ON A WING AND A (GIS) LAYER: PRIORITIZING MIGRATORY BIRD STOPOVER HABITAT ALONG GREAT LAKES SHORELINES

Final report to the Upper Midwest/Great Lakes Landscape Conservation Cooperative

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Table of Contents

Appendices

Introduction

For migratory birds, stopover sites provide essential food resources during a part of the life-cycle when at least some species suffer relatively high mortality (Sillett and Holmes 2002). Stopover habitat has been neglected in many conservation efforts to protect migratory birds, in part because habitats are used for a short time and use can vary depending on many factors that are independent of the characteristics of the site, such as weather conditions during migration. This short and variable window of habitat use makes the process of identifying important areas to protect very challenging. Even so, surprisingly little attention has been devoted to protecting the habitat needed to support this part of the life-cycle. In addition to focusing on this gap in a protection strategy for birds, the work summarized in this report directly addresses issues raised by a review of critical needs in bird conservation (Faaborg *et al.* 2010) which noted that managers and planners need to "reframe the goal of 'more' to 'how much more' and 'where'." This call to action emphasized that even though we lack important information to make some conservation decisions that "…we do know enough to get started with conservation efforts." They eloquently stated the motivation behind this project, which is to translate what we do know into guidance for conservation action. Specifically, in this work we describe a mapping exercise intended to highlight important stopover habitats based on a set of attributes (spatial and ecological features associated with large numbers of migratory birds) derived from literature review and expert opinion. This work presents stopover site attributes and maps for three groups of birds, landbirds, shorebirds, and waterfowl, within 25 km of Lakes Michigan, Huron, Erie, Ontario, and connecting waters.

The Great Lakes, particularly coastal and nearshore areas, provide globally or continentally important stopover sites[1] for all groups of migratory birds: waterfowl, shorebirds, landbirds (defined here as songbirds and raptors), and waterbirds (loons, grebes, cormorants, herons, rails, cranes, gulls, and terns). Much of the Great Lakes coastal aquatic and terrestrial landscapes that once supported migrating birds have been lost or degraded, yet the region continues to support hundreds of millions of migrants during both spring and fall migration. Even this reduced amount of habitat continues to be threatened by development, habitat conversion, water quality degradation, invasive species, recreational and consumptive activities, communication towers, climate change, and associated human responses to climate change, such as alternative energy development (Chipley 2003, Ontario Important Bird Area Project, Soulliere *et al.* 2007a). Accordingly, it is urgent that we better define, protect, restore, and manage migratory bird stopover sites (Faaborg *et al.* 2010) in the Great Lakes region (Great Lakes Wind Collaborative 2011) given current and emerging competing land uses at these sites.

The objective of this project was to identify and score attributes of areas that serve as important stopover sites for migratory birds near the Great Lakes shorelines, and then using these attributes, to map potential stopover habitats across the basin. Thus, this project addresses Theme 5 (ecological connectivity) and provides baseline data for Theme 3 (avian response to climate change), of the Upper Midwest/Great Lakes Landscape Conservation Cooperative and also helps achieve one of the goals of the Upper Mississippi River and Great Lakes Region Joint Venture, gaining a better understanding of

[1] http://iba.audubon.org/iba/prioritySiteIndex.do?priority=Global; http://www.ibacanada/explore.jsp?lang=en

stopover sites. The project also addresses several long term goals of the Great Lakes Restoration Initiative Action Plan, Area 4 (Habitat and Wildlife Protection and Restoration). This project is an essential step towards the ultimate objective of protecting bird habitats on and near the Great Lakes shorelines for the conservation of migratory birds. In addition to helping identify key places where funds available for habitat protection or restoration could be invested, this project should guide the siting of wind energy facilities, and where to focus research designed to understand how migrants are responding to climate change, and other current and projected activities that could disproportionately affect large numbers of migrating birds near the Great Lakes shorelines.

Methods

Our work is based on a literature synthesis and expert opinion. We identified attributes associated with stopover sites that could be mapped with regionally available data layers, developed criteria to score these attributes, and then mapped these scores to indicate the relative importance of stopover sites within our study area.

STUDY AREA

Our study area includes terrestrial and aquatic areas within 25 km of Lakes Michigan, Huron, Erie, and Ontario and connecting waters in Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, and New York, USA and Ontario, Canada (Figure 1). Lake Superior was excluded from this study because, due to the lower rate of land conversion, threats to stopover sites in that region are relatively low. The 25 km boundary was chosen because it approximates the distance inland from the Great Lakes where elevated numbers of birds (relative to areas without major barriers, and best documented for landbirds), occur during migration (Bonter *et al.* 2009, Buler and Dawson 2012).

BIRD GROUPS COVERED

We developed stopover site criteria for waterfowl, shorebirds, and landbirds (including raptors). As little is known about migration habitats for many waterbirds (Soulliere *et al.* 2007a, Wires *et al.* 2010), including loons, grebes, cormorants, herons, gulls, terns, rails and cranes, we did not specify criteria for this diverse group of birds. However, due to overlap in habitats typically used by these bird groups (Soulliere *et al.* 2007b), the criteria for stopover sites for waterfowl and shorebirds may also indicate priority areas for many species of waterbirds. With respect to raptors, the largest concentrations typically occur near the Great Lakes shorelines (Bildstein 2006, Goodrich and Smith 2008). Our criteria for identifying stopover sites for landbirds (non-raptor), which are prey for several species of raptors, include many areas where migrating raptors are found, such as the north shore of Lake Superior (Bardon 2012), and thus we suggest that protecting these priority areas should also help protect raptor migration corridors.

Our methods for identifying and scoring attributes of stopover sites are outlined in bullet form below. Data sources used to map attributes by bird group are described in Appendix 1, specific scoring criteria are listed in Tables 1-3, and procedures for evaluating data layers to map attributes are described in

Appendices 2 and 3. More detailed descriptions of our rationale for identifying and scoring attributes are provided following these bullets, which outline our methodology.

- First, we conducted a comprehensive literature review of papers selected from a bibliography of approximately 1,200 papers on avian migration, and identified attributes associated with sites supporting large numbers of migratory birds during spring migration, when distribution patterns are best known and conservation needs may be greatest.
- We then translated published observations, and the opinions of regional experts, into a set of rules, or "attributes" that could be applied in a GIS environment. In general, these rules focused on distance factors (*i.e.* distance from a Great Lake or other water body), landcover, or a function that included both a distance measure and landcover type. We recognize that vegetation and other site-based characteristics are essential components of evaluating potential stopover habitat, but these factors are not evaluated in our regional GIS-based approach due to a lack of consistent vegetation across the study area. While some landcover sources used in these analyses include detailed vegetation-type categories, our expert team determined that there was enough uncertainty and inconsistency in terms of how these categories were applied across the study area to suggest that we should not attempt to prioritize sites based on factors like tree species composition or vegetation structure. Key habitat descriptors that can be applied in finer scale evaluations are described in each bird group section in this report.
- We scored each attribute independently for each bird group and summed the scores for each unit of analysis, 1 ha, within the study area.
- We prepared maps depicting the distribution of stopover sites for each bird group, by summed attribute score, across the study area.

CRITERIA AND METHODS FOR IDENTIFYING STOPOVER SITES

SCIENTIFIC BASIS FOR IDENTIFYING ATTRIBUTES. Our descriptions of suitable habitat for each bird group builds on earlier synopses of stopover attributes in the western Lake Erie basin (Ewert *et al.* 2006); Great Lakes drainages of Wisconsin (Grveles *et al.* 2011); Chicago Wilderness (Byrne 2008); Saginaw Bay (Ducks Unlimited 2005), and southern Ontario (Bryan *et al.* 2011). These efforts involved steps similar to those described above, and incorporated both extensive literature review, and information from regional experts familiar with habitats used by migrating birds. The work described here updates the attributes defined by these groups based on new research, though in some cases attributes developed at these smaller scales have been simplified or not included due to a lack of appropriate spatial data layers at the basin-wide scale. Our updating of the scientific basis for the definition of key attributes of stopover sites included key word searches in Google Scholar, review of references cited in new literature, and information provided by colleagues in this field on unpublished work, studies in progress (*e.g*., site-specific, NEXRAD, other radar work), and expert opinion. We emphasized results from studies done in the Great Lakes region but also considered information from other parts of North America and Europe where migration and landscape characteristics were similar enough to be applicable to the Great Lakes region.

Based on the weight of evidence from these information sources, including our experts' knowledge of sites associated with concentrations of birds in the study area, we worked with our team of experts to translate observations into rules that could be applied in a GIS environment. Our goal was to define individual attributes that could be evaluated separately (*i.e.*, distance from a Great Lake) but would be added together to achieve a score for each bird group. We chose this approach (an index based on factors associated with habitat use), rather than attempting to build a more integrated multi-factor model (*i.e.,* as could be produced by fitting a multi-variate spatial model to location data depicting areas that are known to be used by migrating birds) because observational data are not available for most areas in our study region, and developing an independent set of attributes facilitates updating the map products with new information and spatial data sets as they become available. Further, we saw a benefit in terms of being able to communicate the outputs of our work to diverse audiences when each attribute was considered independently.

USING AREAS OF KNOWN CONCENTRATIONS OF MIGRANTS TO DERIVE STOPOVER HABITAT ATTRIBUTES. A key assumption that underlies our approach to developing a GIS-based model for characterizing stopover habitat across this large area was that we assumed that characteristics of sites that consistently support high numbers of migrants are good predictors of other sites that support large numbers of migrants. While there are many factors that determine the quality of a site to a migrant (Moore *et al.* 1995; Soulliere *et al.* 2007c; Faaborg *et al.* 2010), and many ways to estimate quality of a site for migrants (Soulliere *et al.* 2007c; Faaborg *et al.* 2010), including rates of mass gain (Dunn 2002, Bonter *et al.* 2007, Seewagen and Slayton 2008, Ktitorov *et al.* 2008, Craves 2009, Seewagen and Guglielmo 2010) and indicators of stress or fat metabolism (see Seewagen *et al.* 2011), there are very few areas in the Great Lakes region where habitat quality has been estimated, or compared to estimates of abundance. Further, we recognize that in some cases migrant abundance may be misleading, as it may not be associated with some measures of stopover quality such as mass gain (Suomala *et al.* 2012). Even using migrant abundance is a challenge, because we lack data from most sites in the Great Lakes region. The inconsistency of abundance data across the region motivated this GIS-based approach, as by developing attributes and mapping them across the region, we hope to help highlight areas that might otherwise be overlooked. Thus, while there is still a great need for more data, our team of experts feel that we have enough information to move forward; this approach represents a key step toward highlighting priority areas at a regional scale. These maps are best seen as a screening tool for choosing among options at larger spatial scales that would be complemented with local information on habitat quality when used to make conservation decisions.

FOCUS ON SPRING MIGRATION. Given the lack of information on migration, especially in fall, we did not attempt to develop separate models of habitat used by any group of migrants during spring and fall migration. Research suggests that the relative abundance of migrants as a function of distance from the Great Lakes (Shieldcastle 2009, Ewert *et al.* 2011), habitat selection (Petrie *et al.* 2002; Petrie and Wilcox 2003; Swanson *et al.* 2003; Keller and Yahner 2007; Kohut 2007), and seasonal differences in migration routes (Bildstein 2006) may all vary between fall and spring migration. The attributes selected, and values for each attribute, primarily reflect migrant distribution in the spring when landbirds, and possibly other bird groups, are most concentrated near large bodies of water like the Great Lakes

(Shieldcastle 2009, Ewert *et al.* 2011) and the Gulf Coast (Buler and Moore 2011). We based our analyses on spring migration distributions and shoreline habitats because: 1) mass gain may be less during spring compared to fall migration (Bonter *et al.* 2007, Deutschlander and Muheim 2009, Suomala *et al.* 2012), suggesting that migrants are relatively vulnerable during this period; 2) waterfowl, and possibly other migrants, may be more food limited during spring migration compared to fall migration (Soulliere *et al.* 2007c), and reserves needed for reproduction are accumulated at spring stopover sites (Petrie and Wilcox 2003, Badzinski and Petrie 2006); 3) land near shorelines is where migrants are likely most susceptible to habitat loss because of development pressure (Bonter *et al.* 2007); and 4) migrants may also be particularly sensitive to phenological mismatches that may occur with climate change (Hall and Root 2012) during the relatively short spring migration. Newton (2006), who reviewed effects of migration on population size, concluded that "any factors that increase the cost of migration, especially in spring, could influence subsequent population size". Additional research is needed to adequately model distribution of fall migrants. Interpretation of waterfowl distribution during fall migration, and to some extent shorebirds, is also confounded by hunting which results in displacement of birds. However, it is likely that many important fall migration areas in our study area are captured by our models.

SPATIAL SCALE OF ANALYSIS. Given that birds apparently select stopover sites at landscape to site-specific spatial scales (Moore *et al.* 1995, Petit 2000, Buler *et al.* 2007, Buler and Moore 2011), it was a challenge to define the appropriate scale of analysis for developing rules to characterize important stopover sites across the Great Lakes region. Initial decisions by birds where to land are presumably based on landscape characteristics (Diehl *et al.* 2003, Chernetsov 2006, Buler *et al.* 2007), such as proximity to major barriers (*e.g.*, the Great Lakes), and intactness of the landscape, but are mediated by extrinsic factors, such as weather, and intrinsic factors, such as condition of the bird. Once a bird has landed at a site, availability of favored foraging substrates (Wood 2011), food resources (Graber and Graber 1983, Bellrose 1980, LaGrange and Dinsmore 1989, Smith *et al.* 2007, Strode 2009, Cohen *et al.* 2012), and shelter from weather and predators (Lindström 1990) may prompt or mediate movement within or between patches and thus influence the distribution of birds at sites across a landscape. Although we considered both landscape and site influences on stopover habitat selection and use by migrants in our models, both of which governed the choice of spatial scale of analysis, the models are based on landscape features because there are insufficient data layers describing site features, such as vegetation structure or plant species composition, at a regional or more local scale.

SPATIAL ANALYSIS UNIT. To describe spatial relationships we used raster data layers with a resolution of 30 m (approximately 0.1 ha) pixels. We aggregated these into 100 m (1 ha) pixels to approximate the minimum size of areas in which migrants move during any one stopover event. The most common, or majority, land cover was assigned to each 1 ha pixel; some fine scale ecological information is lost with this approach. However, this aggregation facilitated data analysis and summarization, is more consistent with the spatial scale at which conservation actions are implemented than a 30 m resolution, and is similar to the approach taken by Stralberg *et al.* (2011). However, we recognize that some areas <1 ha may be very important for birds under some circumstances and may not be identified as stopover sites with this approach if they have been aggregated with a "non-habitat" landcover type.

DATA LAYERS: SOURCES AND ANALYSIS

We developed attributes that could be evaluated with single spatial data layers that were available throughout the study area, or by multiple layers that could be combined to create a layer that encompassed the entire study area, and where we believed the resolution of the data layers was consistent with the spatial resolution that migrating birds use to select stopover sites. These data layers are listed in Appendix 1, and described in Appendix 2, and the methods of applying these data layers are presented in Appendix 3 and graphically displayed in Model Builder for each bird group (Model Builder will be available on The Nature Conservancy's Conserve Online with this report). We used data layers from the Coastal Change Analysis Program (CCAP) for the United States and Provincial Land Cover of Ontario (PLC) as our defaults because these data layers are relatively current and coverage is complete for our study area. Where another data layer provided better resolution or more information than CCAP or PLC, we used these sources (see Appendix 1).

ASSIGNING VALUES TO SPATIAL DATA LAYERS: SCORING AND WEIGHTING.

Scores assigned to attribute values (see Tables 1-3) are based on predicted relative migrant abundance and are designed to inform setting priorities for conservation actions.

Scoring.

For each attribute (*e.g.*, suitable habitat) we assigned scores for different values in the spatial data layer; higher scores were assigned to values thought to be most important to migrants. Each attribute was scored independently using the same scale (0-1), which implies that in general, each of these attributes was considered equally important in terms of defining overall value of a site.

All attributes were weighted equally for landbirds, shorebirds, and waterfowl except distance from the Great Lakes shoreline for landbirds. We based this decision on the consistent research finding of relatively high numbers of migrating landbirds in close proximity to Great Lakes shorelines (see section on Rationale below); patterns related to other attributes did not indicate such consistently high abundance of migrants and hence were not weighted. As the state of our knowledge improves, treating these attributes as individual components of a score provides the opportunity to prioritize other components in future versions of these maps.

BIRD GROUP SPECIFIC SCORING AND RATIONALE FOR SCORING

LANDBIRDS (INCLUDING RAPTORS)

Background and caveat.

For at least some songbird species, migration may be the period of the life cycle when adult birds suffer the highest mortality (Sillett and Holmes 2002, Sarah Rockwell, unpublished data). Landbirds typically use several stopover sites en route between wintering and breeding areas (Moore 2000); these sites provide locations for migrants to refuel and seek shelter from weather and predators (Petit 2000). But not all stopover sites, or the landscapes in which they occur, are of equal value to migrants (Petit 2000, Mehlman *et al.* 2005). The relative importance of stopover sites to overall fitness likely varies by bird group, and species within a bird group, and may also be affected by carry-over effects between wintering and breeding grounds (*e.g.*, Runge and Marra 2005) and extrinsic factors such as habitat distribution and weather. Faaborg *et al.* (2010) summarized these relationships for songbirds: "It is clear that the provision of good habitats well distributed across the landscape in preferred migration pathways seems like a safe strategy to protect en route migrants, with the addition of sites in areas where larger barriers to migration may exist, such as along the Gulf of Mexico or Great Lakes" where "…any little fragment of forest, field, or wetland may be valuable on occasion…".

Although raptors are pooled with landbirds for these analyses, the timing, height of migration, and spatial distribution of their migration differs from many songbirds, even though the highest concentrations of most diurnal raptors are near Great Lakes shorelines (Whitefish Point Bird Observatory, unpublished data; Brandon 2012). Most raptors are thought to concentrate near the Great Lakes due to abiotic factors, such as reluctance to cross large bodies of water, or the distribution of thermals, rather than habitat features such as fragmentation (Goodrich and Smith 2008). Major migratory pathways of raptors, which differ between fall and spring, are described in Bildstein (2006) but are close to Great Lakes shorelines in both migration seasons. Consequently, we did not specifically model the distribution of migrating raptors but many important raptor concentration areas overlap with landbird migration concentration areas, such as Holiday Beach/Big Creek Conservation Area, Ontario[2] and Whitefish Point, Michigan (Michigan Important Bird Areas)[3].

The relative importance of a site may change within a season, between years, and by species (*e.g*., Brawn and Stotz 2001, Simons *et al.* 2004) due to short-term extrinsic factors such as weather and long-term factors such as successional change, changes in abundance of plant species of a site over time, climate change, and modifications of the surrounding landscape. In addition, even similar sites at different latitudes may be of different relative importance due to differences in phenology of prey (Ewert and Hamas 1996), which may be confounded by shoreline characteristics such as nearshore substrate. Many of these nuances cannot be characterized by current data layers, nor by our scoring system, but will be articulated in more detail in narratives produced in Phase II of this project.

We do not provide species-specific descriptions of stopover site attributes as there is insufficient data available to make these determinations. Our scoring system is most applicable to forest-dependent species because they are thought to be the most abundant landbird group migrating through the Great Lakes region compared to migrants characteristic of grasslands (Robertson *et al.* 2011) or wetlands (Meyer *et al.* 2010) whose distribution during migration is poorly known. Further, our characterization of landbird stopover sites is not applicable to species such as Horned Lark (*Eremophila alpestris*), American Pipit (*Anthus rubescens*), and Snow Bunting (*Plectrophenax nivalis*), which are primarily found in agricultural lands, bare soil and unconsolidated shoreline, which we defined as being unsuitable

[2] http://www.bsc-eoc.org/iba/site.jsp?siteID=ON034
[3] http://iba.audubon.org/iba/profileReport.do?siteId=1653&navsite=state

habitat for landbirds. Thus, for a small set of migratory landbird species our current system for identifying stopover habitat is less applicable or not applicable, but future work could include developing layers that focus on these less common groups of migrants.

Attributes selected to score landbird stopover site.

We identified four attributes to score landbird stopover sites based on our literature review and consultation with experts (see Table 1):

1. Distance from a Great Lake or connecting water body,
2. Presence of landcover type classified as suitable habitat,
3. Proportion of suitable landcover type within 5 km of a 1 ha pixel, and
4. Distance from non-Great Lakes permanent bodies of water.

<u>Landbird Scoring formula.</u>

From coastline to 1 km inland, for all suitable landcover types:

- Score = 5

From 1-25 km inland:

- Score (maximum score = 4) = score for distance from a Great Lake or connecting water body **+** score for presence of landcover type classified as suitable habitat + score for proportion of landscape in suitable landcover type within 5 km of a 1 ha pixel + score for distance from non-Great Lakes permanent water bodies.

The scoring criteria for each attribute for landbirds are described in Table 1.

<u>Table 1.</u> Scoring criteria for landbird stopover habitat within 25 km of Lakes Michigan, Huron, Erie, Ontario and connecting water bodies. For this bird group, we divided the study area into two zones – within 1 km of the shoreline, and ≥ 1 km - 25 km from a Great Lake or connecting water body. This scoring reflects the assumption that all habitat very close to a Great Lake or connecting water body will be heavily used by landbirds, regardless of habitat type, context, or distance to another water body. "Pixels" in this table refer to the 1 ha scale pixels developed from the 30 m scale landcover datasets (see Appendix 1 and 2).

Landbird stopover criteria – Areas within 1 km of a Great Lake or connecting water body.

1. Landcover classified as suitable habitat.
   Source data layers: TNC New Vector Shoreline for distance from shore, landcover CCAP 2006 (US) /PLC 1999 (Canada), and " permeable" urban areas (NLCD 2006).
   - 5 = Suitable habitat (see classes below, including urban that is >72% permeable surfaces.
   - 0 = Not suitable habitat; classes such as open water, and urban that is < 72% permeable.

Landbird stopover criteria - areas between 1- 25 km from a Great Lake or connecting water body

1. Landcover classified as suitable habitat.
   Source data layers: Habitat layer (CCAP/PLC classes) + permeable urban [NLCD 2006])
   - 1 = All landcover types that represent natural cover, except for bare land, open water, or palustrine aquatic bed. See description below for more details.
   - 0.5 = Landcover types that have some habitat value, but less than those above: Hay, pasture, or palustrine wetland classes, and urban that is >72% permeable.
   - 0 = classes not included above, such as open water, urban that is <72% permeable.

2. Distance from a Great Lake or connecting water body.
   Applied only to areas with a "suitable habitat" score of 1 or 0.5, distance assessed from the TNC New Vector Shoreline.
   - 1 = 1 km
   - 0 = 25 km
   - In between, score is based on an exponential declining function (e^{-x}) from 1 to 0.

3. Proportion of suitable habitat within a 5 km radius.
   Source: Suitable habitat layer (types scoring 1 or 0.5) assessed for each pixel in a 5 km moving window.
   - 1 = High habitat cover (>40% in 5 km)
   - 1 = Rare habitat (habitat in an area with few other habitats available, <15% in 5 km)
   - 0 = Intermediate (>15% but less than 40%)

4. Distance from other water bodies.
   Source data layers for identifying water bodies: CanVec Hydro, NHD Plus. CCAP, PLC.
   - 1 = Less than 100 m from lake, pond, rivers and streams, and wetlands
   - 0 = Greater than 100 m from lake, pond, rivers and streams, and wetlands

Rationale for selecting landcover type classified as suitable habitat.

Based on descriptions of habitat used by landbird migrants in the Great Lakes region, we classified the following landcover types as suitable landbird habitat: undeveloped cover (forest, including deciduous and evergreen forest, mixed forest, and scrub/shrub; grasslands, including pasture/hay and developed open space; palustrine emergent wetland; palustrine forested wetland; palustrine scrub/shrub); and developed cover where there is ≤ 28% impervious surface (28% threshold value was based on a natural break in percent of impervious surface; patches of natural cover in Chicago were associated with areas ≤ 28% impervious surface). Suitable landbird habitat **does not** include high or medium density developed (>28% impervious surface), cultivated land, unconsolidated shore, bare land, open water, or palustrine aquatic bed.

Rationale for selecting distance from a Great Lake or non-Great Lakes permanent water body

Distance from a Great Lake or connecting water body. As a group, landbird migrants are most abundant in nearshore Great Lakes habitats during migration although some species may be most common inland from the shoreline (Brawn and Stotz 2001), or a short distance away from the immediate shoreline (Hyde 1998). Agard and Spellman (1994) found 18% fewer migrants 3-4 km from the Lake Ontario shoreline compared to the shoreline (5% decline/km) in forested and brushy habitats. Spring and fall migrants, especially spring migrants, were also found to be most abundant within 2 km of Lake Ontario (Kristin France, The Nature Conservancy, unpublished data). Rodewald (2007) reported an 18.7% decline in spring landbird migrants in upland forests up to 5.3 km inland from Lake Erie but significantly higher numbers near shoreline beach ridge forests. Ewert *et al.* (2011) noted a 42% decline in numbers of spring migrants from the Lake Huron shoreline to 0.8 km inland with an overall 18% decline between shoreline habitats and habitats 3.2 km inland. Johansen *et al.* (no date) detected more spring migrants along the Lake Superior shoreline than 1 km inland. NEXRAD studies also indicate that migrants concentrate near Great Lakes shorelines relative to inland areas, up to 10- 50 km (Bonter *et al.* 2009; Buler and Dawson 2012). Declines in the number of migrants with distance from the Great Lakes may be due to fall-out (birds landing when they first reach land), birds accumulating near a barrier, and/or the abundance of aquatic-derived prey (Ewert *et al.* 2011 and references therein). Abundance of potential prey, such as aquatic-borne caddisflies, declines from the shores of the Detroit River and Lake St. Clair at a greater than exponential rate with mean dispersal distance ranging from 650 -1845 m from the shoreline (Kovats *et al.* 1996). The number of midges (Diptera) also declines at a greater than exponential rate along the Lake Huron shoreline in spring (Ewert *et al.* 2011), which coincides with migrant distribution. Consequently, we assigned the highest score to sites in a zone from the shoreline to 1 km inland then decreased scores in a negative exponential manner described by the function $y=e^{-x}$, where e = natural log and x = distance from a Great Lake, with the values of 1 – 25 km normalized to values of 0 - 1. This function is an approximation of the decrease in numbers of landbirds and aquatic-borne prey of insectivorous landbirds landward from the shoreline.

Distance from non-Great Lakes waters. Non-Great Lakes waters, such as streams, rivers, lakes, and permanent wetlands, influence landbird migrant distribution (Nicholls *et al.* 2001, Wilson 2001, Ewert *et al.*, unpublished data) perhaps due to the dispersion of aquatic-borne insects from the water source

(MacDade *et al.* 2011), diverse vegetation structure (Nicholls *et al.* 2001), or as barriers to dispersal resulting in accumulations of migrants. In some landscapes, however, migrants may be more abundant in upland sites compared to riparian habitats (Rodewald and Matthews 2005), or the distance of suitable habitat from a river had no influence of numbers of migrants (Packett and Dunning 2009). Because of the wide array in size and characteristics of these water bodies, and the paucity of information how migrants respond to different types of water bodies, we defined a buffer of 100 m around all non-Great Lakes permanent water bodies as being more favorable for landbird migrants than areas beyond 100 m. This value was primarily selected on the basis of expert opinion. There is little empirical evidence to provide a more refined assessment, although it is likely that different buffer widths apply to water bodies of different sizes, widths (such as different stream orders) and other configurations.

Rationale for defining proportion of suitable landcover types within 5 km of a 1 ha pixel.

Landbirds make decisions where to stopover at multiple spatial scales (Moore *et al.* 1995; Chernetsov 2006). Accordingly, we defined parameters for variables from landscape to site scales for which there were appropriate GIS data layers. Landbirds may make stopover site selection decisions at a 0.5 km (Cashion 2011; Johnson 2012) to 5-10 km scale (Buler *et al.* 2007; Chernetsov 2006, Bonter *et al.* 2009) as they descend to a particular stopover site. Increased mass gain of passerines has been associated with increased amount of suitable cover within a 5 km scale in Europe (Ktitorov *et al.* 2008). Based on estimates of home range sizes of birds at urban (Seewagen *et al.* 2010) and rural stopover sites (Slater 2011) and dispersal of birds at stopover sites (Aborn and Moore 1997, Cochran and Wikelski 2005, Matthews and Rodewald 2010, Ktitorov *et al.* 2010, MacDade *et al.* 2011, references in Buler and Moore 2011), it appears many landbird migrants remain within 100 m to 3 km of sites after landing or settling from the previous night's migration. For instance, the home range (based on 90% fixed kernel home range size) for migrating Ovenbirds (*Seiurus aurocapillus*) in New York City was approximately 3 ha in both spring and fall (Seewagen *et al.* 2010). Longer distance dispersal at a stopover site occurs in some species, 6 km/day for Yellow-rumped Warblers (*Setophaga coronata*) near Lake Erie, Ohio (Buchanan 2008), and up to 30 km for other species near Long Point, Ontario (Mills *et al.* 2011, Taylor *et al.* 2011). We elected to calculate landscape metrics based on the proportion of suitable habitat within a 5 km radius. This scale has been shown to be relevant for many species as well as important for both initial settlement decisions and in the middle of the distance range across species for post-settlement movement (home range or dispersal to an alternative location).

The proportion of the landscape in suitable cover appears to be the best metric for evaluating how the distribution of migrants is affected by the amount and distribution of habitat, including patchiness (Williams 2002, Bender *et al.* 2003, Tischendorf *et al.* 2003, Johnson 2012); Table 1 summarizes how we incorporated these parameters into the GIS model. Studies indicate that the proportion of suitable cover in the landscape is positively associated with migrant density near the Gulf of Mexico (Buler *et al.* 2007) and in the Great Lakes region (Bonter *et al.* 2009). However, in other fragmented landscapes, studies have demonstrated that higher densities of migrating landbirds occur in relatively small patches (Williams 2002), isolated patches in an agricultural landscape (Diehl and Larkin 2003), and isolated patches surrounded by <10% woody cover (Strobl 2010). Relative isolation and size of sites, measured by distance between sites, also influence migrant movements and distribution (Matthews and Rodewald

2010), but defining isolation, and thus connectivity, is difficult (Bender *et al.* 2003, Tischendorf *et al.* 2003). Further, responses of migrants to habitat distribution may be landscape (Skagen *et al.* 1998; Packett and Dunning 2009), patch (Ewert *et al.*, unpublished data), and species-specific. Based on this collective set of studies, then, the highest scores were assigned to sites in landscapes with the least amount of surrounding cover (<15% within 5 km; these sites provide essential refugia) and those within landscapes with the most cover (>40%; these sites provide the best opportunities for refueling and shelter). Sites located in landscapes with intermediate cover (15-40%) may not be as essential as refugia or as high quality refueling sites compared to landscapes with more or less suitable habitat, so these sites were assigned lower scores.

Potential characteristics of stopover habitat beyond the scope of this project.

<u>Patch characteristics.</u> We did not score any patch characteristics, including isolation, distances from other patches, patch size, or ratio of edge versus interior habitat within a patch because of the wide range of responses of landbird migrants to these habitat characteristics. In some areas, abundance of migrants was positively correlated with patch size (Martin 1980, Somershoe and Chandler 2004). In other areas migrant distribution relative to patch size varied by species or spring or fall migration (Keller and Yahner 2007), or there was no relationship between patch size and migrant distribution (Bonter *et al.* 2009). Some migrants may also be more frequent in edge compared to interior portions of a forest patch (Blake and Hoppes 1986, Rodewald and Brittingham 2004, Keller *et al.* 2009). As Buler *et al.* (2007) noted, "In fact, both empirical (McGarigal and McComb 1995, Trzcinski *et al.* 1999, Lichstein *et al.* 2002) and theoretical studies (Fahrig 1997, 1998, 2002) reveal that landscape composition is a better predictor of bird distributions within forests than measures of habitat fragmentation," such as patch size or edge metrics.

<u>Habitat characteristics</u>. Different species of landbirds respond differently to habitat features within a patch, including habitat structure (Parnell 1969), plant species composition (Pollock *et al.* 2004, Strode 2009, Wood 2011), successional stage (Rodewald and Brittingham 2004, Grundel and Pavlovic 2007, Smith and Hatch 2008, Packett and Dunning 2009), prey species and abundance and distribution (Smith *et al.* 2007; Strode 2009), and seasonal differences, such as presence of fruit (Parnell 1969, Parrish 2000). However, there are insufficient studies and few consistent distribution patterns associated with habitat features to consider scoring sites with patch scale resolution even though heterogeneity of a patch, and other patch characteristics (such as edge versus interior) influence the distribution and abundance of migrants and almost certainly, the relative value of a site to migrating landbirds. Generally, it appears there is a positive association of migrating landbirds with 1) more complex vegetation structure; 2) early successional habitat, especially during fall migration; 3) perhaps higher plant species richness; and 4) relatively abundant food resources (Hutto 1985, Martin and Karr 1986, Rodewald and Brittingham 2004, Buler *et al.* 2007). Additional work is needed to better describe these relationships, and many complex interactions among these and other features (Deppe and Rotenberry 2008), including inter-and intra-seasonal variation at and between sites, species-specific foraging preferences, and how birds track resources, before contributions of these factors to stopover site quality can be articulated and mapped confidently. In addition, regional spatial data that can describe

or indicate these relationships would need to be developed. Because these habitat features likely vary significantly at fine scales and hence likely influence bird distributions at fine scales, including the 1 ha scale of our analysis units, we are unable to model their effects at a regional scale.

Interactions among landscape attributes. Although the relative importance of any one attribute may be context dependent (*e.g.*, the importance of the proportion of the landscape in suitable cover may vary with distance from the Great Lakes, peninsulas, orientation of the lake), we did not assign scores or weights to these interactions, except for the 0-1 km distance from a Great Lake where all suitable habitat was assigned a high score. We scored attributes independently to minimize our biases and to clearly articulate the drivers of the score.

SHOREBIRDS

Background and caveats.

Shorebirds are more locally distributed during migration compared to landbirds. Most species occur in moist areas with short and sparse vegetation (Davis and Smith 1998, Farmer and Parent 1997, Shieldcastle 2010), such as mudflats and margins of wetlands, although some species, such as American Golden-Plover (*Pluvialis dominica*), Upland Sandpiper (*Bartramia longicauda*), and Buff-breasted Sandpiper (*Tryngites subruficollis*), characteristically select dry fields or mudflats during migration in the Great Lakes region (Ewert *et al.* 2006, Potter *et al.* 2007, Shieldcastle 2010), and others, such as American Woodcock (*Scolopax minor*), are found in wooded areas with moist soil. Compared to landbirds and waterfowl, there are relatively small numbers of shorebird migrants in the Great Lakes region, but the available sites may be critical for refueling. Protection and maintenance goals by landcover type for shorebirds in the Upper Mississippi River/Great Lakes region Joint Venture, which include much of the study area for this project, are presented in Potter *et al.* (2007).

The greatest concentration of shorebirds within 25 km of the Great Lakes is found near the western basin of Lake Erie, the only regionally important shorebird stopover area as defined by the Western Hemisphere Shorebird Reserve Network[4]; recent evidence suggests this site is of international significance (Baranowski 2007). Shorebirds occur in smaller numbers elsewhere along Great Lakes shorelines, such as Tawas Point (National Audubon Society 2012) and Peninsula Point, Michigan (Skye Haase, unpublished data); Presqu'ile Provincial Park, Long Point, and Hillman Marsh, Ontario (Ross et al. 2003), especially areas with mudflats. Relatively small numbers of shorebirds are found on sand beaches and rocky shores.

Shorebird use of any one site may vary with changes in Great Lakes water levels, precipitation before and during migration and, in the case of managed marshes, with the timing of water-level management (Potter *et al.* 2007). Even the most favored sites may vary within and between migration seasons (see Skagen and Knopf 1994, Warnock *et al.* 1998), which makes identification of shorebird stopover sites particularly challenging, especially along the Great Lakes shorelines. However, we assume those sites used most frequently during migration, and between years, are the most important shorebird stopover

[4] http://www.whsrn.org/sites/list-sites

sites. A mosaic of habitats with varying water depths (up to 5 cm deep and 5-20 cm deep) will likely benefit the largest number of shorebird species given the wide range of habitats used by different species (Potter *et al.* 2007), but this is very difficult to characterize with existing data layers. We have not included shorebird species, such as American Golden-Plover, whose primary stopover habitat is dry, upland fields (O'Neal and Alessi 2008) with this ranking system. Many species of other migrating waterbirds, including waterfowl (Potter *et al.* 2007), rails, herons, and cranes, use sites favorable for shorebird stopover sites.

Attributes selected to score shorebird stopover site.

We identified five attributes to score shorebird stopover sites based on our literature review and consultation with experts (see Table 2):

1. Landcover type associated with suitable habitat,
2. Amount of wetland cover within 3 km radius of suitable landcover type,
3. Patch size,
4. Adjacent cover type within 100 m of suitable landcover type, and
5. Distance from a Great Lake or connecting water body.

<u>Shorebird Scoring formula.</u>

Shorebird score = score for landcover type associated with suitable habitat + score for amount of wetland cover within 3 km radius of suitable landcover type + score for patch size + score for adjacent cover type within 100 m of suitable landcover type **+** score for distance from a Great Lake or connecting water body.

The scoring criterion for each attribute for shorebirds appears in Table 2. For illustrative purposes we mapped the distribution of each criterion independently as well as the summed scores for all attributes (Figure 2).

Table 2. **Conservation priority scores for shorebird stopover habitat within 25 km of Lakes Michigan, Huron, Erie, Ontario and connecting water bodies. Landscape cover type was scored first, and only patches with suitable habitat were scored for the remaining four attributes.**

Shorebird stopover attributes
1. Landcover classified as suitable habitat. *Source data: CCAP(US 2006) & PLC (1999) for landcover, and STATSGO (US) & SLR (Canada) for hydric soils.* 1 = Emergent wetlands 0.5 = Agricultural fields with hydric soils 0.25 = Beach
2. Amount of wetland cover within 3 km radius of suitable landcover type. *Source data: CCAP (US 2006) and PLC (Canada 1999) - applied to any pixels scoring 0.25 or higher in suitable habitat score.* 1 = >40% wetland cover in 3 km radius window 0.5 = 15-40% wetland cover 0.25 = < 15% wetland cover
3. Patch size (patch can include more than one of the "suitable habitat" landcover types shown above) *Source data: same as suitable habitat.* 1 = ≥10 ha (>25 acres) 0.5 = <10 ha (<25 acres)
4. Adjacent cover type within 100 m of the pixel of suitable habitat. Describes presence/absence of a buffer from developed areas or forests. *Source data: same as suitable habitat.* 1 = Undeveloped, non-forest 0.5 = Undeveloped, forest 0 = Developed
5. Distance from a Great Lake or connecting water body. *Source data: TNC New Vector Shoreline.* 1 = ≤3.2 km from shoreline 0.5 = >3.2 km and ≤16 km from shoreline 0 = >16 km from shoreline

Rationale for defining Landcover type associated with suitable habitat.

Shorebirds appear to preferentially select lake-affected estuarine and managed marshes near Great Lakes shorelines, compared to non-Great Lakes ephemeral wetlands and agricultural fields with hydric soils (Baranowski 2007). Similar to playas with longer hydroperiods (Anderson and Smith 2000), estuarine, Great Lakes influenced sites and managed wetlands may support greater invertebrate biomass than ephemeral wetlands or agricultural fields, have more predictable suitable habitat (mudflats and shallow water with little or no vegetation [Davis and Smith 1998]), and consequently may have higher rates of use. During a two-year period, Baranowski (2007) found that managed marshes supported the most shorebird use-days (318,752) followed by lake-affected areas not in managed marshes (148,011) and agriculture fields (18,541). Agricultural fields were used less than wetland areas during both spring and fall migration as has been reported from the Fraser River Delta, British Columbia (Shepherd and Lank 2004), and in Virginia (Rottenborn 1996). Estuarine habitat may be important stopover sites for shorebirds in the Great Lakes, at least in the Lake Erie region, and elsewhere, perhaps particularly those estuaries that were not scoured during periods of high Great Lakes' water levels (Mark Shieldcastle, personal communication).

Rationale for defining amount of wetland cover within 3 km radius of suitable landcover type.

Wetlands with a higher degree of connectivity (*i.e.*, complexes of small, closely spaced wetlands) support a greater diversity and abundance of migrant shorebirds, perhaps especially during dry periods (Taft and Haig 2006a,b). Increased landscape connectivity at stopover sites allows shorebirds to utilize more sites for foraging with less energy output. The number and/or species richness of shorebirds are positively associated with the amount of wetland cover (Niemuth *et al.* 2006, Elphick 2008) at a scale of 3-10 km (Farmer and Parent 1997, Fairbairn and Dinsmore 2001, Webb *et al.* 2010). Local movements of approximately 4 km by a small number of spring migrating Semipalmated Plovers (*Charadrius semipalmatus*) and Dunlins (*Calidris alpina*) in the western Lake Erie basin are consistent with this scale (Keith Norris, The Ohio State University, unpublished data), although one bird moved 20 km. However, in the Great Basin, where stopover habitat is widely dispersed, local movements of shorebirds up to 90 km occur (Plissner *et al.*, unpublished data, cited in Warnock *et al.* 1998); it is unknown if similar dispersion occurs in widely scattered habitats in the Great Lakes region.

From the ranges listed above, the minimum (3 km) was chosen for attribute scoring since some research shows that as the distance between wetlands decreased, and the proportion of the landscape composed of wetlands increased, individual birds moved between wetlands more frequently and moved longer distances from original stopover sites (Farmer and Parent 1997). Hence, the most connected landscapes will likely allow shorebirds to exploit more feeding sites with reduced searching costs, and by choosing the minimum inter-wetland distance cited in literature, we prioritized those landscapes that support high shorebird concentrations with the least amount of competition for resources.

Rationale for defining parameters associated with patch size.

Selection of stopover sites by shorebirds as a function of patch size and perimeter is poorly described. Villani (2010) reported that shorebird densities and abundance in Louisiana was negatively related to field area while Webb *et al.* (2010) found a positive relationship between wetland size and shorebird species richness in the Rainwater basin of Nebraska. We adopted the criterion of 10 ha as a threshold between high and low scoring sites based on Ewert et al. (2006) but acknowledge that this criterion is largely based on expert opinion and has little empirical support.

Rationale for defining parameters associated with adjacent cover type within 100 m of suitable landcover type.

Open, undeveloped habitat adjacent to suitable habitat provides the best shorebird stopover sites (Cole *et al.* 2002, Villani 2010), especially areas relatively free of anthropogenic disturbance (Borgmann 2011). These areas have relatively few predators (Cresswell 1994, Ydenberg *et al.* 2002) and fewer disturbances, which maximizes time available for foraging, thus enhancing mass gain at a stopover site. Based on a summary of studies evaluating shorebird response to anthropogenic disturbance (Borgmann 2011), we adopted 100 m as a threshold from which to differentially score pixels. Although predation rates on shorebirds by raptors, especially Peregrine Falcons (*Falco peregrinus*) and Merlins (*Falco columbarius*), are higher closer to cover (Creswell 1994, Ydenberg *et al.* 2002), including dikes (Butler *et al.* 2003), there are no clear threshold values to score distance to cover based on predation solely so our criterion for adjacent cover type is based on anthropogenic disturbance.

Rationale for defining parameters associated with distance from a Great Lake or connecting water body.

Although there is very little literature quantitatively describing shorebird diversity and abundance as a function of distance from Great Lakes shorelines, it appears that shorebirds concentrate along marine coastlines where, unlike the Great Lakes, dispersal patterns are strongly affected by tidal fluctuations (Rottenborn 1996, Shepherd and Lank 2004). However, Baranowski (2007) found that estuaries in the western Lake Erie basin of Ohio attracted the most diverse and largest number of shorebirds during autumn. Qualitatively, the following species have been noted to concentrate near Great Lakes shorelines in Ohio and/or Michigan: Piping Plover (*Charadrius melodus*), Black-bellied Plover (*Pluvialis squatarola*), American Avocet (*Recurvirostra americana*), Lesser Yellowlegs (*Tringa flavipes*), Willet (*Catoptrophorus semipalmatus*), Ruddy Turnstone (*Arenaria interpres*), Red Knot (*Calidris canutus*), White-rumped Sandpiper (*Calidris fuscicollis*), Baird's Sandpiper (*Calidris bairdii*), Dunlin, Whimbrel (*Numenius phaeopus*), Marbled Godwit (*Limosa fedoa*), Hudsonian Godwit (*Limosa haemastica*), and Sanderling (*Calidris alba*) (Campbell 1968, Peterjohn 1989, Granlund *et al.* 1994, Shieldcastle and Shieldcastle 2003). The criterion used to establish scores for shorebird stopover sites as a function of distance from the Great Lakes is a coarse estimate based on expert opinion (Ewert *et al.* 2006).

Potential characteristics of shorebird stopover habitat beyond the scope of this project.

Although different shorebird species have preferred foraging water depths (Potter *et al.* 2007), especially shallow water or at or near a shoreline (Davis and Smith 1998, Shieldcastle 2009), we did not score areas on the basis of water depth, vegetation height, or vegetation density because 1) each species was not treated separately, 2) water levels at any one site, including those near the Great Lakes shores, vary temporally from very short periods (seiche or amount of precipitation before or during migration) to seasonal and long-term cyclical changes in water levels of the Great Lakes, and 3) lack of consistent, comparable data across the region. Because vegetation species' composition, height and density are dependent on the periodicity and duration of particular water depths, we could not score sites for vegetation characteristics.

WATERFOWL

Background and caveat.

The open waters, deep water marshes, shallow semi-permanent marshes, swamps, and open mudflats of the Great Lakes region support up to 3 million migrating waterfowl (Great Lakes Basin Commission 1975) of approximately 30 species including those typically found on offshore waters of the Great Lakes, such as Long-tailed Ducks (*Clangula hymalis*), to those preferring forested wetlands, such as Wood Ducks (*Aix sponsa*). Soulliere *et al.* (2007c) identified a suite of species, including Tundra Swan (*Cygnus columbianus*), Canvasback (*Aythya valisineria*), and Lesser Scaup (*Aythya affinis*), for which the Great Lakes region provides important migration and wintering sites. Important Bird Areas (IBAs) have been identified for migrating waterfowl on Lakes Michigan, Huron, Erie and Ontario (National Audubon Society 2012). The western basin of Lake Erie, Lake St. Clair and the Detroit River have been identified as being of continental significance in the North American Waterfowl Management Plan during the non-breeding season, especially for Tundra Swan, Canvasback, Lesser Scaup, Redhead (*Aythya americana*), Mallard (*Anas platyrhynchos*), American Black Duck (*Anas rubripes*), Blue-winged Teal (*Anas discors*), American Wigeon (*Anas americana*), Wood Duck, Bufflehead (*Bucephala albeola*), Common Goldeneye (*Bucephala clangula*), and Red-breasted Merganser (*Mergus serrator*).

Waterfowl may spend a disproportionate amount of time at stopover sites compared to other bird groups so stopover sites may be an especially important part of the complete life-cycle dynamics that may affect productivity. For example, up to 51% of the life cycle of the eastern population of Tundra Swans is spent on migration (27% on Great Lakes) (Petrie and Wilcox 2003) and Lesser Scaup may spend up to 42% of their spring migration in Great Lakes waters (Badzinski and Petrie 2008). Consequently, protecting stopover sites for many species of waterfowl may have particularly high conservation value. This may be especially true during spring migration when waterfowl may be food limited compared to fall (Soulliere *et al.* 2007c) and when waterfowl may be storing reserves for reproduction.

The explosion of introduced populations of Dreissenid mussels has altered the relative abundance of waterfowl prey (Ross *et al.* 2005, Schummer *et al.* 2008), affecting different species of waterfowl, and may have long-term effects on abundance (Schummer *et al.* 2008) and perhaps distribution of waterfowl. Future iterations of attribute identification will need to account for the ongoing changes in the biota of Great Lakes and inland waters due to introductions and climate change.

The distribution of waterfowl in the open waters of the Great Lakes is poorly known. Recent work (Norris and Lott 2012), prompted by potential wind energy development, indicates that many waterfowl are concentrated closer to the shores of Lake Erie than in offshore waters. Ongoing work in other parts of the Great Lakes, including Lakes Michigan, Huron and St. Clair, will permit a more complete description of waterfowl distribution offshore soon. Our depiction of waterfowl distribution during migration almost certainly overstates areas important for waterfowl during migration (*e.g.*, Eastern Habitat Joint Venture 2007) and will be more refined as results from current research, especially in offshore waters, become available.

Waterfowl stopover sites, especially those used by dabbling ducks, are often heavily used by shorebirds, and other waterbirds. Habitat distribution for waterfowl, like these other bird groups, varies temporally, especially near the Great Lakes, where interactions between variable water levels and precipitation result in a shifting mosaic of suitable habitat within and between migration seasons and years.

Attributes selected to score waterfowl stopover sites.

We identified five attributes to score waterfowl stopover sites based on our literature review and consultation with experts (see Table 3):

1. Landcover type associated with suitable habitat,
2. Amount of wetland cover within 3 km radius of suitable landcover type,
3. Patch size ,
4. Adjacent cover type within 100 m of suitable landcover type , and
5. Great Lakes water depth (bathymetry).

<u>Waterfowl Scoring formula.</u>

Waterfowl score = score for landcover type associated with suitable habitat + score for amount of wetland cover within 3 km radius of suitable landcover type + score for patch size **+** score for adjacent cover type within 100 m of suitable landcover type + score for Great Lakes water depth (bathymetry).

The scoring criterion for each attribute for waterfowl is described in Table 3.

Table 3. **Conservation priority scores for waterfowl stopover habitat within 25 km of Lakes Michigan, Huron, Erie, Ontario and connecting water bodies.**

Waterfowl stopover attributes

1. Landcover classified as suitable habitat.

Source data: CCAP(US 2006) & PLC (1999) for landcover, and STATSGO (US) & SLR (Canada) for hydric soils.

1 = Mixed emergent marsh adjacent to open water
0.75 = Open water or emergent marsh, not adjacent
0.25 = Palustrine forested wetlands, agricultural fields with hydric soils

2. Amount of wetland cover within 3 km radius of suitable landcover type.

Source data: CCAP (US 2006) and PLC (Canada 1999) - applied to any pixels scoring 0.25 or higher in suitable habitat score.

1 = >40% wetland cover in 3 km radius window
0.5 = 15-40% wetland cover
0.25 = < 15% wetland cover

3. Patch size (patch can include more than one of the “suitable habitat” landcover types shown above)

Source data: same as suitable habitat.

1 = ≥16 ha (40 acres)
0.5 = ≥5 ha (12 acres) and <16 ha (40 acres)
0.25 = <5 ha (12 acres)

4. Adjacent cover type within 100 m of the pixel of suitable habitat. Describes presence/absence of a buffer from developed areas or forests.

Source data: same as suitable habitat.

1 = Undeveloped, non-forest
0.5 = Undeveloped, forest
0 = Developed

5. Great Lakes water depth.

Source data: NOAA Bathymetry

1 = <4 meters
0.5 = 4-6 meters
0.25 = >6 meters

***Rationale for defining landcover type associated with suitable habitat*.**

We adopted the cover types described in Soulliere *et al.* (2007c), wet mudflats, shallow semi-permanent marsh, deep water marsh, and extensive open water, to denote landcover types used by migrating waterfowl in the Great Lakes region. We also included the category forested wetlands, a habitat most frequently used by Wood Ducks, Ring-necked Ducks (*Aythya collaris*), and Hooded Mergansers (*Lophodytes cucullatus*) and occasionally other waterfowl species. We assigned high scores to sites with both mixed emergent marsh and open water as they are likely to support both dabbling and diving ducks. Palustrine emergent marshes have recently been shown to be relatively food rich relative to other wetland sites during spring (Straub *et al.* 2012). Although upland fields (those with non-hydric soil) are used by foraging Canada Geese (*Branta canadensis*) and Tundra Swans, in particular, we did not include these habitats in our analysis because most waterfowl species are restricted to more aquatic habitats during migration.

Rationale for defining parameters associated with amount of wetland cover within 3 km of suitable landcover type.

Given the relatively high concordance in the distribution of shorebirds and dabbling ducks, and that dabbling ducks may be more habitat-limited than diving ducks (Soulliere *et al.* 2007c) we adopted the same measure of wetland cover for both groups. In the Rainwater basin of Nebraska, the amount of wetland cover within 5 km was positively associated with numbers of migrating Northern Pintails (*Anas acuta*) and the number of wetlands within 5 km was positively associated with the number of diving ducks (Brennan 2006), while Webb et al. (2010) found a positive relationship between migrating dabbling ducks and wetland area and amount of wetlands within a 10 km radius in the same area. However, further definition of both the amount of wetland cover that influences distribution of migrating waterfowl and the spatial scale at which this affects waterfowl dispersion requires additional study. We elected to use a 3 km radius to be consistent with shorebird criteria given the high degree of overlap in habitat use between shorebirds and waterfowl.

Rationale for defining parameters associated with patch size.

Larger bodies of water with good water quality are preferred by migrating diving ducks (Korschgen 1989) but the quantitative relationship between relative abundance or density of waterfowl and patch size remains to be described. Although, Paracuellos and Telleria (2004) found species richness of waterfowl increased with pond area in Spain, especially in ponds >10 ha, this data was collected during winter and the breeding season. We adopted criteria for patch size based on Ewert *et al.* (2006) for the western Lake Erie basin (Ewert *et al.* 2006) and by Soulliere *et al.* (2007c) for the Upper Mississippi River and Great Lakes Region Joint Venture; these criteria are based on expert opinion.

Rationale for defining parameters associated with adjacent cover type within 100 m of suitable landcover type.

The intention of this attribute was to incorporate the influence of anthropogenic and other (*e.g.*, predators) disturbance to waterfowl at stopover sites on rankings of stopover habitat value. Borgmann

(2011) suggests maintaining a buffer of at least 200 m to minimize disturbance to waterfowl, a conservative assessment based on a literature review of waterfowl response to different types of disturbance, such as boats and walking. We reduced this buffer to 100 m as some of the pixels characterized as roads also include suitable habitat that would be included in the buffer zone. We also defined buffers based on vegetation characteristics used by predators; wooded areas close to suitable habitat may provide perches that result in higher predation rates, so these were scored at half the value of other undeveloped habitat types.

Rationale for selecting parameters associated with Great Lakes water depth (bathymetry).

Data supporting this attribute include observations that most dabbling ducks forage for invertebrates and plant material in water depths < 0.5 m (Austin and Miller 1995, Johnson 1995, Mowbray 1999, Rohwer *et al.* 2002) while diving ducks forage in water depths < 4 m (Woodin and Michot 2002, Mowbray 2002, Austin *et al.* 1998, Soulliere *et al.* 2007c, Nelms *et al.* 2007), with some species roosting (Nelms *et al.* 2007) or occasionally feeding in water up to 9-20 m deep (Brown and Fredrickson 1997, Titman 1999). One species, Long-tailed Duck, feeds as deep as 66 m in Lake Michigan (Schroger 1951). Norris and Lott (2012) found the largest number of waterbirds during spring and fall migration, mostly waterfowl, within 3.2-10 km of the Lake Erie shore in Ohio, which roughly coincides with the 9-10 m bathymetry in many areas; a small number of waterfowl were found in the center of Lake Erie in water deeper than 10 m. Consequently, we scored areas with a water depth < 4 m highest, and assigned lower scores to deeper water depths (see also Soulliere *et al.* 2007c). We only mapped Great Lakes waters.

Potential characteristics of stopover habitat beyond the scope of this project.

We did not differentially score stopover sites for four different species/habitat guilds of waterfowl (wet mudflat/moist soil, shallow semi-permanent marsh, deep-water marsh, extensive open water) as defined by Soulliere *et al.* (2007c).

We did not account for different types of anthropogenic disturbances in our scoring system because data layers were not available to us that depicted these disturbances consistently across the region. These anthropogenic disturbances, which modify use of otherwise suitable habitat by reducing the amount of time available for foraging or by displacing birds (Knapton *et al.* 2000, Schummer and Eddelman 2003, Pease *et al.* 2005, Dooley *et al.* 2010), include shipping lanes, marinas, public access sites to water, boating traffic or hunting. As data layers become available, it may be possible to evaluate the relative quality of stopover sites based on the type and intensity of different disturbances.

Results and Discussion

The primary outcome of this project is the creation of maps that depict the predicted relative importance of areas in the study areas to migrating birds. In the next phase of the project we will develop a web portal that will allow users to use data layers applied in our models with other data layers (*e.g.*, protected areas), and non-spatial data, to make sound decisions regarding conservation of stopover sites. Here we present a series of representative maps from this project that illustrates the spatial distribution of potential stopover sites with different predicted values. As background, we also show current landcover at the scale of the complete study area (Figure 1). The results presented here include a series of maps that display distribution of scores of each evaluated attribute for shorebirds and the summed shorebird score in the vicinity of the mouth of the St. Clair River, Michigan and Ontario (Figure 2); mapped scores for landbirds (Figure 3), shorebirds (Figure 4) and waterfowl (Figure 5) throughout the study area; and a series of figures which portray landcover and summed scores of each bird group (landbirds, shorebirds, and waterfowl) in unfragmented (Schoolcraft County, Michigan; Figures 6-9), moderately fragmented (Ottawa County, Michigan; Figures 10-13), and highly fragmented (Ottawa County, Ohio; Figures 14-17) landscapes. Similar maps can be made for any geographical unit within the study area at a 1 ha scale resolution, and there will be many options for creating other maps through the on line portal. Instructions for using the GIS data files submitted with this report can be found in Appendix 2.

Our results suggest that most intact landscapes in our study area occur in Michigan's Upper Peninsula and then east around Georgian Bay, Ontario (see Figure 1). In contrast, highly altered landscapes occur around Lake Michigan from central Wisconsin south through northwestern Indiana; in Michigan and Ohio from Saginaw Bay, Michigan to the Lake Erie shoreline near Cleveland and in Ontario from the base of the Bruce Peninsula south and east around Lake Huron, Lake Erie and Lake Ontario and connecting water bodies to Toronto (see Figure 1). For landbirds, these maps indicate that stopover habitat is most available along and near the northern shorelines of Lakes Michigan and Huron and the eastern portion of Lake Ontario and in shortest supply in southern Ontario along Lakes Huron, Erie, and Ontario and connecting waters (Figures 4). Distribution of stopover habitat for shorebirds and waterfowl overlap extensively (Figures 5,6), especially in the corridor from western Lake Erie to Saginaw Bay, Lake Huron and the Niagara "peninsula" of Ontario (land between Lake Ontario and Erie); the overlap is due to the proximity of areas of shallow inshore waters to extensive near shore agricultural lands. Our models further suggest that waterfowl stopover habitats occur in many bays around the Great Lakes, such as Green Bay (Lake Michigan); protected waters in the east end of Lake Ontario; and connecting waters between the Great Lakes such as the St. Mary's River, Detroit River, and Niagara River. In the Great Lakes region, our models indicate that shorebirds currently have the least available habitat, which may have been the case historically as well. Quantitative analyses will be initiated in Phase II of this project to describe these patterns more fully.

The results from this project will provide guidance regarding the spatial distribution and factors affecting viability of stopover sites and can be specifically incorporated into a wide range of plans and planning processes, including the Upper Mississippi River and Great Lakes Region Joint Venture; lake-wide conservation plans for Lakes Michigan, Huron, Erie and Ontario that have been developed by The Nature Conservancy; state wildlife action plans; and other regional plans that include protection of migratory birds, such as the Wisconsin Bird Conservation Initiative and Chicago Wilderness. The models produced with this project build upon stopover models developed earlier as we have incorporated results from new literature in these models. Yet, the regional models lack some detail provided in earlier work where local, fine resolution data layers were available. Users at any one site may find it most valuable to review both the Great Lakes regional model and more localized models when applying this work for conservation purposes.

In year 2 of this project we will supplement the spatial analysis with outreach materials, including 1) a manuscript, which will describe potentially important fine-scale attributes not currently included because data layers are lacking but that could be incorporated at fine scales and/or be evaluated by field practitioners and 2) a web portal, to provide readily available access to this work and analytical applications, including the ability to quantitatively analyze the distribution of scored stopover sites by bird group and different spatial scales. Collectively, these products will describe where the most important stopover sites are located and determine which bird groups have the least available stopover habitat at various spatial scales. In addition, analyses of overlap of scored stopover sites with protected areas will be possible to permit assessment of progress toward conservation goals where stopover goals have been defined. Based on this information, and other information which cannot be depicted with GIS, we will provide guidance that facilitates identification of sites where conservation work can best be implemented for birds migrating through the study area.

The stopover site information will also be provided to the Information Management and Delivery System under development by Scott Sowa, The Nature Conservancy, along with other stopover products, such as bibliographies on stopover sites, and a narrative that provides additional conservation guidance that cannot be summarized by spatial data layers, following the approach we used for the western Lake Erie stopover site project (Ewert *et al.* 2006). By uploading information to the IMDS system, stopover site information can be integrated with other topics to facilitate making efficient, comprehensive conservation decisions.

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Figures

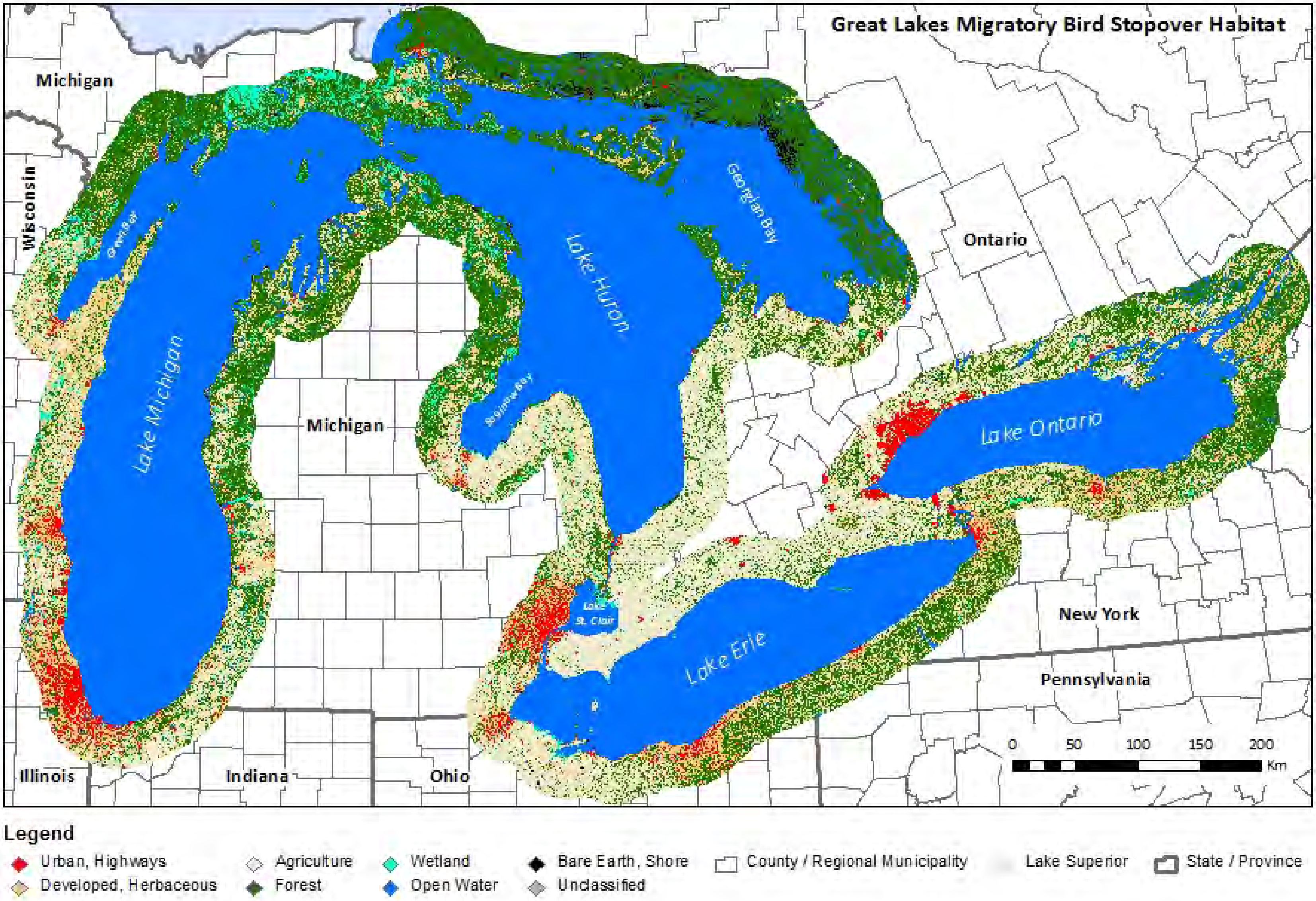
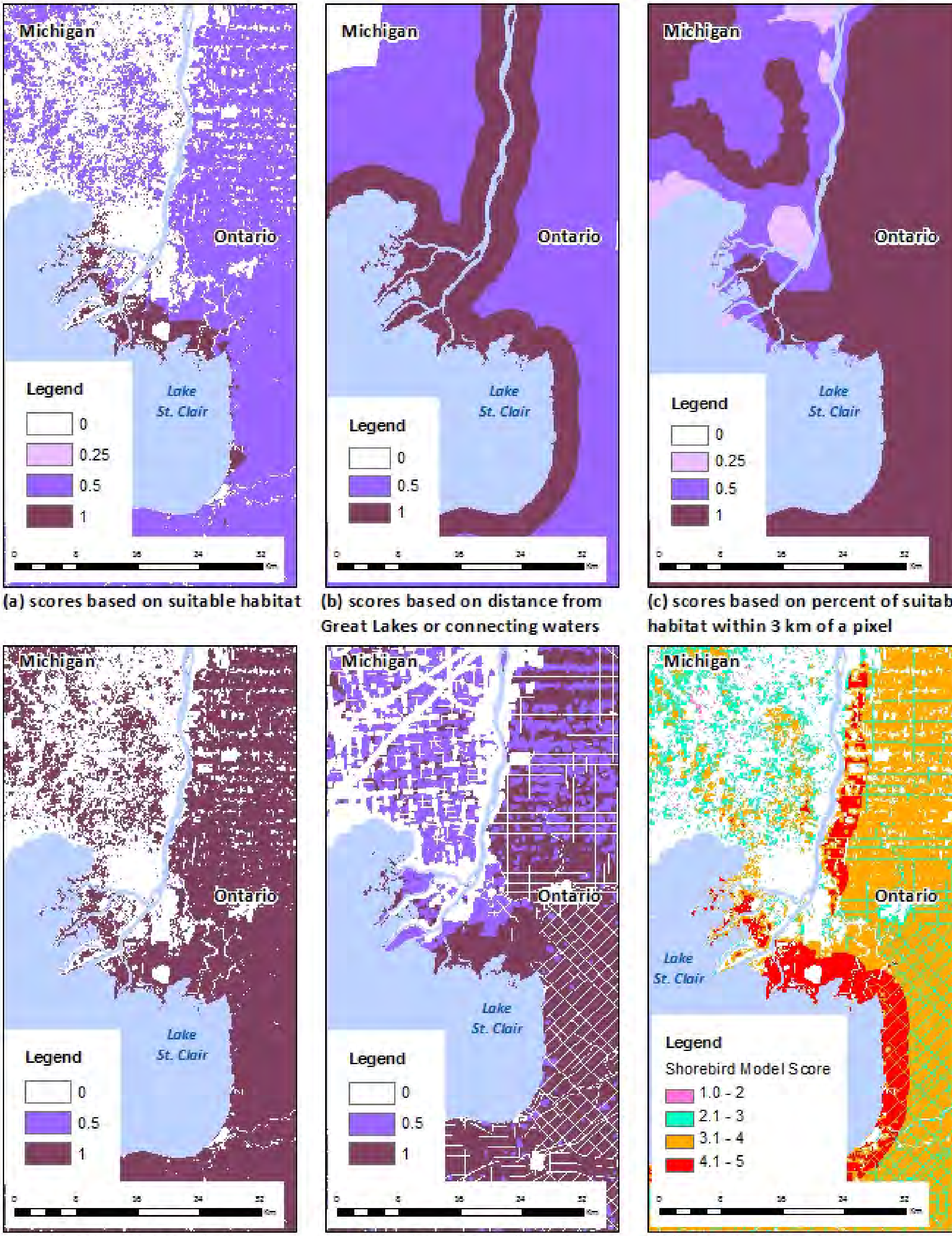


Figure 1: Study Area Land Cover



(a) scores based on suitable habitat

(b) scores based on distance from Great Lakes or connecting waters

(c) scores based on percent of suitable habitat within 3 km of a pixel

(d) scores based on patch size

(e) scores based on adjacent cover

(f) final shorebird score (summed for all attributes)

Figure 2: Distribution of scored attributes and final shorebird score (shorebird model score), Northern Lake St.Clair, Michigan and Ontario.

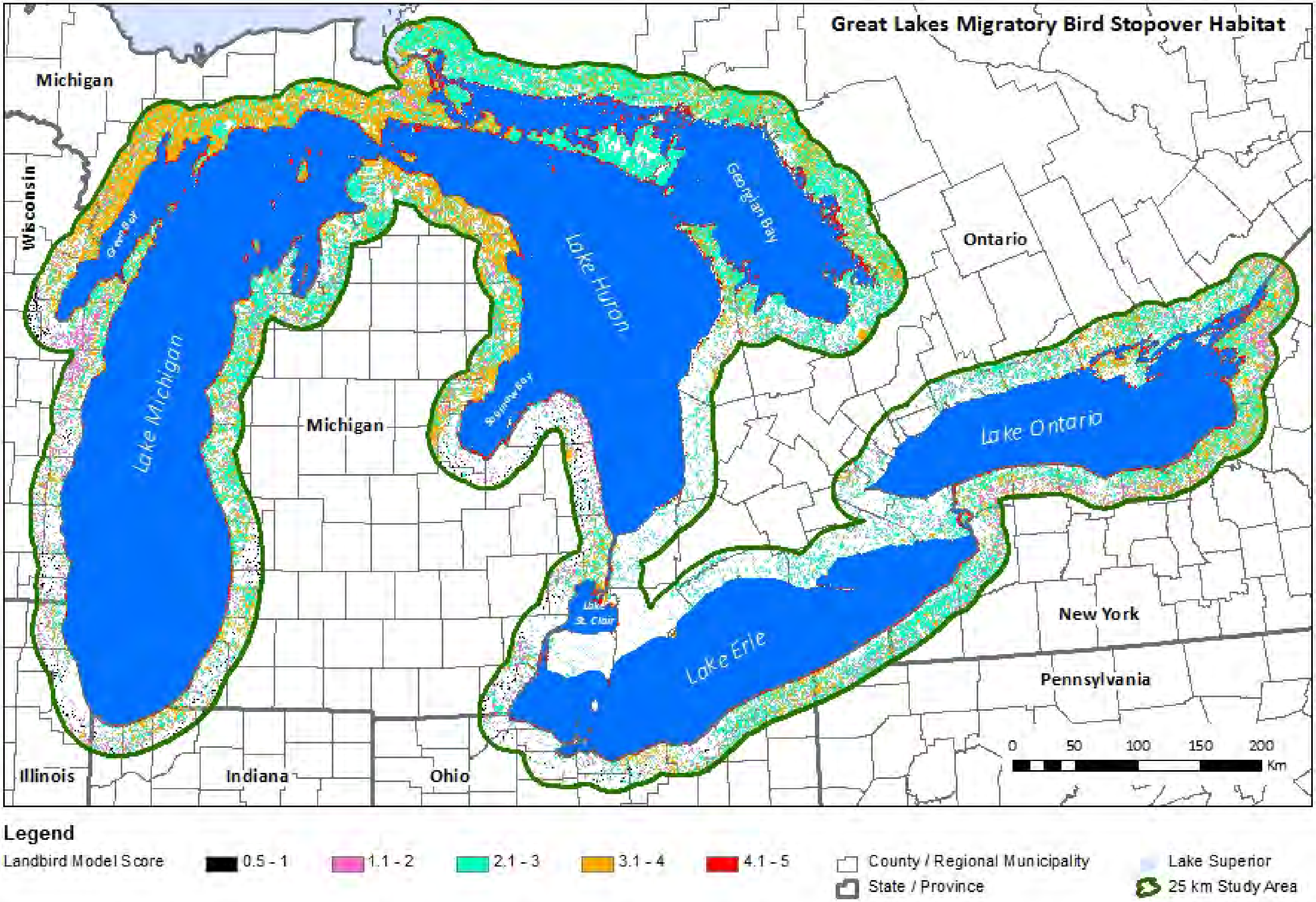
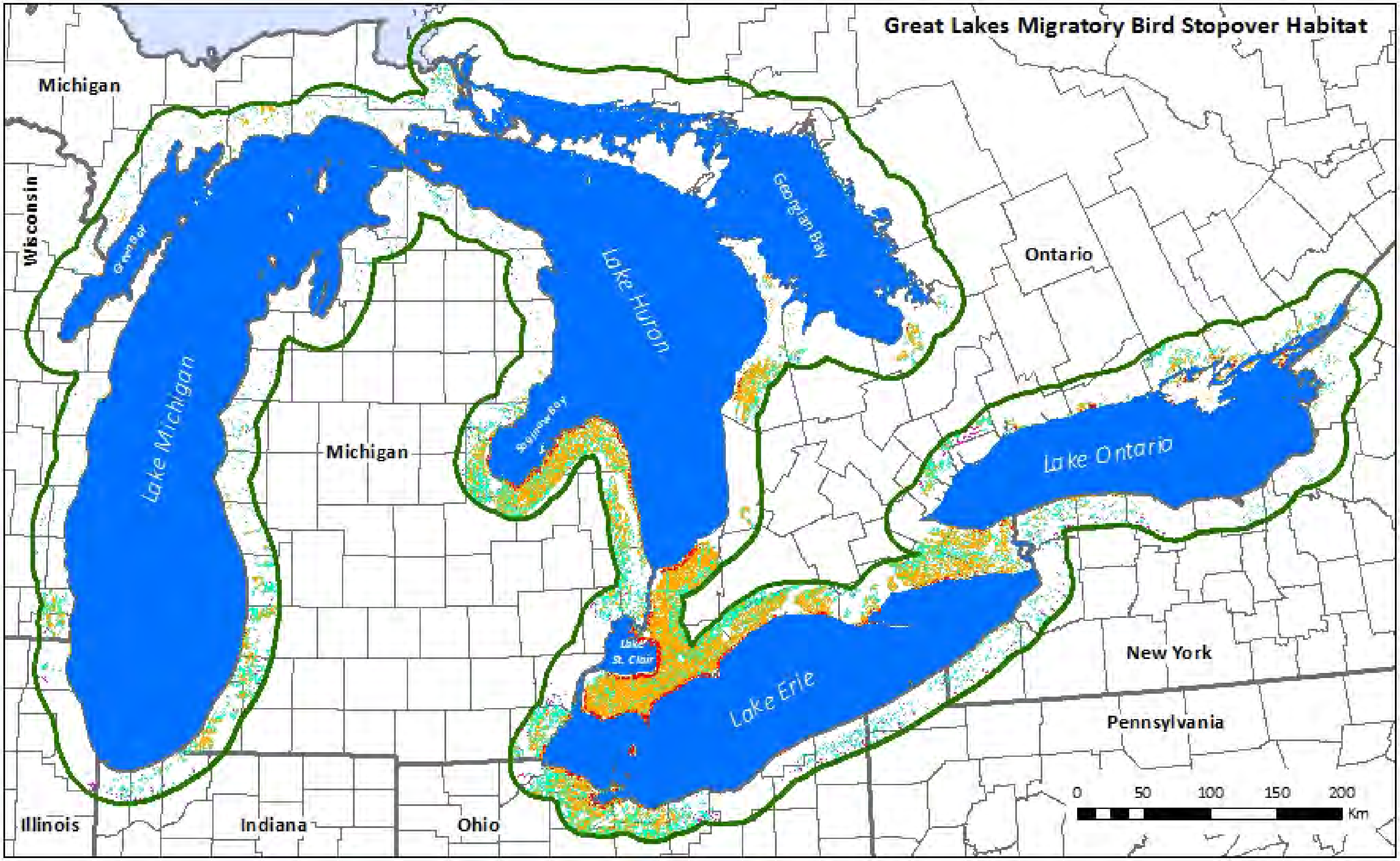


Figure 3: Mapped scores for Landbird stopover sites within 25 km of Lakes Michigan, Huron, Erie, and Ontario and connecting waters. White areas within the study area roughly depict unsuitable habitat given the scale of resolution.



Legend

Shorebird Model Score: 1.0 - 2 | 2.1 - 3 | 3.1 - 4 | 4.1 - 5

County / Regional Municipality

State / Province

Lake Superior

25 km Study Area

Figure 4: Mapped scores for Shorebird stopover sites within 25 km of Lakes Michigan, Huron, Erie, and Ontario and connecting waters. White areas within the study area roughly depict unsuitable habitat given the scale of resolution.

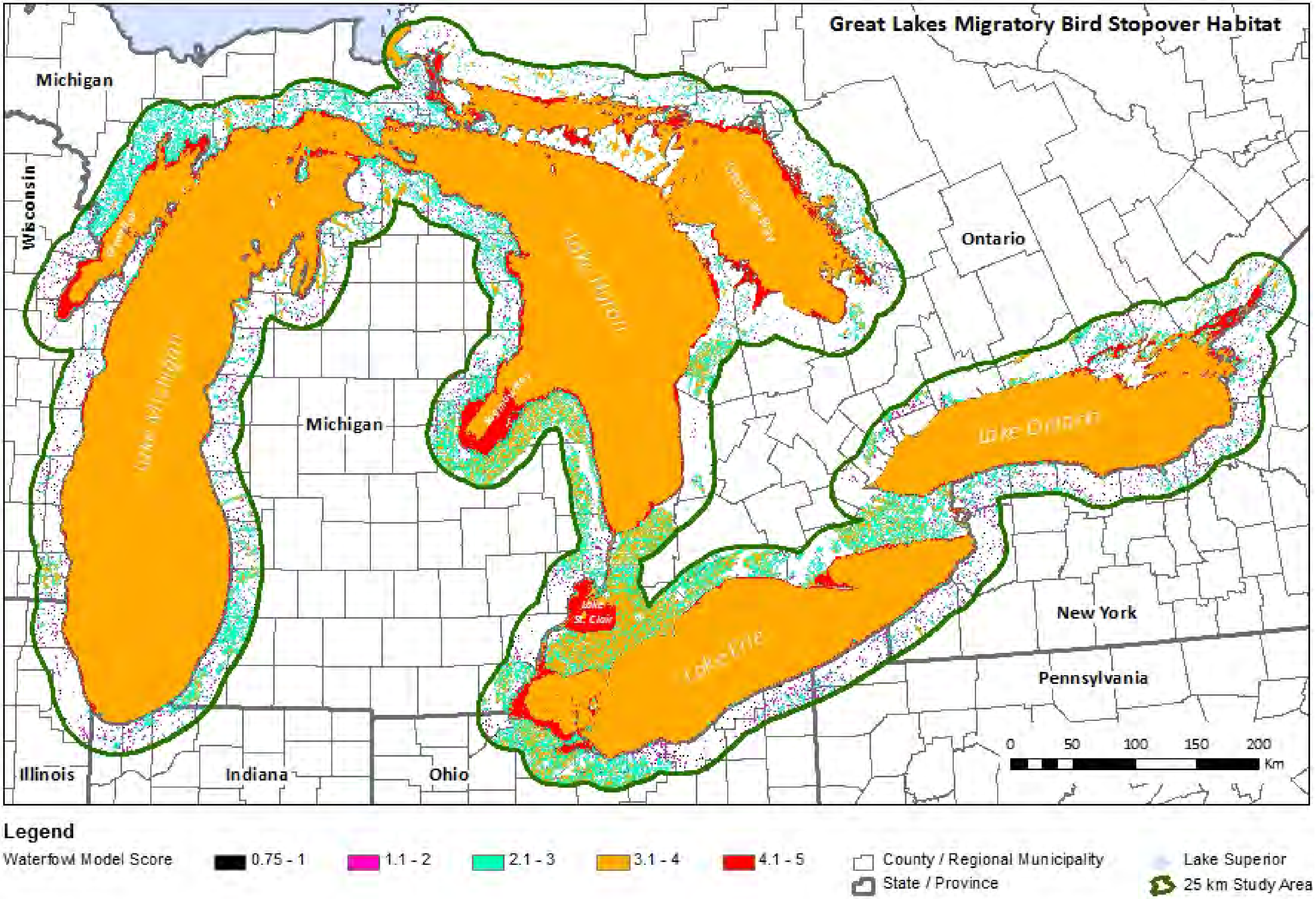


Figure 5: Mapped scores for Waterfowl stopover sites within 25 km of Lakes Michigan, Huron, Erie, and Ontario and connecting waters. White areas within the study area roughly depict unsuitable habitat given the scale of resolution.

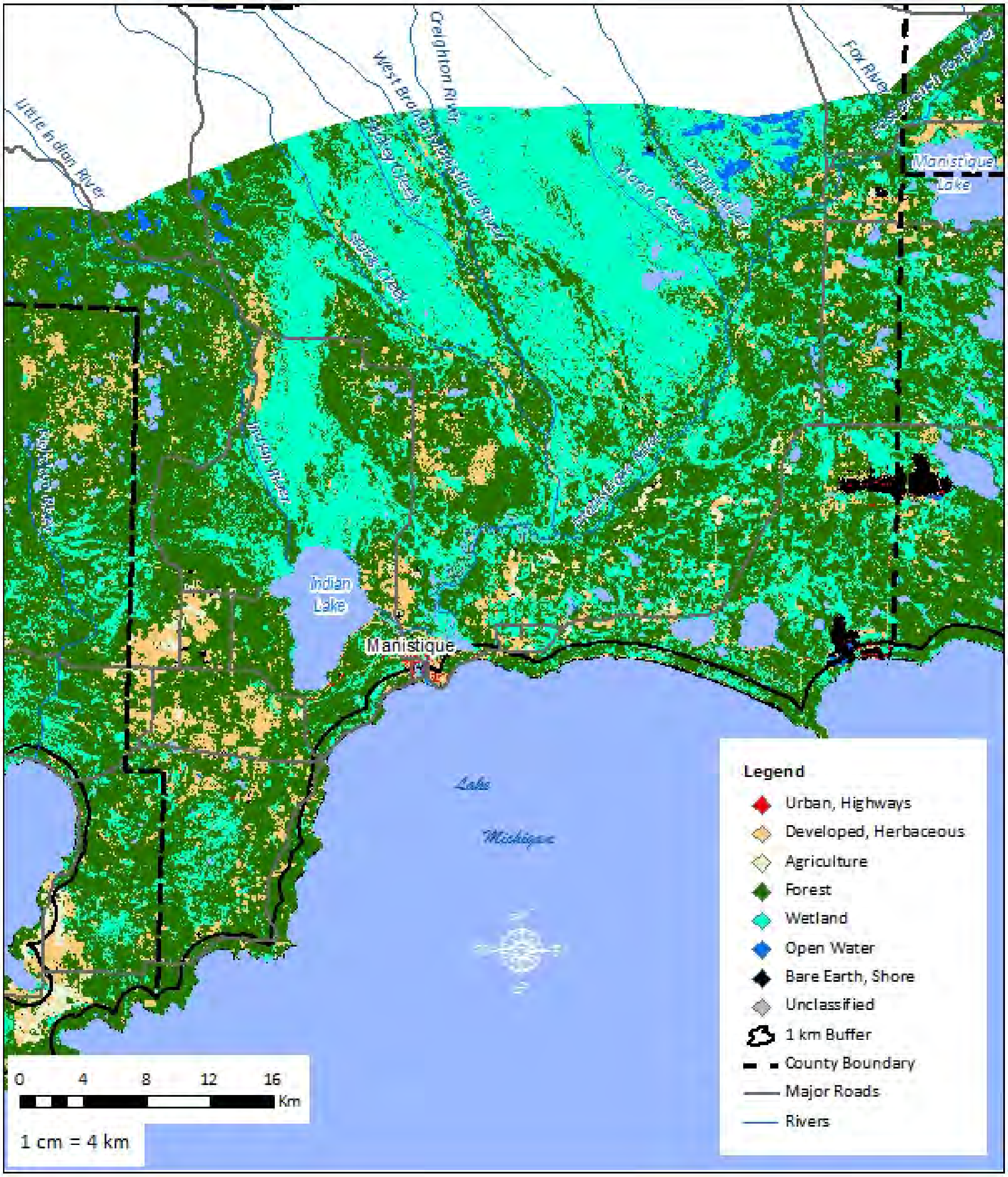


Figure 6: Land Cover of Schoolcraft County, Michigan.

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Great Lakes Migratory Bird Stopover Habitat

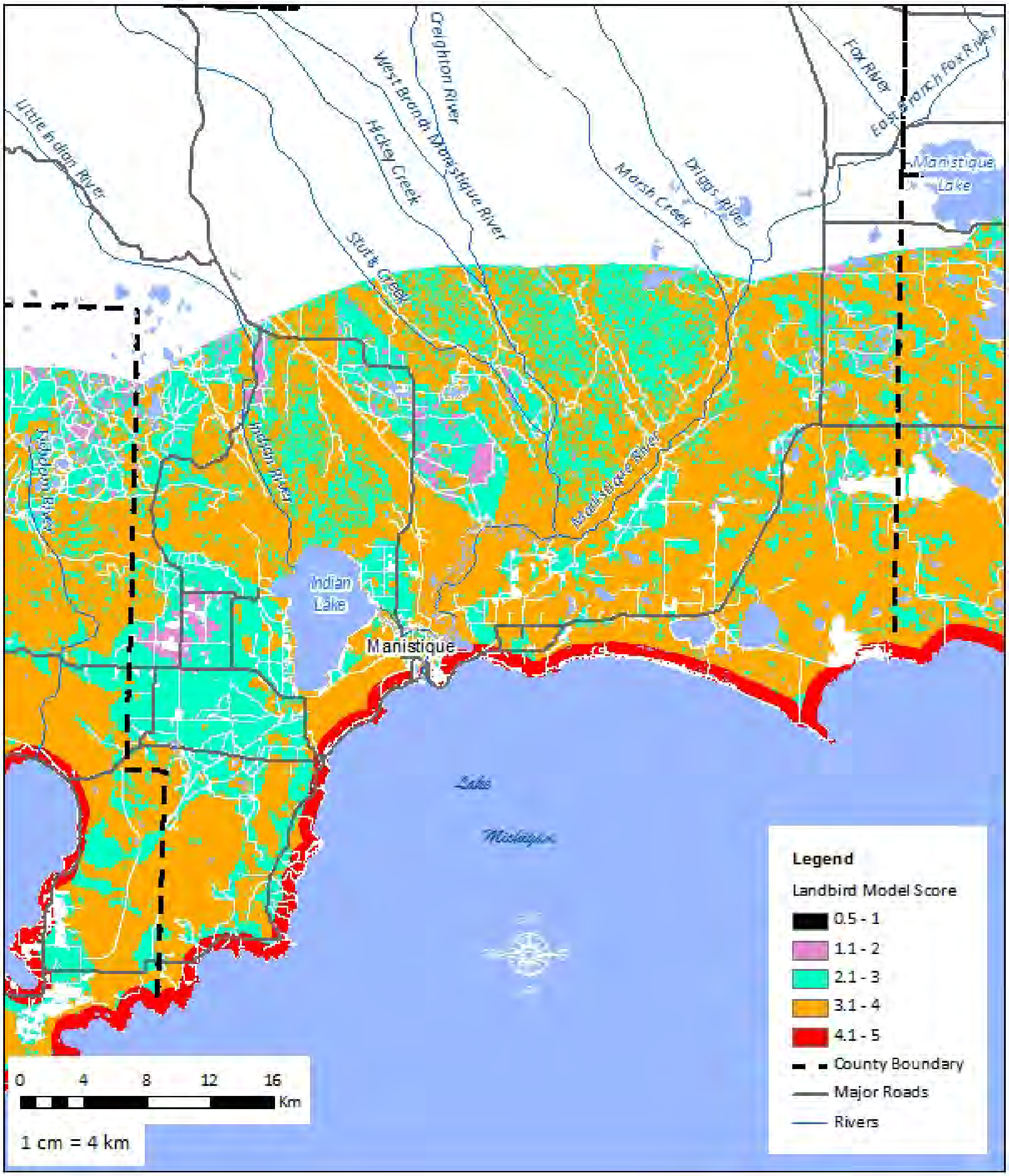

Figure 7: Mapped scores for Landbird stopover sites within 25 km of Lake Michigan, Schoolcraft County, Michigan.
White areas within the study area roughly depict unsuitable habitat given the scale of resolution.

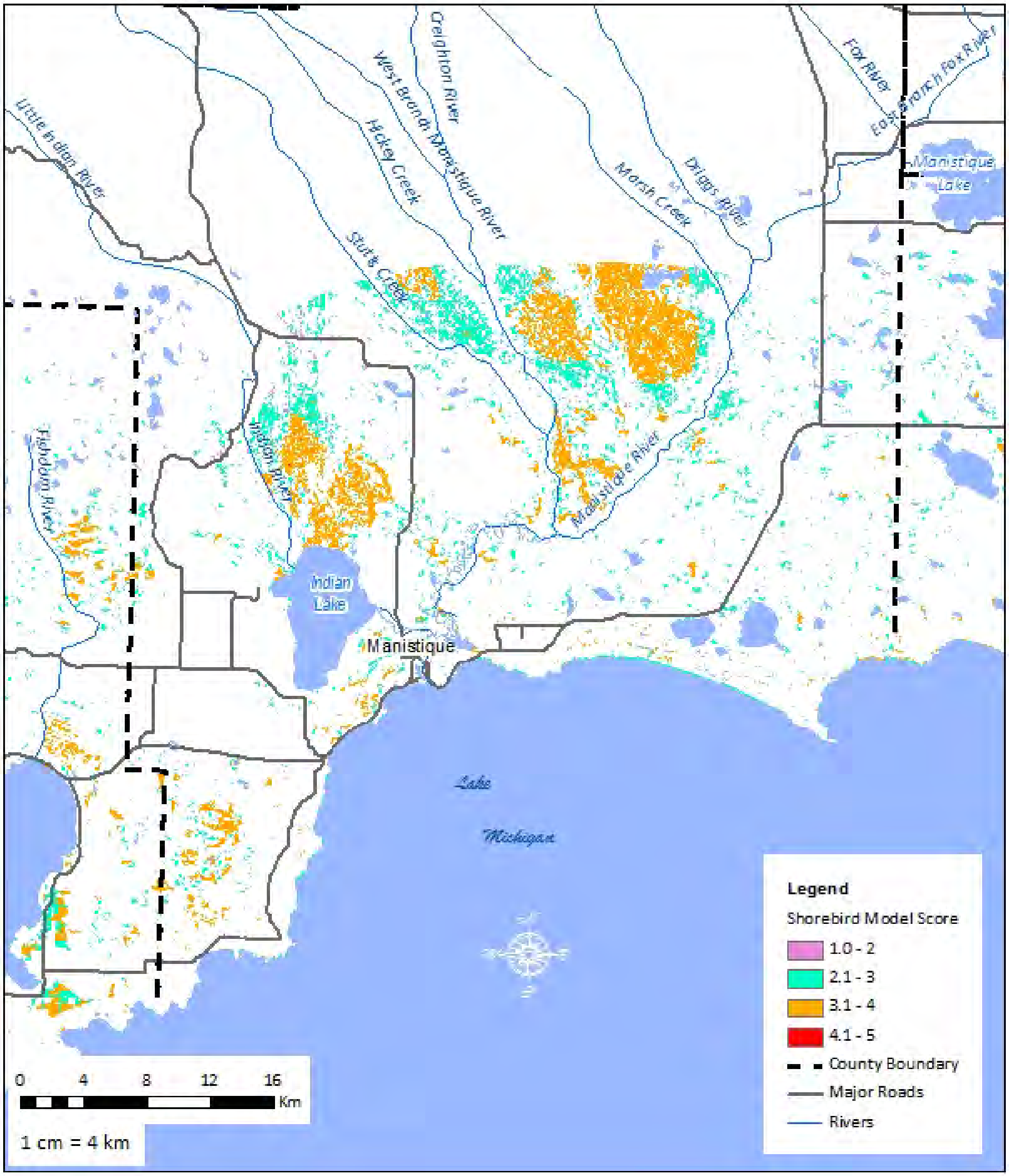

Figure 8: Mapped scores for Shorebird stopover sites within 25 km of Lake Michigan, Schoolcraft County, Michigan.
White areas within the study area roughly depict unsuitable habitat given the scale of resolution.

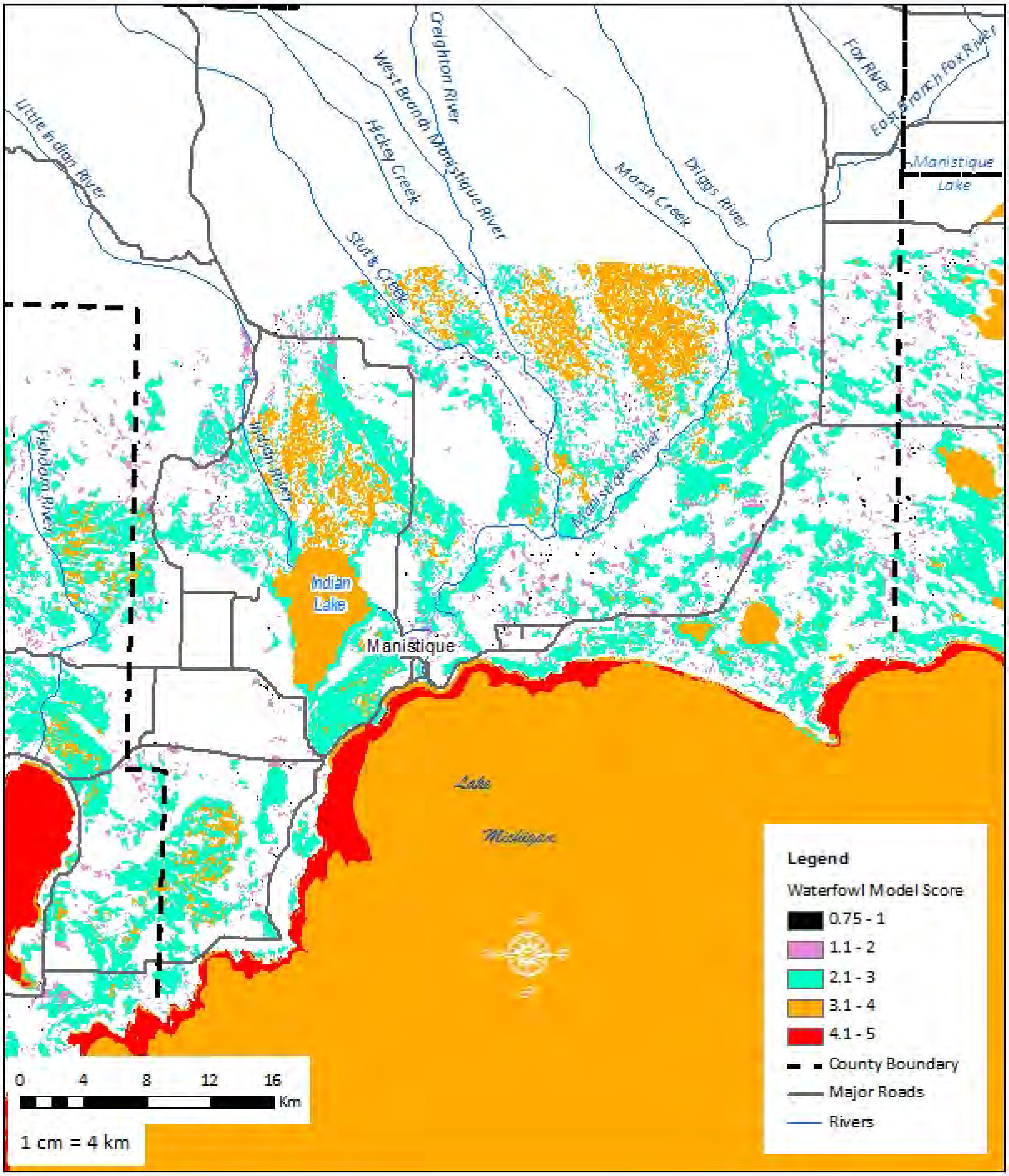

Figure 9: Mapped scores for Waterfowl stopover sites within 25 km of Lake Michigan, Schoolcraft County, Michigan.
White areas within the study area roughly depict unsuitable habitat given the scale of resolution.

The Nature Conservancy

Great Lakes Migratory Bird Stopover Habitat

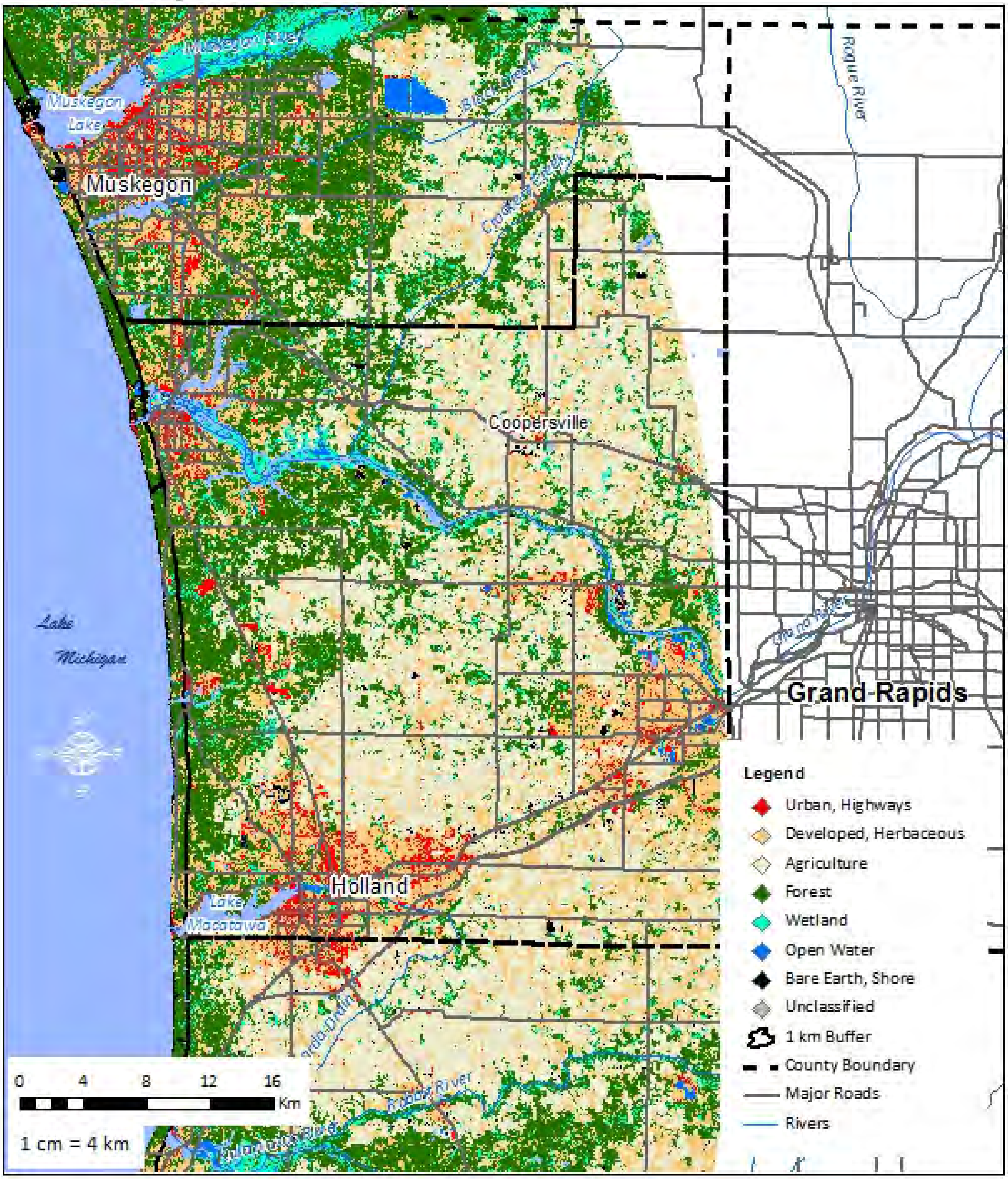

Figure 10: Land Cover of Ottawa County, Michigan.

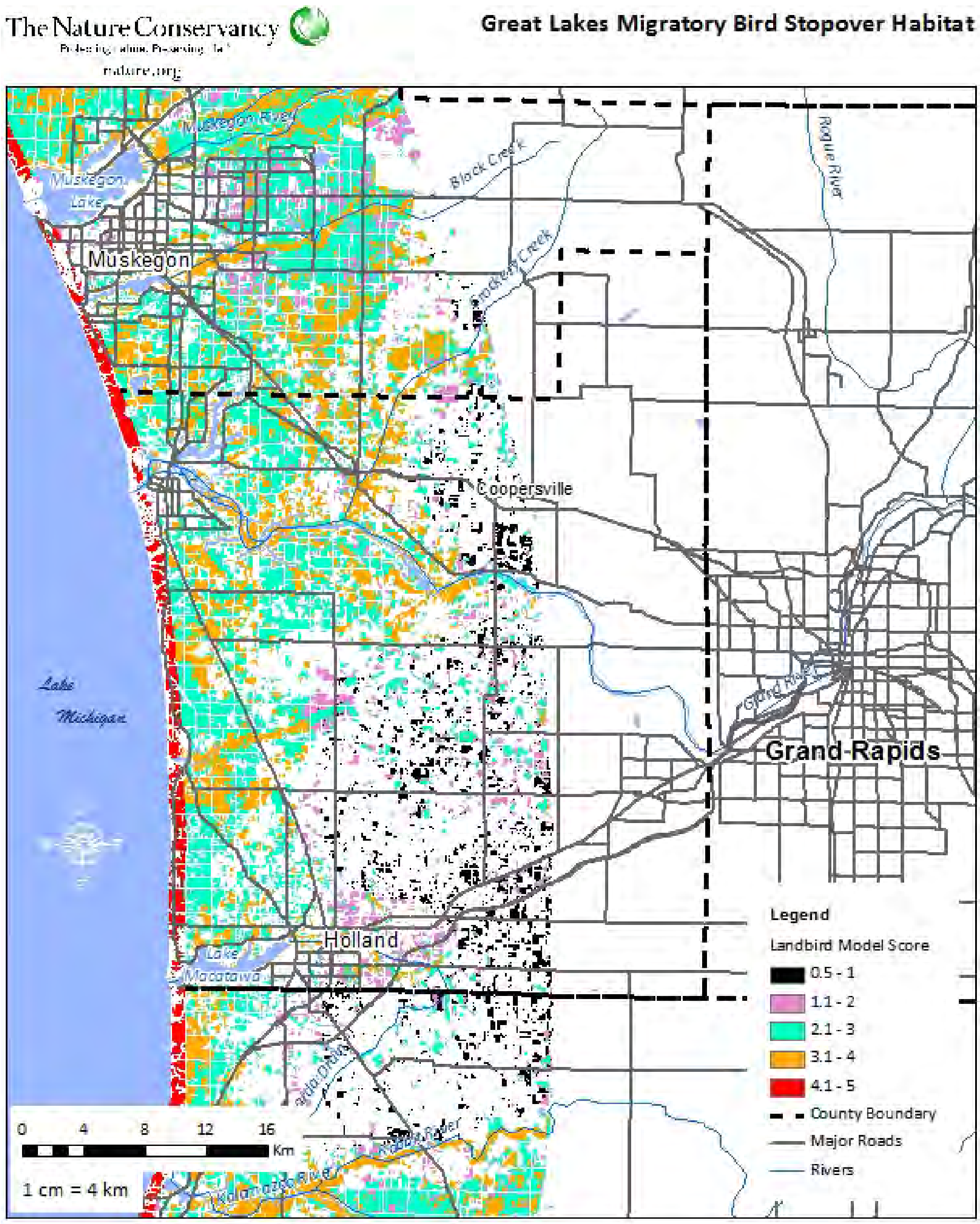

Figure 11: Mapped scores for Landbird stopover sites within 25 km of Lake Michigan, Ottawa County, Michigan.
White areas within the study area roughly depict unsuitable habitat given the scale of resolution.

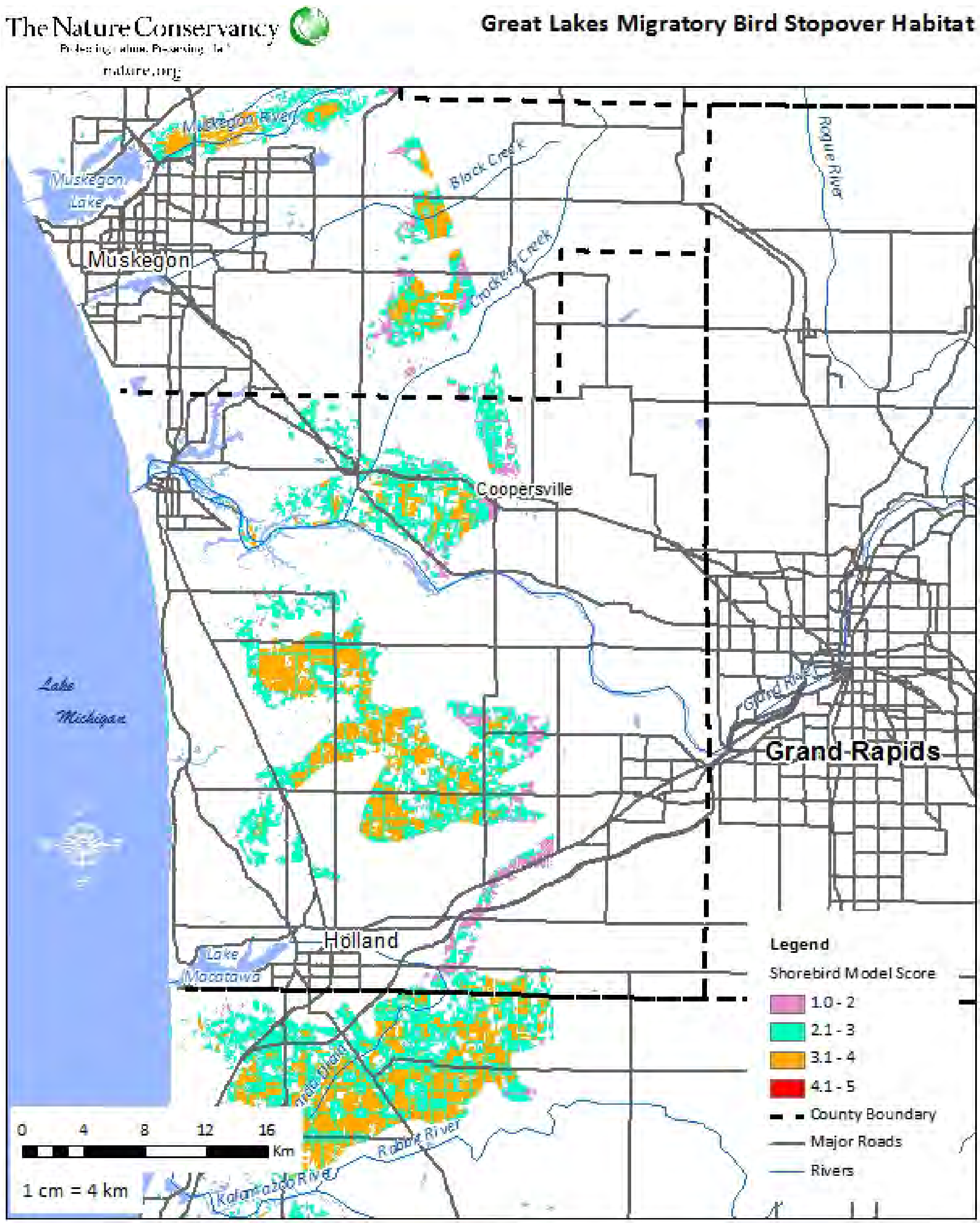

Figure 12: Mapped scores for Shorebird stopover sites within 25 km of Lake Michigan, Ottawa County, Michigan.
White areas within the study area roughly depict unsuitable habitat given the scale of resolution.

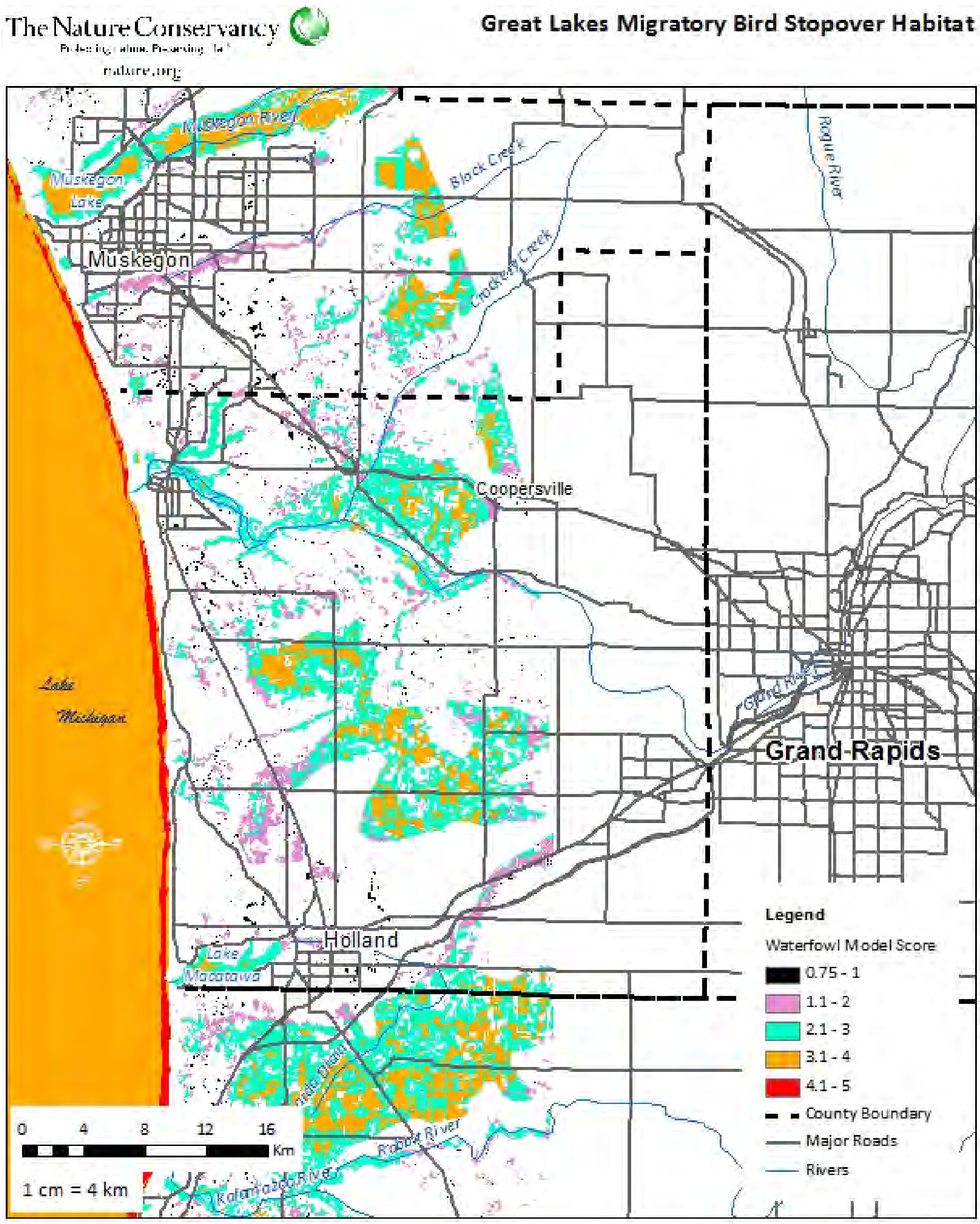

Figure 13: Mapped scores for Waterfowl stopover sites within 25 km of Lake Michigan, Ottawa County, Michigan.
White areas within the study area roughly depict unsuitable habitat given the scale of resolution.

Figure 14: Land Cover of Ottawa County, Ohio.

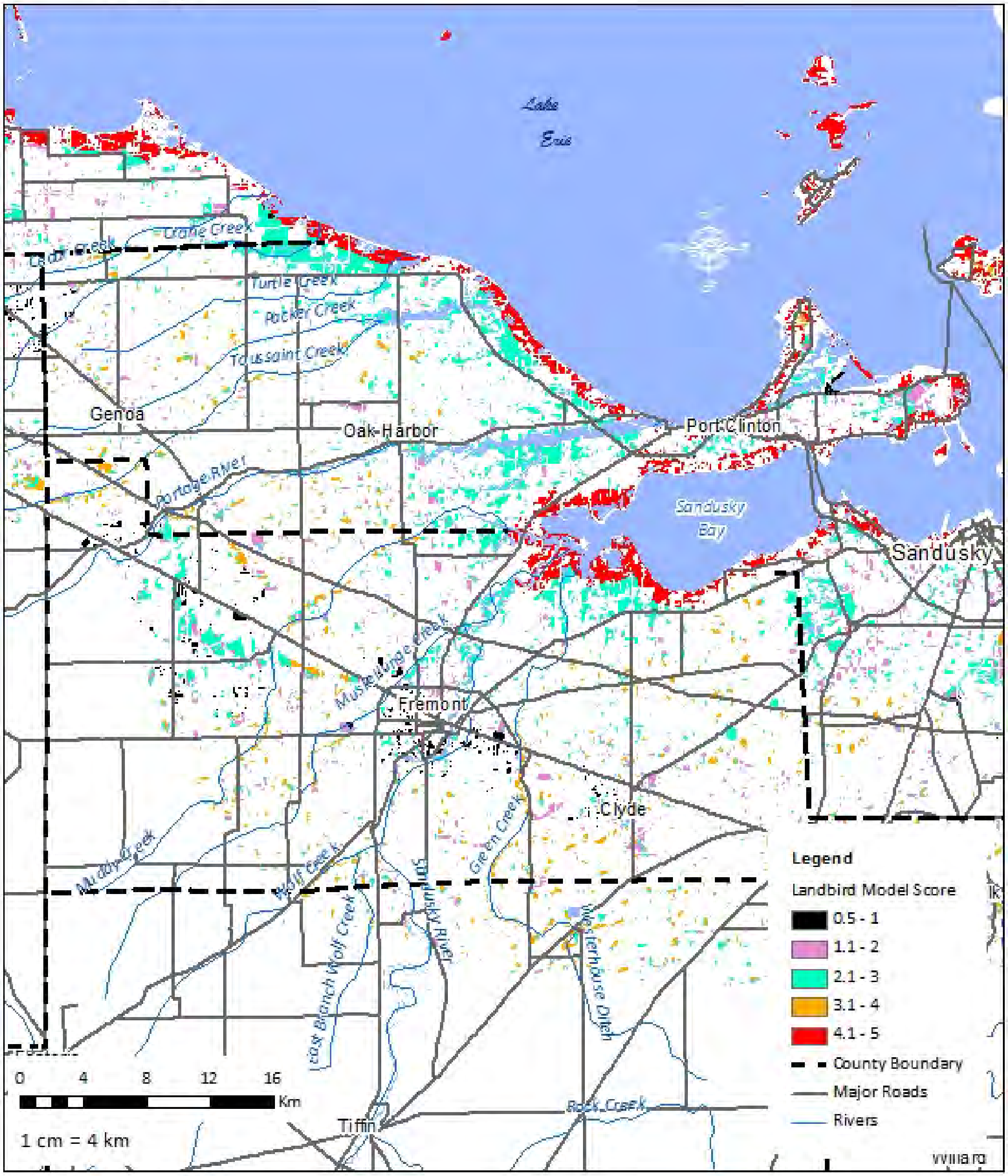

Figure 15: Mapped scores for Landbird stopover sites within 25 km of Lake Erie, Ottawa County, Ohio.
White areas within the study area roughly depict unsuitable habitat given the scale of resolution.

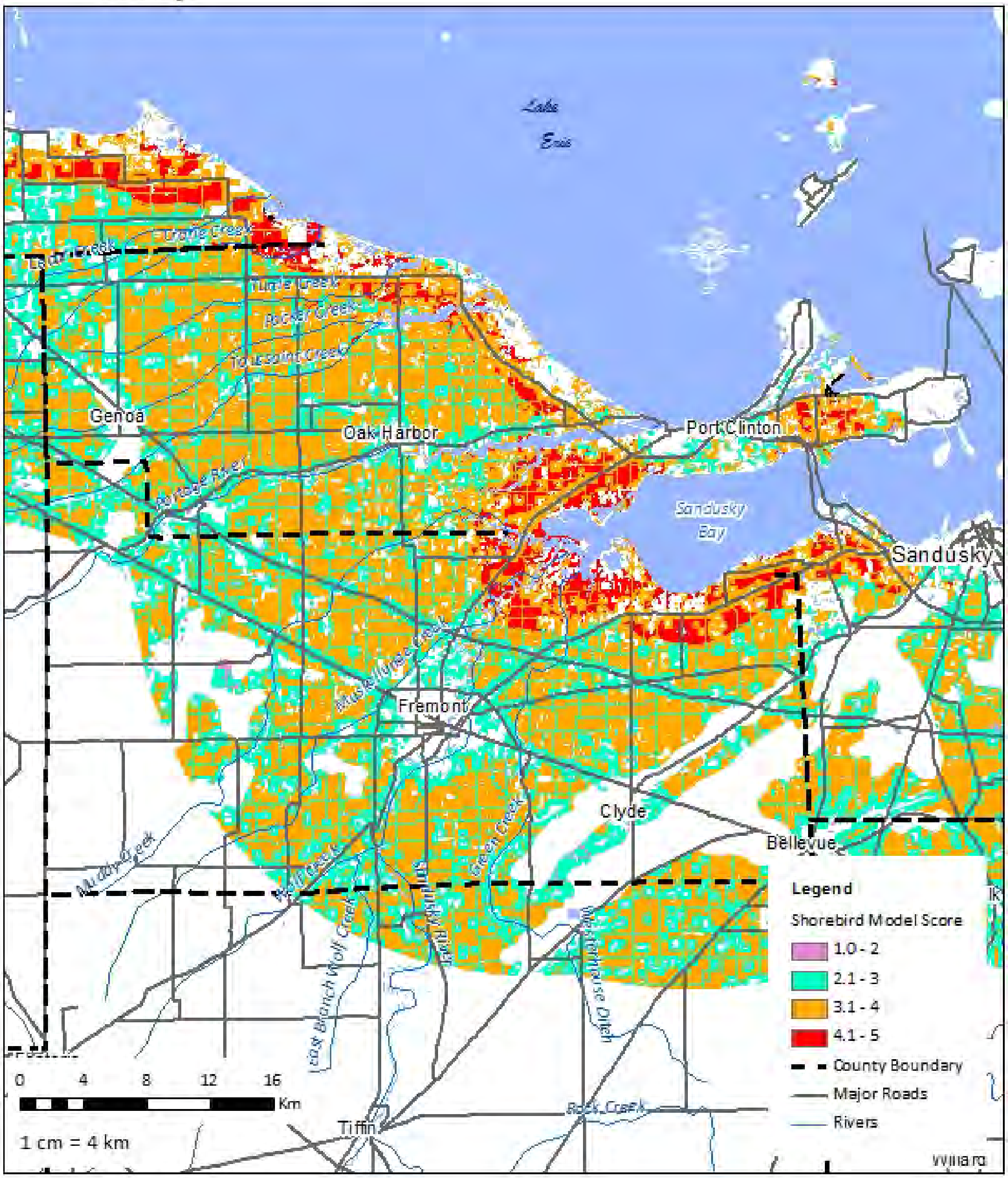

Figure 16: Mapped scores for Shorebird stopover sites within 25 km of Lake Erie, Ottawa County, Ohio.
White areas within the study area roughly depict unsuitable habitat given the scale of resolution.

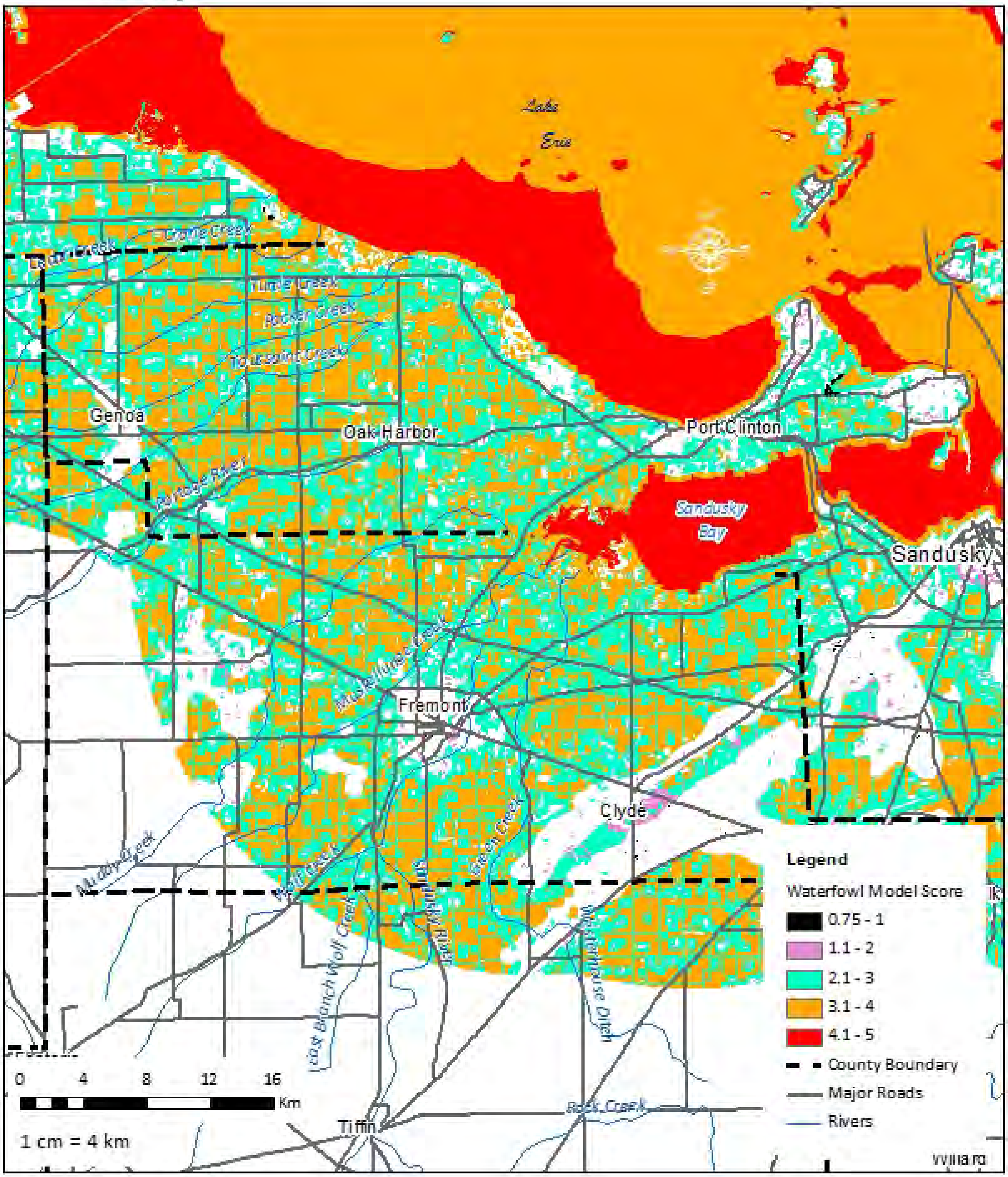

Figure 17: Mapped scores for Waterfowl stopover sites within 25 km of Lake Erie, Ottawa County, Ohio.
White areas within the study area roughly depict unsuitable habitat given the scale of resolution.

Appendices

<u>Appendix 1.</u> Data layers used to depict attributes of stopover habitat for landbirds, shorebirds, and waterfowl within 25 km of Lakes Michigan, Huron, Erie and Ontario, and connecting waters, USA and Canada.

Raster

Name	Source	Date	Resolution
Coastal Change Analysis Program (C-CAP)	National Oceanic and Atmospheric Administration (NOAA)	2006	30 m
National Land Cover Dataset (NLCD)	Multi-Resolution Land Characteristics Consortium (MRLC)	2006	30 m
Provincial Land Cover database (PLC)	Ontario Ministry of Natural Resources	1999	25 m

Vector

NHDplus	Horizon Systems/USEPA/USGS	2005	1:100,000
CanVec Hydro	Natural Resources Canada	2011 edition	1:50,000
U.S. General Soil Map	Natural Resources Conservation Service (NRCS)	2006	1:250,000
Soil Landscape of Canada	Canadian Soil Information Service	1996	1:1,000,000
ESRI Streets	ESRI Maps and Data 10	2010 edition	1:50,000
ESRI Medium Resolution Shoreline	ESRI Maps and Data 10	2010 edition	1:50,000

<u>Appendix 2.</u> Data Preparation Methods

Introduction

This project was conducted using the most current publicly available data that provide approximately equivalent coverage across the entire study area, which is comprised of 140,758square kilometers surrounding Lakes Michigan, Huron, Erie and Ontario and connecting waters. This includes parts of seven US states (Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania and New York) and the Canadian province of Ontario, extending over 1000 km east to west and over 600 km north to south. Developing conforming data across the national boundary was a significant challenge. While we were able to develop GIS layers which were analogous for both sides of the international border, their ages, scales, formats, and resolutions were different. During the course of this project many data were tested for their suitability, but not all data we evaluated were used in the final analysis.

The GIS analysis was conducted entirely on a Dell Precision Mobile M4500 laptop computer with the Intel® Core™ i7-740QM Quad Core 1.73GHz processor and 8Gb of RAM, running 64-bit Microsoft Windows 7 and ESRI ArcGIS 10 for Desktop Advanced with the most current patches and service packs applied. The data sets were large and complex and but using the best currently available commercial hardware made conducting this analysis surprisingly feasible.

We prepared anESRI Model Builder model which, in addition to providing a graphical depiction of the logic of the analysis, contains the actual settings used for all steps of the processing. Model Builder will be provided on The Nature Conservancy's Conserve Online web portal with this final report.

<u>Data Assembly</u>

The following are general descriptions of the data used or evaluated in this project. The italicized descriptions are taken directly from the web site linked to in the theme name.

United States

<u>Coastal Change Analysis Program Regional Land Cover</u> (NOAA)

Effective Date: 2006

Original Resolution: 30 meters

> *The Coastal Change Analysis Program (C-CAP) produces a nationally standardized database of land cover and land change information for the coastal regions of the U.S. C-CAP products provide inventories of coastal intertidal areas, wetlands, and adjacent uplands with the goal of monitoring these habitats by updating the land cover maps every five years. C-CAP products are developed using multiple dates of remotely sensed imagery and consist of raster-based land cover maps for each date of analysis, as well as a file that highlights what changes have occurred between these dates and where the changes were located.*

<u>National Land Cover Dataset Percent Developed Impervious</u> (MRLC)

Effective Date: 2006

Original Resolution: 30 meters

> *The National Land Cover Database (NLCD) Percent Developed Impervious surface provides nationally consistent estimates of the amount of man-made impervious surfaces present over a given area in a seamless form. These raster data sets are derived from Landsat satellite imagery, using classification and regression tree analysis. Values range from 0 to 100 percent, indicating the degree to which the area is covered by impervious features.*

National Hydrography Dataset (NHD Plus)

Effective Date: 2005

Original Scale: 1:100,000

> *The NHDPlus Version 1.0 is an integrated suite of application-ready geospatial data sets that incorporate many of the best features of the National Hydrography Dataset (NHD) and the National Elevation Dataset (NED). The NHDPlus includes a stream network (based on the 1:100,000-scale NHD), improved networking, naming, and "value-added attributes" (VAA's). NHDPlus also includes elevation-derived catchments (drainage areas) produced using a drainage enforcement technique first broadly applied in New England, and thus dubbed "The New-England Method". This technique involves "burning-in" the 1:100,000- scale NHD and when available building "walls" using the national Watershed Boundary Dataset (WBD). The resulting modified digital elevation model (HydroDEM) is used to produce hydrologic derivatives that agree with the NHD and WBD. An interdisciplinary team from the U. S. Geological Survey (USGS), U.S. Environmental Protection Agency (USEPA), and contractors, over the last two years has found this method to produce the best quality NHD catchments using an automated process.*

General Soils Map (USDA)

Effective Date: 2006

Original Scale: 1:250,000

> *The U.S. General Soil Map consists of general soil association units. It was developed by the National Cooperative Soil Survey and supersedes the State Soil Geographic (STATSGO) dataset published in 1994. It consists of a broad-based inventory of soils and non-soil areas that occur in a repeatable pattern on the landscape and that can be cartographically shown at the scale mapped.*

Great Lakes Bathymetry (NOAA)

Effective Date: 2000

Original Scale: Various, by survey and by Lake, final compiled scales range from 1:10,000-1:80,000

Bathymetry of Lakes Michigan, Erie, Saint Clair, Ontario and Huron has been compiled as a component of a NOAA project to rescue Great Lakes lake floor geological and geophysical data and make it more accessible. Lake Superior bathymetry partially completed. The present contours and grids have been partially derived and completely compiled here at NOAA's National Geophysical Data Center (NGDC) using a variety of sources of data including the NOS Hydrographic data base and the Canadian Hydrographic Service (CHS) smooth sheets. This project is a cooperative effort between investigators at the NGDC, the NOAA Great Lakes Environmental Research Laboratory and the Canadian Hydrographic Service. Bathymetric data used for this project have been collected from the Great Lakes in support of nautical charting for at least 150 years by the US Army Corp. of Engineers (before 1970), the NOAA National Ocean Service (after 1970), and the CHS.

Canada

Provincial Land Cover (Natural Resources Canada)

Effective Date: 1999

Original Resolution: 25m

The Ontario Ministry of Natural Resources Provincial Land Cover Raster includes 28 land cover classes and spans the entire landmass of Ontario. The Ontario Land Cover data was derived from digital, multispectral LANDSAT Thematic Mapper data recorded on a range of dates between 1986 and 1997, but the majority of the satellite data frames were recorded in the early 1990s. The forest cutovers and burns were updated from 1996 TM coverage for the Great Lakes forest region and most of the Boreal forest region of the province. It is important to note that the Provincial Land Cover Data Base is generalized land cover. It is NOT appropriate for detailed site-specific large scale studies.

CanVec

Effective Date: 2010

Original Scale: Various, 1:10,000 to 1:50,000

CanVec is a digital cartographical reference product produced by Natural Resources Canada. It originates from the best available data sources covering Canadian territory and offers quality topographical information in vector format that comply with international geomatics standards. CanVec is a multi-source product coming mainly from the National Topographic Data Base (NTDB), the GeoBase initiative (www.geobase.ca) and the data update using Landsat 7 or Spot imagery coverage.
CanVec product contains more than 90 topographical entities thematically organized into 11 distribution themes: Administrative Boundaries, Buildings and Structures, Energy, Hydrography,

Industrial and Commercial Areas, Places of Interest, Relief and Landforms, Toponymy (Place Names), Transportation, Vegetation and Water Saturated Soils.

National Hydro Network

Effective Date: 2004

Original Scale: 1:50,000

> *The National Hydro Network (NHN), for which the standard was officially adopted by the Canadian Council on Geomatics (CCOG) in August 2004, focuses on providing a quality geometric description and a set of basic attributes describing Canada's inland surface waters. It provides geospatial vector data describing hydrographic features such as lakes, reservoirs, rivers, streams, canals, islands, obstacles (e.g. waterfalls, rapids, rocks in water) and constructions (e.g. dams, wharves, dikes), as well as a linear drainage network and the toponymic information (geographical names) associated to hydrography.*
>
> *The NHN forms the hydrographic layer of the GeoBase. The best available federal and provincial/territorial data are used for its production, which is done jointly by the federal government and interested provincial and territorial partners.*

Soil Landscapes of Canada (Canadian Soil Information Service)

Effective Date: 1996

Original Scale: 1:1,000,000

> *The SLCs are based on existing soil survey maps which have been recompiled at 1:1 million scale. Each area (or polygon) on the map is described by a standard set of attributes. The full array of attributes that describe a distinct type of soil and its associated landscape, such as surface form, slope, water table depth, permafrost and lakes, is called a soil landscape.*

North America

ESRI Data and Maps Streetmap (ESRI) (*Not Included in distribution*)

Effective Date: 2009

Original Scale: Various, 1:24,000 – 1:100,000

> *StreetMap Premium for ArcGIS is an enhanced, ready-to-use street dataset that works with Esri's ArcGIS software to provide geocoding, routing, and high-quality cartographic display for the entire United States, Canada, Mexico, and Europe.*

StreetMap Premium, based on commercial street data from NAVTEQ and TomTom, is optimized, structured, and compressed to ensure ease of use and quick deployment.

ESRI Great Lakes Shoreline (ESRI) (*Not included in distribution*)

Effective Date: Various, 1995 - 2002

Original Scale: 1:100,000

U.S. MapData Water Boundaries represents water feature areas within United States. Water boundaries include the following: basic hydrography, naturally flowing water features, man-made channels to transport water, inland bodies of water, man-made bodies of water, seaward bodies of water, bodies of water in a man-made excavation, and special water features.

Data Processing

This project followed a similar methodology to that used by Ewert *et al.* 2006 for mapping migratory bird stopover habitat in the Western Lake Erie Basin. Generally, spatial data that was free, public, and widely available was analyzed using ESRI ArcGIS 10.0 to identify and score various habitats as defined by the authors, regional experts, and informed by an in-depth literature review . The extent of the study included the area 25 km inland from four Great Lakes (Ontario, Erie/Lake St. Clair, Huron and Michigan) and their connecting waters (St. Lawrence Seaway from Crossover Island/Chippewa Bay to Lake Ontario, the Niagara River, the Detroit River, the St. Clair River, and the St. Marys River). Lake Superior was excluded from this study for its perceived lack of threats to stopover sites.

As was done in similar studies previously, migratory birds were divided into three groups: landbirds (including raptors), shorebirds, and waterfowl. Landscape characteristics or attributes considered to be of importance to each of these bird groups were developed, with the understanding that these attributes needed to be framed in way that allowed them to be depicted and analyzed with currently available GIS and data. While this may have reduced the resolution or specificity of some of the attributes, the analysis involved remained complex. Something as simple as distance from Great Lakes shoreline required a multistep process to develop a vector shape that combined data from the US and Canada and matched the boundary of the raster land cover data being used, including the rules for dealing with islands, inlets, bays, river mouths, bridges and international borders. Once the attributes of importance to the bird groups were developed (*e.g.* distance from shore) they were assigned a value based on their meeting certain criteria. For each bird group up to 5 attributes were developed, each of which was assigned a score from 0 to 1. The scores for each attribute for each bird group were summed and a final attribute score ranging from 0 (low) to 5 (high) was produced. Thus it is possible to identify those areas best matching the profile of high value to migratory birds by determining which areas scored highest.

Raster Land Cover

This project utilized data described in Appendix 1. Primary among these data were the two land cover layers: NOAA's 30m resolution 2006 C-CAP and the Ontario Ministry of Natural Resources 25m resolution 2000 Provincial Land Cover Raster. The Canadian data was one file for the entire Province, which covers the entire project area. The C-CAP was downloaded as individual state files and then mosaicked to a new raster. In order to be able to develop a basin-wide land cover raster it was necessary to make the two datasets match as much as possible in both resolution and attributes. Due to the way the raster land cover for Ontario was created, the southern end of Pelee Island and a few scattered spots on the north shores of Lake Huron (Algoma, Manatoulin, and Sudbury Districts) and Ontario (Hastings County, Northumberland County, and Prince Edward Division) were not assigned land cover. These areas were not able to be process as no data existed, and as such no suitable habitat was identified.

To better match the scale of the analyses to areas of habitat likely to be meaningful in the context of bird conservation, it was decided that the entire project would be carried out with 100m pixels using the Great Lakes Albers (NAD 1983) projection rather than smaller pixels. This process was carried out together in ESRI ArcGIS ModelBuilder for each data set: project the data to Great Lakes Albers, extract the study area and resample the data to 100m pixels, using the majority setting where applicable. Once this process was complete, we had similar land cover data sources which could be processed further.

Great Lakes polygons

The second primary data set was the Great Lakes boundary polygon. A great number of interpretations of Great Lakes boundaries exist and they all differ in age, resolution, scale and accuracy. Our project needed one consistent lake boundary shape that would match the shores of the lakes as depicted by the land cover data we were using. Existing lake shapes varied from lake to lake or even within a lake, sometimes putting the lake over the raster land cover and sometimes not reaching the raster shore. It was established early on that one of the most important attributes would be habitat within 1 km of a Great Lake. This being the case we had to take special care to ensure that the lake boundary we used agreed with the raster land cover. Additionally, various depictions of the Great Lakes handled the shore's many irregularities and special cases inconsistently or poorly. In order to ensure the greatest accuracy and conformity with our existing data we created a new version of the Great Lakes, one which matches the interface of the water and the shore as depicted by the C-CAP and PLC data. Figure A2-1 shows and example of how the data was misaligned and how it was improved.

The process required many steps and is based on two data sources- the vector ESRI® MapData™ 2010 U.S. MapData Water Boundaries version of the Great Lakes and the raster land cover layer. As seen in Figure 1, the original version of the lake boundary often had little or no agreement with the shore as represented by the land cover raster. Through a process of buffering, clipping, converting, smoothing, and editing it was possible to create a vector data layer which matched the raster shoreline with a high degree of fidelity. During this process it was necessary to make many judgments about what was the lake shore. It would be entirely reasonable for another version of the Great Lakes to invert or to combine the following examples to derive a different shape of the Great Lakes. We strove to consistently apply our decision-making process across the Great Lakes. In order to create a more literal lake boundary we decided that most deviations from the dominant path of the shore would be made to conform. This resulted in exclusions for things like drowned river mouths with a direct connection to a

Great Lake (*e.g*. Lake Macatawa, Holland, MI; Irondequoit Bay, Rochester, NY), the mouths of major rivers (*e.g*. Fox River, Green Bay, WI; Maumee River, Toledo, OH), and certain embayments (*e.g*. South Baymouth, Manitoulin Island, ON; Rondeau Bay, Shrewsbury, ON; North and South Sandy Ponds, Sandy Creek, NY; Big Creek, Amherstburg, ON). Alternatively, certain additions were made to the shape of the Great Lakes to reflect the dominant path. These would include Burlington Bay, Hamilton, ON; the north shore of Prince Edward County, ONT; Sandusky Bay, Sandusky, OH; portions of the north shore of Georgian Bay, French River Provincial Park, ONT; and Lake George / Lake Nicolet, Sault Ste. Marie, ON.

Figure A2-1. **Data Misalignment**

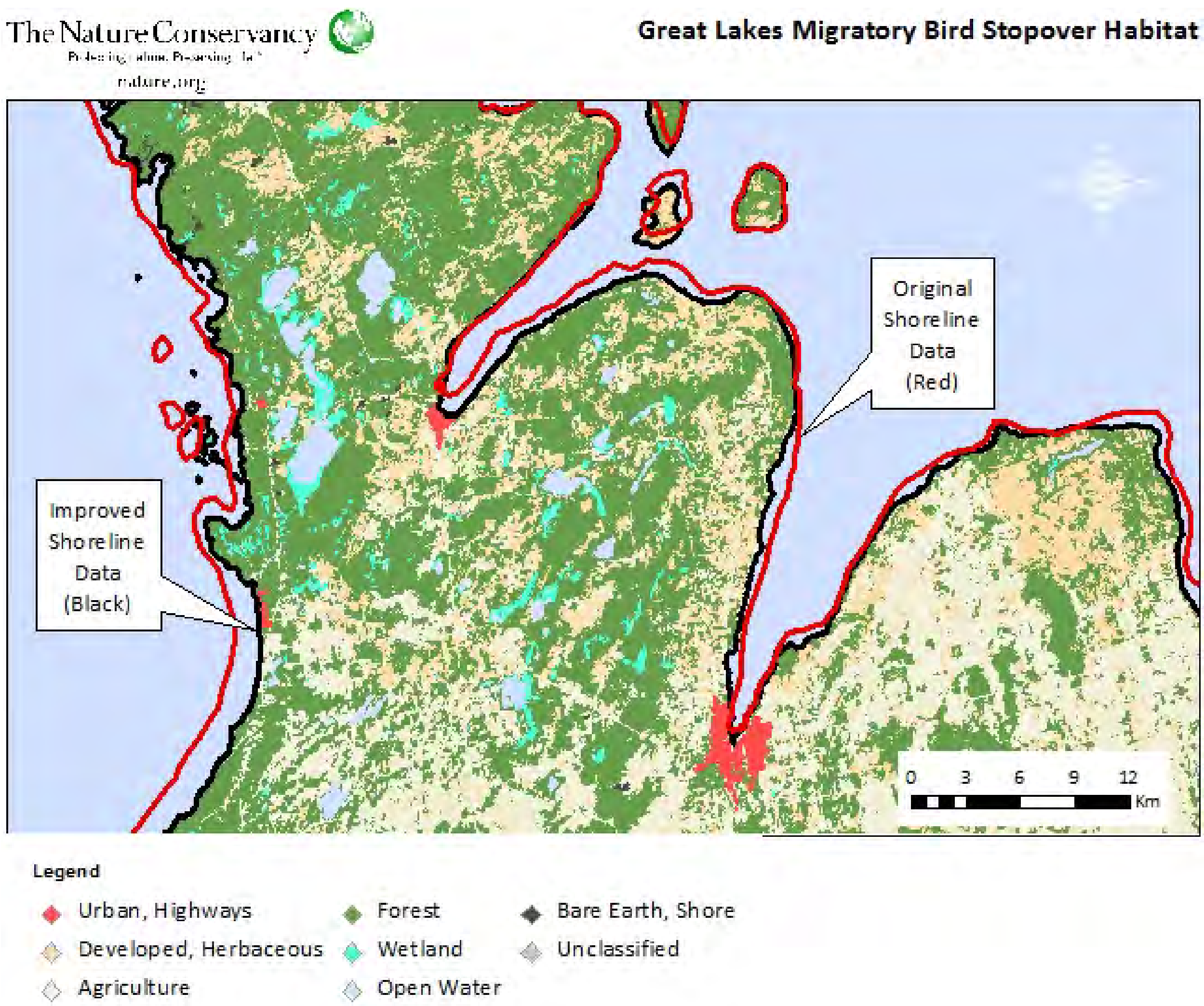

Figure A2-1: Data Misalignmnet

Distance from Great Lakes Shore

A primary reason it was so important to develop a vector shoreline which matched the raster shoreline was the importance of the attributes based on distance from a Great Lake. In particular, the landbird habitat within the first kilometer onshore was weighted higher than all other landbird habitat. Correctly representing that first kilometer was vital. Once the Great Lakes shoreline was established, we were able to move forward with the distance calculation. First was a simple calculation which required creating a Euclidian distance from the shore to 25 km and normalizing the resulting values to a range of 0 to 1 by using this calculation:

$$\text{Normalized } x = (x-\min(x))/(\max(x)-\min(x))$$

where x = the Euclidean distance value. By then subtracting the normalized values from a constant raster with a value of 1, we were able to switch the values so that the highest values were closest to the lake. The resulting score was used in the shorebird attribute *distance from a Great Lake.*

The process for developing the distance score for landbirds was much more complicated because it requires a single value for the first kilometer, then the score declines in a non-linear fashion best described by the function:

$$y = e^{(-x)}$$

where x= the Euclidean distance value, e= the natural logarithm, and y= the distance score. This function does not result in values that fit the exact boundaries as we defined them (the values decline asymptotically, effectively becoming zero before the 25^{th}km), so it was necessary to transform the distance value so that they ranged from a value of 1 at 1 km and 0 at 25 km. By dividing the Euclidean distance (the x value) by 705.88, the resulting distance score values (the y) stretch from 1 to 0 across kilometers 1 – 25. Once we had established a raster with a value of 1 for the first kilometer and a raster that had values that declined in an exponential fashion for kilometers 1-25, we then merged the two rasters.

Hydric Soils

The hydric soils layer is a component of both the Shorebird and Waterfowl attribute *landcover type.* The data we used was selected based on the scale of the mapping units and the similarity of the attributes. The U.S. General Soil Map (STATSGO2) provided a vector soils layer which substantially matched the intent of the Soil Landscapes of Canada (SLC). Both are generalized depictions of the soil and non-soil landscapes, both have attributes that identify soil regions with poor drainage, and each entirely covers its respective portion of the study area. Of all the data used in this project, these layers were the broadest and most generalized. Soils maps generalize the natural variation of the land, even when done at the largest scales, and these are small scale layers. The Canadian SLC has been developed at a scale of 1:1,000,000 and the U.S. General Soil Map is produced at a 1:250,000 scale. This could be compared to the 1:20,000 scale that the more detailed SSURGO in the United States or 1:50,000 for the Detailed Soil Survey (DSS) Compilations of Canada. In addition to providing greater resolution, the larger scale data also has greater complexity in terms of data quantity and structure. SSURGO are done on a county basis, and there are at least 100 counties in our study area. The DSS only covers the major agricultural region of Ontario (*i.e.* it excludes the region north of Lake Superior / Georgian Bay). So while greater detail was available for much of the study area, the General Soil Map and the Soil Landscapes provided sufficient detail and complete coverage.

<u>Appendix 3.</u> Data Analysis Methods

Introduction

This Appendix provides the step-by-step methods used in this project. The analysis was carried out entirely in ESRI ArcGIS 10 and the ModelBuilder files are included with the data distributed with this report. While reference is made to the commands and functions as named in ArcMap, substantially similar functionality is available in many currently available GIS software distributions.

As stated in Appendix 2, the data used in this analysis is widely available, public, and free; the exceptions being the ESRI Maps and Data files depicting the roads and the Great Lakes shorelines. In both cases the ESRI data is a proprietary, processed version of public data sources. It should be possible to reproduce this analysis even without access to the ESRI data by using those public sources. Appendix 2 also contains further detailed information about the data used, its origins, and how it was prepared.

Throughout this Appendix certain points in the analysis are identified as **Final:** to indicate that the result at that point could be useful on its own to be used for other purposes. It will be noted that some layers have a coverage of 40 km. This was done out of an abundance of caution. In order to meet the project deadlines work on the GIS needed to begin before many of the final details of the analysis had been established. To ensure that the data would be able to cover the final distance from shore, we assembled the data using a 40 km Great Lakes buffer. We performed all of the analysis on the data with the 40 km set and extracted the 25 km zone using an extract by mask or clip function. The final model scores were all clipped to the 25 km distance.

Landbirds

<u>*Landbird Attribute 1*</u>

Distance from a Great Lake or connecting water body

Scoring Criteria
0 to 5= distance from the Great Lake, normalized to a scale of 0-5

Method
-Using the TNC New Vector Shoreline, Buffer the shape by 1 km.
-Create a Euclidean Distance layer that extends 24 km from the 1 km buffer
-Use Raster Calculator to normalize the distance values with this expression
-- *Normalized x = (x-min(x))/(max(x)-min(x))*, where x is the Euclidean distance value
- Using Raster Calculator, calculate a 24 km negative exponential decline distance value from the 1 km buffer with this expression:
--*exp(-x)*, where x is the normalized distance value
-Convert the scale from 0.367879 – 1 to 36.7879 by multiplying by 100
-Convert to Integer values
-Subtact 36 from the previous layer to set the lowest value to zero

-Multiply by 1.5625 to stretch the range of values from 0 – 64 to 0 – 100. *This step slightly modifies the shape of the exp(-x) curve by decreasing the slope, or by slightly decreasing the rate of decay of values as they move inland.*
-Divide result by 100 to get continuous negative exponential declining values ranging from 1 – 0
-Extract by Mask to remove Great Lakes

Final: Basin-wide 25 km raster of declining distance values, with the full value of 1 for the first km then declining in a negative exponential manner from 1 to 0 at 25 km

<u>Landbird Attribute 2</u>

Presence of landcover habitat classified as suitable habitat

Scoring Criteria

1=	Natural cover, not including bare land, open water, or palustrine aquatic bed
0.5=	Hay, pasture, palustrine wetland, >72% permeable urban developed
0=	Non habitat

Method for identifying habitat

Step A (Habitat)
-Reclassify the land cover into 4 classes. New classes reflect the attribute scores:

---Old C-CAP Class	**New Class**
---Developed, High Intensity (2)	NoData
---Developed, Medium Intensity (3)	NoData
---Developed, Low Intensity (4)	0
---Developed, Open Space (5)	50
---Cultivated Crops (6)	NoData
---Pasture/Hay (7)	50
---Grassland/Herbaceous (8)	50
---Deciduous Forest (9)	100
---Evergreen Forest (10)	100
---Mixed Forest (11)	100
---Scrub/Shrub (12)	100
---Palustrine Forested Wetland (13)	100
---Palustrine Scrub/Shrub Wetland (14)	100
---Palustrine Emergent Wetland (Persistent) (15)	50
---Unconsolidated Shore (19)	NoData
---Barren Land (20)	NoData
---Open Water (21)	NoData
---Palustrine Aquatic Bed (22)	NoData
---NoData	NoData

---Old PLC Class	**New Cass**
--- Water (1)	NoData
--- Freshwater coastal marsh/inland marsh (5)	50
--- Deciduous swamp (6)	100

--- Conifer swamp (7)	100
--- Open fen (8)	100
--- Treed fen (9)	100
--- Open bog (10)	100
--- Treed bog (11)	100
--- Dense deciduous forest (13)	100
--- Dense coniferous forest (14)	100
--- Coniferous plantation (15)	100
--- Mixed forest, mainly deciduous (16)	100
--- Mixed forest, mainly coniferous (17)	100
--- Sparse coniferous forest (18)	100
--- Sparse deciduous forest (19)	100
--- Recent cutovers (20)	100
--- Old cuts and burns (22)	100
--- Mine tailings, quarries, and bedrock outcrops (23)	NoData
--- Settlement and developed land (24)	NoData
--- Pasture and abandoned fields (25)	50
--- Cropland (26)	NoData
--- Alvar (27)	100
--- Unclassified (cloud and shadow) (28)	NoData
--- NoData	NoData

-Mosaic to New Raster the two layers

Final: Basin-wide 40 km raster layer of suitable landbird habitat, sorted in 3 classes

Step B (Imperviousness)
-Import the 2006 NLCD Percent Developed Imperviousness (*United States only*)
-Extract by Mask to get 40 km study area
-Reclassify to two classes

--**Old NLCD Class**	**New Class**	**Description**
--0-28	1	All pixels less than 28% impervious cover
--28-100	0	All pixels greater than 28% impervious cover
--100-127	NoData	Non-Data values

-Reclassify the C-CAP into two classes to isolate low intensity developed

---**Old C-CAP Class**	**New Class**
---Developed, High Intensity (2)	0
---Developed, Medium Intensity (3)	0
---Developed, Low Intensity (4)	1
---Developed, Open Space (5)	0
---Cultivated Crops (6)	0
---Pasture/Hay (7)	0
---Grassland/Herbaceous (8)	0
---Deciduous Forest (9)	0
---Evergreen Forest (10)	0

---Mixed Forest (11)	0
---Scrub/Shrub (12)	0
---Palustrine Forested Wetland (13)	0
---Palustrine Scrub/Shrub Wetland (14)	0
---Palustrine Emergent Wetland (Persistent) (15)	0
---Unconsolidated Shore (19)	0
---Barren Land (20)	0
---Open Water (21)	0
---Palustrine Aquatic Bed (22)	0
---NoData	NoData

-Use Raster Calculator to add together the reclassed landcover and the reclassed percent developed imperviousness

-Reclassify the new layer

--**Old Class**	**New Class**	**Description**
--0	0	Neither Low Developed nor Low Imperviousness
--1	0	Either Low Developed or Low Imperviousness
--2	50	Both Low Developed and Low Imperviousness
--NoData	NoData	

-Reclassify the new layer to convert NoData to 0

--**Old**	**New**
--0	0
--50	50
--NoData	0

Final: US-wide 40 km raster layer of low intensity developed (C-CAP), low percent developed imperviousness (NLCD), sorted in two classes

Step C
-Use Raster Calculator to add together steps **A + B**

-Reclassify to convert 0 value to NoData

--**Old Class**	**New Class**
--0	NoData
--50	50
--100	100
--NoData	NoData

Final: Basin-wide 40 km raster layer of suitable Landbird habitat, including low percent developed imperviousness in the U.S., sorted in two classes

Step D
-Use 40 km Great Lakes buffer polygon to Extract by Mask the new habitat layer (***step C***)

-Reclassify to set NoData value to 0

--**Old Class**	**New Class**
--50	50
--100	100
--NoData	0

Step E
-Use 1 km Great Lake buffer polygon to Extract by Mask the new habitat layer (***step C***)

-Reclassify

--**Old Class**	**New Class**	**Description**
--50	1	Habitat
--100	1	Habitat
--NoData	0	Not Habitat

Step F
-Use Raster Calculator to add together **steps D + E**

-Reclassify

--**Old Class**	**New Class**	**Description**
--0	NoData	Not Habitat
--1	0	Habitat within 1 km of the shore (Scores separately)
--50	50	Habitat more than 1 km from the shore
--100	100	Habitat more than 1 km from the shore
--NoData	NoData	

Final: Basin-wide 40 km raster layer of suitable Landbird habitat, including low percent developed imperviousness in the U.S., sorted in three classes*. Score of 0 prevents overcounting habitat in the first kilometer.*

<u>Landbird Attribute 3</u>

Percent of suitable landcover type within 5 km of a 1 ha pixel

Scoring Criteria
1= >40% suitable habitat
0= 15% - 40% suitable habitat
1= <15% suitable habitat

Method
-Reclassify suitable habitat from **Attribute 1**, **Step C** to one value (100)

-Use Focal Statistics
--5000 meter (map unit) circle

--Calculate Mean

-Reclassify Values to Scores

--**Old Class**	**New Class**	**Description**
--0-15	25	Low Habitat availability context
--15-40	0	Moderate habitat availability context
--40-10	100	High habitat availability context
--NoData	NoData	

Final: Basin-wide 40km raster layer of suitable Landbird habitat, sorted in 3 classes of habitat density within 5 km radius

<u>Landbird Attribute 4</u>

Distance from non-Great Lakes permanent bodies of water

Scoring Criteria
1= within 100m of lake, pond, river, stream or wetland
0= beyond 100m of lake, pond, river, stream or wetland

Method

Step A (Vector Streams, US)
-Assemble the NHD flowline layers for NHD regions 04, 05, and 07 and Join the appropriate table to allow selection by Cumulative Drainage.
-Use Select by Attribute to select those streams with values greater than 20 square km and export the selection to a new file.
-Merge the three stream layers and clip them to the 40 km Great Lakes buffer.
-Buffer the stream lines by 100 meters then convert the polygon to 100 m cell size raster.
-Reclassify the raster layer to convert NoData values to 0.

Final: U.S.-wide 40 km raster layer of large streams

Step B (Raster Water)
-Reclass the land cover to select out open water and wetlands

---**Old C-CAP Class**	**New Class**
---Developed, High Intensity (2)	0
---Developed, Medium Intensity (3)	0
---Developed, Low Intensity (4)	0
---Developed, Open Space (5)	0
---Cultivated Crops (6)	0
---Pasture/Hay (7)	0
---Grassland/Herbaceous (8)	0
---Deciduous Forest (9)	0
---Evergreen Forest (10)	0
---Mixed Forest (11)	0

---Scrub/Shrub (12)	0
---Palustrine Forested Wetland (13)	100
---Palustrine Scrub/Shrub Wetland (14)	100
---Palustrine Emergent Wetland (Persistent) (15)	100
---Unconsolidated Shore (19)	0
---Barren Land (20)	0
---Open Water (21)	100
---Palustrine Aquatic Bed (22)	100
---NoData	NoData

---**Old PLC Class**	**New Class**
--- Water (1)	0
--- Freshwater coastal marsh/inland marsh (5)	100
--- Deciduous swamp (6)	100
--- Conifer swamp (7)	100
--- Open fen (8)	100
--- Treed fen (9)	100
--- Open bog (10)	100
--- Treed bog (11)	100
--- Dense deciduous forest (13)	0
--- Dense coniferous forest (14)	0
--- Coniferous plantation (15)	0
--- Mixed forest, mainly deciduous (16)	0
--- Mixed forest, mainly coniferous (17)	0
--- Sparse coniferous forest (18)	0
--- Sparse deciduous forest (19)	0
--- Recent cutovers (20)	0
--- Old cuts and burns (22)	0
--- Mine tailings, quarries, and bedrock outcrops (23)	0
--- Settlement and developed land (24)	0
--- Pasture and abandoned fields (25)	0
--- Cropland (26)	0
--- Alvar (27)	0
--- Unclassified (cloud and shadow) (28)	0
--- NoData	NoData

-Mosaic to New Raster the two reclassed landcover layers then Expand the 100 value by 1 cell (100 m).

Final: Basin-wide 40km raster layer of open water and wetlands, with a 100 meter buffer.

Final Landbird Score
Method
-Use Raster Calculator to add all Shorebird layers
--Habitat
--Distance
--Percent Habitat 3 km
--Patch Size
--Adjacent cover

-Reclassify the new layer to replace NoData with 0.

-Convert to floating point.

-Divide by 100 to get a 0 to 5 score for all 40 km.

-Extract by mask to get 25 km score raster layer.

-Extract by mask to remove the Great Lakes.

Final: Standard Landbird habitat score raster layer

Shorebirds

<u>Shorebird Attribute 1</u>

Landcover type associated with suitable habitat

Scoring Criteria
1= Wetlands
0.25= Unconsolidated shore and bare earth ("Beach") adjacent to Great Lakes

Method

Step A
-Reclassify C-CAP so that Palustrine Emergent Wetland (15) has a value of 1; the rest of the classes become 0.
-Reclassify the PLC so that Freshwater Coastal Marsh / Inland Marsh (1) has a value of 1; the rest of the classes become 0
-Merge the two layers to a new raster.
-Multiply the new layer by 100.
-Convert the new layer to an integer.

-Final: Basin-wide 40 km raster of Marsh habitat scored 100, else 0.

Step B
-Use a Con statement to select from the C-CAP the Unconsolidated Shore class (19) and the Barren Earth class (20) and assign them their score value of 0.25, else 0.
-Use a Con statement to select from the PLC the Mine Tailings, Quarries, and Rock Outcrop class (23) and assign the score value of 0.25, else 0.
-Buffer the Great Lakes polygon by 100m and use it to Extract by Mask the C-CAP and the PLC.
-Mosaic to New Raster the two layers.
-Multiply the layer by 100
-Convert the layer to an Integer
-Reclassify the layer so that NoData becomes 0

-Final: Basin-wide 40 km raster layer of shorebired habitat 1 cell (100 meters) onshore from Great Lakes, with "Beach" values scored 25 and the rest scored 0.

Step C (Agriculture on Hydric Soils)

-**Hydric Soils**
--From the U.S. General Soils Map, Select by Attribute from Drainage Class soil classes 'Poorly drained' OR 'Somewhat poorly drained' OR 'Very poorly drained'
--Export the selection to shape.
--From the Soil Landscapes of Canada, Select by Attribute from Drain soil classes 'P' OR 'V' OR 'I'
--Export the selection to shape.
--Merge the two new shapes

--***Final: Basin-wide 40 km raster layer of hydric/poorly drained soils***

-**Agriculture**
--Use Con to select from the C-CAP the Cultivated Crops class (6) and assign it the score value of 0.25, else 0.
--Use Con to select from the PLC the Cropland class (26) and assign it the score value of 0.25, else 0.
--Mosaic to New Raster the two new layers.

--***Final: Basin-wide 40 km raster layer of cropland***.

-**Combine Agricultures and Hydric**
--Use Hydric Soils layer to Extract By Mask Agriculture layer
--Multiply new raster by 2.
--Multiply new raster by 100.
--Convert new layer to Integer.
--Reclassify to convert NoData to 0.

--***Final: Basin-wide 40 km raster of Agriculture on Hydric Soils with habitat having a score of 50 and non-habitat having value of 0.***

Step D
-Use Raster Calculator to add steps A +B + C
-Reclass the new layer to set 0 to NoData

-***Final: Basin-wide 40 km raster of Shorebird habitat with 3 classes***:
Wetlands = 100,
Agriculture on hydric Soils = 50,
"Beach" = 25,
and non-habitat having a value of NoData.

<u>Shorebird Attribute 2</u>
Amount of wetland cover within 3 km radius of suitable landcover type

Scoring Criteria
1= >40% suitable habitat

0.5= >15% and <40% suitable habitat
0.25= <15% suitable habitat

Method
-Reclassify suitable Shorebird habitat layer to value of 100
-Use Focal Statistics
--3000 meter (map unit) circle
--Calculate Mean

-Reclassify to convert percentages to scores

--**Old Class**	**New Class**
--0-15	25
--15-40	50
--40-100	100

-Final: Basin-wide 40km raster layer of suitable Shorebird habitat, sorted in 3 classes of habitat density within 3 km

<u>Shorebird Attribute 3</u>

Patch size

Scoring Criteria
-1 = >10 ha
-0.5 = <10 ha

Method
-Reclassify basin-wide Shorebird habitat to 1 value
-Use Region Group to create patches
--4 neighbors, Zone Group within, no add link field, exclude “0” (non-habitat)
-Use Con to select and assign values
--If Count >10, True = 100, Else = 50
-Use Con to select and assign values to Great Lakes patches
--If Count >8,000,000, True = 25, Else = 0
-Use Raster Calculator to add together the two previous layers

-Reclassify new layer

--**Old**	**New**	**Description**
-- 50	50	Habitat patch less than 10 ha
--100	100	Habitat patch greater than 10 ha
--125	0	

-***Final: Basin-wide 40 km raster layer of suitable Shorebird habitat patches, sorted in two classes of patch size.***

<u>Shorebird Attribute 4</u>

Adjacent cover type within 100 m of suitable landcover type

Scoring Criteria

1=	Undeveloped, non-forest (hay, pasture, agriculture, bare soil, unconsolidated shore)
0.5=	Undeveloped, forest (All forest types, shrublands)
0=	Developed (Expanded by 100m)

Method

-Reclassify land cover into 3 classes

--Good Habitat=	0
--Forest=	1
--Developed=	100

---**Old C-CAP Class**	**New Class**
---Developed, High Intensity (2)	100
---Developed, Medium Intensity (3)	100
---Developed, Low Intensity (4)	100
---Developed, Open Space (5)	100
---Cultivated Crops (6)	0
---Pasture/Hay (7)	0
---Grassland/Herbaceous (8)	0
---Deciduous Forest (9)	1
---Evergreen Forest (10)	1
---Mixed Forest (11)	1
---Scrub/Shrub (12)	1
---Palustrine Forested Wetland (13)	1
---Palustrine Scrub/Shrub Wetland (14)	1
---Palustrine Emergent Wetland (Persistent) (15)	0
---Unconsolidated Shore (19)	0
---Barren Land (20)	0
---Open Water (21)	0
---Palustrine Aquatic Bed (22)	0
---NoData	NoData

---**Old PLC Class**	**New Class**
--- Water (1)	0
--- Freshwater coastal marsh/inland marsh (5)	0
--- Deciduous swamp (6)	1
--- Conifer swamp (7)	1
--- Open fen (8)	1
--- Treed fen (9)	1
--- Open bog (10)	1
--- Treed bog (11)	1
--- Dense deciduous forest (13)	1
--- Dense coniferous forest (14)	1
--- Coniferous plantation (15)	1
--- Mixed forest, mainly deciduous (16)	1
--- Mixed forest, mainly coniferous (17)	1
--- Sparse coniferous forest (18)	1

--- Sparse deciduous forest (19)	1
--- Recent cutovers (20)	1
--- Old cuts and burns (22)	1
--- Mine tailings, quarries, and bedrock outcrops (23)	0
--- Settlement and developed land (24)	100
--- Pasture and abandoned fields (25)	0
--- Cropland (26)	0
--- Alvar (27)	1
--- Unclassified (cloud and shadow) (28)	NoData
--- NoData	NoData

-Use Expand to grow all cells with value of 100 by 100 meters (1 cell).
-Mosaic to New Raster the two layers.

Final: Basin-wide 40 km raster layer of land cover within 100 meters of shorebird habitat, sorted in three classes.

-Use Focal Statistics to Sum land cover within 2 adjacent cells
--5x5 cell rectangle, Sum
---0= only good habitat surrounding
---1-50= only forest surrounding
---100+= development within 300 meters

-Use Con to select and assign values
--if 0 then 100, else 0
--if >=1 and <=50 then 50, else 0

-Use Raster Calculator to add road influence
--ESRI Data "streetscarto" layer
--Select by Attribute Carto classes 1-6
--Export to shape
--Rasterize at 100 meters
---Road cells given a value of 1000
--Reclassify to give NoData the value of 0
--add together roads raster layer and adjacent habitat raster layer

-Reclassify new layer to apply road effect

--**Old Class**	**New Class**
--0	0
--50	50
--100	100
--1000	0
--1050	0
--1100	0

Final: Basin-wide 40 km raster of Shorebird Adjacent Habitat, sorted in three classes of adjacent land use:

-200 meters to Beneficial Habitat = 1 (100)
-200 meters to Forest= 0.5 (50)
-300 meters to Development= 0 (0)
-100 meters (presence of 100 meter cell) for Roads=0 (0)

<u>Shorebird Attribute 5</u>

Distance from a Great Lake or connecting water body

Scoring Criteria
-1= <3.2 km from shore
-0.5= >3.2 km and <16 km from shore

Method
-Convert Euclidean Distance raster layer to Integer
-Use Con to select and assign scores
--distance < 3.2 km = 100, else 50
--distance > 16 km = 20, else 0

-Use Raster Calculator to add the two layers

-Reclassify

--**Old**	**New**	
--50	50	(>3.2 km and <16 km)
--75	0	(>3.2 km and >16 km)
--100	100	(<3.2 km)

-Final: Basin-wide 40 km raster layer of distance, sorted into 3 classes

Final Shorebird Score

Method
-Use Raster Calculator to add all Shorebird layers
--Habitat
--Distance
--Percent Habitat 3 km
--Patch Size
--Adjacent cover

-Reclassify the new layer to replace NoData with 0.

-Convert to floating point.

-Divide by 100 to get a 0 to 5 score for all 40 km.

-Extract by mask to get 25 km score raster layer.

-Extract by mask to remove the Great Lakes.

Final: Standard Shorebird habitat score raster layer

Waterfowl

Waterfowl Attribute 1

Landcover type associated with suitable habitat

Scoring Criteria

1=	Mixed Emergent Marsh + Open Water
0.25=	Palustrine forested wetlands, agriculture on hydric soils
0.75=	Open water, emergent marsh

Method

Step A (Suitable Landcover Types)

-Reclassify land cover into 3 classes

--Non-habitat=	0
--Forested Wetland=	25
--Open Water, Emergent Marsh=	100

---**Old C-CAP Class**	**New Class**
---Developed, High Intensity (2)	0
---Developed, Medium Intensity (3)	0
---Developed, Low Intensity (4)	0
---Developed, Open Space (5)	0
---Cultivated Crops (6)	0
---Pasture/Hay (7)	0
---Grassland/Herbaceous (8)	0
---Deciduous Forest (9)	0
---Evergreen Forest (10)	0
---Mixed Forest (11)	0
---Scrub/Shrub (12)	0
---Palustrine Forested Wetland (13)	25
---Palustrine Scrub/Shrub Wetland (14)	0
---Palustrine Emergent Wetland (Persistent) (15)	75
---Unconsolidated Shore (19)	0
---Barren Land (20)	0
---Open Water (21)	75
---Palustrine Aquatic Bed (22)	75
---NoData	NoData

---**Old PLC Class**	**New Class**
--- Water (1)	75
--- Freshwater coastal marsh/inland marsh (5)	75
--- Deciduous swamp (6)	25
--- Conifer swamp (7)	0
--- Open fen (8)	0

--- Treed fen (9)	0
--- Open bog (10)	0
--- Treed bog (11)	0
--- Dense deciduous forest (13)	0
--- Dense coniferous forest (14)	0
--- Coniferous plantation (15)	0
--- Mixed forest, mainly deciduous (16)	0
--- Mixed forest, mainly coniferous (17)	0
--- Sparse coniferous forest (18)	0
--- Sparse deciduous forest (19)	0
--- Recent cutovers (20)	0
--- Old cuts and burns (22)	0
--- Mine tailings, quarries, and bedrock outcrops (23)	0
--- Settlement and developed land (24)	0
--- Pasture and abandoned fields (25)	0
--- Cropland (26)	0
--- Alvar (27)	1
--- Unclassified (cloud and shadow) (28)	NoData
--- NoData	NoData

-Mosaic to New Raster the two layers.

-Final: Basin-wide 40km raster of suitable waterfowl landcover habitat

Waterfowl Attribute 2
Amount of wetland cover within 3 km radius of a 1 ha pixel of suitable landcover type

Scoring Criteria
1= >40%
0.5= >15% and <40%
0.25= <15%

Method
-Reclassify suitable habitat to 100
-Use Focal Statistics
--3000 meter circle, Mean

-Reclassify to assign scores

--**Old Class**	**New Class**
--0 – 15	25
--15 – 40	50
--40 -100	100
--NoData	NoData

-***Final: Basin-wide 40 km raster layer of suitable waterfowl habitat, sorted in 3 classes of habitat density within 3 km***

Step B (Marsh+Water Focal Flow)

-Reclassify land cover into 3 classes

--Non-habitat=	5
--Marsh Habitat=	9
--Open Water=	1

---**Old C-CAP Class**	**New Class**
---Developed, High Intensity (2)	5
---Developed, Medium Intensity (3)	5
---Developed, Low Intensity (4)	5
---Developed, Open Space (5)	5
---Cultivated Crops (6)	5
---Pasture/Hay (7)	5
---Grassland/Herbaceous (8)	5
---Deciduous Forest (9)	5
---Evergreen Forest (10)	5
---Mixed Forest (11)	5
---Scrub/Shrub (12)	5
---Palustrine Forested Wetland (13)	5
---Palustrine Scrub/Shrub Wetland (14)	5
---Palustrine Emergent Wetland (Persistent) (15)	9
---Unconsolidated Shore (19)	5
---Barren Land (20)	5
---Open Water (21)	1
---Palustrine Aquatic Bed (22)	9
---NoData	NoData

---**Old PLC Class**	**New Class**
--- Water (1)	1
--- Freshwater coastal marsh/inland marsh (5)	9
--- Deciduous swamp (6)	5
--- Conifer swamp (7)	5
--- Open fen (8)	5
--- Treed fen (9)	5
--- Open bog (10)	5
--- Treed bog (11)	5
--- Dense deciduous forest (13)	5
--- Dense coniferous forest (14)	5
--- Coniferous plantation (15)	5
--- Mixed forest, mainly deciduous (16)	5
--- Mixed forest, mainly coniferous (17)	5
--- Sparse coniferous forest (18)	5
--- Sparse deciduous forest (19)	5
--- Recent cutovers (20)	5
--- Old cuts and burns (22)	5
--- Mine tailings, quarries, and bedrock outcrops (23)	5
--- Settlement and developed land (24)	5

--- Pasture and abandoned fields (25)	5
--- Cropland (26)	5
--- Alvar (27)	5
--- Unclassified (cloud and shadow) (28)	NoData
--- NoData	NoData

-Mosaic to New Raster the two layers.
-Use Focal Flow to depict how cells over the threshold 7 will “flow” from high values (9) to low values (0)
-Reclass result to separate

--**Old Class**	**New Class**	**Description**
--0 -1	0	Not Habitat
--1- 255	100	Habitat

-- Water cells have a value of 100 where they are adjacent to Marsh/Palustrine Emergent/Palustrine Aquatic Bed

Step C (Agriculture on Hydric)
-Use Agriculture on Hydric Soils from Shorebird Attribute 1, Step C
-Reclassify to appropriate score

--**Old Class**	**New Class**
--0	0
--50	25
--NoData	NoData

Step D
-Use Raster Calculator to add together Steps **A+B+C**
-Reclassify to convert 0 to NoData and make fit to scale

--Old Class	**New Class**
--0	NoData
--25	25
--75	75
--175	100
--NoData	NoData

-Reclassify to convert NoData to 0

--**Old Class**	**New Class**
--25	25
--75	75
--175	100
--NoData	0

Step E
-Reclassify the Great Lakes raster to help deal with lake/shore matching

--**Old Class**	**New Class**

--0	200
--NoData	0

-Use Raster Calculator to add together Steps D+E
-Reclassify new layer to final habitat scores (attribute scores 200 or greater are the result of stitching lake and shore, and are resolved in favor of land cell values)

--**Old Class**	**New Class**
--25	25
--75	75
--100	100
--200	75
--225	25
--275	75
--300	100
--NoData	NoData

Final: Basin-wide 40 km raster layer of suitable waterfowl habitat, sorted in 3 classes

<u>Waterfowl Attribute 3</u>

Patch size

Scoring Criteria

-1=	>16 ha
-0.5=	>5 ha and <16 ha
-0.25=	< 5 ha

Method
-Reclassify Waterfowl habitat layer to one value
-Region Group
--4 neighbors, Zone Group within, no add link field, no exclude

-Use Con to select sizes and assign values

--<5 =	25, else 0
-->5 and <16 =	50, else 0
-->16 =	100, else 0

-Use raster calculator to add all three layers back together

-Reclassify new layer to change NoData to 0

-Use Raster Calculator to add in Great Lakes

-***Final: Basin-wide 40 km raster layer of suitable waterfowl habitat, sorted in three size classes***

<u>Waterfowl Attribute 4</u>

Adjacent cover type within 100 m of suitable landcover type

Scoring Criteria

-1= Undeveloped, non-forest (hay, pasture, agriculture, bare soil, unconsolidated shore)

-0.5= Undeveloped, forest (All forest types, shrublands)

-0= Developed (Expanded by 100m)

Method

-Reclass landcover into three classes

--Good Habitat= 0

--Forest and Shrub= 1

--Developed= 100

---**Old C-CAP Class**	**New Class**
---Developed, High Intensity (2)	100
---Developed, Medium Intensity (3)	100
---Developed, Low Intensity (4)	100
---Developed, Open Space (5)	100
---Cultivated Crops (6)	0
---Pasture/Hay (7)	0
---Grassland/Herbaceous (8)	0
---Deciduous Forest (9)	1
---Evergreen Forest (10)	1
---Mixed Forest (11)	1
---Scrub/Shrub (12)	1
---Palustrine Forested Wetland (13)	1
---Palustrine Scrub/Shrub Wetland (14)	1
---Palustrine Emergent Wetland (Persistent) (15)	0
---Unconsolidated Shore (19)	0
---Barren Land (20)	0
---Open Water (21)	0
---Palustrine Aquatic Bed (22)	0
---NoData	NoData

---**Old PLC Class**	**New Class**
--- Water (1)	0
--- Freshwater coastal marsh/inland marsh (5)	0
--- Deciduous swamp (6)	1
--- Conifer swamp (7)	1
--- Open fen (8)	1
--- Treed fen (9)	1
--- Open bog (10)	1
--- Treed bog (11)	1
--- Dense deciduous forest (13)	1
--- Dense coniferous forest (14)	1
--- Coniferous plantation (15)	1
--- Mixed forest, mainly deciduous (16)	1
--- Mixed forest, mainly coniferous (17)	1

--- Sparse coniferous forest (18)	1
--- Sparse deciduous forest (19)	1
--- Recent cutovers (20)	1
--- Old cuts and burns (22)	1
--- Mine tailings, quarries, and bedrock outcrops (23)	0
--- Settlement and developed land (24)	100
--- Pasture and abandoned fields (25)	0
--- Cropland (26)	0
--- Alvar (27)	1
--- Unclassified (cloud and shadow) (28)	NoData
---NoData	NoData

-Use Expand to grow all cells with value of 100 by 100 meters (1 cell).

-Mosaic to New Raster the two layers.

Final: Basin-wide 40 km raster layer of land cover adjacent to suitable waterfowl habitat.

-Use Focal Statistics to Sum land cover within 2 adjacent cells
--5x5 cell rectangle, Sum

---0=	only good habitat surrounding
---1-50=	only forest or shrub surrounding
---100+=	development within 300 meters

-Use Con to select values and assign scores
--if 0 then 100, else 0
--if >=1 and <=50 then 50, else 0

-Use Raster Calculator to add the new layers together

-Reclassify new raster to give NoData the value of 0 and convert 0 to 10

--**Old Class**	**New Class**
--0	10
--50	50
--100	100
--NoData	0

-Use Raster Calculator to add Great Lakes to new layer
--Constant value of 200

-Reclass new raster to resolve overlap

--**Old Class**	**New Class**
--0	NoData
--10	0
--50	50
--100	100

--200	100
--210	0
--250	50
--300	100
--NoData	NoData

-Use Raster Calculator to add road influence
--ESRI Data “streetscarto” layer
--Select by Attribute Carto classes 1-6
--Export t to shape
--Rasterize at 100 meters
---Road cells given a value of 1000

--Reclassify to give NoData the value of 0
--add together roads raster layer and adjacent habitat raster layer

-Reclassify new layer to apply road effect

--**Old Class**	**New Class**
--0	0
--50	50
--100	100
--1000	0
--1050	0
--1100	0

Final: Waterfowl Adjacent Cover Attribute
Beneficial Land Cover Classes within 200m = 1 (100)
Forest Land Cover within 200m = 0.5 (50)
Development within 300m = 0
Road within 100m (100m cell present)=0

Waterfowl Attribute 5

Great Lakes water depth (bathymetry)

Scoring Criteria
1= <4 meters
0.5= >4 m and <6 m
0.25= >6 meters

Method

Step A
-Assemble individual raster lake bathymetry files into one file with correct resolutions and projection
-Trim overlaps and non-Great Lake waters by using the TNC New Great Lake polygon to extract by mask.
-Reclassify resulting file into 4 classes

--**Old Class**	**New Class**
--0 – 4	100

--4 – 6	50
-- >6	25
--NoData	0

Step B

-Fill in shoreline gaps using a different raster layer of depths < 9 meters

--Reclassify to a constant value and convert NoData to 0

--**Old Class**	**New Class**
--100	100
--NoData	0

Step C

-Use Raster Calculator to add the two bathymetry layers

-Reclassify the resulting layer

--**Old Value**	**New Value**
--0	0
--25	25
--50	50
--100	100
--125	25
--150	50
--200	100

Final: Basin-wide raster layer of Great Lakes bathymetry sorted into 3 classes

Final Waterfowl Score

Method

-Use Raster Calculator to add all 5 Waterfowl Attribute layers

--Suitable Habitat
--Amount of suitable habitat within 3 km
--Patch size
--Adjacent cover
--Bathymetry

-Reclassify the new layer to replace 0 with NoData.

-Convert to floating point.

-Divide by 100 to get a 0 to 5 score for all 40 km.

-Extract by mask to get 25 km score raster layer.

Final: Standard Waterfowl habitat score raster layer