Nesting Mallard (*Anas platyrhynchos*) Habitat Site Selection and Management Using GIS

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Approved:

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Abstract

Ducks Unlimited’s Saginaw Bay priority zone in eastern Michigan is highly concentrated area of wetland habitat patches. A set of criteria to prioritize these wetlands is needed so that managers can most effectively decide where to focus conservation efforts in the area. Nesting mallard (Anas platyrhynchos) pairs were chosen as the target species to base conservation decisions on. A GIS based model was created using a series on inputs including distance to development, distance to existing reserves, state acquisition areas, wetland density, the Habitat Evaluation Network, and habitat connectivity. This model produced a visual representation of the best wetland patches for mallard populations. It can be easily modified to accommodate different species or criteria, and can be effectively be used by managers to make future conservation decisions.
Introduction

Ducks Unlimited’s (DU) land protection program in the Great Lakes Atlantic Region, although relatively new, has already proven important to preserving biotic communities and open lands. By cataloging and analyzing protected lands in the Great Lakes states, this project makes it possible to target areas which would benefit from protection, whether it is to expand existing areas, or to provide good habitat to waterfowl. The question is no longer whether or not to conserve land, but which land to conserve. This can be a daunting question considering increases in land values and the financial constraints of organizations such as DU. DU and others must ensure that efforts are focused on lands that will provide the most conservation value.

In order to make logical and effective decisions about which parcels of land to protect, environmental managers must understand the preferences of the species that the conservation efforts are based around, and apply that knowledge to the decision making process (Newbold and Eadie 2004). Making management decisions based around a single species is often the simplest and most practical approach, especially when it is an “umbrella” species, which is to say protecting that particular species will also protect the habitat of other species that share its range. Trying to base conservation decisions on a range of different species needs and ranges becomes daunting. The question then shifts from “What is the best way to protect habitat” to “If this strategy is implemented over this strategy, how many more or fewer species will be included in the protection plan” (Newbold and Eadie 2004). This can become complex and even wasteful. For these reasons, I have chosen to focus on nesting mallards (Anas platyrhynchos) as a key species of wetland habitat protection.

The focus of this project will be on conserving wetlands for waterfowl habitat in the Saginaw Bay region of Michigan. Surrounding Saginaw Bay are an incredible number of
wetlands that are invaluable for waterfowl, yet even today, few lands in the Saginaw Bay area are protected or conserved. Criteria are needed to decide which wetland sites in the area have the most crucial needs for protection of waterfowl by Ducks Unlimited. Hypothetically, criteria can to be applied to a much broader landscape than Saginaw Bay to identify areas of high priority wetlands.

A problem with creating general preservation criteria is that the needs of a species may vary considerably. In fact, even mallards may vary in home range size and in preference for wetland density (Mack 2003). Though it is known that wetland density is positively correlated with mallard populations, exact relationships of wetland areas and quality versus mallard populations are not known. The same is true of home range sizes; we may know that bigger is better, but not how much space is necessary per density of birds (Mack 2003). There are also many social factors that go into land acquisition. Land trusts and similar organizations are constrained by finance, social pressures to preserve or not preserve certain lands, and to create preserves in an aesthetically pleasing manner. This project will focus on determining criteria that can be modified or expanded as more is discovered about the habitat sizes of mallards and other species that this model is applied to.

**Study Area**

Michigan’s Saginaw Bay is the largest watershed in the state, covering 22,556 square kilometers (EPA 2007). It also contains America’s largest uninterrupted freshwater coastal system. The area currently faces many challenges including sedimentation, nutrient loading and declining fisheries (EPA 2007). Increased development in the area is leading to habitat loss and water contamination issues. The major site of development is in and around Bay City, MI, which
is a major port located at the south end of the Bay (Figure 1). Despite these problems, this area has a high concentration of wetlands, and its mix of urban and natural areas makes it an important conservation area for Ducks Unlimited.

**Mallards and Habitat Selection**

Newbold and Eadie (2004) found that mallard populations were positively correlated with high amounts of wetland density. Their research suggests that small scattered wetland patches support more mallard populations, which is to say that mallards prefer wetland edges over interiors. In one study, small wetlands only made up 6.7% of the total wetland cover, but accounted for 43% of mallard use (Gilmer *et al.* 1975). This is due to the fact that mallards use associated upland areas such as forests for breeding purposes (Newbold and Eadie 2004). The lack of upland cover in open wetlands means fewer mallard pairs. In fact, even dense uplands can make good mallard habitat. Areas that exceed 50% tree cover are frequently used by mallards as nesting sites (Gilmer *et al.* 1975).

Although mallards use small wetland patches most commonly, their home range can be quite large. The average mallard pair frequents 240 hectares of wetland area, and this has been known to range up to 760 hectares, although this was a one time case and not believed to be the norm (Gilmer *et al.* 1975). This leads to several key conclusions about how a model for mallard habitat selection should be constructed. Mallard habitat must have a high wetland density, but also have small wetland patches with associated forest uplands, and be large enough in total area to account for mallard home range.
Social Considerations

Social considerations are also important for deciding which areas are suitable for purchase. Due to financial, staffing, and managerial constraints, it is not always possible to purchase an area of land, even if it appears to be valuable ecologically. In fact, social considerations may even trump biological concerns if the biological differences between sites appear to be minor compared to the cost of vary social values (Prendergast et. al 1999). Due to this fact, this study tries to select the best mallard habitat that will also be the most attractive to potential buyers, such as DU.

For the purposes of this study, three social considerations are taken into account. First, it is more likely that lands will be purchased when they are adjacent to existing reserves or otherwise protected lands (Prendergast et. al 1999). Managers like to have large tracts of land, and there has been a recent push towards preserving bigger parcels to give species a wider range of protected habitat. Second, reserve designers prefer that land they purchase be further from development for a number of reasons (perceived value as wild and undisturbed, less chance of disturbance, usually better quality habitat, fewer urban interface issues, etc.) and so this land is more likely to be purchased (Miller and Hobbs, 2002). Lastly, organizations such as the Nature Conservancy and the Fish and Wildlife Service have mapped priority acquisition areas (US Forest Service). Acquisition areas have been found to be of high quality for a specific purpose, such as habitat, or are in an area that is desirable for conservation. Land within these areas is pre-approved for purchase and should be considered due to the ease of procurement.
Methods

Site selection criteria for the GIS analysis use the following inputs. Each input was designated as an ecological or social value depending on why it is being included in the analysis. This designation is used in the overall scoring matrix for the site selection. A complete list of criteria and scores is found in Table 1.

**Wetland patches:** Wetlands from the National Wetlands Inventory were dissolved by proximity to produce the wetland parcels which served as the base layer for the analysis. I removed any wetlands that were already conserved (i.e. overlapping with the Conservation and Recreation Lands layer). Each patch then had its patch centroid created (to the nearest 0.1 ha), and central points served as the analyses points. The data for this analysis were provided by the National Wetlands Inventory Update for Southern Michigan, created by US Fish and Wildlife Service and modified by Ducks Unlimited.

**Existing Reserves:** Distance from each wetland patch to existing protected lands was estimated using DU’s Conservation and Recreation Lands layer, which is a working database of all protected lands within the five state Great Lakes area, either for recreation or conservation purpose. Wetland patches that share boundaries with existing preserves were given the highest score and the assigned score decreased the further the patch was from an existing preserve. The distance layer produced was reclassified to produce the scores used in the final analysis. This input was designated as a social value; waterfowl do not care how far away habitat is from other habitat, due to flight and migration. However, habitat is more likely to be purchased when it is adjacent to existing reserves, as reserve designers prefer large reserves, and to expand on existing ones. That data for this analysis is the Conservation and Recreation Lands Layer, created by Ducks Unlimited.
**Existing Development**: Land cover data were used to calculate the distance from each wetland patch to existing development. Roads and utility corridors were excluded from the analysis, because although they are technically development, nesting waterfowl are not typically affected by roads (LaGrange and Dinsmore 1989). When this analysis is repeated for more sensitive species, roads can be included in this input. Wetland patches that are further away from development received a higher score than those that are closer to development. The distance layer produced was reclassified to produce the scores used in the final analysis. This input was designated as a social value, as mallards do not care how close habitat is to development, and often use urban areas as resting or feeding sites (Brodsky and Weatherhead 1984). They have been known to nest in very close proximity to humans. However, reserve designers prefer that land they purchase be further from development for a number of reasons (perceived value as wild, less chance of disturbance, usually better quality habitat, less urban runoff, etc.) and so this land is more likely to get purchased. The data used for this analysis are the IFMAP/GAP Lower Peninsula Land Cover for 2001, created by Michigan DNR.

**Wetland density**: Creating contiguous habitat is important, and therefore areas of high wetland density received a higher score. Isolated patches received a lower score. Each square mile area, as determined by the waterfowl breeding priority layer, had its wetland density calculated. This was done by calculating the percentage of wetland coverage in each square mile block. Emergent wetlands were ranked higher than forested wetlands for this analysis, due to their greater importance for nesting waterfowl. For this reason, areas that have a great amount of forested wetlands may appear to have a lower wetland density in the analysis. This input was designated as an ecological value. The data for this analysis include the calculated wetland patches from National Wetlands Inventory Update for Southern Michigan, created by US Fish
and Wildlife Service and modified by Ducks Unlimited, and the Great Lakes Habitat Evaluation Network Square Mile Grid, created by Ducks Unlimited

**Protection priorities:** This input came from a layer created by Ducks Unlimited to show how land should be managed for breeding mallards. Called the Habitat Evaluation Network (HEN), each square mile in the Great Lakes region was assigned a Strategy value (protect, protect and restore, protect and restore with caution, or outside mallard area). Wetland patches were given scores according to these classifications. For instance, wetlands that fall within an area that has a Strategy value of ‘protect’ received the highest score, ‘protect and restore’ received the next highest score. A value of ‘protect’ means that the site is valuable habitat without any restoration work required. Sites that require restoration but are still good habitat are designated in the ‘protect and restore’ and ‘protect and restore with caution’ categories. Those wetland patches that fall within areas that are not important to mallards received the lowest scores. This input is designated as an ecological value, as it concerns what areas contain suitable habitat for waterfowl. In addition, the HEN model can be used to locate wetland patches with associated forested uplands, since this data are included in the original analysis. The data for this analysis are the Great Lakes Habitat Evaluation Network Square Mile Grid, created by Ducks Unlimited

**Acquisition Areas:** Wetlands that fall within the management/acquisition zones of the Huron-Manistee National Forest were given higher scores in this category than other patches, because these wetlands would be preapproved for purchase. Only a small portion of the acquisition area was located within the study zone, but was still included in the analysis so that this type of input can be used in future models, and because wetland patches are much more likely to be purchased when they are located within this acquisition area. The scoring system
used for this input varies slightly; the wetland patch receives a score of 4 if it is inside the acquisition area, and a score of 0 if it is not. This input is a social value, as it is up to reserve designers to designate these acquisition areas, and thus decide where purchases are most likely to be made. The data for this analysis are the Management Areas for Huron/Manistee National Forests, created by Huron-Manistee National Forests.

**Habitat Connectivity:** Connectivity is a more complicated metric than the proceeding one, and thus more complex GIS analysis is required. As development continues to fragment habitat, patch sizes continue to grow smaller, and the functional connectivity of the dispersed population could influence diet and even mean the difference between locating food and starving (Nikolakaki 2004). Connectivity is an estimate of how easy it is for a population to move from one habitat patch to another; a well connected patch could therefore serve as a feeding or nesting ground, or as a stepping stone to get to a larger habitat patch (Schippers *et al.* 1996). Because of this, the presence of many bird species in a habitat fragment is affected by both the size of the fragment, and its degree of connectivity (Nikolakaki 2004).

For this analysis, the principles of graph theory were applied the to wetland habitat data. In graph theory, a graph is made up of nodes, in this case the habitat patches, and edges, the distance or cost distance between the nodes (Bunn *et al.* 2000). If two of the nodes on the graph do not occur adjacently, the shortest path between the two nodes will have to go through other nodes, using them as stepping stones (Bunn *et al.* 2000). This is the primary reason that connectivity is vital to this assessment; well connected habitat patches provide safer and shorter paths to other patches of habitat.

Typically, a cost is associated with each edge in a graph depending on how difficult it is to travel the length of that edge. This is because the landscape is heterogeneous, and therefore
different land cover types will have different costs associated with traversing them (Nikolakaki 2004). For instance, for terrestrial animals, moving from one habitat patch to another by crossing a road has a greater cost than getting to another patch by using a forest corridor, or even a farm field. Because mallards can and do fly great distances to reach habitat, they are able to travel in straight line Euclidean paths (Gilmer et al. 1975). There is no greater cost associated with flying over a city to reach habitat than with flying over a forest. Therefore, for this analysis the only cost associated with the edges will be the distance between the nodes. In other analyses for other species, additional costs would have to be included.

The wetland patches used in this analysis were derived from the National Wetlands Inventory (NWI) survey of wetland locations and types for southern Michigan, created by the US Fish and Wildlife Service and modified by Ducks Unlimited in Ann Arbor, MI. Each patch was used to create a geometrical patch centroid for use as nodes in the graph analysis. Since mallards can fly, no travel cost data were associated with the network and the only impedance was the length of the edges in the network, or how far away each patch was from every other patch. Using this network, an edge list of shortest paths from each habitat node to every other habitat node was created.

Using the Network X python module and the previously created edge list, a script was utilized (see Python script, Appendix A) that looped through each of the points and determined its betweenness value (or degree). This is a measure of how well connected each point is in the overall network. Patches with a high connectivity value are given a higher score for this metric than patches with a low connectivity value.

Each wetland patch derived in the first step receives a score of 1-4 for each criterion. This produced an overall score of 3-12 for the ecological inputs, and a score of 3-12 for the social
categories. Then, each wetland patch is placed into one of four prioritization categories. These are classified according to ecological and social values. The four categories are: high ecological/high social, high ecological/low social, low ecological/high social, and low ecological/low social. In both ecological and social values, a score of 8 or above counts as high. In this way, it was possible to choose high quality wetland areas. More inputs can certainly be added to this model simply by adding values to the overall scores in each category. Figure 2 contains a graphical representation of this system.

**Results**

**Distance to existing reserves:** The results from this analysis followed a distribution that approaches normality. None of the categories dominated. This is due to the relatively even distribution of existing protected areas across the landscape. Most of the wetland patches that were close to an existing reserve were located along the borders of the Au Sable State Forest, which is a large reserve in the northwest portion of the study area (Figure 3). This result is summarized in Table 2.

**Distance to development:** The majority of wetland patches (47.7%) were found very close to development and only 17 patches (<0.1%) were found in the furthest distance class. This is an indication of the growing suburban sprawl in the Saginaw Bay area. It is difficult to locate wetland patches that are located any distance from sources of pollution or disturbance (Figure 4). Because of this result, this metric probably has less of an influence on the overall site selection (Table 3).

**Wetland Density:** The majority of wetland patches were found in areas of high wetland density (55.1%). This is not surprising, since the reason Saginaw Bay was selected for this
analysis was in part due to the large amount of wetland areas located there. Only a small portion of the landscape was found to have a low wetland density (Figure 5; Table 4).

**Protection Priorities:** The majority of wetland patches were found to lie in the first (protect, 32.0%) and last (not important, 64.1%) protection priority classes, with few patches falling in between the two classes. This is an important result because it shows that much of the land in Saginaw Bay is unsuitable for mallard habitat, despite high scores in other metrics such as wetland density (Figure 6). This is one of the most important metrics in the analysis; even if a wetland patch appears to have high scores in every other input, if the area is not suitable for mallard habitat, mallards will not use it. It is also assumed for purposes of this analysis that a square mile that received a strategy value of “Protect” (or a 4 in this analysis) will also contain or be near by associated forested uplands. This result is summarized in Table 5.

**Acquisition Areas:** This result is not all that informative in this analysis, because only a very small portion of the study area. The vast majority of wetland patches fell outside the Huron-Manistee acquisition area, in the northern part of the study area (Figure 7). Since this metric was mainly included for use in applying this model to other locations, it is almost negligible in this study. This result in summarized in Table 6.

**Habitat Connectivity:** This result shows that only 13.5% of the wetland patches are well connected, or serve as important stepping stones, in the landscape. This is an expected result, as logically most habitat patches would not be well connected in a fragmented, highly developed area like Saginaw Bay. The patches that are well connected tend to occur in the middle of areas of high wetland density, and especially around the edges of existing reserves. Figure 8 shows the connectivity of all patches and Figure 9 shows only the best connected patches. The best connected patches are spread out throughout the study area, but seem to be more clustered in the
Northwest, near Au Sable State Park. The majority of well connected patches are very small, with a mean area of 2.24 ha. Figure 10 shows the size distribution of the best connected habitat patches. This means that in this landscape, small patches serve as important stopovers between larger patches. Since mallards prefer small patches to larger ones (Gilmer et al. 1975), it is likely that the patches that mallards will most likely use in Saginaw Bay will be small, clustered, well connected patches. This result is summarized in Table 7.

**Synthesis:** Once the scores of 1-4 from the proceeding metrics are applied to the previously described scoring model, 1290 wetland patches that fit the desired criteria were designated as high priority. The majority of wetland patches were designated as the lowest priority, and the 2nd priority patches represented the second highest category (Figure 11). This result is probably due to the fact that not many patches were included in the acquisition area, and so the social value score for the majority of the patches was underrepresented, resulting in placement in the 2nd priority category (high ecological score, but low social score). This result is summarized in Table 8.

In theory, any of the 1290 high priority patches would serve as good mallard habitat. However, this analysis was done in an attempt to find a group of wetland patches that could be preserved together to make up mallard home ranges of approximately 240 hectares (Gilmer et al. 1975). From Figure 12, a number of locations where this objective could be achieved become clear. The southern portion of the study area contains many, high quality wetland patches, and could be a good location for reserves. The northern central part of the study area, especially around the Au Sable State Forest, is the other location with a number of clustered, high quality wetland patches.
Recommendations

The area in between two sections of the Au Sable State Forest, in the Northwest part of the study area, would be the best location for a new reserve, as illustrated in Figure 12. This area contains a number of top priority wetlands according to the prioritization model used in this analysis, and is large enough to include several mallard home ranges. In addition, the wetlands in this area are in close proximity to a high quality, well managed preserve, the Au Sable State Forest. Many of the other high priority wetland areas bordered protected lands. However, many of those protected lands were hunting clubs or parks and recreational areas. Although these types of land uses could also potentially create safe areas for mallard populations, land adjacent to a state forest is more desirable simply because protecting this land would create a larger contiguous tract. The state forest was designated as such in the first place for its high quality habitat, and hopefully lands adjacent to the state park would share this high caliber, as is often the case. The location around the state forest is ideal since choosing wetlands adjacent to a state forest means that the mallards will be guaranteed the forested upland areas that they require for nesting purposes. Finally, creating a reserve in the area shown in Figure 12 would help to protect some of the gaps in between areas of the state forest, and potentially create more connected habitat or a corridor between the northern and southern areas of the forest.

It is recommended that Ducks Unlimited focus their efforts on all wetlands designated as high priority within Saginaw Bay, with special consideration given to those surrounding the Au Sable forest. This is a qualitative judgment based on where I believe the most logical location for a reserve is. In order to manage these sites for nesting mallards, it is also recommended that any area being reviewed for purchase be at least 250 hectares in size, and contain or border associated uplands. Timber management on the upland nesting sites should be minimal,
especially during nesting season, and forests should be well stocked in order to provide as much ground cover for nests as possible (Gilmer et al. 1975). Both upland areas and wetland areas should have as little disturbance from recreation and management activities as possible in order to promote mallard nesting (Gilmer et al. 1975).

**Discussion**

Other factors have to be included in a habitat analysis before the reserves are located. Factors such as the availability of the land (whether it is purchasable or not), the current ownership of the land and the price of the property are not present in the model used for this analysis. Rather the process described here is intended for managers to use to decide what areas to focus their purchasing efforts towards.

For this analysis, the majority of patches received a very low social score. This was due to two main factors. First, the amount of development in the region was such that very few patches were far enough away from developed zones to receive a good score according to the parameters used in this analysis. Second, a full third of the score for the social ranking was based on the state acquisition areas, few of which were in the study areas. This input was mainly included to be used in future applications of this model, and it could have skewed the results in this analysis slightly by lowering overall social value scores.

It was surprising that the wetlands along the bay itself were not given higher priority scores, since the coastal wetlands in this area have historically been of high quality and have been used by many waterfowl. This could be due to several factors. First, these patches could have been considered not well connected because they occur on the outer edge of the habitat network used to calculate patch connectivity. This would result in a lower ecological score for
those patches. In addition, the nature of the data itself could be an issue. The wetlands along the bay were found outside of the study area in some instances. Figure 4, the map of wetland density indicates a lower than expected density along the southern shore of the bay.

Despite these problems, the results provide a picture of the quality of wetlands for mallards in Saginaw Bay. Many high priority areas are found in areas of dense wetlands, are well connected to the surrounding habitat, and make excellent mallard habitat. Future applications of this model are sure to be species specific or otherwise tailored to suit specific needs of the manager. The model is flexible enough so that parameters can easily be altered, or inputs added to meet additional needs of users.

**Literary Citations**


Acknowledgment
I would like to thank Dr. Daniel Richter, Nicholas School of the Environment and Earth Studies, for advising this study. I would also like to thank John Fay, Nicholas School of the Environment and Earth Studies, for technical support. Robb MacLeod, Blair Shaman and the staff of Ducks Unlimited in Ann Arbor, MI provided data and technical support. Finally, the Edna Bailey Sussman Fund for funding living expenses during the study period.
# Tables and Figures

## Table 1. Site Selection Model Input Details

<table>
<thead>
<tr>
<th>Resource Criteria and Measurement Unit</th>
<th>Description and Rationale</th>
<th>Detail</th>
<th>Score</th>
<th>Social or Ecological</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distance to Existing Protected Sites (meters)</strong></td>
<td>-Distance to nearest existing protected land in the DU CARL layer &lt;br&gt;-Land is more often purchased and therefore more likely to be preserved when it is nearby existing protected land &lt;br&gt;-Site managers try to create contiguous preserves</td>
<td>0-519</td>
<td>4</td>
<td>Social</td>
</tr>
<tr>
<td></td>
<td></td>
<td>519-1731</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1731-3463</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;3463</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Distance to Development (meters)</strong></td>
<td>-Distance to nearest developed land using IFMAP/GAP 2001 land cover dataset &lt;br&gt;-Sites closer to development are less likely to be successfully preserved</td>
<td>0-700</td>
<td>1</td>
<td>Social</td>
</tr>
<tr>
<td></td>
<td></td>
<td>700-1600</td>
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<td>1600-4900</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;4900</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td><strong>Wetland Density (# of wetlands/1 mile radius)</strong></td>
<td>-Number of wetlands within a one mile radius of each wetland &lt;br&gt;-Sites with more surrounding wetlands create more contiguous habitat &lt;br&gt;-More dense wetland areas create more opportunities for nesting and migration stopovers &lt;br&gt;-Wetland patches obtained from National Wetland Inventory Data, US Fish &amp; Wildlife and Ducks Unlimited</td>
<td>0-1.83</td>
<td>1</td>
<td>Ecological</td>
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<td></td>
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<td>1.83-5.6</td>
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<td></td>
<td>10.6-26</td>
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<td></td>
</tr>
<tr>
<td><strong>Important for waterfowl habitat (DU classification system)</strong></td>
<td>-Each square mile classified as to its importance for waterfowl habitat &lt;br&gt;-Important to preserve wetlands that waterfowl will use and are high quality. It is not worth it to preserve land that is not useful for waterfowl &lt;br&gt;-Data from Great Lakes Habitat Evaluation Network Square Mile Grid, by Ducks Unlimited</td>
<td>Not Important</td>
<td>1</td>
<td>Ecological</td>
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<tr>
<td></td>
<td></td>
<td>Protect and Restore w/ Caution</td>
<td>2</td>
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<td>Protect and Restore</td>
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<tr>
<td></td>
<td></td>
<td>Protect</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td><strong>Acquisition Areas</strong></td>
<td>-Land within the acquisition area is preapproved for purchase and thus is far more likely to be preserved. &lt;br&gt;-Data from Management Areas for Huron/Manistee National Forests, created by Huron-Manistee National Forests.</td>
<td>Not within</td>
<td>0</td>
<td>Social</td>
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<td></td>
<td>Within</td>
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<tr>
<td><strong>Connectivity (Betweenness Score)</strong></td>
<td>-Well connected habitat patches create a more contiguous habitat and can provide corridors to create larger home ranges</td>
<td>3-5</td>
<td>1</td>
<td>Ecological</td>
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<td>12-20</td>
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### Table 2. Results of distance to existing reserves analysis

<table>
<thead>
<tr>
<th>Distance to closest reserve (m)</th>
<th>Score for analysis</th>
<th># of patches</th>
<th>% of patches</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-519</td>
<td>4</td>
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<td>2</td>
<td>26,742</td>
<td>31.79</td>
</tr>
<tr>
<td>&gt;3463</td>
<td>1</td>
<td>11,183</td>
<td>13.29</td>
</tr>
</tbody>
</table>

### Table 3. Results of distance to existing development analysis

<table>
<thead>
<tr>
<th>Distance to closest development (m)</th>
<th>Score for analysis</th>
<th># of patches</th>
<th>% of patches</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;4900</td>
<td>4</td>
<td>17</td>
<td>0.02</td>
</tr>
<tr>
<td>1600-4900</td>
<td>3</td>
<td>12,468</td>
<td>14.82</td>
</tr>
<tr>
<td>700-1600</td>
<td>2</td>
<td>31,505</td>
<td>37.45</td>
</tr>
<tr>
<td>0-700</td>
<td>1</td>
<td>40,144</td>
<td>47.71</td>
</tr>
</tbody>
</table>

### Table 4. Results of wetland density analysis

<table>
<thead>
<tr>
<th>Wetland Density (# of wetlands/1 mile radius)</th>
<th>Score for analysis</th>
<th># of patches</th>
<th>% of patches</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.6-26</td>
<td>4</td>
<td>46,344</td>
<td>55.08</td>
</tr>
<tr>
<td>5.6-10.6</td>
<td>3</td>
<td>25,694</td>
<td>30.54</td>
</tr>
<tr>
<td>1.83-5.6</td>
<td>2</td>
<td>10,118</td>
<td>12.03</td>
</tr>
<tr>
<td>0-1.83</td>
<td>1</td>
<td>1988</td>
<td>2.36</td>
</tr>
</tbody>
</table>

### Table 5. Results of habitat classification analysis

<table>
<thead>
<tr>
<th>Classification</th>
<th>Score for analysis</th>
<th># of patches</th>
<th>% of patches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protect</td>
<td>4</td>
<td>26,898</td>
<td>31.97</td>
</tr>
<tr>
<td>Protect and Restore</td>
<td>3</td>
<td>1826</td>
<td>2.17</td>
</tr>
<tr>
<td>Protect and Restore W/ Caution</td>
<td>2</td>
<td>1551</td>
<td>1.84</td>
</tr>
<tr>
<td>Not Important</td>
<td>1</td>
<td>53,902</td>
<td>64.07</td>
</tr>
</tbody>
</table>

### Table 6. Results of acquisition area analysis

<table>
<thead>
<tr>
<th>In acquisition area?</th>
<th>Score for analysis</th>
<th># of patches</th>
<th>% of patches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>4</td>
<td>388</td>
<td>0.46</td>
</tr>
<tr>
<td>No</td>
<td>1</td>
<td>83,218</td>
<td>98.91</td>
</tr>
</tbody>
</table>

### Table 7. Results of patch connectivity analysis

<table>
<thead>
<tr>
<th>Betweenness Score (Node degree)</th>
<th>Score for analysis</th>
<th># of patches</th>
<th>% of patches</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-20</td>
<td>4</td>
<td>11,389</td>
<td>13.54</td>
</tr>
<tr>
<td>7-11</td>
<td>3</td>
<td>15,677</td>
<td>18.63</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>23,799</td>
<td>28.29</td>
</tr>
<tr>
<td>3-5</td>
<td>1</td>
<td>33,401</td>
<td>39.70</td>
</tr>
</tbody>
</table>
Table 8. Results of habitat site selection

<table>
<thead>
<tr>
<th>Priority</th>
<th># of patches</th>
<th>% of patches</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>1290</td>
<td>1.53</td>
</tr>
<tr>
<td>2nd</td>
<td>37,671</td>
<td>44.78</td>
</tr>
<tr>
<td>3rd</td>
<td>1386</td>
<td>1.65</td>
</tr>
<tr>
<td>Low</td>
<td>43,787</td>
<td>52.04</td>
</tr>
</tbody>
</table>

Figure 1.

Saginaw Bay, MI
Figure 2. Graphical Representation of Scoring System

<table>
<thead>
<tr>
<th>Ecological Values</th>
<th>Social Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Third Priority</td>
<td>High Priority</td>
</tr>
<tr>
<td>Ecological &lt;= 7</td>
<td>Ecological &gt;= 8</td>
</tr>
<tr>
<td>Social &gt;= 8</td>
<td>Social &gt;= 8</td>
</tr>
<tr>
<td></td>
<td>Low Priority</td>
</tr>
<tr>
<td></td>
<td>Secondary Priority</td>
</tr>
<tr>
<td></td>
<td>Ecological &gt;= 8</td>
</tr>
<tr>
<td></td>
<td>Social &lt;= 7</td>
</tr>
<tr>
<td></td>
<td>Ecological &lt;= 7</td>
</tr>
<tr>
<td></td>
<td>Social &lt;= 7</td>
</tr>
</tbody>
</table>
Figure 3.

Saginaw Bay Wetlands Prioritization
Distance To Existing Protected Sites

Score/meters to nearest site
- Existing Sites
- 1/≤3463
- 2/1731-3463
- 3/≥1731
- 4/0-619

Projection: MI Georef
1/24/08
Figure 4.

Saginaw Bay Wetlands Prioritization
Distance To Existing Development

Score/meters to development:
1/0-700
2/700-1600
3/1600-4900
4/>4900

1/24/08
Projection: MI Georef
Figure 6.

Saginaw Bay Wetlands Prioritization
Important Waterfowl Habitat

Score
1/Outside Mallard Area
2/Protect and Restore w/ Caution
3/Protect and Restore
4/Protect

1/24/08
Projection: MI Georef
Figure 7.

Saginaw Bay Wetlands Prioritization Acquisition Areas

Score
- Purple: Inside State Acquisition Area
- Green: Outside State Acquisition Area

1/24/08
Projection: MI Georef
Saginaw Bay Wetlands Prioritization
Patch Connectivity

Score / Betweenness Value
- 1 / 3 - 5
- 2 / 6
- 3 / 7 - 11
- 4 / 12 - 20

1/24/08
Projection: MI Georef
Figure 9.

Saginaw Bay Wetlands Prioritization
Best Connected Patches

1/24/08
Projection: MI Georef
Figure 10.

Size Distribution of Best Connected Patches

<table>
<thead>
<tr>
<th>Patch Size (ha)</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0.013; 5.856)</td>
<td>110</td>
</tr>
<tr>
<td>[11.699; 17.542)</td>
<td>100</td>
</tr>
<tr>
<td>[40.914; 46.757)</td>
<td>90</td>
</tr>
<tr>
<td>[52.6; 58.443]</td>
<td>80</td>
</tr>
</tbody>
</table>

[Chart showing size distribution with bins and counts]
Figure 11.

Saginaw Bay Wetlands Prioritization
Figure 12.

Saginaw Bay Wetlands Prioritization
Appendix A. Python script for determining wetland patch connectivity scores

# Import the standard modules
import sys, os, arcgisscripting

# Import networkx module
import networkx as NX

# Create the gp object
gp = arcgisscripting.create()

# Get the input variables
Edge_dbf = r"U:\connectivity\edgelist.dbf"
Nodes_FC = r"U:\connectivity\WetlandNodes.shp"

# Create the Graph
G = NX.XGraph()

# Loop through the dbf file and add each edge to the Graph
edgeRecs = gp.SearchCursor(Edge_dbf)
edgeRec = edgeRecs.Next()
while edgeRec:
    fN = int(edgeRec.FNODE_)
    tN = int(edgeRec.TNODE_)
    nL = float(edgeRec.LENGTH)
    G.add_edge(fN, tN, nL)
    edgeRec = edgeRecs.Next()

# Delete the cursor object to free the dbf file
del edgeRec, edgeRecs

# Calculate degree and add the field
flds = gp.ListFields(Nodes_FC,"Degree")
if not flds.next():
    gp.AddField_management(Nodes_FC,"Degree","LONG")

# Create update cursor
NodeRecs = gp.UpdateCursor(Nodes_FC)
NodeRecs.Reset()
NodeRec = NodeRecs.Next()
while NodeRec:
    NodeID = NodeRec.EDGES_CL_
    NodeDegree = G.degree(NodeID)
    NodeRec.Degree = NodeDegree
    NodeRecs.UpdateRow(NodeRec)
    NodeRec = NodeRecs.Next()

# Release the cursors
del NodeRec, NodeRecs