Development of a Natural Areas Integrity and Restorability Index and Application to Lands of the Chicago Region

Part 1 – GIS Analysis

INHS Technical Report 2011 (13)

By
Diane L. Szafoni, Chad Hickman, Dr. Brian D. Anderson and Tari A. Tweddale

1 Contents

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2 Executive Summary

This project was conceived during the Rapid Implementation Phase of the Illinois Natural Areas Inventory (INAI) project. A series of workshops were held where county Conservation District (CD) and Forest Preserve District (FPD) staff from Northeastern Illinois participated. Staff at these agencies expressed the belief that, due to the rapid pace of development, few new areas will be found in the Chicago Region that can meet the standards of the Illinois Natural Areas Inventory. They expressed a need for identification of lands that have the capacity to be restored to natural area quality using modern restoration techniques, and also that occur in a landscape context that will allow them to be viable over the long-term once restored. They argued that this process should be conducted by an independent, objective, scientific team and be endorsed by the State of Illinois to ensure acceptance by their boards and their communities. The county CD and FPD staff also reiterated the necessity of identifying this “next tier” of lands worthy of public investment before most of these opportunities are lost.

The goal of this project was to identify a series of landscape-scale characteristics related to biotic and landscape integrity that could be used to quickly identify potential areas for protection. “Landscape Integrity Criteria” were used to identify data to perform a Geographic Information System (GIS) analysis of undeveloped lands in the Chicago Region. This GIS analysis identified lands that, if restored, have the potential for long-term ecological integrity. These landscape integrity and restorability criteria were aligned with the qualifying size criteria for registration of lands as Illinois Land and Water Reserves (a state designation resulting in protections almost as strong as Illinois Nature Preserve Dedication), to identify “large grade C’s” that could currently qualify or be restored to qualify for designation as Land and Water Reserves. Smaller areas of undeveloped land of other community types were included if adjacent to larger qualifying parcels for the purposes of building a “connected system of conservation lands. This analysis provides a score that is used in a ranking system, developed in conjunction with INHS Scientists, to establish a hierarchical assessment of the intrinsic capacity of landscapes to sustainably support native flora and fauna with restoration.

A “Restorability Index” was also developed that would allow the analysis of the relative potential for restoration of undeveloped lands on a case by case basis. Armed with the “Inventory of Landscapes of Ecological Importance” and the “Restorability Index,” land managers can identify opportunities and priorities for large-scale restoration in the context of their unique management and restoration capacities.

There has been some early interest in the products of this study. The scope and methods of this project was discussed with James Anderson, Natural Resource Manager at the Lake County

Forest Preserve and Jesse Elam, Senior Planner at the Chicago Metropolitan Agency for Planning.

3 Introduction

The landscapes of Illinois have changed greatly in the past 200 years. Before European settlement, Illinois was 41% forest, 55% prairie, and the remaining 4% open water and wetlands (Cordle, Szafoni and Greer, 2002). Illinois has lost over 90% of its original wetlands, 99.9% of its original prairie, and 36% of its forest. Much of the conversion of Illinois' land to agriculture was largely complete by the early 1900s. Today, most of the land conversion in Illinois is due to expanding urban areas (IDNR, 1996). McGrath (2005) calculated the total urban land areas for major cities in the United States, and found that Chicago increased in size from 708 square miles in 1950, to 960 square miles in 1960, 1,277 square miles by 1970, 1,498 square miles by 1980 and 1,585 square miles by 1990. This more than doubled the urban area (an increase of 877 square miles) in 40 years.

Illinois' population grew from 55,211 in 1820 (just after statehood in 1818) to 12,419,293 in 2000 (U.S. Census Bureau, 2000). The ten year period from 1990 – 2000 saw 8.6% increase in Illinois' population. Population is projected to increase an additional 8.2% between 2000 and 2030 (U.S. Census Bureau, 2000). Land development has increased even faster than population. The Sierra Club (US Census Bureau data) did a study of urban sprawl and found that Chicago's population increased by one percent from 1970 to 1990, while its urbanized area grew by 24 percent.

The scattered pattern of modern development not only consumes an excessive amount of land, it fragments the landscape. Numerous studies have shown the negative ecological effects of forest fragmentation in the landscape (Wilcox and Murphy, 1985, Robertson et al, 1995). As forest areas are divided and isolated by roads and development, interior habitat decreased. This coupled with increased human disturbance and the spreading of opportunistic edge species results in the populations of many animals become too small to persist.

Besides the negative effect on animal populations through the loss of wildlife habitat and migration corridors, normal ecosystem functions such as absorption of nutrients, recharging of water supplies and replenishment of soil are disturbed or destroyed (Saunders et al., 1991). Water quality has been degraded in many rivers and streams and many of Illinois' remaining wetlands have been altered by filling, drainage and impoundment, livestock grazing, logging, direct discharges of industrial wastes and municipal sewage, and indirect pollution from urban and agricultural runoff.

Today, with urban land continuing to sprawl into the surrounding landscape, there is an even more urgent need to accurately identify and protect the most important unprotected natural lands in the state before they are lost.

The Illinois Department of Natural Resources (IDNR), and Conservation and Forest Preserve Districts have many programs for land acquisition, easements, and other forms of land and resource protection. Timely knowledge of where key lands and corridors are situated would facilitate these processes.

The purpose of this study was to develop a way of assessing the landscape quickly, efficiently and frequently. A spatial analysis using existing statewide digital data and Geographic Information System (GIS) software was used because it met the project goals. Indeed, the use of GIS software and landscape ecology has been a proven tool to aid the locating of remaining areas of ecological significance.

3.1 Past Illinois Studies

3.2 Resource Rich Areas

The IDNR has long recognized the value of a landscape level approach to identify natural resources. Past research, such as the Inventory of Resource Rich Areas (RRA) (Suloway et al., 1996), has evaluated the distribution of recognized ecological resources in Illinois. The Resource Rich Areas report identified and characterized areas rich in biological resources by Illinois Environmental Protection Agency (IEPA) watersheds. A list of ecological characteristics and functions of large ecological reserves, and criteria to identify and evaluate these areas was developed. Eight hundred sixteen watersheds were evaluated using existing data appropriate for GIS analysis. These datasets included: percent of forest and wetlands from the 1995 Critical Trends Assessment Project land cover, total area of Illinois Natural Areas Inventory (INAI) sites, total length of Biologically Significant Streams (BSS), as well as supplemental data such as state and federally owned land, Illinois Nature Preserves, and natural divisions. The four variables of percent forest cover, percent wetland cover, total area of INAI, and total length of BSS were given equal weight. Each watershed was ranked against all other watersheds for each variable. Watersheds were placed into 10% quantiles for each variable and given a score of 10 points for the top quantile, 9 for 81-90% quantile, 8 for 71-80% quantile, etc. Watersheds in which variables did not occur were given a 0 score for that variable. The scores for each variable in each watershed were summed. The maximum possible cumulative score was 40. Watersheds were considered to be rich in resources if their cumulative score ranked in the top 10%. This study, with its watershed -scale analysis was fine as a first attempt to identify important wildlife habitats. However, this process could have been improved by a finer scale analysis of potential sites for protection or restoration, more detailed assessment of landscape variables, and the input of plant and animal scientists. The current project addresses this shortcoming.

3.2.1 Green Infrastructure

Whereas Resource Rich Areas aggregated ecological information at the watershed level, Green Infrastructure looked at all possible blocks of undeveloped land individually (Szafoni, 2006). The components of Green Infrastructure consist of core reserves - large patches of natural vegetation, and corridors connecting the core reserves. The corridors are wide swashes of vegetation that provide corridors for wildlife movement, and connections between the core reserves. Together, the core reserves and corridors represent the most efficient means of connecting the largest and highest natural quality lands remaining in Illinois.

The core reserves or *hub*s are blocks of land that provide living space and areas of origins and destinations for plants and animals. *Links* are the connecting corridors that tie the hubs. These linear remnants of natural land allow plants and animals to move from one hub to another, helping to ensure long-term survival and continued diversity. The hubs and links can range in size, function and ownership, but in order to be successful, they need to be provided long-term protection.

Hubs identified in the proceeding process were next characterized based on the relative importance as potential habitat for wildlife. The ecological parameters used include measures of size such as the area of critical habitat types within the hub, presence of natural communities or of unique natural resources, amount of protected areas, and spatial relationships. Threat parameters include development pressures, remoteness from roads, and road density within the hubs. Weighting factors were applied to the final results and a final rank for each hub was derived. The ranked hubs were divided into 3 natural breaks and the top third was used in the corridor analysis.

All potential corridor types were combined with the creation of forest and wetland layers to assess the quality or cost of using these corridors to move between hubs. A GIS technique called lease-cost path analysis was used to determine the best paths between the top one third of hubs. In this analysis, the 'cost' is a measure of the difficulty for wildlife to travel along the corridors. The best corridor is the pathway between two hubs with the fewest obstacles (roads, bridges, and urban areas), and the most favorable habitat (forest, grassland, wetlands), was the least-cost path.

The goal of this study was the creation of a statewide, GIS database of habitat 'hubs' and connecting 'corridors' that can be used to help identify the important wildlife habitat remaining in Illinois. While this study was a fine first attempt to incorporate more landscape ecology principles, the ranking system employed needed refinement and evaluation by botanists, mammalogists, herpetologists, and ornithologists to better reflect the needs of these species. This weakness has been addressed in the current project.

3.3 Literature Review

Many landscape scale studies use satellite imagery as a way of assessing vegetation canopies at a regional scale (Reinke and Jones, 2006). An early research project that used satellite imagery and GIS for a regional assessment of natural areas was the Maryland Green Infrastructure project (Weber et al. 2006). In this study, large contiguous blocks of natural areas (hubs) and interconnecting natural corridors were identified using satellite imagery, and ranked using GIS software. A variety of digitally available ecological and development risk parameters were used for the assessment. Maryland is currently using the results as a guide for land conservation efforts, and it has been expanded to a multi-state scale for the Chesapeake Bay program.

An evaluation process was developed in many studies to identify potential ecologically significant areas. Several studies champion the idea of 3-level systems of evaluation. Vance (2009), assessing wetlands in Montana, and Faber-Langendeon (2007) at NatureServe used a 3-level system with four categories of data - biotic, abiotic, size, and landscape context. Higgins et al. (2007) also devised a 3-level system of evaluation, but used conservation indicators in three major categories – Biodiversity Status (size, condition, landscape context), Conservation Management Status (intent, tenure, effective management, potential), and Impacts and Threats Status (severity, scope). Tierney et al. (2009) employed a 3-level system of evaluation, using metrics of status and trends in structure (size, snag abundance, percent of stand in late-succession, and amount of coarse woody debris), composition (tree regeneration, condition, biotic homogenization, presence of deer browse and invasive exotic plants), and function (tree growth and mortality rates, soil chemistry – acid stress and nitrogen saturation) in temperate forests in the northeastern United States. Regardless of which metrics are use used to evaluate the landscape, Parkes and Lyon (2006) and Tierney et al. (2009) maintain that it is critical that the landscape-scale assessment used meets state policy and legislative requirements. To that end, they feel it is necessary to set regional targets and evaluate progress.

In this project, we have expanded on the Resource Rich Areas study to include all of the study area, not just select watersheds. We adapted the methods used in the Maryland study (Weber et al. 2008 to Illinois, adding a grassland land cover category to the forest and wetland categories. We evaluated the parameters used in the Maryland study for appropriateness in Illinois, and included additional parameters, if statewide data sets were available. We used three-level system: Ecological, Spatial and Threat parameters. Finally, we had mammalogists, ornithologists, herpetologists, and botanists assess the value of the parameter and suggest weights used in the final ranking.

4 Methods

The study area for this project was Northeastern Illinois (Greater Chicago Region). For purposes of some of the GIS analysis, all of the Illinois, Wisconsin, Indiana, and Michigan watersheds of the Upper Illinois River were included. The Hydrologic Unit Code (HUC) Watersheds (USDA

Natural Resources Conservation Service, 2002) was used for the outline of the study area (Figure 1).

The base land cover data used for this study was the United States Department of Agriculture, National Agricultural Statistics Service (USDA-NASS) Cropland Data Layer (CDL) for 2007 (Figure 2) (USDA, National Agricultural Statistics Service, 2007). The specifications for this data are as follows:

"The USDA, NASS Cropland Data Layer (CDL) is a raster, geo-referenced, crop-specific land cover data layer with a ground resolution of 56 meters. The CDL is produced using satellite imagery from the Indian Remote Sensing RESOURCESAT-1 (IRS-P6) Advanced Wide Field Sensor (AWiFS) collected during the current growing season. Ancillary classification inputs include: the United States Geological Survey (USGS) National Elevation Dataset (NED), the USGS National Land Cover Dataset 2001, and the National Aeronautics and Space Administration (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS) 250 meter 16 day Normalized Difference Vegetation Index (NDVI) composites. Agricultural training and validation data are derived from the Farm Service Agency (FSA) Common Land Unit (CLU) Program. The NLCD 2001 is used as non-agricultural training and validation data" (USDA, National Agricultural Statistics Service, 2007).

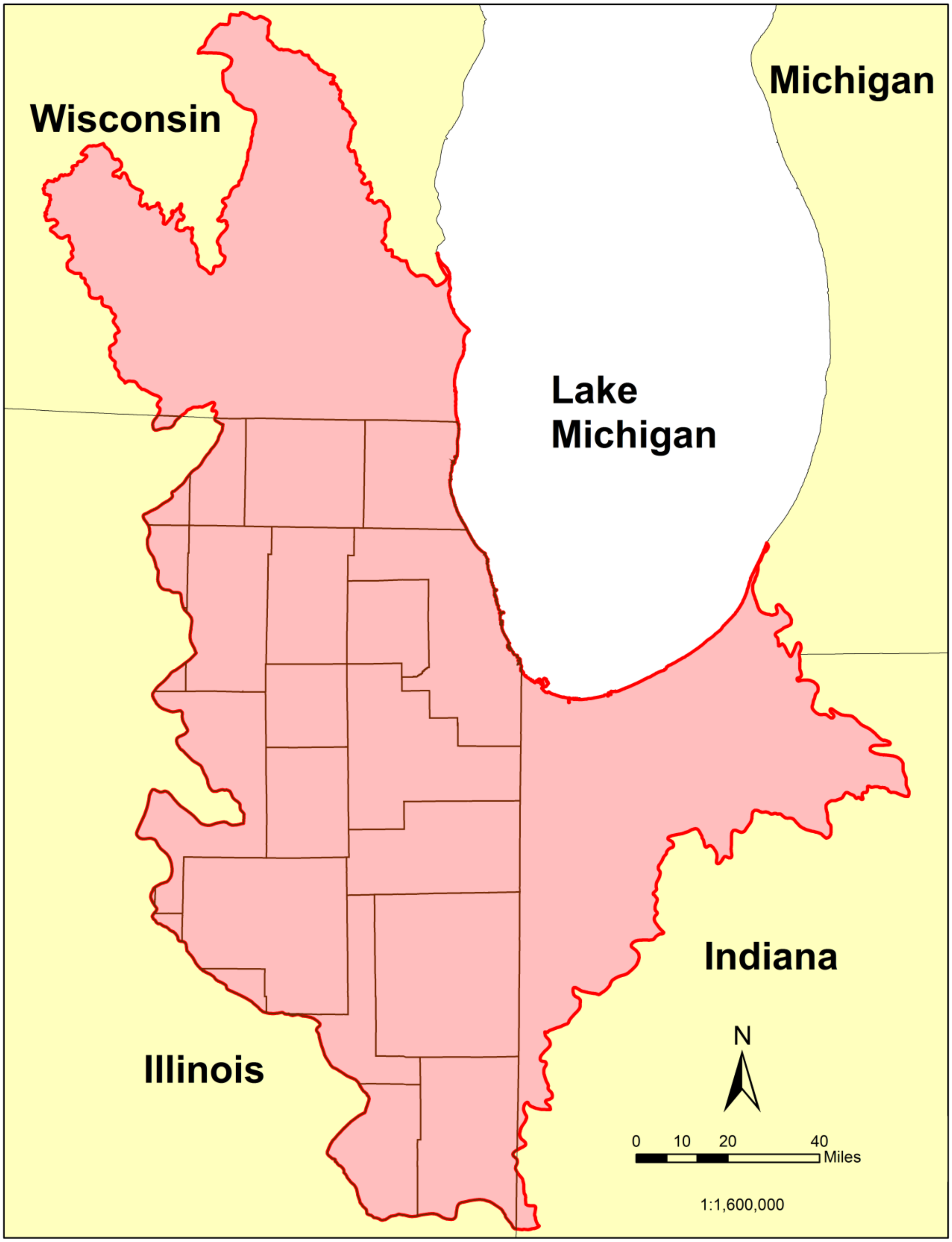


Figure 1. Study area.

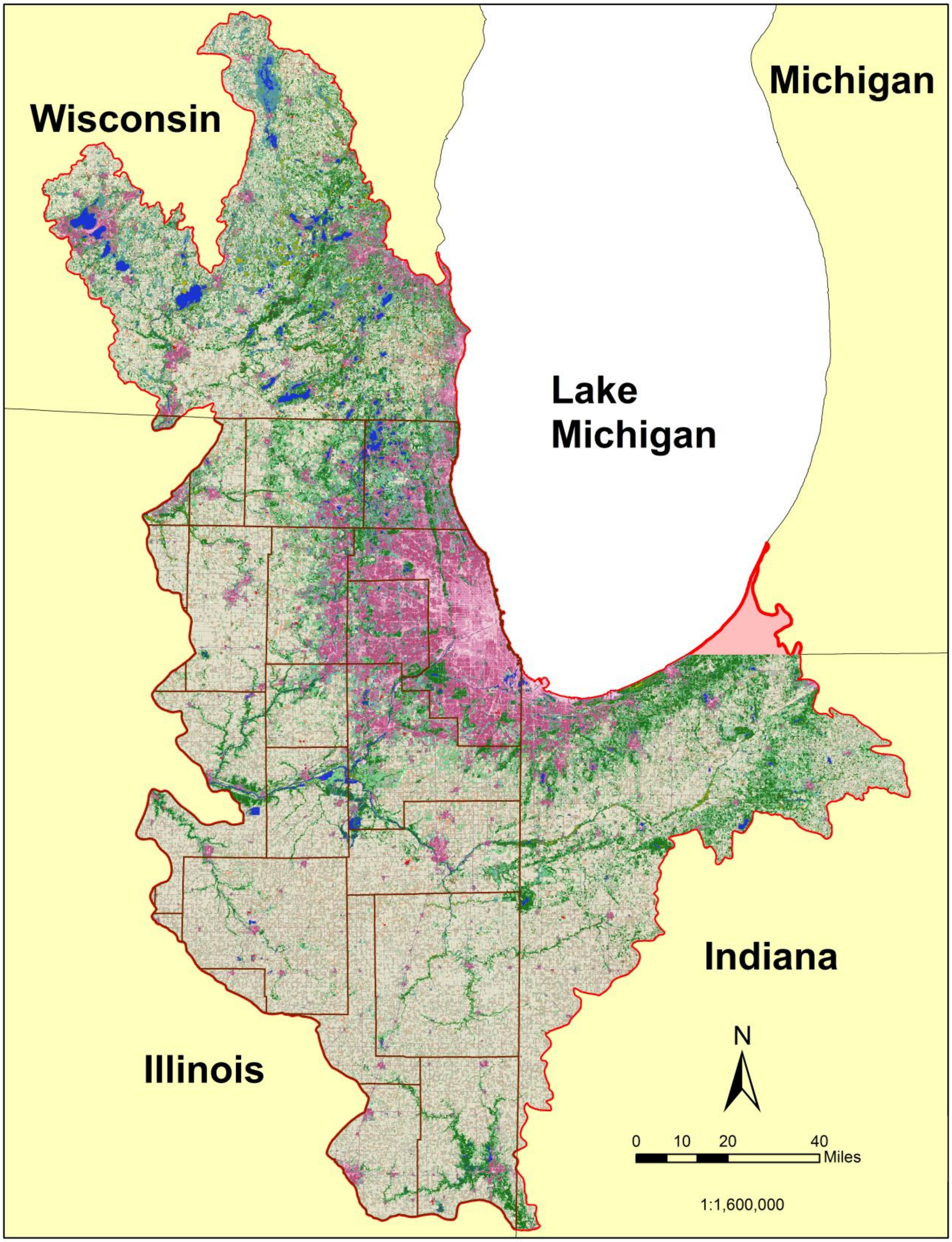


Figure 2. Original USDA-NASS 2007 land cover.

Major roads were buffered from the center lines to the distances appropriate to the road type (Interstates were buffered out to a distance of 30 meters, US and State Highways to 16 meters and County Roads to 12 meters.), and “erased” from the land cover data (NAVTEQ, 2007). This step was done to mask out the vegetation canopy that often hangs over the roads, thereby giving the false illusion of more intact forested tracts.

After removing roads from the NASS-CDL land cover, the Forest, Grassland and Wetland land cover categories were extracted for separate analysis (Table 1).

Forest	**Grassland**	**Wetland**
Min. Size: **100 acres**	**Min. Size:** **80 acres**	**Min. Size:** **50 acres**
63 Woodland	62 Grass/Pasture	87 Wetlands
141 NLCD Deciduous Forest	171 NLCD Grassland Herbaceous	190 NLCD - Woody Wetlands
142 NLCD Evergreen Forest	181 NLCD Pasture/Hay	195 NLCD - Herbaceous Wetlands
143 NLCD Mixed Forest		

Table 1. NASS 2007 Land Cover categories used in the GIS analysis.

Size constraints, based on the criteria for registration as Illinois Land and Water Reserves (1994), were applied to each land cover category: Forest >= 100 acres, Grassland >= 80 acres, Wetland >= 50 acres (Land and Water Reserve, 1994). Figures 3-5 shows the extent of each land cover category that remained.

Figure 3. Forests at least 100 acres in size.

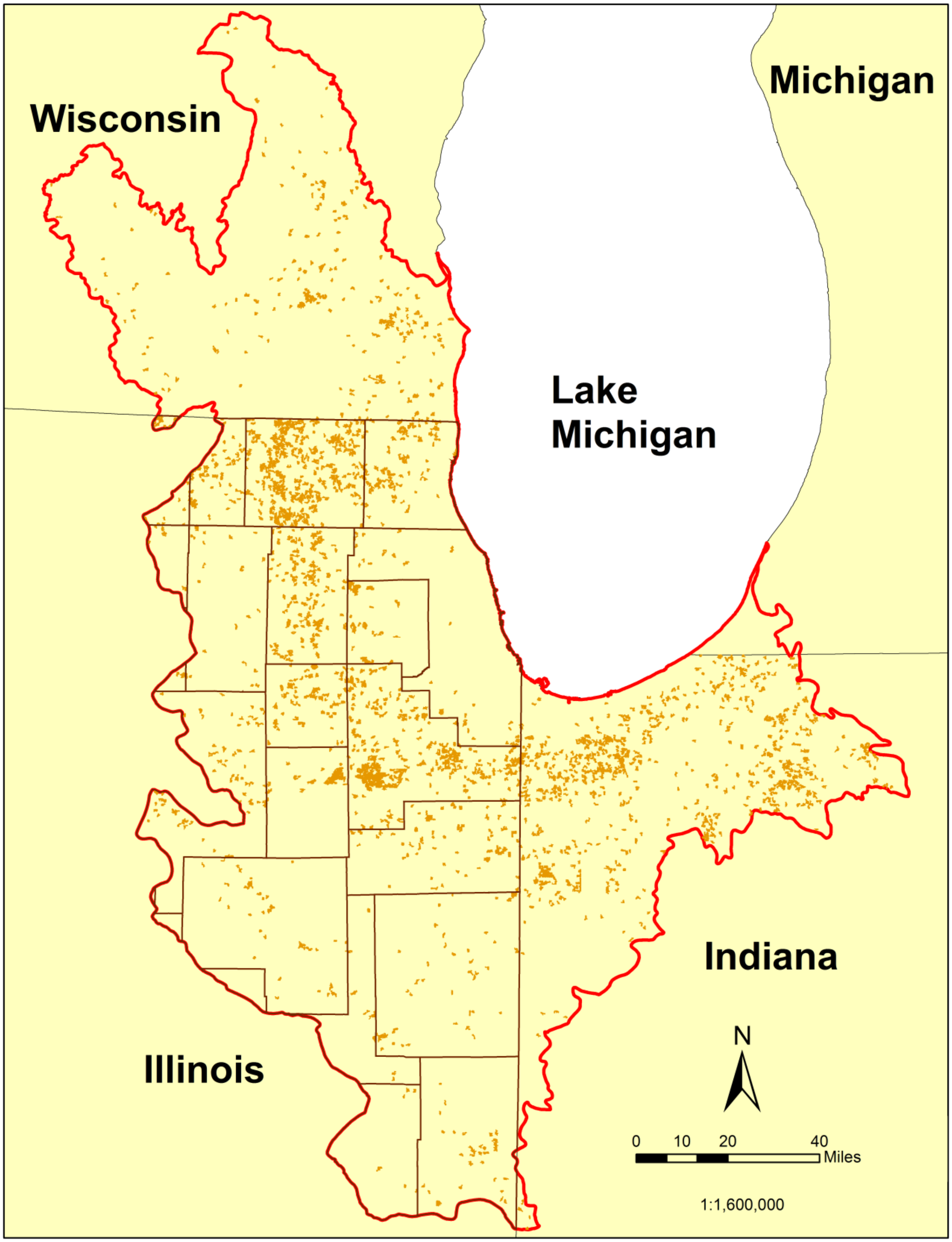


Figure 4. Grasslands at least 80 acres in size.

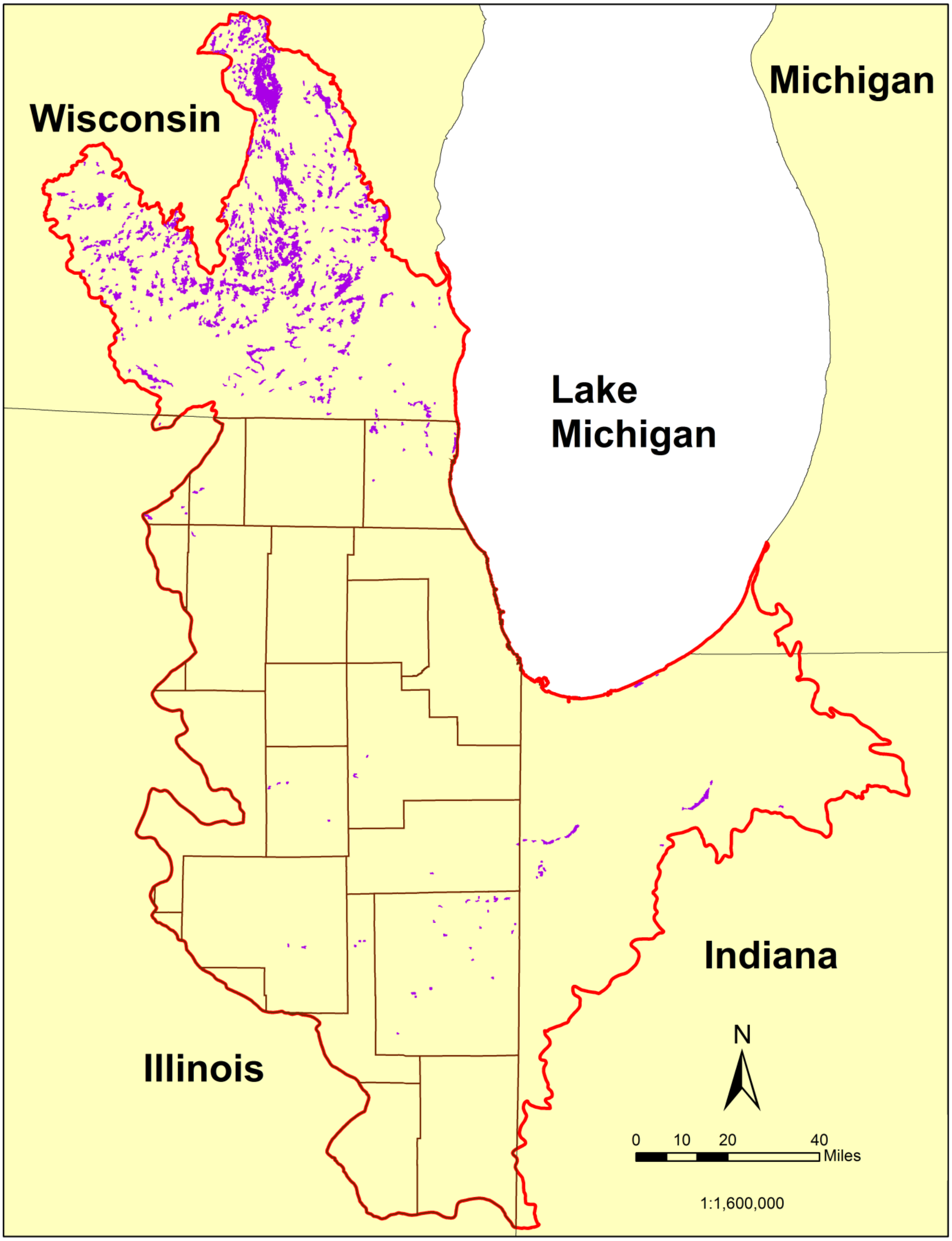


Figure 5. Wetlands at least 50 acres in size.

After selecting the desired land cover categories and applying the size constraints, the resulting Forest, Grassland, and Wetland tracts were evaluated for Landscape Integrity using a suite of data layers and ArcGIS software (ESRI, 2009). The data layers are grouped into Ecological Parameters, Spatial Parameters, and Threat Parameters (Table 2) employing a 3 tier analysis as previously discussed. The parameters chosen were those available as statewide GIS data sets. The ecological parameters used include presence of various ecological quality indicators such as natural communities, amount of protected areas, and presence of unique natural resources. The spatial parameters used include measures of the shape of the area, amount of interior gap or "holes" of different land cover types, and nearness to tracts of similar type. The threat parameters used include development pressures, such as amount of road density, remoteness from roads, and adjacency to agricultural and urban areas.

Type	Source	Date	Cell Size/ Resolution	Source Data
Ecological				
Area of (various) Land Use Category	USDA, National Agricultural Statistics Service 2007 Illinois Cropland Data Layer (CDL)	2007	56 meter	Indian Remote Sensing RESOURCESAT-1 (IRS-P6) Advanced Wide Field Sensor (AWiFS)
Area of Threatened and Endangered Species[1]	Threatened and Endangered Species, Rare Communities, and Valuable Natural Resources of Illinois, Edition 2.0	2009	1:24,000	Illinois Department of Natural Resources, Natural Heritage Database Program
Area of Public Land[1]	Illinois Natural History Survey's 1:100,000 Scale Illinois Gap Analysis Stewardship Layer	2003	1:100 000	Illinois Natural History Survey
Area of Nature Preserves – IDNR (forest and grassland only)[1]	Nature Preserves, Land and Water Reserves, and Natural Heritage Landmarks in Illinois	2009	1:24,000	Illinois Department of Natural Resources, Natural Heritage Database Program
Area of Railroad Prairie Remnant (grassland only)[1]	Prairie Remnants for the Illinois Dept. of Transportation, based on U.S. Geological Survey 1:100,000 Digital Line Graph file, railroad layer	2004	1:100,000	Illinois Natural History Survey, from U.S. Geological Survey railroad data

Type	Source	Date	Cell Size/ Resolution	Source Data
Area of Appropriate Soil (grassland = prairie, forest = forest, wetland = hydric)[1]	SSURGO Soils in Illinois	2007	1:12,000	U.S. Dept. of Agriculture, Natural Resources Conservation Services
Area of Interior Forest (forest only)[1]	USDA, National Agricultural Statistics Service 2007 Illinois Cropland Data Layer (CDL)	2007	56 meter	Indian Remote Sensing RESOURCESAT-1 (IRS-P6) Advanced Wide Field Sensor (AWiFS)
Area of Flood Zones (wetland only) [1]	Illinois State Water Survey (ISWS) – digitized from FEMA FIRM maps	1996	1:6,000 to 1:24,000	Illinois 100-year and 500-year floodzones
Length of Stream Width BSC Diversity ranking[2]	Integrating Multiple Taxa in a Biological Stream Rating System – Diversity component	1997-2006	1:100,000	Illinois Natural History Survey, from U.S. Geological Survey data
Number of Stream Sources and Junctions (wetland only)[2]	National Hydrography Dataset (NHD) Flowline – Medium-resolution (based on Digital Line Graph Data (DLG)	1999 (1994)	1:100,000	U.S. Geological Survey in cooperation with the U.S. Environmental Protection Agency
Illinois GAP Predicted Species Distributions for Bird and Herps (Reptile and Amphibian) Species in Greatest Need of Conservation (SGNC)[3]	Illinois Natural History Survey's 30m x 30m Amphibian, Bird, Reptile Predicted Species Distribution Models.	2003	30 meter	Illinois Natural History Survey
Spatial				
Proportion of Interior gap (holes) in area[1]	USDA, National Agricultural Statistics Service 2007 Illinois Cropland Data Layer (CDL)	2007	56 meter	Indian Remote Sensing RESOURCESAT-1 (IRS-P6) Advanced Wide Field Sensor (AWiFS)
Patch Shape – used V-LATE software[4]	Vector-based Landscape Analysis Tools Extension (V-LATE) 1.1 for ArcGIS 9.x	2005	N/A	Centre for Geoinformatics (Z_GIS) at Salzburg University
Nearness to Area with same Land Cover Type (nearest neighbor) – used V-LATE software[2]	USDA, National Agricultural Statistics Service 2007 Illinois Cropland Data Layer (CDL)	2007	56 meter	Indian Remote Sensing RESOURCESAT-1 (IRS-P6) Advanced Wide Field Sensor (AWiFS)

Type	Source	Date	Cell Size/ Resolution	Source Data
Threat				
Remoteness from Roads within 1 mile (1609 meters) - NAVTEQ[2]	NAVTEQ's NAVSTREET Street Data	2007	5 meter	NAVTEQ, 425 W. Randolph St., Chicago, IL 60606
Road Density - NAVTEQ	NAVTEQ's NAVSTREET Street Data	2007	5 meter	NAVTEQ, 425 W. Randolph St., Chicago, IL 60606
Proximity to Urban Area[2]	USDA, National Agricultural Statistics Service 2007 Illinois Cropland Data Layer (CDL)	2007	56 meter	Indian Remote Sensing RESOURCESAT-1 (IRS-P6) Advanced Wide Field Sensor (AWiFS)
Adjacent to Agriculture (wetlands only - buffer distance for forest and forested wetlands = 275ft, 550ft, 1100ft, all other land use categories = 162ft, 325ft, 650ft[2]	USDA, National Agricultural Statistics Service 2007 Illinois Cropland Data Layer	2007	56 meter	Indian Remote Sensing RESOURCESAT-1 (IRS-P6) Advanced Wide Field Sensor (AWiFS)

Table 2. List of GIS data layers used for analysis. [1]units = acres, [2]units = meters, [3]units = richness, [4] = index.

The individual parameters for each land cover type were reviewed and weighted by six INHS ecologists covering a broad range of disciplines. The scientist's indicated if the parameter was worth keeping, and suggested a weight to apply. The parameter remained if more than half of the scientists voted to keep it. Once a parameter was selected, the average of the suggested weight was calculated to determine a final weight. The parameter choices and weights are listed in Tables 3–5.

Forest Parameters	INHS Scientists Retain (yes)	INHS Scientist Retain (no)	Weight (average)
Ecological			
Total area of forest	4	2	3
Area of T & E species	6	0	3
Area of public land	4	2	2
Area of nature preserves	5	1	2
Area of forest soils	4	2	2
Area of interior forest	6	0	4
Stream length BSC Diversity	4	2	2
SGNC bird species	5	1	2
SGNC herp species	6	0	3
Spatial			
Proportion of interior gap area in hub	5	1	3

Forest Parameters	INHS Scientists Retain (yes)	INHS Scientist Retain (no)	Weight (average)
Patch shape	4	2	2
Proximity to other forest tracts (nearest neighbor)	6	0	3
Threats			
Remoteness from roads	4	2	2
Road density	6	0	3
Proximity to urban area	4	2	3

Table 3. Forest parameters and weights used in the analysis.

Grassland Parameters	INHS Scientists Retain (yes)	INHS Scientist Retain (no)	Weight (average)
Ecological			
Total area of grassland	5	1	4
Area of T & E species	6	0	3
Area of public land	4	2	2
Area of nature preserves	4	2	2
Area of prairie soils	5	1	2
Area of railroad prairie remnant	6	0	3
Stream length BSC Diversity	6	0	3
SGNC bird species	6	0	4
SGNC herp species	5	1	3
Spatial			
Proportion of interior gap area in hub	5	1	3
Patch shape	5	1	3
Proximity to other forest tracts (nearest neighbor)	4	2	2
Threats			
Remoteness from roads	4	2	2
Road density	6	0	2
Proximity to urban area	4	2	2

Table 4. Grassland parameters and weights used in the analysis.

Wetland Parameters	INHS Scientists Retain (yes)	INHS Scientist Retain (no)	Weight (average)
Ecological			
Total area of wetland	6	0	4
Area of T & E species	5	1	2
Area of public land	4	2	2
Length of headwater streams within wetland	2	4	1
Area of flood zone	5	1	2
Area of hydric soils	5	1	3
Stream Length BSC Diversity	5	1	3
SGNC bird species	6	0	3
SGNC herp species	6	0	3
Spatial			
Proportion of interior gap area in hub	5	1	3
Patch shape	4	2	2
Proximity to other forest tracts (nearest neighbor)	5	1	2
Threats			
Remoteness from roads	5	1	3
Road density	6	0	3
Proximity to urban area	4	2	3
Adjacent to agriculture	4	2	2

Table 5. Wetland parameters and weights used in the analysis.

Parameters overlaid with the land cover are Threatened and Endangered Species, Public lands, Nature Preserves, Railroad prairie remnants (grassland only), Soils, Interior forest (forest only), Flood Zones (wetland only), Proximity to Urban Areas, and Adjacency to Agriculture (wetland only), Length of BSC Streams, Number of Stream Sources and Junctions (wetland only), SGNC Birds and Herps (Reptiles and Amphibians) – see Appendix I for a complete species list, Remoteness from Roads, and Road density. The Vector-based Landscape Analysis Tools Extension for ArcGIS software (V-LATE, 2005) was used to calculate patch shape and distance to the same land cover type - nearest neighbor. Detailed steps on the analyses for all parameters can be viewed in Appendix II. Pearson's Correlation Coefficient, which measures the degree of association between two variables, was calculated for all parameters.

The final, weighted parameters were combined (ecological + spatial – threats) for each of the land cover categories (Forest, Grassland, and Wetland) to derive a final rank. To avoid double or triple counting, only the first instance of the Proximity to Urban Areas and Adjacency to Agriculture were used in the final tally. The results were divided into three groups (High, Medium and Low) using the Natural Breaks function in ArcGIS.

Finally, all the areas of ranked Forest, Grassland, and Wetland land cover categories were combined to create a mosaic of the 3 land cover types. The original land cover data was examined to identify any neighboring Forest, Grassland, or Wetland areas that did not meet the initial size restraints. If these areas touched the mosaics, they were added. For example, a 150 acre forest and 50 acre grassland were combined in the mosaic and a 10 acre forest that neighbors 50 acre grassland is added to the mosaic. This gives a more complete picture of the surrounding landscape and includes areas animals may use if they can 'cross' the grassland.

5 Results and Discussion

The Forest, Grassland, and Wetland tracts were ranked within their land cover categories to give a sense of how each area compared to another. Each parameter was assigned an importance weight based on the advice of INHS scientists and the literature (Tables 3-5). This was also necessary as there were slight differences in parameter types used for each land cover type. The individual, weighted parameters for each area were then added together (for ecological and spatial parameters) or subtracted (for threat parameters). Details on all steps of the analyses are in Appendix II. Maps of the results of these individual calculations are shown in Appendix III. Figures 6-9 shows the final 3 rankings for each of the land cover types.

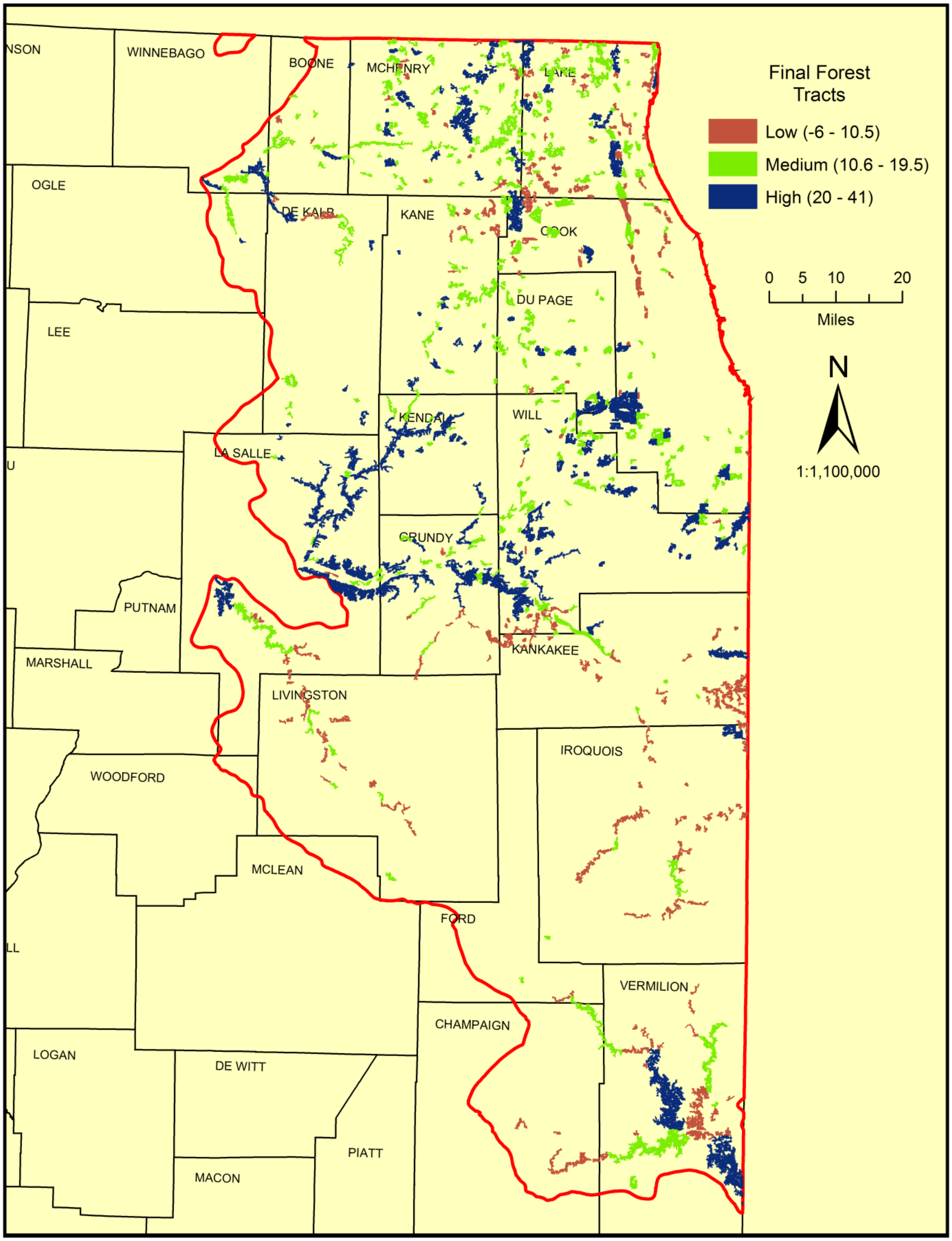


Figure 6. Final Forest rankings

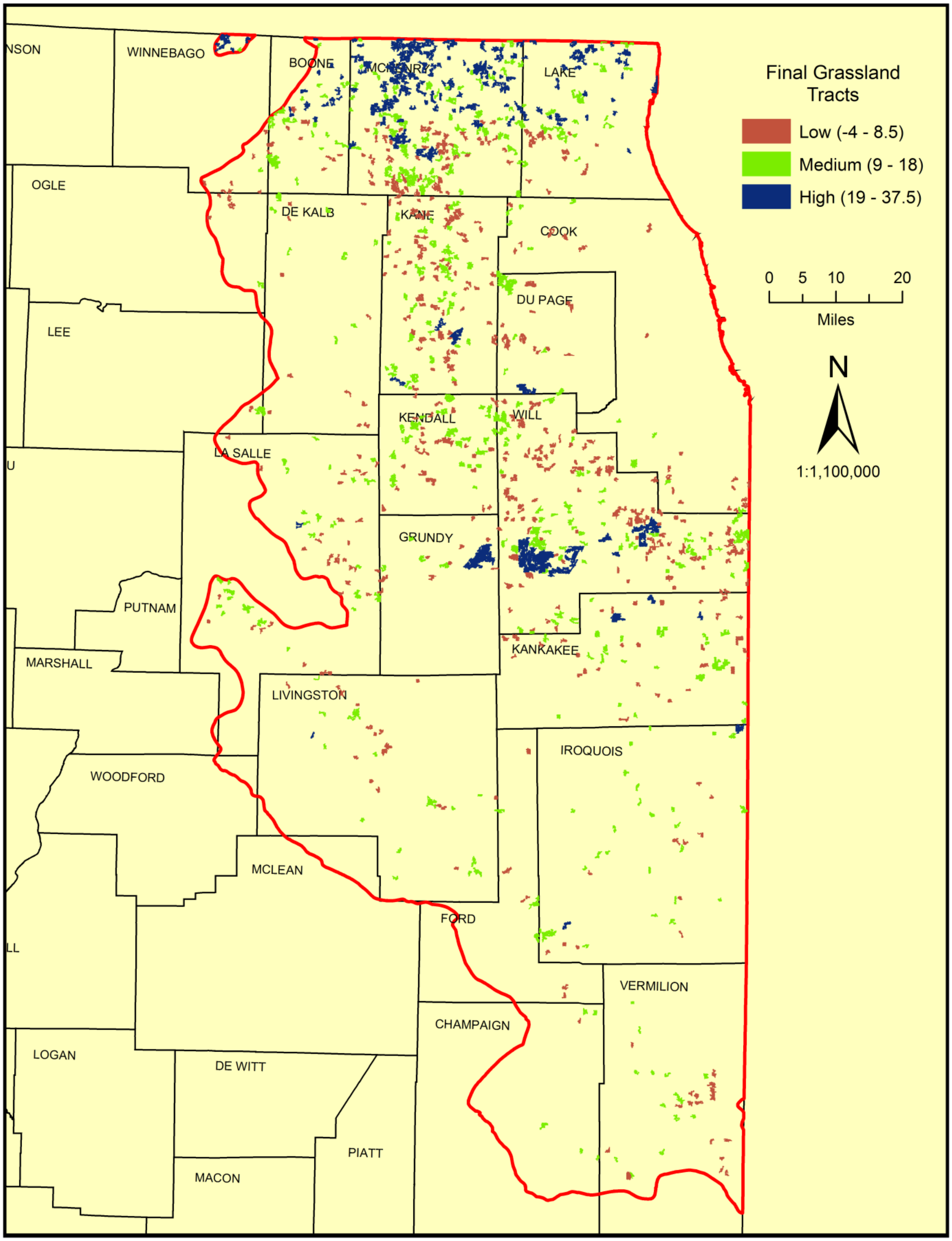


Figure 7. Final Grassland rankings.

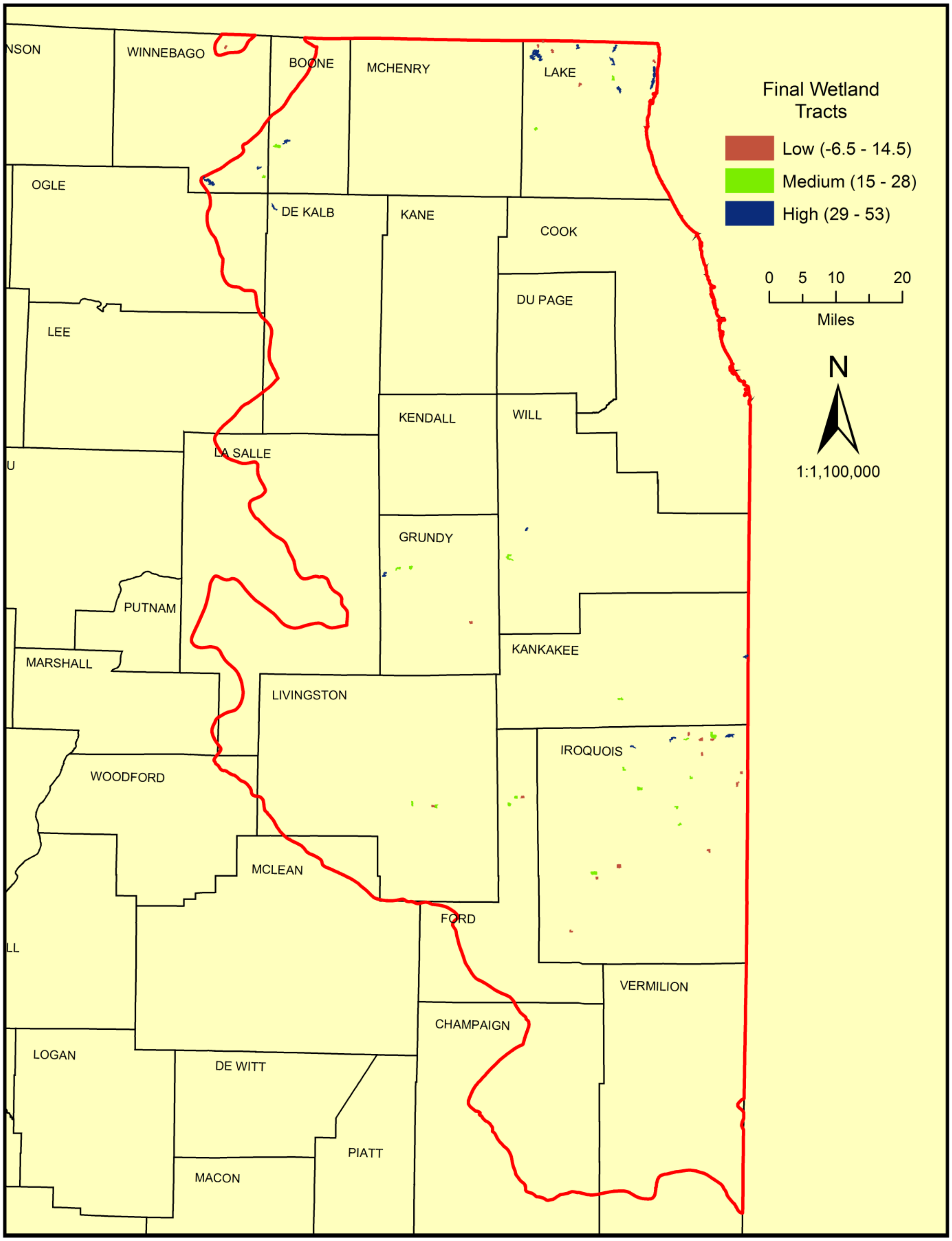


Figure 8. Final Wetland rankings.

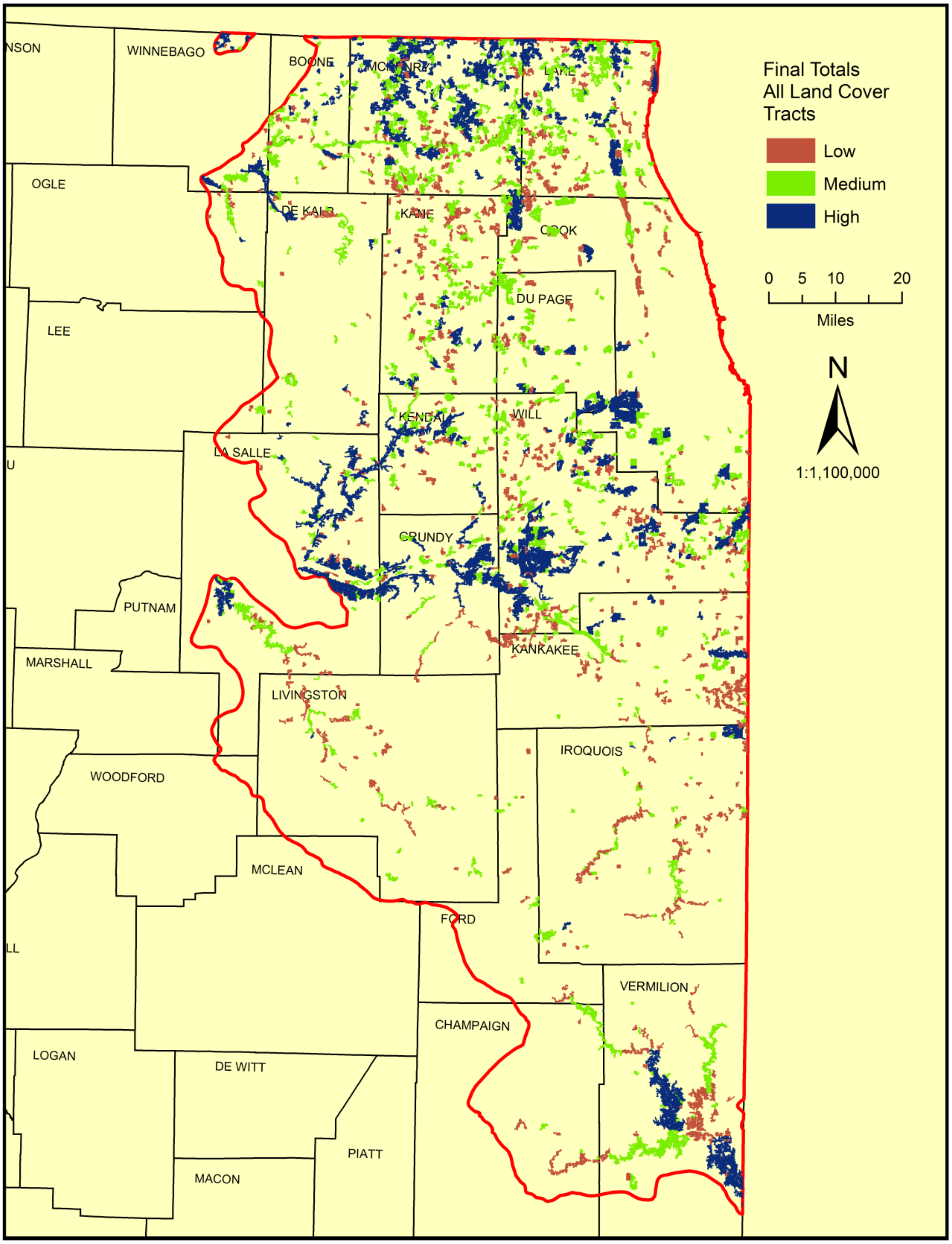


Figure 9. All Land Cover final rankings.

Pearson's Correlation Coefficient analysis was calculated for the parameters in the Forest, Grassland, and Wetlands categories to test for parameters looking at the same thing (strong correlation). Several highly correlated parameters were dropped after the Pearson test was performed. The results of this analysis and the parameters retained are listed in Tables 6-8. Correlation coefficient values greater than 0.8 (positively correlated), or less than –0.8 (inversely correlated) were considered strong correlation and are indicated in gray in the tables. Less than 20% of the parameters were highly correlated (> 80%). A few of the highly correlated parameters were retained and are explained in more detail below.

For Forest, total area and proportion of interior gap were strongly correlated. This can be explained by the fact that the larger the area, the greater the likelihood of interior gaps, so both were retained. Remoteness from Roads (1 mile) and Road Density and Proximity to Urban (275 feet) were also correlated. This is to be expected, as the number of roads increases with urban density, so all three were retained. The correlation between Road Density and Presence of Forest Soil is hard to explain and appears to be an anomaly, so both were retained.

Wetland parameters were strongly correlated for the presence of Threatened and Endangered Species and Public land. Since most of the known locations for Threatened and Endangered Species are on public land, a strong correlation is justified and both were retained. As expected, there was a strong correlation between the Presence of Hydric Soil and Flood Zones. The Flood Zones are found primarily along streams in Illinois, and can remain underwater for long periods of time. The wetland tracts, like grasslands, show a strong correlation for SGNC Birds and Herps. The acreage of Grassland and Wetlands in Illinois are small, much smaller than that for Forests. It is to be expected that the "Species in Greatest Need of Conservation (SGNC)" are found in these tracts. The SGNC Birds and Herps were also strongly correlated to the presence of Hydric Soils. The increased peril of Wetlands in Illinois reflects the strong correlation between these parameters. Many of the SGNC Herps require water for some part of their lifecycle, so the habitat requirements for these species would include water or wetlands. We decided to retain both SGNC Birds and Herps.

Forests	Total Area	T & E Species	Public Land	Nature Preserve	Presence of Forest Soil	Interior Forest	Stream Length BSC Diversity	SGNC Birds	SGNC Herps	Proportion Interior Gap	Patch Shape	Nearest Neighbor	Remoteness From Roads 1 mile	Road Density	Proximity to Urban Area 275 ft	Proximity to Urban Area 550 ft	Proximity to Urban Area 1100 ft
Total Area	1.00																
T & E Species	0.24	1.00															
Public Land	0.29	0.67	1.00														
Nature Preserve	0.26	0.57	0.56	1.00													
Presence of Forest Soil	0.30	0.57	0.60	0.39	1.00												
Interior Forest	0.63	0.29	0.38	0.26	0.31	1.00											
Stream Length BSC Diversity	0.22	0.33	0.34	0.23	0.53	0.19	1.00										
SGNC Birds	0.04	0.44	0.49	0.27	0.65	0.14	0.28	1.00									
SGNC Herps	0.04	0.41	0.48	0.26	0.63	0.14	0.30	0.95	1.00								
Proportion Interior Gap	0.87	0.21	0.23	0.22	0.22	0.54	0.17	0.01	0.01	1.00							
Patch Shape	0.58		0.19	0.20	0.23	0.30	0.22	0.02	0.02	0.60	1.00						
Nearest Neighbor	-0.12	-0.06	-0.05	-0.04	-0.07	-0.15	-0.07	-0.04	-0.03	-0.13	-0.21	1.00					
Remoteness From Roads 1 mile	0.20	0.62	0.68	0.40	0.77	0.27	0.48	0.73	0.72	0.14	0.16	-0.06	1.00				
Road Density	0.30	0.65	0.65	0.45	0.83	0.33	0.51	0.65	0.63	0.24	0.25	-0.07	0.86	1.00			
Proximity to Urban 275 ft	0.16	0.54	0.64	0.39	0.58	0.27	0.29	0.59	0.58	0.08	0.08	-0.04	0.82	0.66	1.00		
Proximity to Urban 550 ft	-0.02	0.01	0.04	-0.02	0.08	-0.02	0.03	0.14	0.14	-0.01	0.00	-0.03	0.07	0.08	-0.04	1.00	
Proximity to Urban 1100 feet	0.02	0.08	0.04	-0.01	0.11	0.02	0.05	0.11	0.10	0.03	0.05	-0.02	0.07	0.08	-0.04	-0.01	1.00

Table 6. Pearson Correlation Coefficient analysis for Forested tracts. The shaded cells indicate those with significant positive correlations.

Grasslands	Total Area	T & E Species	Public Land	Nature Preserve	Presence of Prairie Soil	Railroad Remnant	Stream Length BSC Diversity	SGNC Birds	SGNC Herps	Proportion Interior Gap	Patch Shape	Nearest Neighbor	Remote-ness from Roads 1 mile	Road Density	Proximity to Urban area 162 ft	Proximity to Urban area 325 ft	Proximity to Urban area 650 ft
Total Area	1.00																
T & E Species	0.35	1.00															
Public Land	0.31	0.63	1.00														
Nature Preserve	0.24	0.39	0.41	1.00													
Presence Prairie Soil	0.35	0.31	0.28	0.13	1.00												
Railroad Remnant	0.12	0.10	0.11	0.09	0.12	1.00											
Stream Length BSC Diversity	0.20	0.15	0.08	0.06	0.31	0.13	1.00										
SGNC Birds	0.07	0.17	0.08	0.07	0.17	-0.02	0.01	1.00									
SGNC Herps	0.05	0.17	0.08	0.07	0.17	-0.02	0.00	0.97	1.00								
Proportion Interior Gap	0.62	0.34	0.28	0.21	0.30	0.05	0.15	0.13	0.11	1.00							
Patch Shape	0.40	0.27	0.20	0.12	0.17	0.01	0.10	0.14	0.14	0.57	1.00						
Nearest Neighbor	-0.11	-0.05	-0.04	-0.01	-0.07	0.01	-0.03	-0.13	-0.14	-0.12	-0.16	1.00					
Remoteness from Roads 1 mile	0.02	0.05	0.04	0.02	0.22	0.12	0.08	0.05	0.05	0.02	0.04	0.01	1.00				
Road Density	0.34	0.31	0.29	0.13	0.66	0.13	0.27	0.26	0.26	0.35	0.27	-0.08	0.22	1.00			
Proximity to Urban 162 feet	0.06	0.23	0.29	0.06	0.29	0.00	-0.01	0.16	0.16	0.14	0.20	0.00	0.19	0.30	1.00		
Proximity to Urban 325 feet	-0.03	0.01	0.00	0.00	0.03	-0.01	-0.02	0.07	0.06	0.00	0.00	-0.03	0.06	0.09	-0.05	1.00	
Proximity to Urban 650 feet	-0.02	0.04	0.06	0.07	0.05	-0.01	0.01	0.07	0.06	-0.01	0.03	-0.01	0.14	0.04	-0.04	-0.01	1.00

Table 7. Pearson Correlation Coefficient analysis for Grassland tracts. The shaded cells indicate those with significant positive correlations.

Wetlands	Total Area	T & E Species	Public Land	Head water Stream	Flood zone	Presence of Hydric Soil	Stream Length BSC Diversity	SGNC Birds	SGNC Herps	Prop. Interior Gap	Patch Shape	Nearest Neighbor	Remote-ness to Roads	Road Density	Prox. to Urban Area 162ft	Prox. to Urban Area 325ft	Prox. to Urban Area 650ft	Adj. to Agric. Area 162ft	Adj. to Agric. Area 325ft	Adj. to Agric. Area 650ft
Total Area	1.00																			
T & E Species	-0.04	1.00																		
Public Land	-0.04	0.81	1.00																	
Headwater Stream	-0.04	0.47	0.40	1.00																
Flood zone	-0.06	0.64	0.69	0.36	1.00															
Presence of Hydric Soil	-0.07	0.67	0.65	0.45	0.86	1.00														
Stream Length BSC Diversity	-0.03	0.23	0.32	0.23	0.44	0.40	1.00													
SGNC Birds	-0.07	0.49	0.50	0.46	0.74	0.85	0.34	1.00												
SGNC Herps	-0.07	0.46	0.48	0.41	0.73	0.86	0.36	0.96	1.00											
Proportion Interior Gap	0.73	-0.03	0.00	-0.09	-0.06	-0.08	-0.04	-0.10	-0.09	1.00										
Patch Shape	0.50	0.00	0.03	-0.07	-0.05	-0.09	0.06	-0.13	-0.13	0.57	1.00									
Nearest Neighbor	-0.13	0.14	0.11	0.22	0.27	0.35	0.14	0.36	0.38	-0.16	-0.19	1.00								
Remoteness Roads	-0.03	-0.04	-0.04	-0.04	-0.06	-0.07	-0.03	-0.07	-0.07	0.02	-0.05	-0.08	1.00							
Road Density	-0.04	0.24	0.30	0.27	0.33	0.48	0.03	0.51	0.51	-0.04	-0.06	0.21	-0.04	1.00						
Proximity to Urban 162 ft	-0.03	0.31	0.19	0.22	0.20	0.31	0.12	0.22	0.23	-0.10	-0.05	0.15	-0.03	0.10	1.00					
Proximity to Urban 325 ft	-0.02	0.58	0.57	0.19	0.53	0.43	0.38	0.25	0.25	0.03	0.05	0.04	-0.02	0.10	-0.01	1.00				
Proximity to Urban 650 ft	0.32	-0.11	-0.12	-0.07	-0.17	-0.20	-0.08	-0.20	-0.22	0.33	0.30	-0.53	0.03	-0.11	-0.11	-0.08	1.00			
Adjacent Agric. 162feet	0.47	-0.09	-0.10	-0.08	-0.06	-0.04	-0.11	-0.03	-0.02	0.37	0.37	-0.10	0.12	0.00	-0.10	-0.03	0.16	1.00		
Adjacent Agric. 325feet	-0.04	0.04	0.06	-0.03	0.00	0.01	0.05	-0.01	0.01	-0.05	-0.10	0.02	-0.04	0.04	0.03	-0.01	-0.02	-0.28	1.00	
Adjacent Agric. 650feet	-0.05	0.03	0.07	0.01	0.05	0.06	0.13	0.01	0.05	-0.05	-0.08	0.04	-0.05	0.03	0.11	-0.02	-0.05	-0.34	0.80	1.00

Table 8. Pearson Correlation Coefficient analysis for Wetland tracts. The shaded cells indicate those with significant positive correlations.

A total of 1,780 land cover tracts were analyzed in the northeastern Illinois study area (Table 9). This number includes 768 Forest, 955 Grassland, and 57 Wetland tracts. The parameters listed in Tables 6-8 were used to rank each tract, following the methods described above.

Land Cover	Acres	Number of Tracts	Percent (by area)	Number with Rank Low	Number with Rank Medium	Number with Rank High
Forest	342,425	768	62.5%	256	348	164
Grassland	199,869	955	36.5%	455	365	135
Wetland	5,956	57	1.0%	17	21	19
Total	548,249	1,780	100%	728	734	318

Table 9. Land Cover categories in ranked tracts.

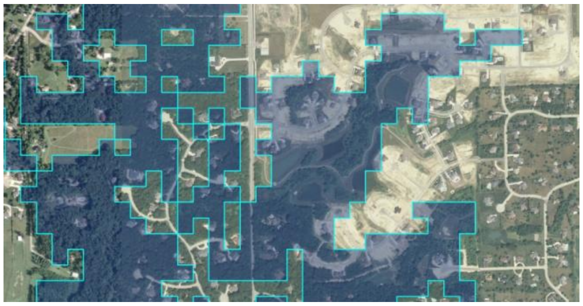
Quality Assurance/Quality Control (QA/QC)

The land tracts were derived from the 2007 NASS-CDL data. There are some complications associated with the analysis of landscape scale data obtained through remote sensing. The most apparent issues are of spatial compatibility and data quality. The most critical are the time of the year when the imagery was collected and relative positional accuracy between datasets (the satellite imagery and the other GIS layers used in the analysis). In addition, without field-based observations of native vegetation condition the relative natural quality of tracts is not distinguishable using satellite remote sensing data.

All the ranked forests, grasslands, and wetlands were compared to the 2007 NAIP aerial photos to identify any discrepancies. The NASSCDL data is classified into the various land cover types based on the reflectance of sunlight 'bouncing' off the vegetation and back to the satellite camera. Since this data is collected in a matrix of 56 meter cells or pixels, only the land cover type that makes up the majority of the cell is identified. The source satellite imagery used to create the NASS-CDL data is also collected during the growing season of April 1 through September 30 (leaf on). This can result in 'missed' classification of small inholdings of land cover types (less than 56 meters), or missed structures under tree canopies. To assess this issue, the final tracts were checked for accuracy by comparing the land cover types classified in the (56 meter) NASS-CDL data to the (1 meter) 2007 NAIP aerial photography. The NAIP 2007 data was chosen because it was collected the same year as the NASS satellite imagery, and from the growing season (leaf-on).

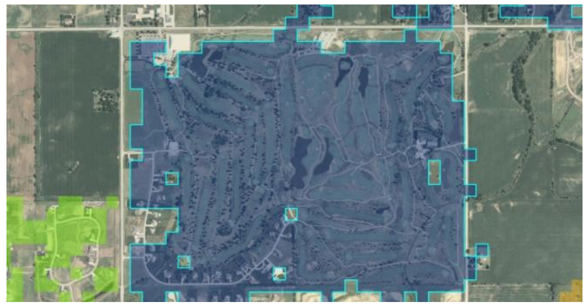
Ninety-six Forest tracts totaling 32,329 acres and 491 Grassland tracts totaling 98,374 acres were identified as having classification issues or were "culturally exploited." None of the Wetland tracts were affected. The term "culturally exploited" in the context of this study, implies a limitation within a given tract that may prevent restoration efforts. Land cover misclassification, presence of residential area(s), presence of manicured areas (i.e. golf courses), and agricultural activity were the most common examples of cultural exploitation. Some examples of the classification problems are illustrated in Figure 10. Tracts that exhibited these types of discrepancies in 50% or more of their total area were determined to be culturally exploited. Tracts that exhibited discrepancies in 50% or less of their total area were determined not to be culturally exploited. While this approach to quality assurance and quality control (QA/QC) may quickly preclude a certain number of tracts from restoration, driving by the site would still be necessary in order ultimately determine if a tract is suitable for restoration. Application of the Restorability Index to each tract eligible for restoration would allow comparison across tracts. The field-based site assessment and calculation of the Restorability Index for each qualifying tract would be a significant undertaking and did not fall within the scope of this project. This project was, however, designed to provide Conservation Districts and Forest Preserve Districts the tools to undertake such assessments on a county by county basis.

After the analysis, all three land cover types were combined to create a mosaic to identify Landscapes of Ecological Importance (LEIs) (see Figure 11). This was done, based on the recommendation of INHS scientists, and methods of other studies (Weber, 2006). There are a total of 919 LEIs in the study area (Table 10). Appendix IV has the complete list of LEIs by ID, along with the rank. This number includes 672 forest tracts, 464 grassland tracts, and 57 wetland tracts. Since the LEIs are a mosaic of the 3 land cover types, most LEIs have more than one land cover. The total acres for each land cover type represent just the part of the LEIs with no cultural exploitation.



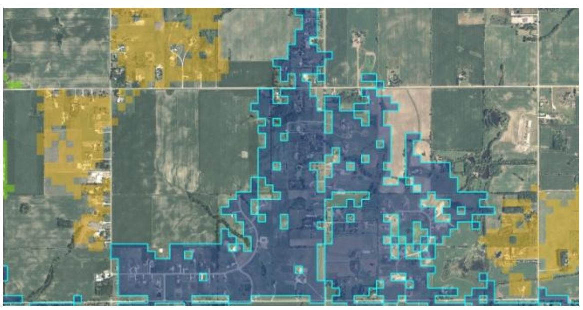
Houses located in Forest tract.

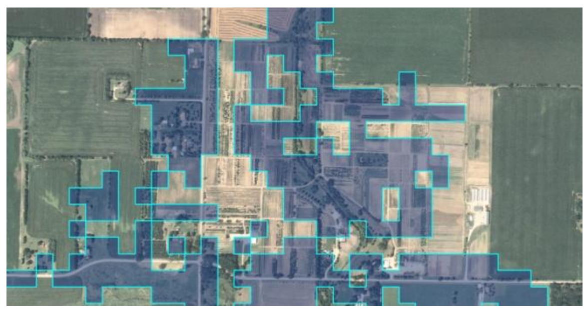
Unconnected houses in Forest tract.



Possible incorrectly classified Forests tract surrounded by Wetland tract.

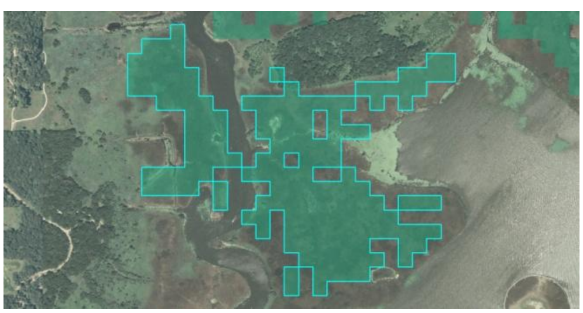
Golf course classified as grassland tract.





Houses located in Grassland tract.

Tree farm classified as Grassland tract.



Unclassified Wetland adjacent to Wetland tract.

Figure 10. Examples of classification problems with NASS-CDL data.

Land Cover	Total Acres	Number of LEI	Percent (by area)	Rank Low	Rank Medium	Rank High
Forest	310,095	672	74.3%	225	293	154
Grassland	101,495	464	24.3%	221	189	54
Wetland	5,956	57	1.4%	17	21	19
Total	417,547	919*	100%	463	503	277

Table 10. Land Cover for Landscapes of Ecological Importance (LEI) with no cultural exploitation. (* Some LEIs have more than one land cover type.)

The undeveloped (gray) land cover was added back into the LEIs (Figure 12). These gray areas were composed of different land cover types and fell below the initial size filters, but are adjacent or connected to the newly designated LEIs (Figure 12). Adding these areas back in gives a better sense of the true extent of the area of interest in a land conservation project, and accommodates species which exploit a variety of land covers for different parts of their life histories, for example species which breed in forest cover but may also forage in grasslands or wetlands. The QA/QC process was not applied to these additions to LEIs.

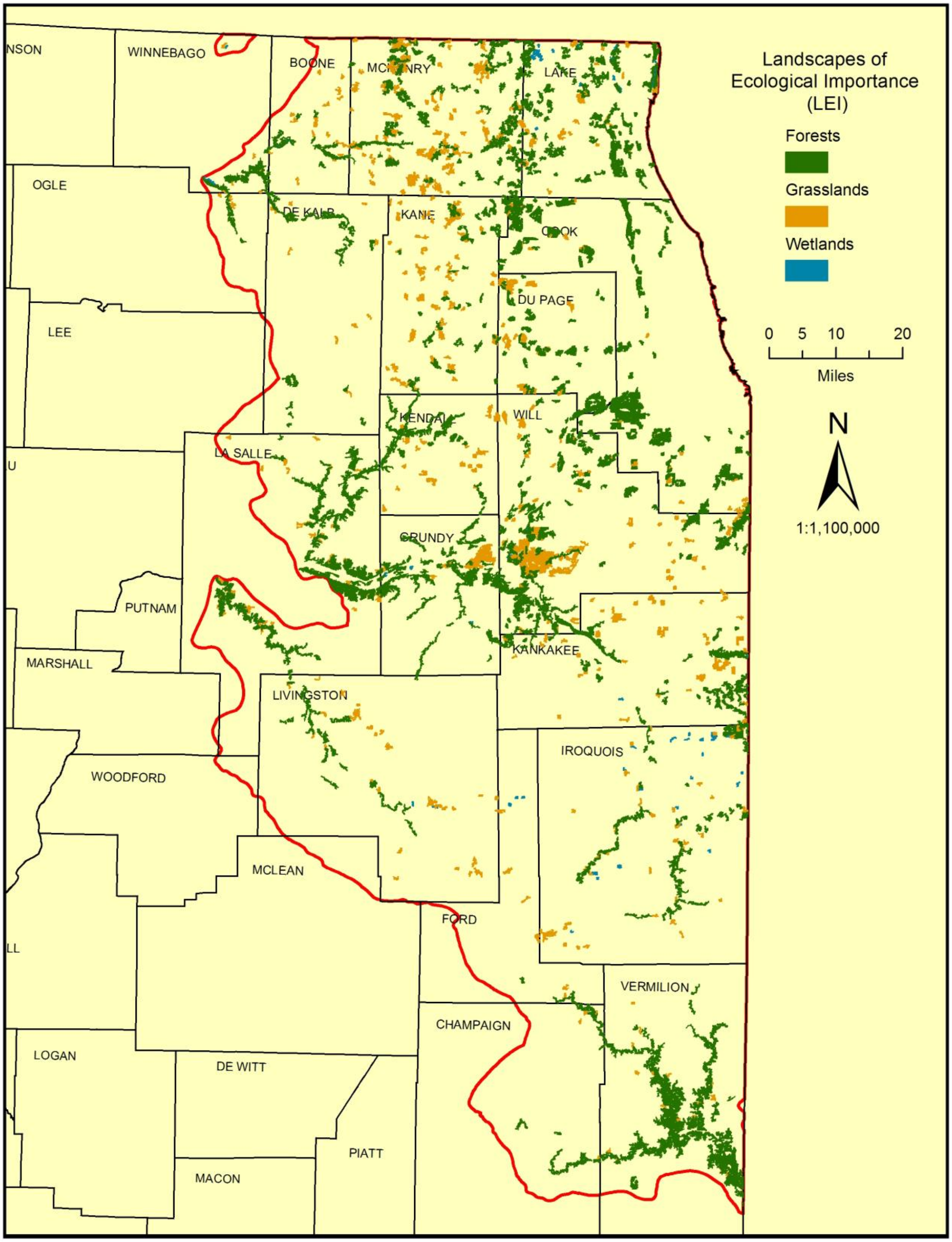


Figure 11. Forest, Grassland, and Wetland LEIs that are not culturally exploited.

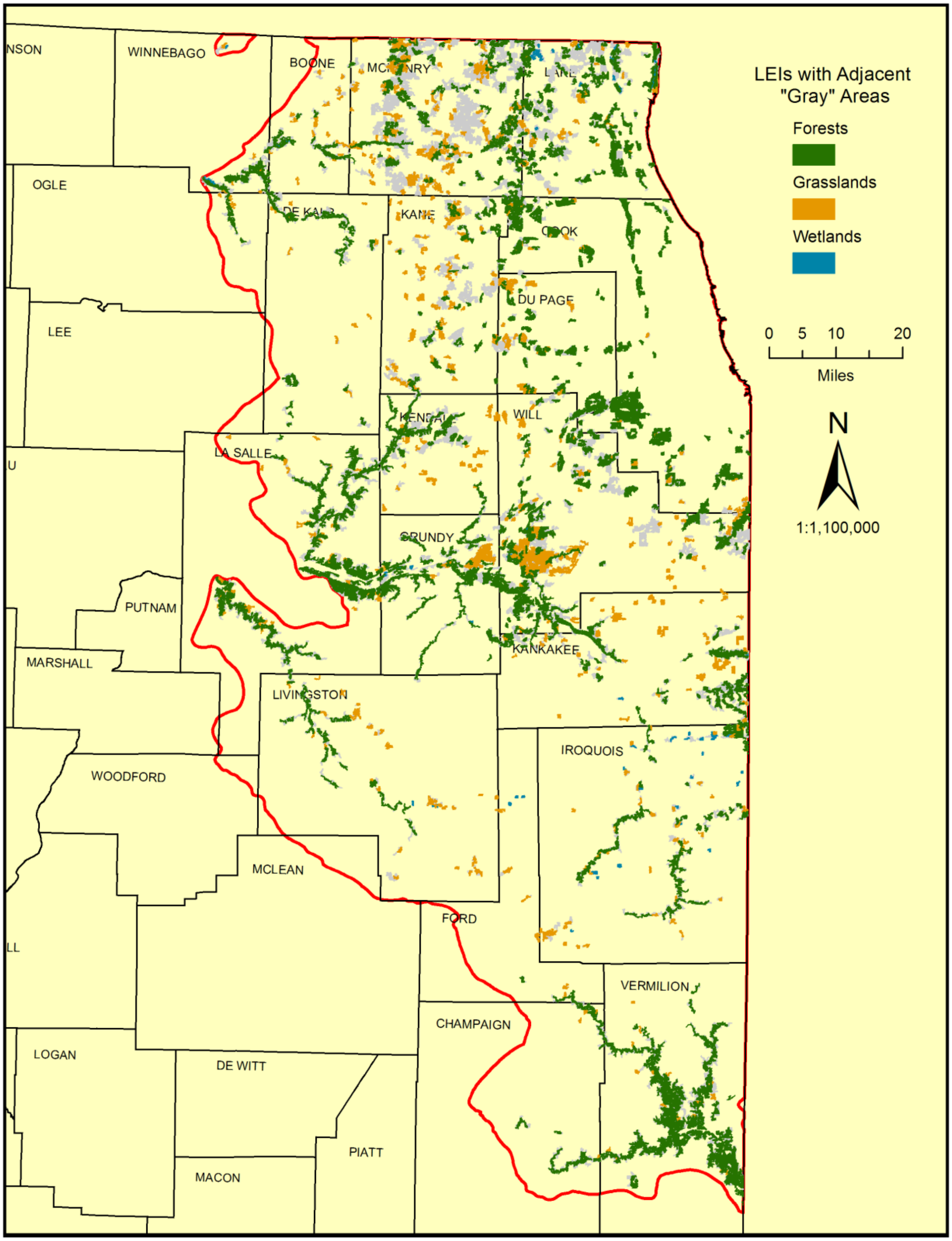


Figure 12. Forest, Grassland, and Wetland LEIs that are not culturally exploited. Adjacent "gray" areas at least 50 acres in size are shown in gray.

Finally, we looked at the relationship between LEIs and natural areas from the Illinois Natural Areas Inventory - INAI (Table 11). This was done to see which areas encompassed or were adjacent to areas already recognized as supporting significant natural resources. The comparison was done using the INAIs from the 1970's assessment, since natural areas identified in the INAI Update will not officially be added to the INAI until they are reviewed and approved for addition to the INAI by the Illinois Department of Natural Resources' Natural Areas Evaluation Committee per administrative rule. Appendix V has the complete list of INAI areas within the LEIs. Figure 13 identifies the number of natural areas by INAI category that is in spatial proximity to the LEIs. The close association of natural areas with LEIs suggests high potential for constructing connected systems of conservation lands that might be resilient to region wide threats like climate change and invasive species.

	Number of sites	Acreage
LEIs with INAI Sites	919	726,217
INAI with Category I	107	32,445
INAI with Category II	189	50,447
INAI with Category III	135	38,515
INAI with Category IV	37	3,000
INAI with Category VI	60	2,926

Table 11. Landscapes of Ecological Importance (LEI) areas encompassing INAI sites. NOTE: If a natural area is recognized in multiple categories, the acreage is counted again for each new category. In other words, summing the acreage of natural areas associated with LEIs for all categories will result in an overestimation of total acres of natural area associated with LEIs.

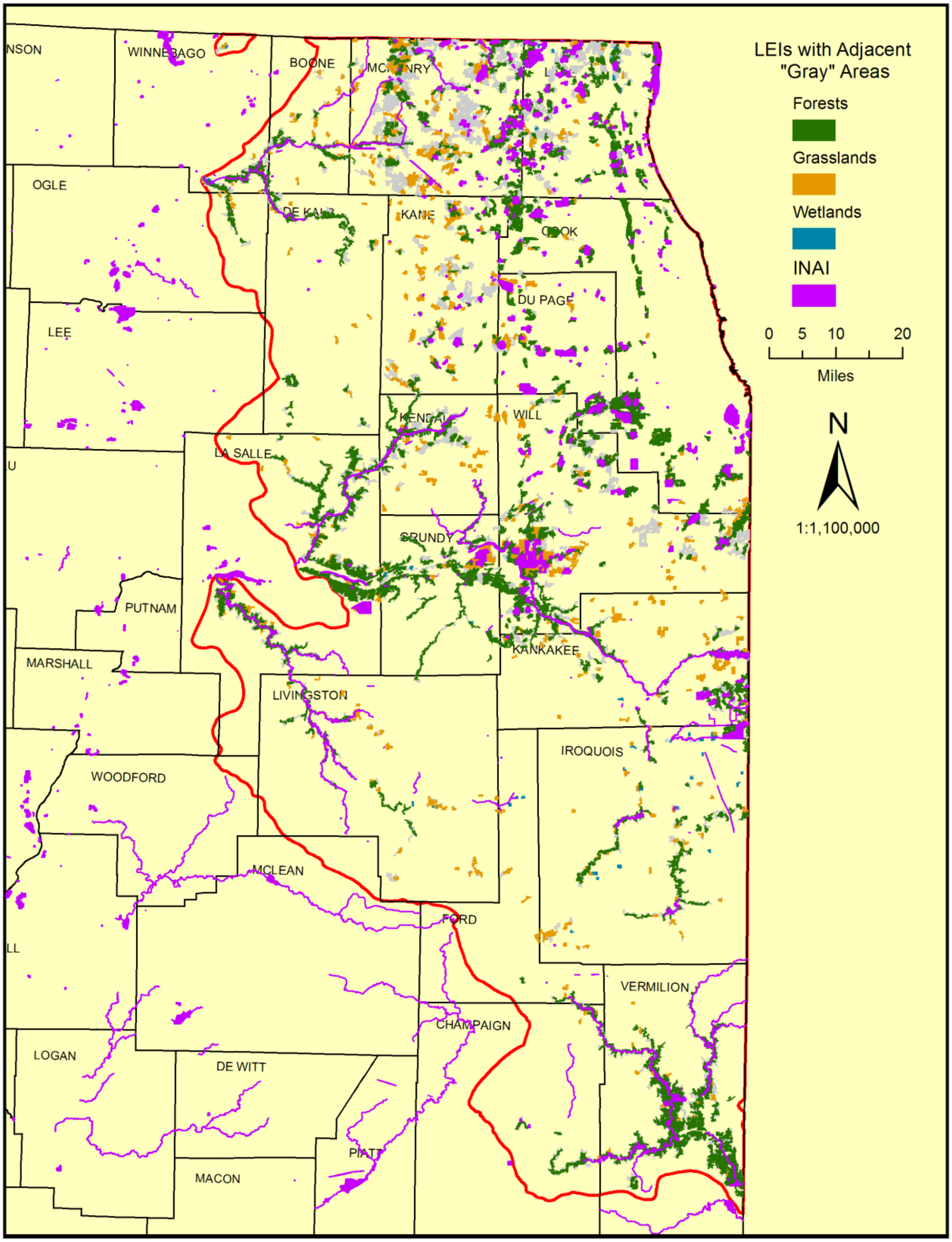


Table 13. LEIs with adjacent 'gray' areas and INAI sites.

6 Summary

The goal of this project was to test the methods of using landscape scale characteristics to identify areas of potential ecological importance using statewide GIS data. The NASS-CDL land cover data is released annually, so this process can be repeated yearly, allowing annual assessments of conservation outcomes. There are also many other sources of satellite imagery, some with higher resolution. We used only statewide digital data layers, so that this GIS analysis could be extended statewide. However, this study can easily be repeated statewide or regionally if additional data layers become available. If better defined or more precise boundaries are needed for LEIs, higher resolution imagery, where available, could be employed to re-map them.

A future step would be to examine the most efficient avenues of connectivity between LEIs, designing buffer areas around the LEIs, and assessing intrinsic flora and fauna potential within them (i.e., conduct natural community grading and assessment of restorability). An assessment of the connectivity between INAI natural areas, LEIs, and all other conservation lands is needed to cast a vision of what the "Connected System of Conservation Lands" (Connected System) that the Vital Lands Project has recently called for will actually look like.

Another important next step would be to promote the formal recognition of LEIs by the Illinois Nature Preserves Commission as properties that will qualify or at least have high potential for qualifying for designation as Illinois Land and Water Reserves. The statewide identification of LEIs and assessment of their natural quality and restorability, at least for a representative number of them statewide, may be necessary to convince the Nature Preserve Commission that such an acknowledgement is justified.

Finally, designating the elements of Connected Systems and further identifying the alternatives for potential connections between those elements is also an important step in designing a scientifically defensible Green Infrastructure Plan. However, the LEI's were identified solely on their capacity for supporting important components of Illinois' native flora and fauna. The Connected System will not only help protect Illinois' native flora and fauna against region-wide threats like climate change, but it will also provide many ecosystem services, like stormwater retention, groundwater recharge, recreational opportunities, clean air and water. While lands identified for inclusion in the Connected System should have the highest priority for delivering ecosystem services, a comprehensive analysis of land protection needs should be conducted relative to each service to assess whether addition lands should be included in a Green Infrastructure plan beyond those identified as important to achieving the vision for a Connected System of Conservation Lands.

Finally, this project sets the stage for a new generation of conservation work, the era of conservation connectivity. The LEIs will provide the matrix in which the gems that are Illinois' natural areas will thrive.

7 References

Cordle, L., D. L. Szafoni, D. M. Greer. 2002. Land Cover of Illinois in the Early 1800s. Vector Digital Data. Illinois Natural History Survey, Champaign, Illinois.

ESRI. Copyright 2009. ArcGIS 9.3.1. Environmental Systems Resource Institute, Redlands, California.

Faber-Langendoen, D. 2007. Overview of NatureServe Methodology for Ecological Integrity Assessment. NatureServe, Arlington, VA.

Higgins, J, R. Unnasch, and C. Supples. 2007. Ecoregional status measures version 1.0: Framework and technical guidance to estimate effective conservation. The Nature Conservancy, Arlington, VA.

Illinois Department of Natural Resources. 1996. Illinois Land Cover, An Atlas. Critical Trends Assessment Project – Phase 2. Illinois Department of Natural Resources, Springfield, Illinois.

Land and Water Reserves. 1994. 17 Illinois Administrative Code, Chapter V: Nature Preserves Commission, part 4010, Register of land and Water Reserves, Subpart A: General Provisions.

McGrath, D. 2005. More evidence on the spatial scale of cities. Journal of Urban Economics 58(2005): 1-10.

NAVTEQ. ©2007. NAVSTREET Street Data. Vector Digital Data. NAVTEQ Global Corporate Headquarters/ North America, 425 West Randolph Street, Chicago, Illinois.

Parkes, D. and P. Lyon. 2006. Towards a national approach to vegetation condition assessment that meet government investors' needs" A policy perspective. Ecological Management and Restoration 7(S1): S3-S5.

Reinke, K and S. Jones. 2006. Integrating vegetation field surveys with remotely sensed data. Ecological Management and Restoration 7(S1): S18-S23.

Robertson, S. K., Thompson III, F. R, Donovan, T. M, Whitehead, D. R., and Faaboru, J. 1995. Regional forest fragmentation and the nesting success of migratory birds. Science 267:1987-1990.

Saunder, Denis A., Richard J. Hobbs, and Chris R. Margules. 1991. Biological Consequences of Ecosystem Fragmentation: A Review. Conservation Biology 5(1): 18-32.

Sierra Club Factsheet. Population Growth and Suburban Sprawl: A Complex Relationship. www.sierraclub.org/sprawl

Suloway, L., M. Joselyn, and P. W. Brown. 1996. Critical Trends Assessment Project Phase II – Inventory of Resource Rich Areas in Illinois. An Evaluation of Ecological Resources. Illinois Department of Natural Resources, Springfield, Illinois.

Szafoni, D. 2006. Location and Condition of Terrestrial and Wetland Habitats. In, Development and Expansion of the Natural Resource Data and Information Systems in Support of the Illinois Comprehensive Wildlife Conservation Plan (Project T-02-P-001-Final). November, 2006. Illinois Natural History Survey Technical Report 06/05.

Tierney, G. L, D. Faber-Langendoen, B. R. Mitchell, W. G. Shriver and J. P. Gibbs. 2009. Monitoring and evaluating the ecological integrity of forest ecosystems. Front Ecol. Environ 7(6): 308-316.

U.S. Census Bureau. 2000. Your Gateway to Census 2000. http://www.census.gov/main/www/cen2000.html

USDA, Natural Resources Conservation Service. 2002. Illinois 12-digit Hydrologic Units (1:24,000). Vector digital data. USDA, Fort Worth, Texas.

USDA, National Agricultural Statistics Service, 2007. Illinois Cropland Data Layer *Edition:* 2007 Edition. Raster digital data. USDA, NASS Marketing and Information Services Office, Washington, D.C.

Vance, Linda K. 2009. Assessing Wetland Condition with GIS: A Landscape Integrity Model for Montana. A Report to the Montana Department of Environmental Quality and the Environmental Protection Agency. Montana Natural Heritage Program, Helena, MT. 23 pp. plus appendices.

V-LATE. 2005. Vector-based Landscape Analysis Tools Extension 1.1 for ArcGIS 9.x. Centre for Geoinformatics (Z_GIS) at Salzburg University, AUSTRIA. http://www.geo.sbg.ac.at/larg/

Weber, Ted, Anne Sloan, and John Wolf. 2006. Maryland's Green Infrastructure Assessment: Development of a comprehensive approach to land conservation. Landscape and Urban Planning 77(206): 94-110.

Weber, Theodore C., Peter J. Blank, and Anne Sloan. 2008. Field Validation of a Conservation Network on the Eastern Shore of Maryland, USA. Using Breeding Birds as Bio-indicators. Environmental Management, 41:538-550.

Wilcox, B. A. and D. D. Murphy. 1985. Conservation Strategy: the Effects of Fragmentation on Extension. The American Naturalist 125(6): 879-887.