

# A Three Year Assessment of a GIS Based Patch Analysis to Identify Priority Conservation Areas in Michigan



Prepared by:

Edward H. Schools, Brian J. Klatt, Bradford S. Slaughter, Michael R. Penskar, Joelle L. Gehring

Michigan Natural Features Inventory

P.O. Box 30444

Lansing, MI 48909-7944

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## Executive Summary

To insure sustainable natural resource use, land management decisions should be based upon a foundation of sound and comprehensive ecological information. Contemporary land managers, however, continue to face steep challenges in obtaining sufficient fiscal and staff resources to carry out their activities. These challenges highlight the need for scientifically sound information that will assist in deciding where to direct scarce programmatic resources. Increased knowledge and analyses about the critical natural features of the landscape, such as ecological communities that perform important ecosystem functions, endangered and threatened species, species of greatest conservation need, and rare ecological communities, will improve the State of Michigan's ability to make wise decisions regarding the conservation and management of areas identified as having high ecological value.

This study represents an initial assessment after three years of a planned 10 – 20 year effort to develop a GIS model and a corresponding field methodology for identifying and verifying high priority conservation areas. The goal of the effort was to improve the ability of the Michigan Department of Natural Resources (MDNR) to identify terrestrial and aquatic areas of high ecological value. To do so with respect to terrestrial areas (the focus of this report, with aquatic analyses to follow under separate cover), we developed a vegetation patch analysis and subsequently conducted field sampling throughout Newaygo County and its vicinity. Patches of vegetation were scored based on their area, core area, and proximity to similar vegetation types. Field sampling was employed to test the efficacy of the vegetation patch analysis as well as the effectiveness and applicability of metrics developed to assess the diversity and quality of a patch's flora (vascular plant species), natural community structure, and avian community assemblage. Field sampling was conducted in 2006, 2007, and 2008 in selected patch types, with detailed statistical analyses conducted for a single patch type, upland deciduous forest, to evaluate the efficacy of the vegetation patch model and the effectiveness and applicability of the floristic, ecological, and avian metrics and derived indices. All field sampling took place on public lands.

A total of 19 metrics were collected in the field or derived from field data. The analysis included eight metrics to assess ecological community structure, six metrics to assess floristic quality, and five metrics to assess avian community structure. Fifty-four upland deciduous sample cells had at least one set of metrics assessed and 39 sample cells had the complete suite of metrics assessed. Using the Fisher-Jenks natural breaks algorithm, test cells were assigned to a high, moderate, or low category based on the patch analysis score of the vegetation patch containing the cell. A discriminate function analysis was used to determine which of the metrics could be used to determine the membership of a test cell in the high, moderate, or low category. Two metrics, the presence of interior bird species and the presence of red maple (*Acer rubrum*) were determined to be predictors of membership in a high, moderate or low category. With presence of interior bird species being a positive indicator for high quality patches and the presence and abundance of red maple being an indicator of low quality patches. Further analysis of the red maple metric indicates that its usefulness as an indicator metric may have been compromised by proximity of upland forest test cells to wetlands.

While the patch model presented here appears to work well for predicting high quality upland deciduous forest habitat (based on the presence of interior bird species), it is not known whether the model will be as applicable to other community groups and is unlikely to work as well for small patch size communities. In addition, there is no evidence to indicate that the model is predicting high quality forest patches for other taxa or a wider suite of ecological functions. Thus, future efforts may be better focused on developing coarse grain approaches to *a priori* identification of high biodiversity areas, rather than on identifying community-specific areas. The coarse-grain effort should be ultimately followed by community-specific and species-specific modeling to address fine-grained issues of rare communities and species.

In general, future modeling and testing efforts should include the following aspects:

- Assuring grain appropriateness of metrics used to test models
- Increase the robustness of the models by incorporating factors other than patch measures (e.g. soils, topography, aspect, etc.)
- Produce specific models for the ecosystem function of interest instead of expecting one model to represent a wide range of functions
- Thorough consideration of metric selection and experimental design as part of the model development and testing regime

- Test and calibrate the metrics to the community type or model being tested
- Use a four-point rule instead of an eight point rule to define patch connectedness, or use hexagon shaped planning units, in the patch model
- Evaluation of correlation between metrics, along with removal of redundancy and selection of cost effective quantitative variables as metrics
- Include additional animal taxa as metrics
- Sample geographic areas rather than a single community type
- Include private lands in the sampling effort

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## INTRODUCTION

To insure sustainable natural resource use, resource management decisions should be based first and foremost on a foundation of sound scientific information. Additionally, as fiscal and staff resources always impose some degree of limitation on programmatic implementation, it is important that natural resource managers have available not only information that is scientifically sound, but also aids them in deciding where to direct scarce programmatic resources. Thus, information that is most useful in making natural resource management decisions should meet two criteria: 1) it is scientifically-based; and 2) it helps decision-makers determine where to direct programmatic resources for the greatest return for those resources.

Many types of data currently exist, such as land use, distribution and abundance of rare species, distribution of wetlands, etc., that can be integrated into analyses of Michigan's natural resources and can inform resource management decisions. The Michigan Department of Natural Resources (MDNR) has on-going management initiatives that have integrated these and other available data to formulate natural resource management strategies; these initiatives include: forest certification, development of a Wildlife Action Plan (Eagle 2005), and the biodiversity conservation planning process. An important component of these initiatives is the identification of areas of high ecological value or significance for conservation. Ideally, identification of these high ecological value areas should be based on information collected from systematic field inventories. However, such inventories have not been completed for most of the state due to funding constraints.

In lieu of having information from field surveys, Geographic Information System (GIS) based models have been developed to help identify potential areas of high ecological value or conservation significance. GIS based models using landscape metrics are often used as predictors of ecological processes (Wagner 2005). Reliable models can greatly aid in filling gaps in field-based data. However, it must be kept in mind that these are, in fact, computer models, and are based on limited information. As such, the models need to be systematically tested and verified before they can be generally applied with confidence.

Additionally, the models should be refined as more and more scientifically-based information from the field or in the form of remote sensing data become available. This iterative process provides information that meets the criteria of useful management information outlined above, i.e., that which is scientifically-based and which aids managers in directing the use of scarce programmatic resources. The process also provides progressively more reliable information on which to base natural resource management decisions and where fiscal and human-capital resources should be directed.

The goal of this project is to improve the MDNR's ability to identify areas of high ecological value in order to assist natural resource managers in developing the most efficient and effective plans for sustainable natural resource management. This can be achieved by developing an effective modeling approach for identifying areas of potential high conservation value on the landscape based on existing data sets, systematically surveying these areas to assess their ecological condition, and using this information to refine the models. Specific objectives of this project include: 1) beginning development of a GIS model that identifies areas of high ecological value statewide using currently available data; 2) evaluate the accuracy of this model based on field metrics generally accepted to indicate ecological value; and 3) develop recommendations as to the next generation of GIS models. Specifically, this analysis examined the efficacy of a GIS patch analysis model to predict areas of high quality upland forest. The accuracy of the model predictions were then tested by gathering field metrics on a variety of variables and comparing them to the GIS-based predictions.

This project was envisioned to be the first step in a 10- to 20-year effort that will lead to a scientifically-sound, statewide GIS-based analysis and identification of potential high quality ecological areas, and subsequent prioritized biological surveys of these areas in order to aid the efforts of conservation planners. Thus, the ultimate outcome of this project is to provide information that will inform conservation and land use decisions by federal, state, and local government agencies, as well as other entities and help contribute to sustainable management of the natural resources of the State of Michigan.

## METHODS

The methods employed in this study consisted of three primary components: 1) a GIS- based land cover patch analysis to classify remotely sensed upland deciduous forest patches as to whether they were likely of low, medium, or high quality from an ecological perspective; 2) collection of field metrics used to evaluate ecological quality of the patches; and 3) analyses to determine the level of agreement between the GIS predictions and measured ecological quality.

The patch analysis considered a number of screening criteria, including land use, degree of fragmentation, core area size, and proximity of patches. The field metrics fell into three broad classes: natural community measures (e.g. vegetation structure, soil compaction, logging history, etc.); floristic measures (e.g. total number of plant species present, number of native plant species present, etc.); and avian measures (e.g. bird species diversity, number of interior bird species present, etc.). Comparison of the GIS predictions and field metrics were accomplished via multivariate analysis of variance (MANOVA) and discriminant function analysis.

### **Patch analysis methodology**

In this analysis, land cover patches of the MDNR Integrated Forest Monitoring, Assessment and Prescription (IFMAP) land cover dataset (MDNR 2001) were scored for their area, core area, and connectivity to patches of the same land cover type. For purposes of this study, patches were defined as contiguous cells of the same land cover class using an eight point rule. Under the eight point rule, cells connecting along a side or at a corner are considered contiguous.

The IFMAP dataset is a raster dataset of 30 X 30-meter resolution cells derived from remotely-sensed Landsat Thematic Mapper imagery. A total of 35 different land cover classifications are identified in the IFMAP dataset. For this study, the 35 land cover types were aggregated into 16 general land cover types comprised of the following: Upland Deciduous Forest, Upland Coniferous Forest, Upland Mixed Forest, Lowland Deciduous Forest, Lowland Coniferous Forest, Lowland Mixed Forest, Grassland, Shrub, Non-forested Wetland, Pines, Pasture/Parks, Agriculture, Sand/Soil, Bare Soil/Rock, Urban, and Water.

The Agriculture, Bare Soil/Rock, Urban, and Water land cover categories were not scored in the analysis. Including the IFMAP land cover categories of Pines and Pasture/Parks cover types in an analysis of more natural habitat types can be problematic. The IFMAP dataset does not differentiate well between natural pine stands and pine planta-

tions managed for fiber production. In a similar vein, the Pasture/Parks cover type could include natural grassland systems or heavily managed and manicured grassland systems. It was decided to include these cover types because they can provide better buffering from anthropogenic effects and better linkages between intact systems than agricultural row crop areas and urban areas. While the Pines and Pasture/Parks cover types are included in the analysis, they are penalized in the scoring methodology.

Three software packages, ARCGIS, FRAGSTATS, and SPSS were utilized in the analysis. Because of file size limitations, the state was divided into 13 different regions for the analysis, 10 in the Lower Peninsula and 3 in the Upper Peninsula (Figure 1).

Each cover type patch was scored for three fairly standard landscape-level measures: area, core area, and proximity to similar patches. Scores ranged from zero to four, with zero being a low score, e.g., no core area or no connectivity, and four the highest score for each criterion. Some land cover types occur as larger contiguous patches than do other types in Michigan. To account for the differential in normally occurring patch size distributions, cover types were classified into large patch or small patch communities with different thresholds used to score patch area (Table 1). Large patch communities consisted of Grassland, Upland Deciduous Forest, Upland Coniferous Forest, Upland Mixed Forest, Lowland Deciduous Forest, Lowland Coniferous Forest, Lowland Mixed Forest, Shrub, Pines, and Pasture/Parks. Small patch communities were Non-forested Wetland and Sand/Soil.

The study initially included two additional variables, edge contrast and shape. Subsequent testing showed that the core area and edge contrast criteria were positively correlated with each other and the area and shape criteria were negatively correlated with each other. Core area and edge adjacency were likely correlated because FRAGSTATS incorporates adjacent cover types into the calculation of patch core area. The negative correlation between area and shape was likely an artifact of the IFMAP dataset and the method FRAGSTATS uses to calculate shape. When testing a raster dataset, FRAGSTATS assigns a perfect shape score to a square. The greater the deviation from a square, the lower the shape score. In the IFMAP dataset, larger areas tend to be convoluted patches connected together by narrow strips or at the corners of cells. This gives large patches a relatively high edge to area ratio and a subsequent low FRAGSTATS shape score. Another issue when scoring patches for shape was the inherent linear shape of some cover type patches. For example, lowland riparian forests in Michi-

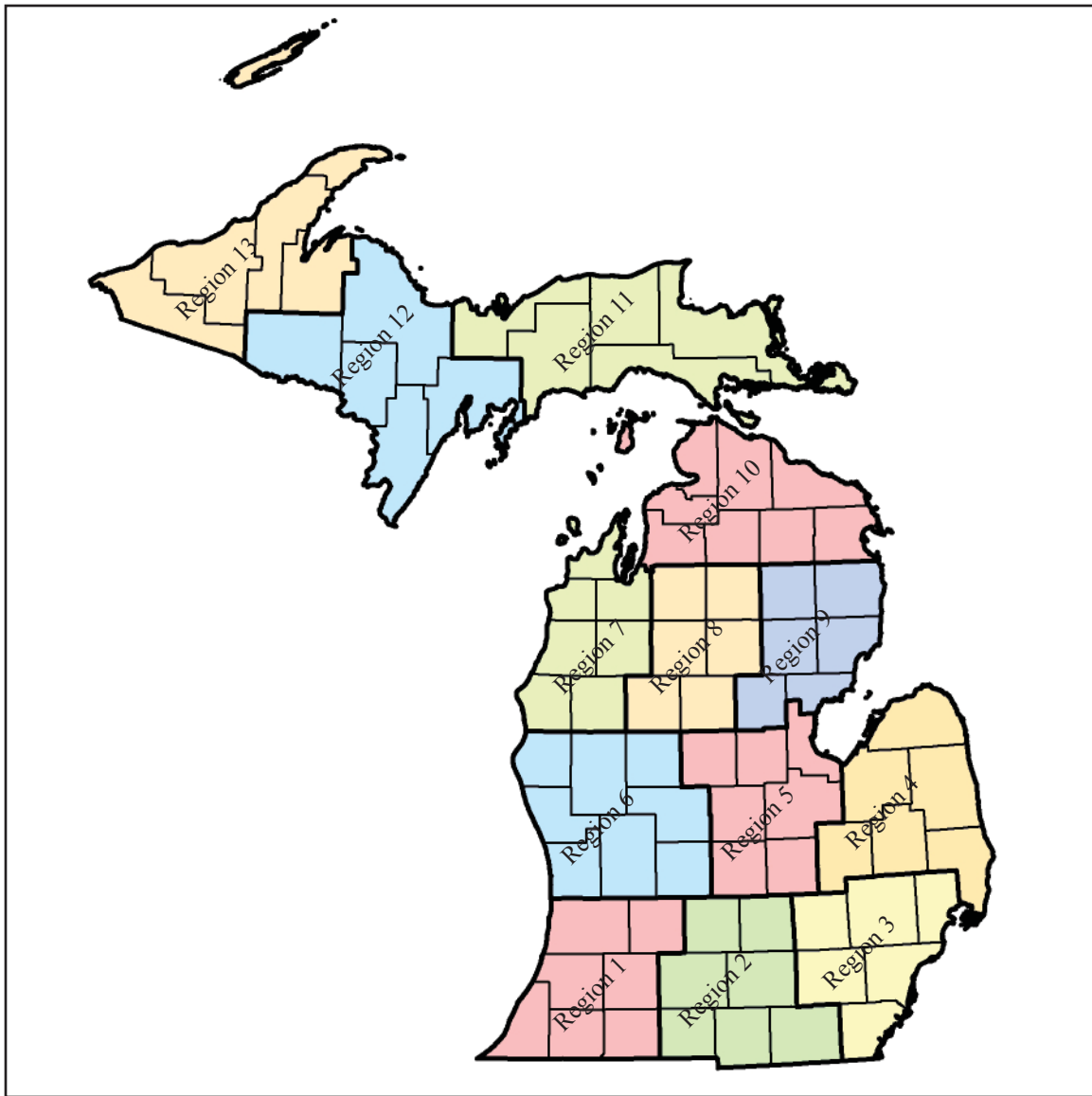


Figure 1. Regional breakdown for patch models

Table 1. Area scoring thresholds for large and small patch communities.

Patch score	Thresholds	
	Small Patch	Large Patch
1		0 < area < 20 hectares
2	0 ≤ area < 2 hectares	20 hectares ≤ area < 1000 hectares
3	2 hectares ≤ area < 20 hectares	1000 hectares ≤ area < 2000 hectares
4	20 hectares ⇒ area	area ⇒ 2000 hectares

gan's southern Lower Peninsula and coastal beach areas tend to naturally occur as linear patches, which resulted in lower scores for these cover type patches. As a result, edge contrast and shape were removed from the analysis, and only area, core area, and proximity to similar patches were used in the final analysis.

#### Area Scoring

Area measurement is a straightforward count of the number

of 900 m<sup>2</sup> cells in each patch. Using ArcGIS, patches were scored for area based on the thresholds in Table 1.

#### Core Area Scoring

FRAGSTATS was used to determine patch core area, or the area minimally impacted by the effects of patch edges. FRAGSTATS utilizes user determined depth of impacts from adjoining cover types to determine the patch core area. The depths need not be symmetrical, e.g., grasslands

may have impacts reaching 100 meters into a forest patch while the forest has impacts reaching 30 meters into the grassland. Edge depth values for each cover type used in this study can be found in Table 2. Values were selected in increments of 30 meters in recognition of the IFMAP land cover 30 meter cell size.

Each patch was given a score from zero to four based on the percentage of the patch considered core area. Core area scores were assigned using the thresholds summarized in the Table 3.

#### *Proximity Scoring*

Each patch was given a zero to four score based on its proximity to similar patches. FRAGSTATS assigns an open ended proximity value to each patch. The proximity score was assigned by using SPSS and ArcGIS to assign patches to groups using a two-step cluster analysis. The cluster analysis was performed individually on each cover type for each of the thirteen analysis regions of the state. Ranges for the proximity scores varied from patch type to patch type and from region to region. Those patches given a zero proximity value by FRAGSTATS were given a proximity score of zero.

#### *Final scoring*

Area, core area, and proximity scores were then summed for each patch, resulting in a total score for each patch ranging from one to 12. A score of 12 would indicate a large cover type patch with a high percentage of core area

in close proximity to other similar cover type patches. Because of previously discussed issues with the Pines and Pasture/Parks cover type patches, they were scored for each criterion, but their summed criteria scores were halved. This resulted in total patch scores for these cover types ranging from 1.5 to six.

#### **Model evaluation**

While the GIS model was created for the entire State of Michigan, all sampling took place within Region 6 of the model. In addition to constraining testing to Region 6, only the upland deciduous forests land cover type was tested. Consequently, all results will speak to only upland deciduous forests within Region 6 of the model.

#### **Region 6 description**

Region six consists of six counties in the middle-western area of the Michigan Lower Peninsula. This region includes parts of two ecoregional sections, VI and VII (Albert, 1995). Within Section VII there are three subsections: the Highplains subsection (7.2), the Newaygo Outwash Plains subsection (7.3), and the Manistee subsection (7.4). Within Section VI there are two subsections: the Ionia subsection (6.4), and the Allegan subsection (6.3). Subsections 6.3 and 6.4 can be further subdivided into four sub-subsections: Jamestown (6.3.3), Southern Lake Michigan lakeplain (6.3.2), Greenville (6.4.2), and Lansing (6.4.1) (Figure 2). All but two sample cells were located in ecoregional Section VII (Figure 2).

**Figure 2. Ecoregional sections and subsections within Region 6 of the patch model. Sample sites are shown in black.**

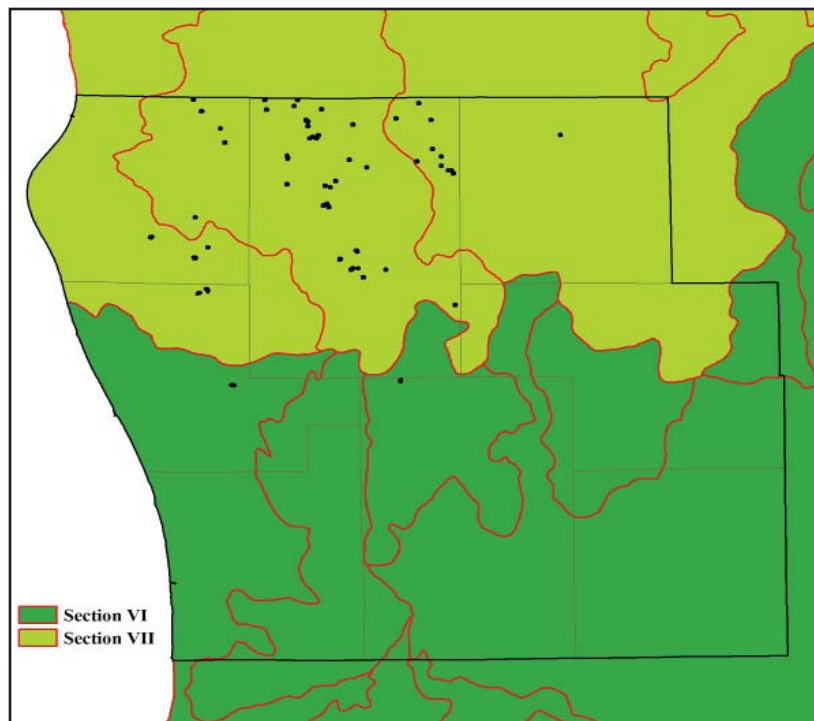


Table 2. Edge contrast depths in meters

Edge contrast	Developed	Agriculture	Grassland	Shrub	Upland deciduous	Upland mixed	Upland conifers	Water	Lowland deciduous	Lowland mixed	Lowland coniferous	Open wetland	Bare soil/rock
Developed	0	0	0	0	0	0	0	0	0	0	0	0	0
Agriculture	0	0	0	0	0	0	0	0	0	0	0	0	0
Grassland	120	60	0	30	30	30	30	0	30	30	30	0	0
Shrub	120	60	0	0	30	30	30	30	30	30	30	30	30
Upland deciduous	210	210	90	60	0	0	0	30	0	0	0	60	120
Upland mixed	210	210	90	60	0	0	0	30	0	0	0	60	120
Upland conifers	210	210	90	60	0	0	0	30	0	0	0	60	120
Water	0	0	0	30	30	30	30	0	30	30	30	0	0
Lowland deciduous	210	210	90	60	0	0	0	30	0	0	0	60	120
Lowland mixed	210	210	90	60	0	0	0	30	0	0	0	60	120
Lowland coniferous	210	210	90	60	0	0	0	30	0	0	0	60	120
Open wetland	90	90	0	0	30	30	30	0	30	30	30	0	30
Bare soil/rock	0	0	0	0	30	30	30	0	30	30	30	30	0

Table 3. Core area scoring thresholds.

Patch score	Threshold
<b>0</b>	No core area
<b>1</b>	$0 < \text{core area} \leq .1$
<b>2</b>	$0.1 < \text{core area} \leq 0.25$
<b>3</b>	$0.25 < \text{core area} \leq 0.5$
<b>4</b>	$0.5 < \text{core area}$



### Region 6 Land Cover Summary

When examined at an Anderson Level 1 classification (Anderson 1976), Region 6 is dominated by the agriculture and forest cover types. Table 4 shows the percentages of each land use/land cover type and Figure 3 is a graphic of the Region 6 land use/land cover.

The region contains a number of public land holdings, most notably the Manistee National Forest. In addition to the Manistee National Forest, sampling took place on the Ionia Recreation Area, Flat River State Game Area, Langston State Game Area, Portland State Game Area,

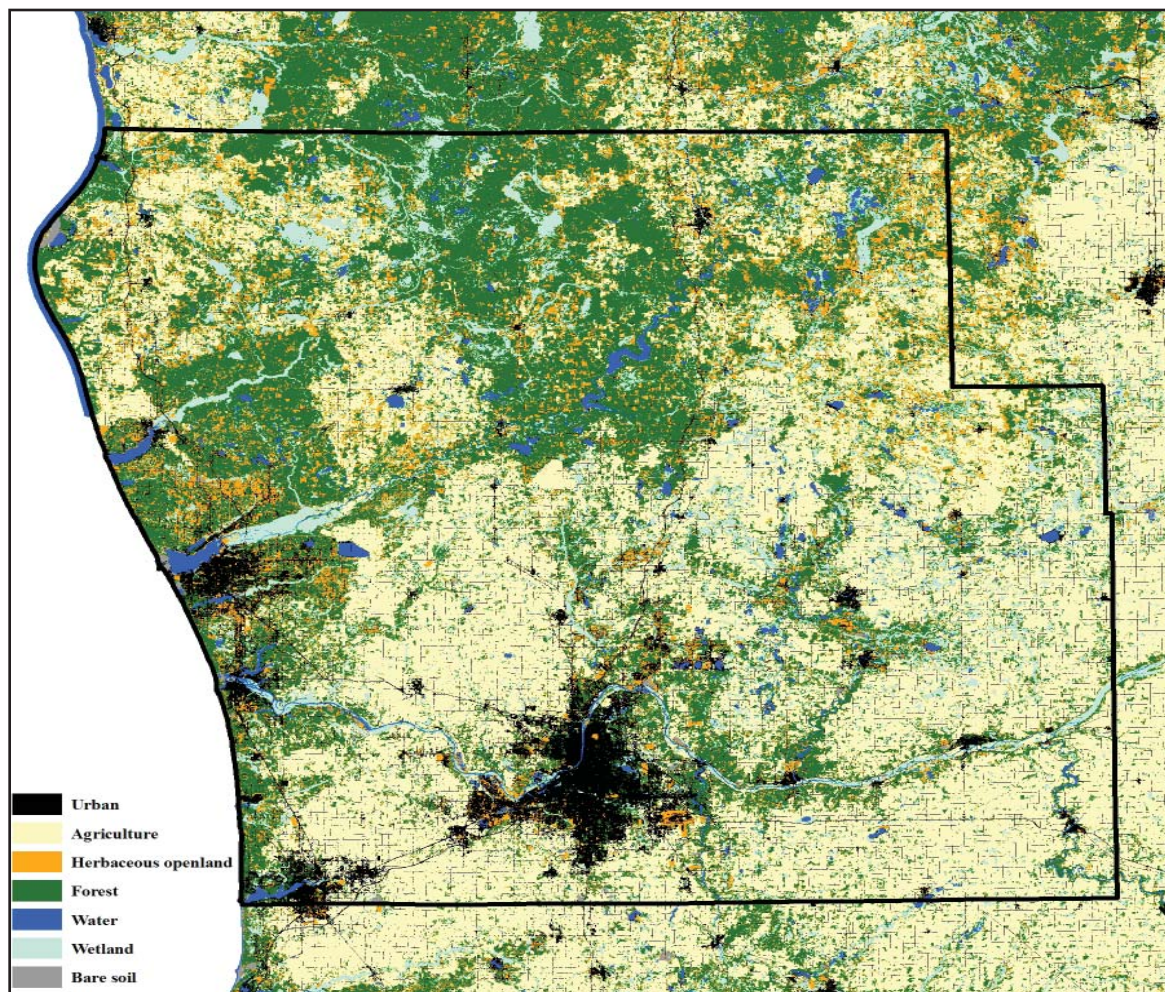
Muskegon State Game Area, Martiny Lake State Game Area, Haymarsh Lake State Game Area, Edmore State Game Area, and the Rogue River State Game Area. State and federal land accounts for approximately 7.8% of the region land base.

### Region 6 upland forest results

In Region 6, there were 32,105 upland forest patches. These patches ranged in size from <1 hectare to 20,763 hectares (Figure 4). Patch core areas ranged from zero to 15,147 hectares. The percentage of a patch considered core area ranged from 0% to 100%. Those patches that were 100% core area tended to be small patches embedded within other forested land cover types where those other types did not provide a hard edge, e.g., a patch of upland deciduous forest embedded within lowland deciduous forest. FRAGSTATS assigned open ended proximity values ranging from zero to 59329.8, with zero representing an isolated patch and 59329.8 representing a patch highly connected to similar cover type patches. The distribution of upland deciduous patch scores in Region 6 can be seen in Table 5.

**Table 4. Amount and percentage of land cover types within Region 6.**

Cover type	Hectares	Percent cover
Urban	98808	7.26%
Agriculture	532237	39.12%
Herbaceous openland	142967	10.51%
Forest	402615	29.59%
Wetland	148985	10.95%
Bare soil	5300	0.39%
Water	29540	2.17%



**Figure 3. Land use/land cover types within Region 6.**



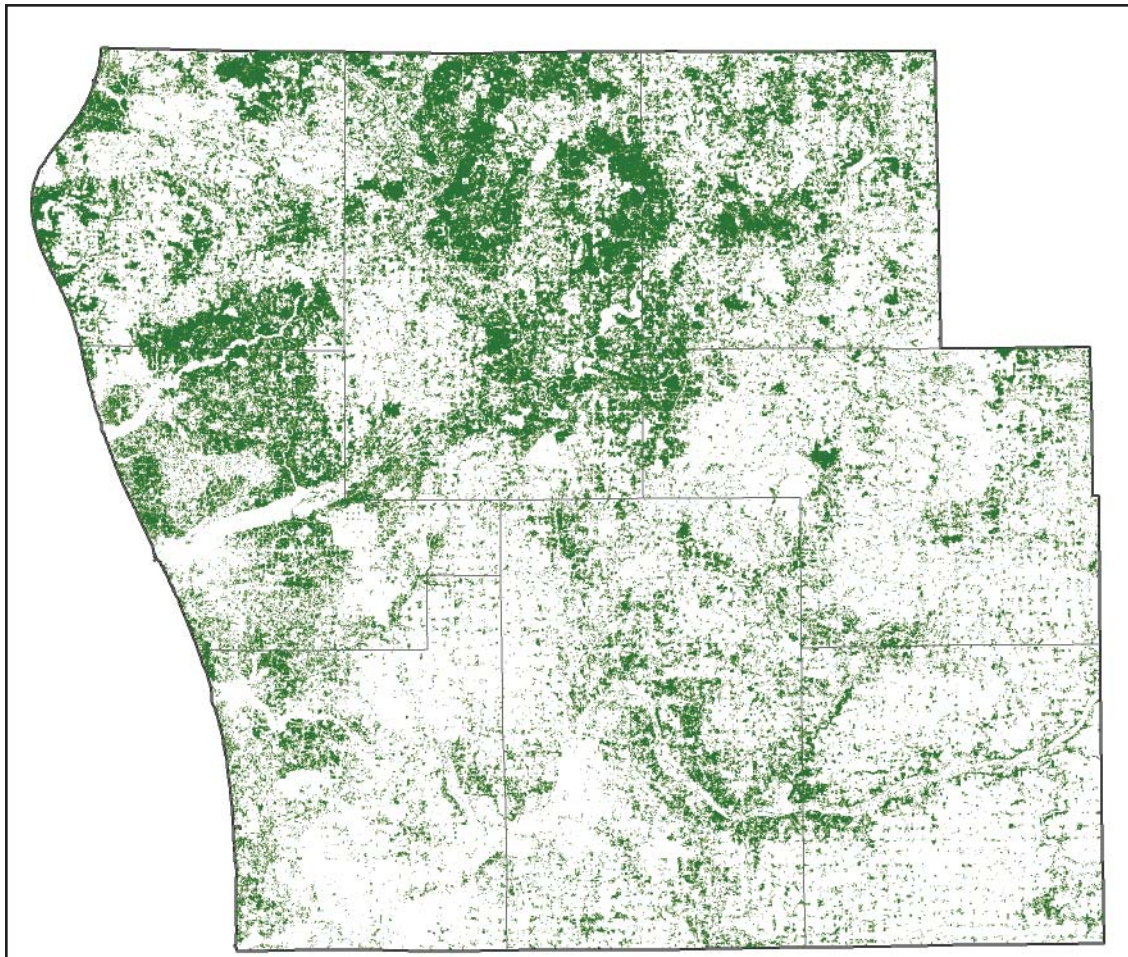


Figure 4. distribution of upland deciduous forest patches within Region 6.

Table 5. Distribution of upland deciduous forest patch scores within Region 6.

Patch scores	Number of patches
1	0
2	13
3	28922
4	1444
5	1190
6	244
7	69
8	120
9	93
10	7
11	2
12	1

Field sampling took place in 28 different upland deciduous patches. The patches ranged in size from 11 hectares up to 20,763 hectares. Sixteen of the patches were over 100 hectares. Ten were over 1000 hectares. Several patches are larger than the reported size because their true extent exceeds the boundary of Region 6. The extent of these patches was clipped by the Region 6 boundary.

### Site selection methodology

#### 2006

In 2006 field sampling was confined to Newaygo County. Field metrics were recorded in randomly selected 10-ha (24.7 ac) sample cells within upland deciduous forest cover type patches. A grid of 10-ha sample cells was intersected with the IFMAP land cover dataset. Those sample cells that consisted of a minimum of 85% of upland deciduous forest or upland mixed forest and were completely contained on public land (state or federal) were included in an initial pool of potential sample cells. Public land was determined using the Conservation and Recreation Lands dataset (Ducks Unlimited, 2006). Eight hundred eighty-seven potential sample cells met these criteria. From the initial pool of 887 potential sample sites, 47 were randomly selected. This random set was then randomly ordered. If field visits determined that a cell was not usable for some reason (e.g., incorrect land cover classification, recent management action), that cell was removed from sampling and the next cell on the list was sampled.

#### 2007

In 2007, a similar method for selecting sample cells was used except for the land cover dataset. In 2007, the 10-ha sample cells were first located within photo-interpreted

polygons delineating the dry mesic northern forest natural community type instead of using the IFMAP upland deciduous land cover. In addition, the test cell had to fall completely within the photo-interpreted polygon. This selection process resulted in 34 potential sample cells within Newaygo County, on public land and within a dry-mesic northern forest community type.

## 2008

In 2006 and 2007, sampling efforts took place in upland deciduous forest patches that scored at the higher end of the patch scoring spectrum. No lower scoring patches were sampled in either 2006 or 2007. Consequently, survey efforts in 2008 focused on surveying upland deciduous forest cover type patches ranked as low to moderate scoring in order to collect field metrics from a sufficient number of patches in this cover type across a gradient of model scoring. In order to meet the selection criteria, including being contained on public land, some sampling efforts in 2008 were conducted outside of Newaygo County.

A set of upland deciduous forest patches with patch scores in the middle of the scoring spectrum, and completely contained on public land, were identified and selected. For those moderate scoring patches of sufficient size, 10-hectare cells from a fixed grid were designated as sample sites. If the patch size and shape did not allow fixed grid sample cells to be completely contained within the patch boundaries, square 10-hectare cells were randomly placed within the patch. This produced a total of 34 potential sample cells from moderate scoring patches. From this set ten random sample cells in moderately scoring patches were selected for sampling efforts.

The size and shape of patches with scores at the lowest end of the scoring spectrum did not allow for placement of square 10-hectare sample cells. For these lower scoring patches, the entire patch served as the sample site. An initial set of 26 lower scoring patches was selected, with patches ranging in size from 10.4 to 19.2 hectares. An aerial photo review of the initial 26 patches was then used to reject potentially non-qualifying patches, e.g. those with no visible or reasonable access or those lacking a sufficient extent of contiguous forest vegetation. Ten lower scoring patches were finally selected for sampling.

## Choice of Metrics

### *Natural community metrics*

Prior to field surveys, several potential indicators of natural community structure and function were identified to assess ecological integrity of upland forest systems (Noss 1990, 1999, McElhinny et al. 2005, Lindenmayer et al. 2000, 2006). Qualitative metrics were developed to score each indicator on a scale of 1 (poor) to 4 (excellent). The

following indicators (and their variable designation) were scored for upland forests:

### *Buffer width (BUFFER)*

The width and identity of cover type(s) adjacent to the plots was identified and scored as one attribute of landscape intactness.

### *Broader land use (LANDUSE)*

The percentage and identity of natural cover types (broadly defined as non-plantation forests, wetlands, and natural grasslands) in a 3-km radius centered on each plot was assessed and scored as the second attribute of landscape intactness.

### *Presence of roads, railroad tracks, or other development (DEVELOP)*

This indicator was developed to assess impacts of development *within* plots. Roads lead to fragmentation and soil compaction, and serve as conduits for dispersal of non-native and native weedy species, as well as providing vehicular and foot access to adjacent lands. Included within this category were abandoned logging roads and snowmobile/off-road vehicle trails.

### *Soil compaction/erosion (SOILDIST)*

This indicator served as a broader measure of soil compaction, including compaction away from roads or other developments that was associated with logging activity, grazing, or other undefined disturbances. Soil compaction and erosion can result in reduced tree recruitment and alteration of lower strata.

### *Vegetative structure (VEGSTRUC)*

The maintenance of stand structural complexity is important for the preservation of forest biodiversity (Lindenmayer et al. 2006). This indicator was developed to assess the “naturalness” of forest patches by assessing stand age class diversity, vertical heterogeneity and structure, horizontal heterogeneity (e.g., presence of canopy gaps, micro-sites, etc.), species composition, and tree regeneration. Deviation from “natural” conditions was estimated based on published and unpublished descriptions of relatively undisturbed reference stands of appropriate forest types (Cohen 2000, 2002, Kost et al. 2007).

### *Presence of red maple (REDMAPLE)*

In the absence of frequent fires that shaped composition and structure of oak- and oak-pine – dominated forest, fire-sensitive red maple (*Acer rubrum*) has increased in the understory of these systems, often assuming dominance in the subcanopy, shrub, and ground layers. Differential herbivory by white-tailed deer may also give red maple a competitive advantage against oaks (Abrams 1998). Red



maple has also increased in mesic forest communities, likely the result of timber management, deer herbivory, and other disturbances. In addition to indicating the lack of an important process (fire) in oak- and oak-pine – dominated systems, red maple causes degradation of these sites by producing dense canopy and sub-canopy shade that prevents regeneration of oaks and eliminates understory species that require high levels of light, in addition to depositing recalcitrant leaf litter that lowers fire frequency and severity (Abrams 2005).

#### *Coarse woody debris (COARSEWD)*

An abundance of literature (e.g., Harmon et al. 1986) supports the importance of coarse woody debris in supporting a variety of ecological functions, including serving as a substrate for decomposers, a foraging substrate for other organisms, protection for wildlife, and reducing soil erosion and improving soil structure.

#### *Evidence of logging (LOGHIST)*

Logging removes large canopy trees and often leads to succession to different stable states. Large trees are an important source of food and shelter for wildlife. Removal of upland conifers (e.g., white pine, red pine, and hemlock) has altered the structure and successional trajectory of dry-mesic and mesic forests throughout northern Lower Michigan (Cohen 2002).

#### *Herbivore impacts (DEERBRWS)*

This indicator focused on browse and other impacts of white-tailed deer (*Odocoileus virginianus*). Overabundant deer may alter nutrient cycling and soil dynamics (through nutrient addition and trampling) and may act as vectors for long-distance seed dispersal, potentially facilitating invasion by non-native species or ruderal natives. Differential browsing may lead to population declines and ultimately extirpation of ground flora species, as well as changes in tree species composition. The impacts of deer on upland forests are widely reported (e.g., McShea and Rappole 1992, Mladenoff and Stearns 1993, Balgooyen and Waller 1995, Waller and Alverson 1997, Augustine and Frelich 1998, Didier and Porter 2003, Horsley et al. 2003, Rooney and Waller 2003, Ruhren and Handel 2003, Kraft et al. 2004).

#### *Presence of invasive species (INVASIVE)*

The presence, abundance, and distribution of invasive species were assessed for each plot. This indicator focused on species that pose particularly significant threats to upland forest communities, such as garlic mustard (*Alliaria petiolata*), honeysuckles (*Lonicera* spp.), and multiflora rose (*Rosa multiflora*) (Kost et al. 2007).

#### *Botanical metrics*

Prior to field studies, a number of floristic variables

were considered as possible metrics for corroborating the GIS patch analysis model, particularly with respect to correlating to natural community quality, which is largely dependent on the condition and composition of the vegetation present. Due to the fact that general species richness measures were employed in other aspects of the study, such as the assessment of migrating and nesting bird diversity, sampling to catalogue the full range of vascular plant richness for each class of patch type (i.e. high, medium, and low scoring classes) was selected to mirror these allied metrics. Through the use of the Michigan Floristic Quality Assessment System (FQAS) (Herman et al. 2001), a number of related measures could be tested, including total vascular species richness (both with and without non-native species), Floristic Quality Index (FQI) (with and without non-native species), and average Coefficient of Conservatism (COC) (with and without non-native taxa). Further rationale for using the Michigan FQAS in this study was based on the successful use of these metrics in an extensive study of riparian sites in southern Lower Michigan (Goforth et al. 2001, 2002). For the riparian study, floodplain forests were selected and stratified by their narrow (<125m), medium (125-250m), and large (250-500m) buffer sizes to assess differences in biodiversity, function, and quality. Because of the strong similarity to the context of riparian study, the use of the Michigan FQAS was a logical choice for floristic variables with which to test the GIS patch analysis.

Floristic quality assessment systems, which derive from a natural area assessment protocol devised by Wilhelm and Ladd (1988) have been prepared and applied in the Chicago Region and are now in wide use, including such principalities as North and South Dakota and adjacent grasslands (Northern Great Plains Floristic Quality Assessment Panel 2001, Mushet 2002), Missouri (Ladd 1993), Illinois (Taft et al. 1997), Ohio (Andreas et al. 2004), Ontario (Oldham et al. 1995), portions of Pennsylvania (Miller and Wardrop 2006), and elsewhere. There is also a growing literature on the applicability and efficacy of floristic quality assessment as these systems are compiled and tested (Lopez and Fennessy 2002, Cohen et al. 2004, Bourdaghs et al. 2006, Miller and Wardrop 2006).

A Floristic Quality Assessment is a relatively objective means of assessing the ecological integrity of a site, or making comparisons among different sites. The basis of the FQA is an inventory of the plant species that occur on a site, compiled during a reconnaissance, typically a “meander survey,” of the site in question. From this inventory a list of all the plant species found on the site is tabulated.

Each plant species native to Michigan has been assigned a “coefficient of conservatism” or “C-value.” C-values range from 0 – 10 and represent “an estimated probability that a

plant is likely to occur in a landscape relatively unaltered from what is believed to be a pre-settlement condition.” In other words, plants with a low numerical rating can be found in a wide range of habitats and areas of disturbance, while those with a high number are “almost always restricted to a pre-settlement remnant, i.e. a high quality natural area” (Herman, et al. 2001).

From the coefficients of conservatism for the species found on a site, an index, referred to as the Floristic Quality Index (FQI), can be calculated as follows:

$$FQI = [(\sum C_i)/n] \sqrt{n}$$

Where:

$C_i$  – the coefficient of conservatism of each of the native species found on the site

$n$  – the number of species found on the site

The calculation can be done by considering either only those species on the site which are native to Michigan, or by considering all of the species found, whether native or non-native. The latter approach helps to differentiate between sites with similar numbers of native species, but differing with respect to number of non-native species, thus providing a more comprehensive evaluation of the floristic quality of a site.

The metrics used to evaluate the plant community in this study include: total species number (TOTSPP), total native species number (TOTNAT), all species mean coefficient of conservatism (MEANCALL), native species mean coefficient of conservatism (MEANCNAT), Floristic Quality Index for all species (FQIALL), and Floristic Quality Index for native species (FQINAT).

#### **Avian metrics**

The quality or condition of the animal community focused on the breeding bird community and specifically variables such as the avian diversity index, species composition, species guilds, and conservation value of individual species. Field metrics for the animal community were obtained by conducting breeding bird point counts in sample cells. The following metrics were collected or calculated to assess the avian community: number of species in a plot (NO\_SPECIES), Avian Conservation Significance (ACS) (Panjabi et al. 2005, Twedt, 2005), individuals of interior sensitive nesting species in a plot (INT\_SPP), individuals of exotic species such as European starling (*Sturnus vulgaris*), English sparrow (*Passer domesticus*), and house finch (*Carpodacus mexicanus*) or invasive brown headed cowbirds (*Molothrus ater*) in a

plot (NO\_INVAS), and number of individual birds overall within a plot (NO\_BIRDS). Interior species are those commonly described as sensitive to forest fragmentation (Ehrlich 1988).

The Avian Conservation Significance (ACS) of a patch was calculated as the sum of the Concern Rating (CR) for each species detected which had been multiplied by the individual species’ territory density in the patch using the formula

$$ACS = \sum_{i=1}^n ((CR_i * TDR_i) / 1000)$$

where:

- ACS = Avian Conservation Significance,
- CR = Concern Rating derived from regional Partners in Flight (PIF) concern scores as;  $CR = \text{LOG GAMMA}(\text{PIF CONCERN SCORE})^2$ ,
- TDR = Territory Density Rating derived from observed territory densities as;  $TDR = 10 * \text{LOG}_2(\text{OBSERVED DENSITY})$ , for observed densities of 1 to 50 territories / 100 ha.

(Twedt 2005). The CR for species was directly related to the PIF designated measures of Concern Scores (Panjabi et al. 2005, Twedt 2005).

#### **Sampling methodology**

##### *Natural community sampling*

All field metrics were scored based on thorough meander surveys of each sample site. Landscape context indicators (buffer width and broader land use) were scored based on sample site surveys and aerial photo interpretation of the surrounding area(s). Indicators of natural community condition and threats were assessed by qualitatively scoring and averaging the appropriate metrics across the sample site. The score for each metric reflected the assessed “average” condition of each sample site. Only the target community (upland forest) was scored within each sample site; inclusions of wetlands or grasslands were not scored. The mechanics of scoring the natural community quality and condition are listed in Appendix A.

##### *Plant community sampling*

The field metrics for the plant community were obtained by conducting timed-meander surveys (Goff 1982) in which we continued to survey until 10 minutes had passed with no additional species being detected, at which time we terminated the survey. To capture species emerging over the course of the growing season, we surveyed in early (late May-early July) and late (August-September) periods. Difficult to identify species were collected and identified later using resources and equipment not available in the field.

In practical application, the edges of the various plant communities were often not well defined, so we used guidelines to help determine what area to include in the survey. In plots where a forested plant community was adjacent to an open plant community, a vertical line extending from the edge of the tree canopy to the ground was used to define the edge. Using this delineation, small areas of non-target plant communities became embedded in the sample plot target community and were included in the survey area. Thus, an upland forest with a small vernal pool might have some wetland species, or a lowland forest with a small rise might harbor upland species. Portions of the sample plot containing non-target natural communities that were outside of the above delineation were not sampled.

#### *Avian community sampling*

##### 2006

In the first year of sampling, a grid of nine points was established within each sample cell. Each point was 50 meters from an edge and 100 meters from other points. An eight minute point count was performed at each of the nine accessible points within each cell. Point counts began 15 minutes before sunrise and continued until 1030 hours. No data were collected during periods of inclement weather such as rain, fog, or a wind speed greater than 20 km per hour. After arriving at the point count site, observers were allowed a one-minute acclimation period before conducting the point count. All birds observed (aurally and visually) were recorded within the 50-m fixed radius point count; birds beyond this distance were recorded as well, with detailed information recorded on their distance from the observer (variable circular plot method). Gender of the birds was recorded whenever possible. Birds flying over the site were noted as such but were not used in further analysis. No playbacks or sounds were used to attract birds into the point count location. Sampling took place between the end of May and the end of June. Each site was visited twice during the sample period.

##### 2007 and 2008

In 2007 and 2008, each site was visited only once during the sampling period. Instead of nine eight minute counts within each sampling cell we performed a single 20 minute point count at a random point within the sample cell. Although many other studies have used a 5 – 10 minute point count, the 20-minute point count allowed us to

observe more avian diversity with the most efficiency given the difficulties of traveling to each point count site (Huff et al. 2000). To be able to approximate the same sample effort between 2006 and subsequent years, two of the nine point counts within each 2006 sample site were randomly selected and combined for analysis.

#### **Data analysis**

The ArcGIS Fisher-Jenks natural breaks algorithm (Slocum 1999, de Smith 2009) was used to place the survey cells into a high, moderate, or low grouping, based on the patch score the sample cell fell in. Based on the above distribution, the Fisher-Jenks algorithm placed sample cells with a patch score of three into the low category, cells with a patch score of four and six into the moderate category and cells with a patch score of seven or higher into the high category.

The field metrics values were then tested against the high, moderate, and low categories to determine if any of the metrics could be used to determine membership in one of the categories. This testing was accomplished using the discriminant function analysis tools of SPSS 17 (SPSS, 2008). Discriminant function analysis is used to determine which, if any, variables are useful in discriminating between two or more groups (that is, does a variable reliably identify which group a particular subject belongs to). In the present study, the groups were defined as high, moderate, or low patch score groups. The subjects were the individual patches, and the potentially discriminating variables were the field metrics associated with natural communities, plants, and birds.

The SPSS discriminant function analysis procedure involves a step-wise approach. Using MANOVA calculations, a model is built step-by-step, where each step determines which variable most differentiates between the groups. If the F-value for that variable is sufficiently large the variable is entered into the model and the procedure repeated. The resultant model is made up of only those variables that significantly contribute to discriminating between the groups (i.e., those variables that makes a significant contribution to predicting the group membership of a particular subject). The discriminant function thus built is analogous to a multiple regression equation in that it is a combination of the variables, each weighted by a coefficient representing the relationship between the group scores and the variables, that best discriminates between the groups.

## RESULTS AND DISCUSSION

A total of 54 upland deciduous sample cells were visited by at least one of the disciplines. Sample cell centroids ranged from 3 meters to 979 meters from a road (Michigan Center for Geographic Information 2008) with an average distance of 381 meters from a road. Sample cell centroids ranged from 0 meters to 1,889 meters from a National Wetlands Inventory (NWI) wetland (U.S. Fish and Wildlife Service circa 1980) with an average distance of 382 meters from a wetland. Examining the broader land use in a three-kilometer buffer of the sample site centroids, the percentage of natural lands ranged from 56% to 99%. Twenty out of 54 sample sites had greater than 90% natural land cover types in the three-kilometer buffer. Fifty out of 54 sample sites had greater than 70% natural land cover types in the three-kilometer buffer.

Of these 54 sample cells, 39 had all three sets of metrics (natural community, plant community, and avian community) measured. In several cases, multiple sample cells were located within the same land cover patch. Where there were multiple sample cells within the same land cover patch, the field metrics for those cells were averaged, producing one metric value for each land cover patch. After averaging, there were 28 samples to test against the patch scores. Patch scores for these 28 samples ranged from a low of three to a high of 12. Figure 5 shows a frequency distribution of the scores.

### Field sampling results

The mean, variance, and standard deviation for ecological context and condition scores, plant community scores, and avian community scores are found in Tables 6 - 8. Complete scores are found in Appendix B.

### Data analysis results

Two metrics, the number of interior bird species and presence of red maple were identified as significant predictors of group membership. Classification coefficients for both metrics are presented in Table 9. The discriminant analysis selected no other metrics as a predictor of low, moderate, or high group membership.

#### *Red maple*

With regards to red maple, it should be kept in mind that high abundance of red maple is considered to be a negative indicator of ecological integrity for oak-dominated, upland deciduous forests, as the presence of red maple indicates the lack of fire, possible disturbance of the area due to logging, and succession of the oak forest toward a maple-dominated community. A low metric score indicates a high abundance of red maple and lower ecological integrity. Thus, we would expect that high quality patches would have a high value for the red maple metric (indicating a low abundance of red maple). Conversely, low quality patches would have a low red maple metric score, indicating a higher abundance of red maple at the site. While the discriminant function analysis indicated that the red maple metric was a significant indicator of group membership, we found that the mean red maple metric was highest for low scoring patches, indicating an absence of red maple, and was lower for high scoring patch groups, indicating a higher presence of red maple in the higher scoring patches than in the lowest scoring patches. This is the opposite of our predictions. Moderate scoring patches had the lowest mean red maple metric score (Table 6) indicating a greater presence of red maple in moderate scoring patches than in lower or higher scoring patches. Ranking the patch score

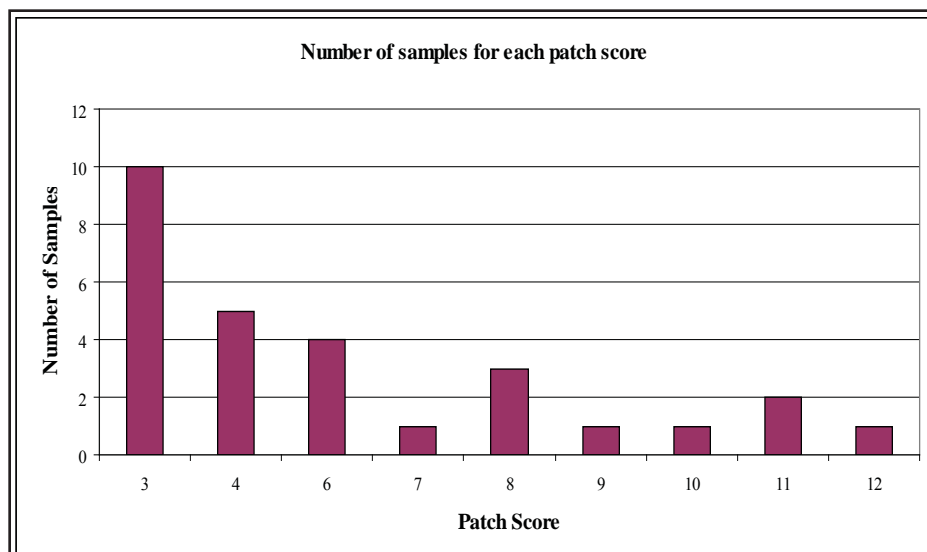


Figure 5. The number of upland deciduous forest sample cells for each patch score.

Table 6. Averaged ecological context and condition scores.

Metric	Low scoring patches			Moderate scoring patches			High scoring patches		
	Mean	Variance	St. Dev.	Mean	Variance	St. Dev.	Mean	Variance	St. Dev.
BUFFER	3.0	0.2	0.5	3.4	0.2	0.5	3.3	0.7	0.9
LANDUSE	3.0	0.3	0.6	3.4	0.4	0.7	3.5	0.2	0.4
DEVELOP	2.6	0.2	0.5	2.6	0.5	0.7	2.4	0.1	0.3
SOILDIST	2.2	0.6	0.8	2.6	0.3	0.6	2.5	0.1	0.4
VEGSTRUC	1.8	0.3	0.5	1.7	0.4	0.7	1.8	0.3	0.5
COARSEWD	2.2	0.7	0.9	1.9	0.4	0.7	2.1	0.4	0.6
INVASIVE	3.1	0.5	0.7	3.4	0.2	0.4	3.4	0.2	0.4
REDMAPLE	2.8	1.4	1.2	1.8	0.4	0.7	2.2	1.0	1.0

Table 7. Averaged botanical scores.

Metric	Low scoring patches			Moderate scoring patches			High scoring patches		
	Mean	Variance	St. Dev.	Mean	Variance	St. Dev.	Mean	Variance	St. Dev.
TOTSPP	51.7	283.1	16.8	41.3	74.0	8.6	54.1	420.1	20.5
TOTNAT	47.9	282.8	16.8	38.9	52.4	7.2	48.0	309.1	17.6
MEANCALL	4.0	0.2	0.4	4.1	0.2	0.4	3.3	3.4	1.8
MEANCNAT	4.4	0.3	0.5	4.4	0.2	0.4	3.5	3.9	2.0
FQIALl	28.4	20.5	4.5	26.3	9.7	3.1	25.6	143.4	12.0
FQINAT	29.5	20.5	4.5	27.1	11.3	3.4	26.6	148.1	12.2

Table 8: Averaged avian scores.

Metric	Low scoring patches			Moderate scoring patches			High scoring patches		
	Mean	Variance	St. Dev.	Mean	Variance	St. Dev.	Mean	Variance	St. Dev.
NO_SPECIES	8.6	14.5	3.8	9.8	6.5	2.5	9.8	9.8	3.1
ACS	122.5	2277.7	47.7	156.9	2728.5	52.2	152.1	2747.2	52.4
INT_SPP	5.2	2.0	1.4	9.3	3.1	1.8	9.7	28.9	5.4
NO_INVAS	0.5	0.7	0.8	0.5	0.6	0.8	0.5	0.3	0.5
NO_BIRDS	12.1	11.7	3.4	16.6	24.8	5.0	16.7	57.0	7.5

Table 9. Discriminate function classification coefficients for the red maple and interior species metrics.

Classification Function Coefficients

	Jenks grouping		
	1	2	3
REDMAPLE	2.099	-1.007	-0.606
INT_SPP	1.501	3.935	3.08
(Constant)	-7.889	-18.386	-11.96

Fisher's linear discriminant functions



groups from lowest to highest by the average red maple metric would put the moderate scoring patches at the lowest rank, followed by the highest scoring patches, and the lowest scoring patches with the highest rank. Figure 6 shows the distribution of red maple metric scores by patch score.

Several factors may limit the effectiveness of red maple abundance as a test of the patch model. As noted earlier, a greater presence of red maple typically indicates a lower ecological integrity in oak dominated upland forest systems because of fire suppression, land management history, and resultant succession to a maple-dominated community. In our study the red maple metric has a weak positive correlation with the logging history metric, with a Pearson correlation coefficient of 0.357,  $p = 0.011$ , significance at the 0.05 level,  $N = 50$ .

Additionally, as red maple is an indicator of wetland plant communities, the scoring for red maple may also be affected by the proximity of the sample cells to wetland areas. And indeed, the red maple scores were positively correlated with the distance from wetlands with a Pearson correlation coefficient of 0.372,  $p = 0.008$ , significance at the 0.01 level,  $N = 50$ . Figure 7 shows the sample site red maple score versus the distance of the sample cell centroid from a National Wetland Inventory wetland (U.S. Fish and Wildlife Service circa 1980).

The correlation between distance from a wetland and the metric score seems to indicate a relationship that may compromise the reliability of utilizing red maple as a

metric for testing upland deciduous forest communities. When plotting the sample site distance to a wetland, the sites in the higher ranked group tend to fall along a gradient of distance from wetlands. Instead of falling along a gradient, the distance from a wetland for the sites in the lower ranked group tend to clump with gaps in the distance from a wetland (Figure 8). The three low ranking sites, over a thousand meters from a wetland, all had high red maple metric scores indicating an absence of red maple in the sample area.

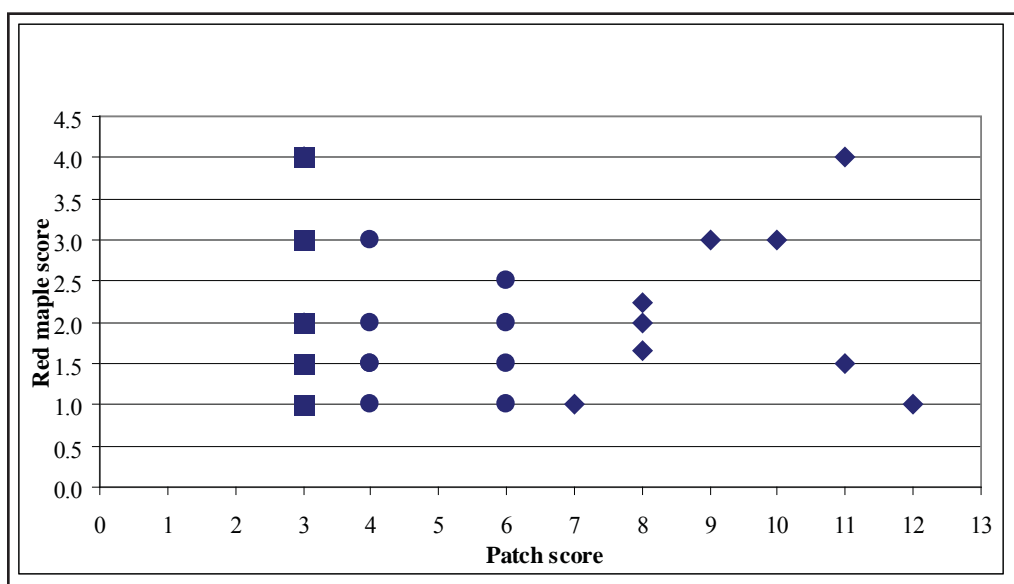
#### *Interior birds*

The presence of interior birds as a reliable predictor of the patch quality is consistent with the methods used to determine patch quality. Upland deciduous forests tend to be a large patch type and patch scoring was based on patch size and the percentage of core area. Larger forest patches will tend to have a higher percentage of core area and therefore tend to be higher ranked in the model. These large patches provide the necessary habitat requirements for interior birds. Thus, high patch score can be considered a good predictor of high quality habitat for interior bird species. Interestingly, interior bird species observe and assess the canopy from above to determine areas suitable for nesting, not unlike the satellites used to detect the Thematic Mapper land cover data used in the model.

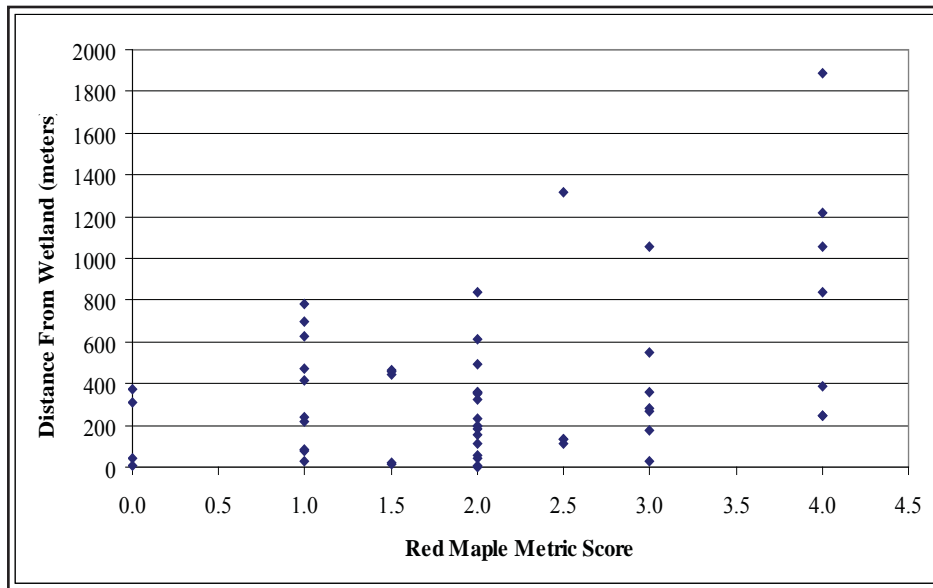
#### **Efficacy of the metrics**

##### *Landscape context*

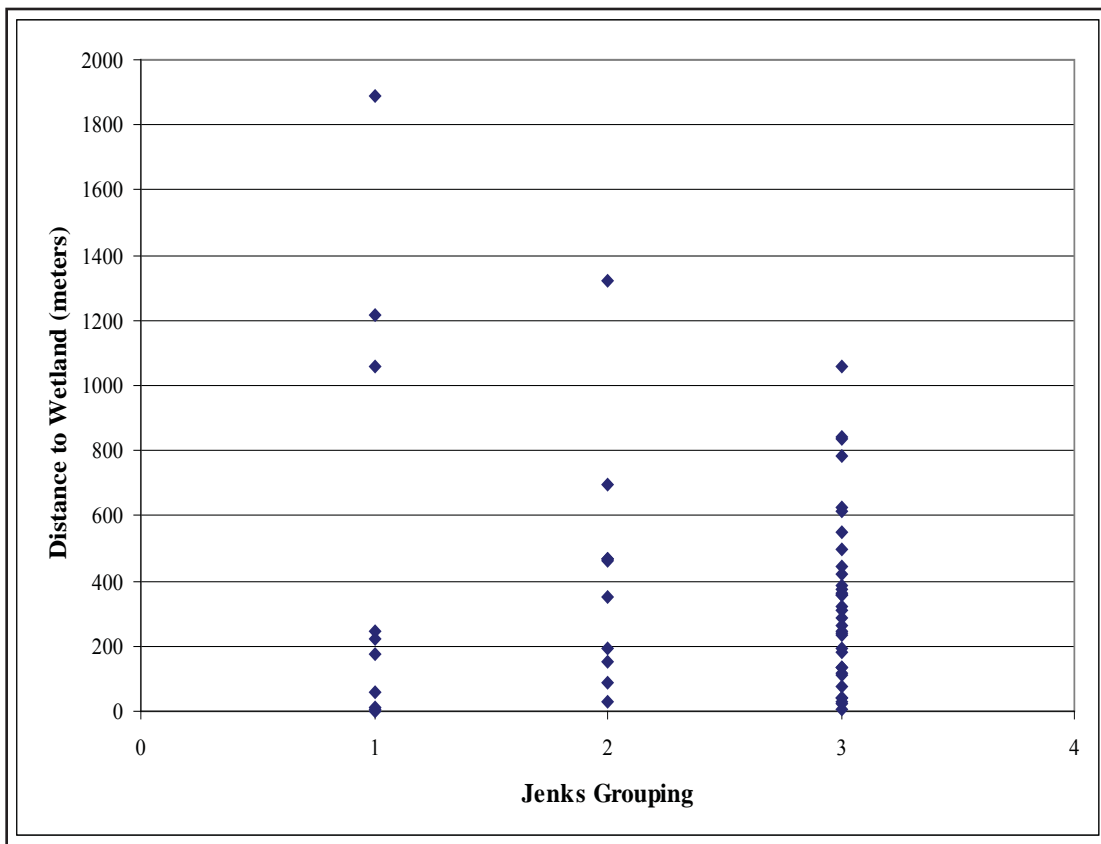
The lack of correlation between patch scores and the scores for several field metrics may be a function of the land use patterns within the area of Region 6 where sampling



**Figure 6. Red maple score by patch score. Patches with the lowest score, indicating low ecological quality are square, moderate scoring patches are round and highest scoring patches are diamonds.**



**Figure 7. Sample site red maple score versus the distance of the sample cell centroid from a National Wetland Inventory wetland.**



**Figure 8. Sample site distance from an NWI wetland by Jenks grouping using all sample sites.**

took place. In Region 6 approximately 46% of the area is converted to human dominated uses (agriculture and urban). Twenty-nine percent of the non-converted cover types are forested types. The area within Region 6 where most sampling took place, however, is markedly different than the larger Region 6 landscape (Figure 4).

To examine the larger land use context the sample sites are located in, we compared the land use characteristics within one-kilometer and three-kilometer buffers of the 54 sample

sites and 54 randomly selected sites within Region 6. It was found that sampling to test the patch model took place within a matrix of larger upland forest patches in an area that is less dominated by human converted land cover types than other parts of Region 6 (Table 10).

This could explain why metrics such as the number of avian invasive species, the buffer size, and broader land use metrics did not help to explain patch scores or membership in the high, moderate, or low groups. If

**Table 10. A comparison of cover types within one and three kilometer buffers of sample sites and random points within Region 6.**

	Non-converted cover types		Forest cover types	
	Range of % non-converted cover types	# sites with > 90% non-converted cover types	Range of % of forest cover types	# sites with > 70% forest cover types
Sample site 1 km buffers	70 - 100	51 of 54	35 - 99	51 of 54
Randomly placed 1 km buffers	5 - 100	11 of 54	1 - 93	11 of 54
Sample sites 3 km buffers	66 - 99	20 of 54	40 - 86	30 of 54
Randomly placed 3 km buffers	9 - 99	6 of 54	5 - 89	5 of 54

the area immediately surrounding the sample sites is not converted to human-dominated land cover types, and the larger landscape is relatively un-converted, metrics measuring the surrounding cover types and levels of disturbance may not have enough variance to explain group membership.

Other metrics dependent on the larger landscape condition also may not have enough variance to explain group membership. Avian invasive species showed low variance in samples, regardless of the modeled quality of the sample area. This could be explained by the upland forest community type that was sampled and the larger landscape where sampling took place. Several studies demonstrate that cowbird abundance and detection are related to landscape scale habitat patterns (Howell 2007, Donovan 1997, Coker 1995). The large upland forest patches we sampled, and the larger landscape that we sampled in, are generally not conducive to large cowbird populations.

#### *Scale issues*

Part of the lack of corroboration between metrics and patch scores may come from measurement scales. The patch model was based on a remote sensed land cover dataset. This land cover dataset is a measure of the canopy surface. The remote sensed Thematic Mapper imagery used to create the land cover dataset does not observe or assess sub-canopy conditions. As observed in this study, metrics such as level of development, logging history, coarse woody debris, soil disturbance, vegetation structure and FQI scores are localized measures of site condition. These metrics are assessments of sub-canopy impacts that are not discernible with the type of data used in the model.

#### *Sampling bias*

A number of metrics, in particular the measures of natural

community integrity, showed little variation across a range of modeled patch scores. The scores for metrics such as soil disturbance, development, presence of coarse woody debris, and vegetation structure will be influenced by local land management decisions. Restricting sampling to public lands, which tend to be managed differently than private lands, may have introduced a sampling bias that reduces the effectiveness of these metrics as a test of the patch model.

#### *Correlation of Metrics*

In addition to the landscape context and scale issues, correlation between the metrics may limit the usefulness of the metric suite we utilized for testing. In particular, the field scores for a number of the natural community assessment metrics were correlated. Two plant community metrics, the FQI mean coefficient for all species and the FQI mean coefficient for native species, are positively correlated to the natural community vegetation structure metric (Table 11).

#### **Efficacy of the model**

Patch models built on landscape scale metrics are often used to predict ecological processes and can be used to explain processes such as species distributions (Wagner 2005) but the correlation between landscape indices and ecological processes can be inconsistent (Tischendorf 2001). Models based on categorical data derived from remotely sensed imagery, such as the one presented here, are subject to classification errors that can propagate through an analysis (Wagner 2005). The accuracy assessment for the IFMAP land cover dataset used in this analysis “*showed that at Level 1 (major land cover classes) the land cover map had an overall accuracy of 88%, at Level 2 (division of major land cover classes) for the non-forested classes the map had an accuracy of 81% and at Level 3 (major forest types) for the forested classes the*



accuracy was 68%” (MDNR 2004). The analysis presented here did not include estimates of uncertainty caused by potential classification errors.

While a patch model is suitable for many landscape studies, some ecological processes and functions are better

represented by gradients or continually varying surfaces (Gustafson 1998). In short, it is unlikely that one model will be able to accurately predict all possible ecological processes or areas important for conservation.

**Table 11. Pearson’s correlation coefficients for significantly correlated metrics.**

Metrics		Pearson’s Correlation Coefficient	Significance	Level (2 tailed)
BUFFER	INVASIVE	0.401	0.003	0.01
LANDUSE	VEGSTRUC	0.301	0.029	0.05
LANDUSE	COARSEWD	0.306	0.026	0.05
LANDUSE	INVASIVE	0.383	0.005	0.01
DEVELOP	SOILDIST	0.496	<0.001	0.01
SOILDIST	VEGSTRUC	0.545	<0.001	0.01
SOILDIST	INVASIVE	0.571	<0.001	0.01
VEGSTRUC	COARSEWD	0.627	<0.001	0.01
VEGSTRUC	INVASIVE	0.4	0.003	0.01
VEGSTRUC	REDMAPLE	0.475	<0.001	0.01
COARSEWD	REDMAPLE	0.334	0.017	0.05
VEGSTRUC	MEANCALL	0.607	0.001	0.01
VEGSTRUC	MEANCNAT	0.581	0.002	0.01

## CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER MODEL DEVELOPMENT AND TESTING

This study represents an initial assessment after three years of a planned 10 – 20 year effort. The initial land cover patch model seems to work well at ranking patch types that tend to occur in large patches. Forest interior nesting birds, a group of organisms that rely on the tested land cover type, correlate with patch ranking, indicating the model will predict interior nesting bird species habitat. Because no other cover types have been tested one cannot conclude the patch model works equally well with other land cover types.

The initial patch model does not correlate well with many of the metrics we chose to examine. This is likely due to several reasons, including sampling bias introduced by the sample site selection methodology, sampling methodology, model scale versus sampling scale issues, and the relative heterogeneity of the sample sites. Robust testing of the land cover patch model and the suite of metrics will require further sampling in a range of cover types and across a broader geographic area than that presented here.

As noted in the Introduction, due to the ever present limitation of available resources, there continues to be a need for tools that will assist resource managers in determining where limited financial and human resources should be directed to result in the best “return on investment” to the natural resource. While the patch model presented here appears to work well for predicting high quality upland deciduous forest habitat (based on the presence of interior bird species), it is not known whether the model will be as applicable to other community groups and is unlikely to work as well for small patch size communities. In addition, there is no evidence to indicate that the model is predicting high quality forest patches for other taxa or a wider suite of ecological functions. Thus, future efforts may be better focused on developing coarse grain approaches to *a priori* identification of high biodiversity areas, rather than on identifying community-specific areas. The coarse-grain effort should be ultimately followed by community-specific and species-specific modeling to address fine-grained issues of rare communities and species.

In general, future modeling and testing efforts should include the following aspects:

- Assuring grain appropriateness of metrics used to test models
- Increase the robustness of the models by incorporating factors other than patch measures (e.g. soils, topography, aspect, etc.)
- Produce specific models for the ecosystem function of interest instead of expecting one model to represent a wide range of functions
- Thorough consideration of metric selection and experimental design as part of the model development and testing regime
- Test and calibrate the metrics to the community type or model being tested
- Use a four-point rule instead of an eight point rule to define patch connectedness, or use hexagon-shaped planning units, in the patch model
- Evaluation of correlation between metrics, along with removal of redundancy and selection of cost effective quantitative variables as metrics
- Include additional animal taxa as metrics
- Sample geographic areas rather than a single community type
- Include private lands in the sampling effort

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# Appendix A

## Natural Community Metric Criteria



## Upland Mesic Forest Field Metric Criteria

Field Metric	Metric rating criteria			
	4 = Excellent	3 = Good	2 = Fair	1 = Poor
<b>Landscape context**</b>				
Buffer width	Occurrence is buffered by +/- natural land >100m on entire periphery.	Occurrence is well-buffered (50-100m) on >75% of periphery.	Occurrence is well-buffered on >50% of periphery or narrowly buffered (25 to 50m) on >75% of periphery.	Occurrence poorly buffered (<25m on entire periphery), or not buffered.
Broader land use	Natural (matrix) landcover dominates (>75% of landscape).	Landscape is partially natural (50-75%), remainder agricultural. Agricultural areas are isolated by natural cover.	Landscape predominantly agricultural, with some natural cover (33-50%). Natural lands are isolated by agricultural fields.	Landscape urban or suburban, or almost completely agricultural (<33% natural, natural lands being isolated, small pockets).
<b>Site intactness</b>				
Presence of roads, RR tracks, or other (residential, industrial, commercial) development	Occurrence is unfragmented by roads or other development.	Occurrence is very locally impacted by development (est. <10% area impacted).	Occurrence moderately impacted by development (est. <25% of area impacted). Road(s) built through wetland.	Occurrence is significantly impacted by roads and/or other development (est. >25% of area impacted). Roads, trails, pipelines, etc. significantly alter wetland hydrology.
Soil compaction/erosion	Soil essentially undisturbed, except along trails or nearby roads.	Soil locally disturbed, but that portion occupying <10% of area.	Soil moderately disturbed, but unplowed.	Soil plowed, or significantly compacted by logging equipment, or leaf litter removed.
<b>Community structure and function</b>				
Vegetative structure	Vegetative structure within expected range of variation. Canopy, understory and groundlayer vegetation typical for particular community type. Good patchiness, canopy gaps present.	One (but not more) of the following is true: canopy trees are of the same size class, understory is absent or atypical, groundlayer is depauperate or atypical, or site lacks canopy gaps and patchiness.	Two of the attributes described for Grade 2 sites are true. May display poor patchiness or low presence of canopy gaps.	Vegetative structure significantly altered at all three levels. Trees immature or of a single size class. Understory poorly developed. Ground-layer vegetation significantly reduced or absent.

**Upland Mesic Forest Field Metric Criteria, cont.**

Presence of rotting logs and snags	Highly decomposed rotting logs common on forest floor. Many logs moss-covered, moist. Snags common.	Highly decomposed rotting logs common on forest floor. Many logs moss-covered, moist. Snags rare.	Rotting logs in advanced stages of decomposition rare. Logs in less advanced stages of decomposition (little to no moss cover, etc.) occasional to common.	Forest floor lacks decomposing wood. Rotting logs absent or rare. Woody substrate is restricted to small fallen branches, if present.
Pit-and-mound topography	Forest floor is characterized by diverse pit-and-mound topography, with pits and mounds of various sizes.	Majority (>75%) of forest floor is characterized by diverse pit-and-mound topography, with pits and mounds of various sizes.	Pit-and-mound topography present, but not common, and likely of recent origin. Lack of pits and mounds indicate former savanna conditions or plowing.	Pit-and-mound topography absent. Site was likely pre-settlement savanna, or was plowed.
Evidence of logging	No evidence of logging, or only very minor cutting without species elimination.	Selective cutting, but large, old trees of all typical species remain.	Widespread cutting >50 years before present. Canopy trees mature.	Widespread cutting <50 years before present. Canopy trees immature and/or of small diameter.
Herbivore impacts: deer and other large mammalian herbivores	Signs of deer presence (browsing, trails, scat) rare.	Occasional browsing—fewer than 10% of stems of preferred species (buds on woody plants or anything liliaceous) clipped, and preferred species still abundant. Deer trails and scat noticeable.	Moderate level of browsing—10 to 25% of stems of preferred species clipped. Deer trails and scat common.	Severe browsing. Browse lines visible on shrubs and trees (that topiary look on Juniperus); preferred species prominently browsed and/or rare or absent from site, and less preferred species also browsed. Deer trails and scat abundant.
Species-specific tree mortality (due to insects or disease rather than shade suppression, windthrow, etc.)	No evidence of conifer or hardwood die-off due to pests (hemlock woolly adelgid, emerald ash borer, beech bark disease, anthracnose, etc.). Past die-off of large American elm is expected and not scored.	Very little die-off noted. Less than 10% of individuals of any tree spp. affected by insect or fungal pests. These trees widely scattered or in isolated patches.	Tree die-off significant. Up to 25% of the canopy affected by pests or pathogens.	Extensive die-off of canopy trees noted. Greater than 25% of canopy trees are affected by pests or pathogens.



**Upland Mesic Forest Field Metric Criteria, cont.**

Presence of invasive non-native and/or native vascular plant spp.	Invasive species of significant impact absent. Other non-native spp. may be present, in low numbers.	Invasive spp. of significant impact present, but highly localized (limited to edges or small, widely spaced colonies).	Invasive spp. of significant impact present, occasional. May locally dominate community (<25%).	Invasive spp. of significant impact common or dominating >25% of occurrence.
* Includes mesic northern forest, mesic southern forest	** METRIC ASSESSED OUTSIDE THE BOUNDARIES OF THE 10 HA SAMPLE CELL.			

## Upland Oak and Oak-Pine Forest Field Metrics

Field Metric	Metric rating criteria			
	4 = Excellent	3 = Good	2 = Fair	1 = Poor
<b>Landscape context**</b>				
Buffer width	Occurrence is buffered by +/- natural land >100m on entire periphery.	Occurrence is well-buffered (50-100m) on >75% of periphery.	Occurrence is well-buffered (25 to 50m) on >75% of periphery.	Occurrence poorly buffered (<25m on entire periphery), or not buffered.
Broader land use	Natural (matrix) land-cover dominates (>75% of landscape).	Landscape is partially natural (50-75%), remainder agricultural. Agricultural areas are isolated by natural cover.	Landscape predominantly agricultural, with some natural cover (33-50%). Natural lands are isolated by agricultural fields.	Landscape urban or suburban, or almost completely agricultural (<33% natural, natural lands being isolated, small pockets).
<b>Site intactness</b>				
Presence of roads, RR tracks, or other (residential, industrial, commercial) development	Occurrence is unfragmented by roads or other development.	Occurrence is very locally impacted by development (est. <10% area impacted).	Occurrence moderately impacted by development (est. <25% of area impacted). Road(s) built through wetland.	Occurrence is significantly impacted by roads and/or other development (est. >25% of area impacted). Roads, trails, pipelines, etc. significantly alter wetland hydrology.
Soil compaction/erosion	Soil essentially undisturbed, except along trails or nearby roads.	Soil locally disturbed, but that portion occupying <10% of area.	Soil moderately disturbed, but unplowed.	Soil plowed, or significantly compacted by logging equipment, or leaf litter removed.
<b>Community structure and function</b>				
Vegetative structure (especially presence of oak and pine regeneration as seedlings, saplings, and understory trees)	Canopy, understory and groundlayer vegetation typical for particular community type. Good heterogeneity. Oaks and/or pines show ample regeneration in all size classes.	One (but not more) of the following is true: canopy trees are of the same size class, understory is absent or atypical, groundlayer is depauperate or atypical, or site is homogeneous.	Two of the following are true: canopy trees are of the same size class, understory is absent or atypical, groundlayer is depauperate or atypical. Poor heterogeneity.	Vegetative structure significantly altered at all three levels. Trees immature or of a single size class. Understory poorly developed. Groundlayer vegetation significantly reduced or absent.

## Upland Oak and Oak-Pine Forest Field Metrics

Presence of red maple ( <i>Acer rubrum</i> )	Red maple uncommon or occasional, not a significant component (cover >25%) in any stratum. All size classes represented. Monodominant stands absent.	Red maple occasional. May be a significant component (cover >25%) of one stratum.	Red maple occasional to common, comprising >25% cover in two strata.	Red maple common to abundant, comprising >25% cover in the canopy, subcanopy, and shrub layers.
Coarse woody debris	Coarse woody debris present and abundant in all expected size and decomposition classes. Snags and cavity trees common.	See excellent rating, but lacking snags and/or cavity trees.	Coarse woody debris absent over a significant portion of the forest (>25%). Size class and decomposition classes poorly represented. Snags and cavity trees, if present, are rare.	Coarse woody debris nearly absent. Only small branches and recent treefall present. Decomposition minimal. Snags and cavity trees absent.
Evidence of logging	No evidence of logging, or only very minor cutting without species elimination.	Selective cutting, but large, old trees of all typical species remain.	Widespread cutting >50 years before present. Canopy trees mature.	Widespread cutting <50 years before present. Canopy trees immature and/or of small diameter.
Herbivore impacts: deer and other large mammalian herbivores	Signs of deer presence (browsing, trails, scat) rare.	Occasional browsing—fewer than 10% of stems of preferred species (buds on woody plants or anything liliaceous) clipped, and preferred species still abundant. Deer trails and scat noticeable.	Moderate level of browsing—10 to 25% of stems of preferred species clipped. Deer trails and scat common.	Severe browsing. Browse lines visible on shrubs and trees (that topiary look on Juniperus); preferred species prominently browsed and/or rare or absent from site, and less preferred species also browsed. Deer trails and scat abundant.

**Upland Oak and Oak-Pine Forest Field Metrics**

Species-specific tree mortality (due to insect pests, fungus, or disease)	No evidence of tree die-off due to pests (gypsy moth, oak wilt, pine rust, etc.).	Very little die-off noted. Less than 10% of individuals of any tree spp. affected by insect or fungal pests. These trees widely scattered or in isolated patches.	Tree die-off significant. Up to 25% of the canopy affected by pests or pathogens.	Extensive die-off of canopy trees noted. Greater than 25% of canopy trees are affected by pests or pathogens.	
Presence of invasive non-native and/or native vascular plant spp.	Invasive species of significant impact absent. Other non-native species may be present in low numbers.	Invasive spp. of significant impact present, but highly localized (limited to edges or small, widely spaced colonies).	Invasive spp. of significant impact present, occasional. May locally dominate community (<25%).	Invasive spp. of significant impact common or dominating >25% of occurrence.	
* Includes dry southern forest, dry-mesic southern forest, dry-mesic northern forest	** METRIC ASSESSED OUTSIDE THE BOUNDARIES OF THE 10 HA SAMPLE CELL.				

