures NR-16 through NR-18.

Figure NR-17: Water proximity by stand (4-level darker colors are higher scores).

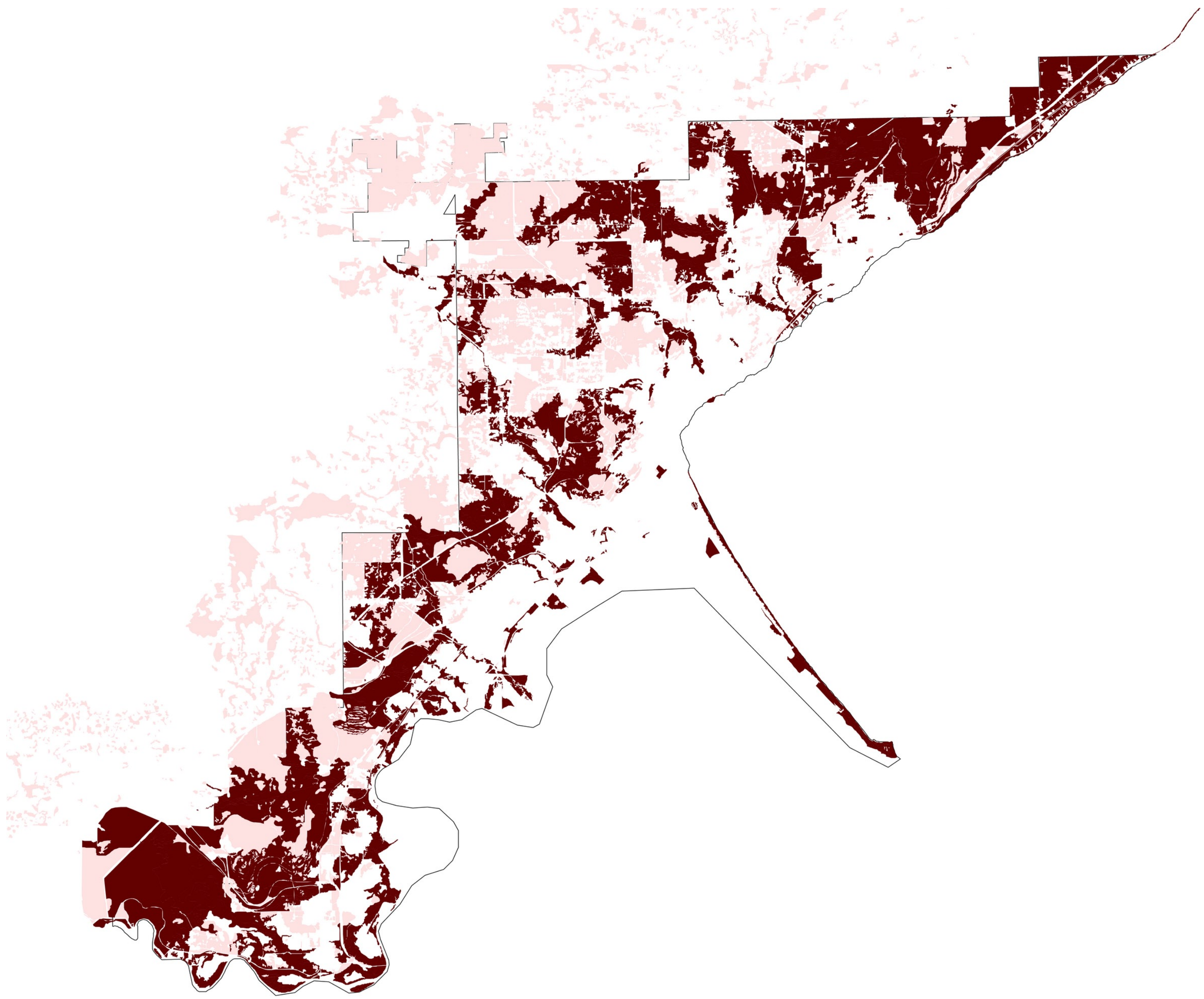


Figure NR-18: Forest type by stand (4-level, darker colors are higher scores).

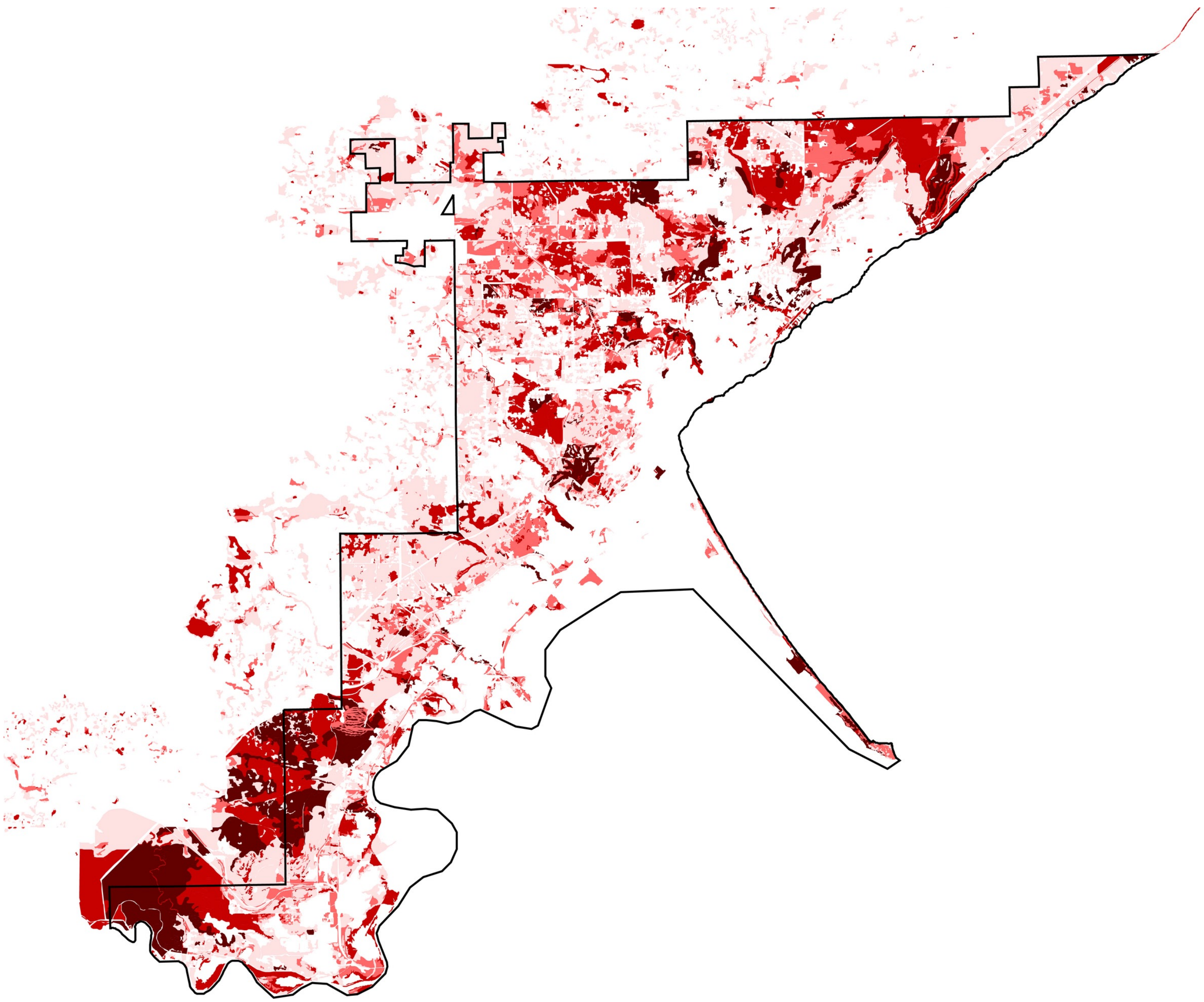
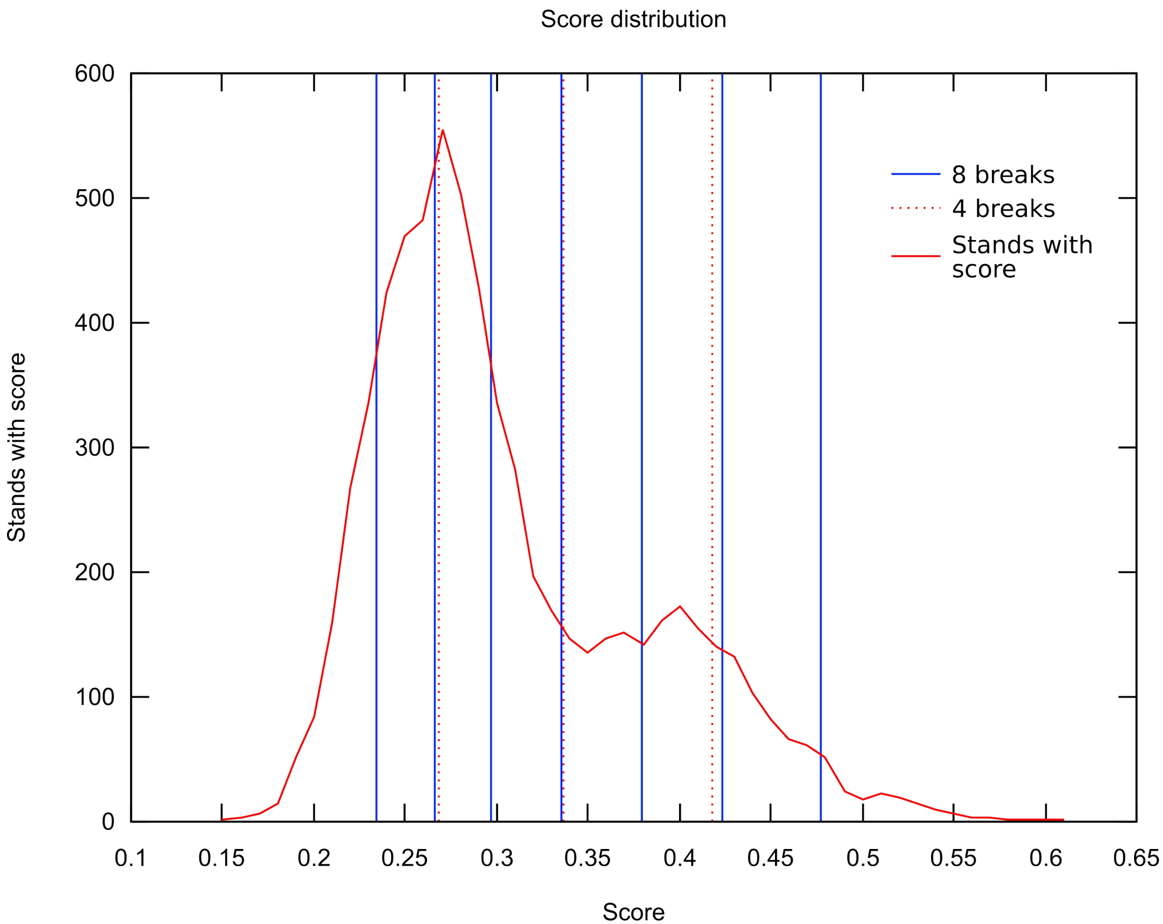


Figure NR-19: The distribution of scores or ranks for all stands.



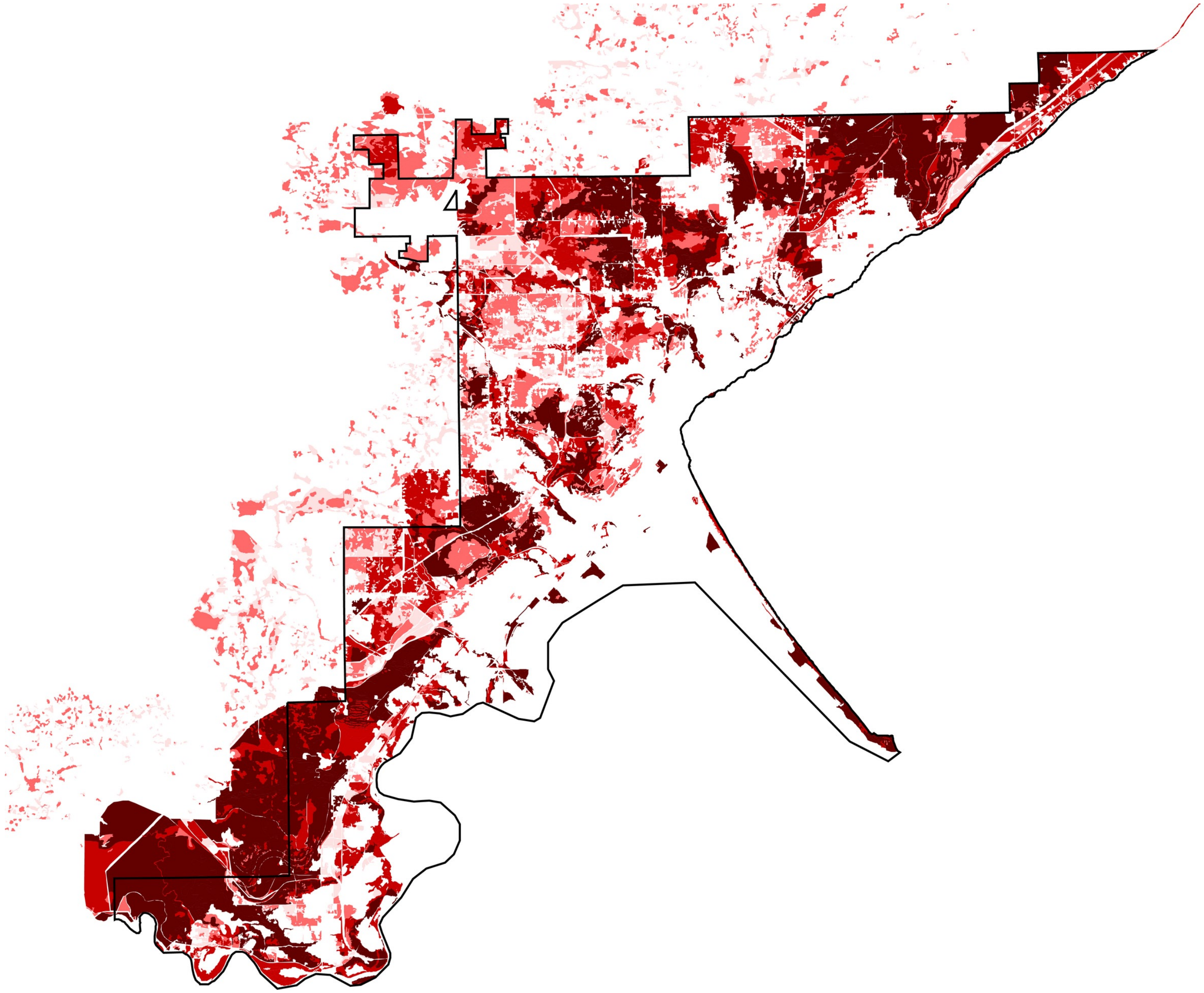
Results

Score distribution

The distribution of scores or ranks for all stands is shown in Figure NR-19. Scores ranged from 0.15 to 0.6, to score zero or one a stand would need to score all zeroes or all ones on each individual attribute, which is unlikely. also shows the break points for a 4 and 8 level classification using ArcView's "natural breaks" classification scheme. These classifications should not be over-interpreted, they are an aid to visualization only. When using a map of these stands and scores we would strongly encourage the user to use an 8 level classification. Using the 8 level classification makes it much easier to identify cases where stands are in different classes but not very different from each other (any pair of adjacent classes, e.g. 3 and 4), and to identify cases where more significant differences exist (any pair of non-adjacent classes, e.g. 3 and 5).

Figure NR-20 illustrates the distribution of ecological value. Ecological value is based on the analysis of stands previously described in the report.

Figure NR-20: Map of regions of high ecological value in Duluth.



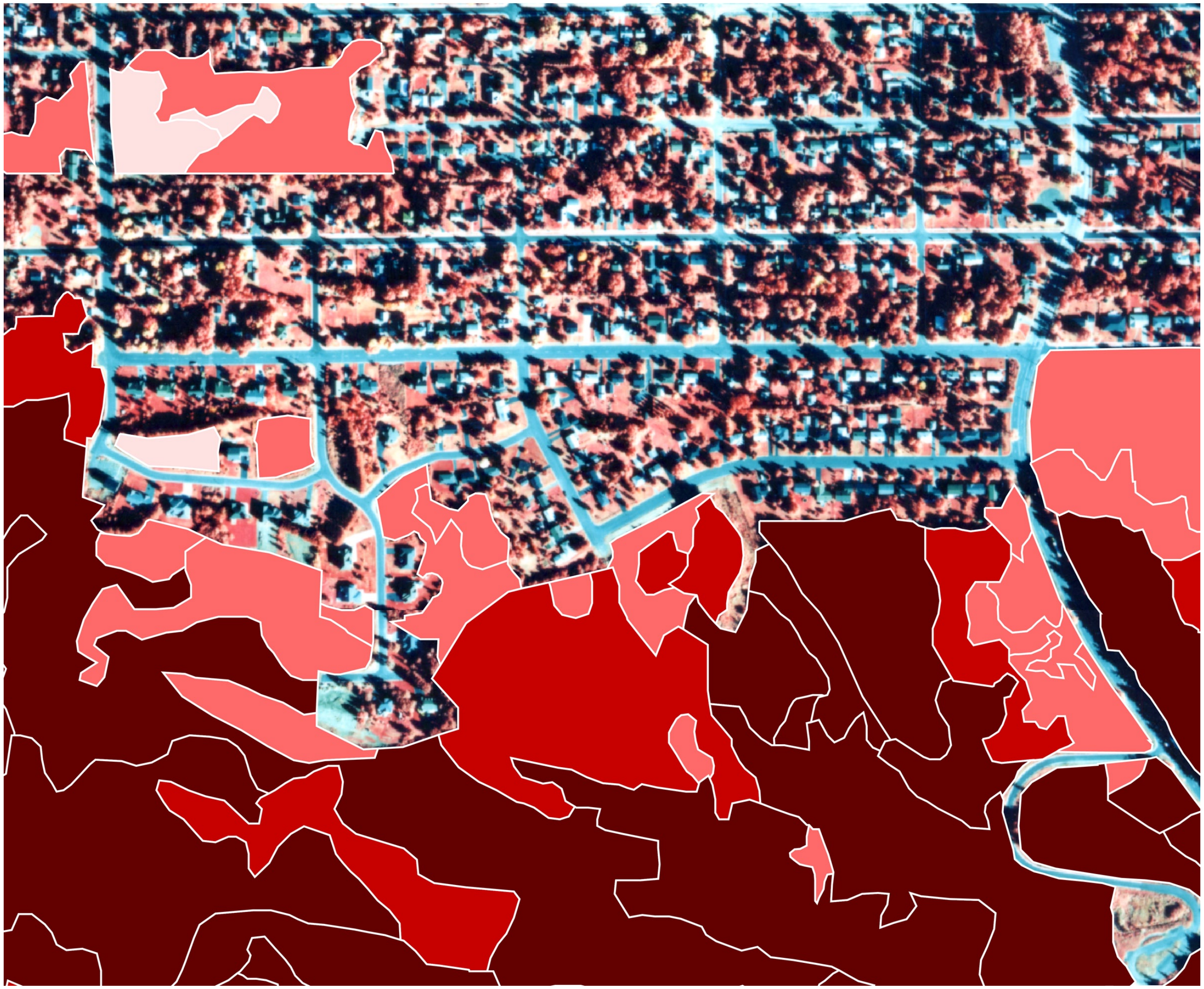
Application

Figure NR-21 shows how the Natural Resource Assessment can be used in land use decisions. For instance, when making regulatory decisions for the undeveloped area (vegetated areas in Figure NR-21), or place a development within it, the ecological value map should be used as a guide.

Figure NR-21: Possible application scenario for results.

Figure NR-22 shows that the vegetated land adjacent to existing housing scores lower on the left than on the right, suggesting that the area on the left might be the better area to consider for development.

Figure NR-22: Possible application scenario for results.



Caveats and things to bear in mind

This Natural Resource Assessment scores and ranks almost seven thousand stands of natural or semi-natural land cover within the city of Duluth. The Assessment is intended for large scale planning and screening applications. While providing an excellent starting point for evaluating specific sites, any project tied to a specific site should conduct an early on-site inspection and consult other map layers as necessary. The Assessment cannot subsitute for site specific investigation and analysis.

Stands of natural land cover may have value for reasons not considered by this analysis, and low scoring stands should not be regarded as disposable without further site specific analysis.

Bibliography

Biodiversity Guidebook, 1995, Ministry of Forests and Range, Canada.

Csa_type_ field	Description	Number	Total area
Agriculture	Agriculture	6	46.4
Ash	Ash	968	2625.5
Ash/Aspen	Ash/Aspen	2	20.9
Ash/B.Fir	Ash/Balsam Fir	2	39.4
Ash/W.Cedar	Ash/White Cedar	3	7
Aspen	Aspen	1138	11382.1
Aspen/B. Fir	Aspen/Balsam Fir	3	25.4
Aspen/Birch	Aspen/Birch	105	2187
Aspen/N.Hardwood	Aspen/Northern Hardwood	59	2117.1
Aspen/Oak	Aspen/Oak	2	38.6
B. Fir/B. Spruce	Balsam Fir/Black Spruce	1	1.4
B. Fir/W. Cedar	Balsam Fir/White Cedar	1	1.8
B. Fir/W. Spruce	Balsam Fir/White Spruce	1	2
Balsam Fir	Balsam Fir	12	37.8
Bare Soil	Bare Soil	10	72
Birch	Birch	115	1432.8
Birch/Aspen	Birch/Aspen	13	218.1
Birch/N.Hardwood	Birch/Northern Hardwood	5	518.2
Birch/Red Pine	Birch/Red Pine	1	5.3
Birch/W. Cedar	Birch/White Cedar	2	14.7
Black spruce	Black spruce	95	454.3
Cottonwood	Cottonwood	2	1.2
Jack Pine	Jack Pine	14	20.8
LF	LF	5	3
Lowland Brush	Lowland Brush	1258	3517.8
Lowland Grass	Lowland Grass	483	1019.7
Lowland Hardwood	Lowland Hardwood	117	439.9
Marsh	Marsh	106	439.2
N. Hardwoods	Northern Hardwoods	151	2431.2
N.Hardwood/Aspen	Northern Hardwood/Aspen	1	9.7
N.Hardwood/Birch	Northern Hardwood/Birch	1	10.7
Non-Permanent Wa	Non-Permanent Wa	111	116.1
Oak	Oak	16	237.2
Permanent Water	Permanent Water	235	459
Recreation Devel	Recreation Devel	89	1050
Red & White Pine	Red & White Pine	5	21
Red Pine	Red Pine	98	200
Roads	Roads	37	115.2
Rock Outcrop	Rock Outcrop	154	191.1
Scotch Pine	Scotch Pine	5	32.4
Upland B. Spruce	Upland Black Spruce	1	1
Upland Brush	Upland Brush	438	1705.9
Upland Grass	Upland Grass	767	2290.7
Urban Development	Urban Development	114	728
W. Cedar/Aspen	White Cedar/Aspen	2	23.6
W. Spruce/Aspen	White Spruce/Aspen	1	2.1
W. Spruce/B. Fir	White Spruce/Balsam Fir	3	13.4
W. Spruce/R. Pin	White Spruce/R. Pin	1	2.1
W. Spruce/W. Pin	White Spruce/W. Pin	1	1.1
W.Spruce/Aspen	White Spruce/Aspen	1	7.5
White & Red Pine	White & Red Pine	1	9.4
White Cedar	White Cedar	3	9.6
White Pine	White Pine	40	240.2
White Pine/Spruce	White Pine/Spruce	1	2.9
White Spruce	White Spruce	26	45.2
Willow	Willow	24	56.7
[Blank]	Non-forested wetland	103	395.7
Industrial Devel	Industrial Development	116	2045.9