Using GIS to Create a Gray Wolf Habitat Suitability Model and to Assess Wolf Pack Ranges in the Western Upper Peninsula of Michigan

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Abstract

Gray wolves are often difficult for biologists, forest planners, and wildlife managers to study and predict movements and habits. The controversy over wolves in the Midwest is growing with the delisting of the gray wolf from the Threatened and Endangered Species List. Growing populations of wolves have increased sightings and contact between humans and wolves. Geographic Information Systems (GIS) is a tool that can be utilized by planners and managers to identify wolf habitats and possible areas of human – wolf conflict. This study uses GIS to take information from written literature on wolf habitat and preferences of wolf locations and ranges in the Western Upper Peninsula of Michigan and compare these to a model of wolf range suitability developed in this study. The model developed by this study utilizes four raster layers (landuse/land cover, road density, population density, and deer population density) classified to create suitability ranges. The model created indicates the presence of abundant suitable habitat in the Upper Peninsula of Michigan.

Introduction

The gray wolf or eastern timber wolf (*Canis Lupus Lycaon*) is the largest member of the Canid family of wild dogs (Michigan Department of Natural Resources (MI DNR), n.d.). Gray wolves were historically found throughout Michigan's Upper and Lower Peninsula. By 1960, due to superstitions, angst from cattle farmers, bounties on hides, and a variety of other reasons, gray wolves in Michigan were almost completely eradicated.

The gray wolf was given full legal protection in Michigan in 1965 and protected by the federal government under the Endangered Species Act (ESA) in 1973 (MI DNR, n.d.). In 1974 a wolf recovery program was started in Michigan to reintroduce the gray wolf into its historic habitat and in 1991, the first documented reproduction of gray wolves since 1950 occurred in Michigan (Schadler and Hammill, 1996). The population has been on the rise since 1995 in Michigan (MI DNR, n.d.). With the delisting of the gray wolf population in the Great Lakes region from the federal list of threatened and endangered species (US Fish and Wildlife Service (USFWS), 2007), it is increasingly important to identify and protect wolf habitats for the future.

Gray wolves do not need wilderness, but they do need large areas of contiguous forest for their home ranges to support their preferred food (MI DNR, n.d.). One major threat listed by the USFWS was the loss or

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modification of habitat (USFWS, n.d.). It is important to understand what habitats wolves are occupying to provide base line data for a study area. Spatially delineating suitable habitat for large carnivores within mixed landscapes is beneficial to assessing recovery potentials and managing animals to minimize human conflicts (Mladenoff et al., 1999).

The goal of this research was to determine if documented and described wolf habitat is a good indicator of where wolves live in a real dynamic environment. Wolves can live in a variety of different habitat types and are extremely adaptable creatures. However, there is documentation that describes wolf habitats for the Upper Great Lakes region that can be used as a general indicator of optimal wolf habitat. The factors that determine wolf habitat are made up of thresholds and forest cover types that biologists feel describe wolf habitat the best. Some of these factors include population density, road density, landuse/land cover type, and prey density. Specifically, research and thresholds studied by Mech and Boitani (2003), Mladenoff et al. (1995), Mladenhoff et al. (1999), Paquet et al. (1999), Potvin et al. (2005), and Wydeven et al. (2001) were used as the basis for classification in this study.

In this analysis, the above factors were used to determine prime wolf habitat. The results of this study are compared to known wolf pack ranges to see how they correspond. Wolf mortality data from 2006 was also compared with road and population densities to see if a correlation exists. Hopefully, findings can be used by wildlife managers to plan for future increases in populations and to better protect gray wolf habitat and the species as a whole.

Study Area

Wolf pack ranges for the study area were collected from the Michigan DNR, Michigan Technological University (MTU) and the Ottawa National Forest. Radio telemetry from 2000 and 2005 was used to create ranges for packs based on the minimum convex polygon method. Supplemental field methods of live-trapping, winter track counts, and howling surveys help refine range data and give a more complete picture. For the purpose of this study, the pack ranges were limited to those within the proposed study area.

The Western Upper Peninsula as described in this study contains Baraga, Gogebic, Houghton, Iron and Ontonagon counties. This area is approximately 14,611 square kilometers and encompasses 34% of the Upper Peninsula's total area. The human population of the area is 89,607 and accounts for 30% of Upper Michigan's population (based on 1995 TIGER Census Data from the Michigan Geographic Data Library, n.d.).

The landscape of the Western Upper Peninsula is mostly categorized by diverse coniferous and deciduous forests. A large portion of this study area is dominated by the Ottawa National Forest (Figure 1). This forest consists of 1.5 million acres containing three separate wilderness areas (Ottawa National Forest, n.d.). The Western part of Upper Michigan consists of gently rolling hills ranging in elevation from 600 feet near Lake Superior to 1,800 feet near the Michigan/Wisconsin border.

Forestry has been the mainstay of the local economy since the 1900's. This logging results in an environment that supports large white-tailed deer populations. Agriculture is limited in the western portion of the study area.

Methods

Wolf Pack Ranges

Figure 1. Location of study area in Upper Michigan showing the Ottawa National Forest boundary.

Wolf pack ranges used in this study were obtained from two reports. The first report was "*Recovery of the Gray Wolf (Canis lupus) in Upper Michigan*" by MTU (2002) created for the Michigan DNR. The second was a gray wolf summary report for the Ottawa National Forest by the Michigan DNR (2005). Territories for the wolf ranges were determined using telemetry data and field tracking methods of live-trapping, winter track counts, and howling surveys. Wolves were fitted with radio collars and tracked by monitoring corresponding frequencies of each wolf either on the ground or through aerial surveys. Territories were created for ranges with 30 or more telemetry locations according to procedures outlined by T.K. Fuller in "*Population dynamics of wolves in north-central Minnesota*" (1989). The minimum convex polygon method was used to create the ranges. Locations isolated more than 5 kilometers from other telemetry points were not considered unless they occurred as clusters of radio locations at those points and there was regular movement between locations (MI DNR, 2005).

Since no actual telemetry data was obtained for this study, the method chosen was to take the ranges from the previously noted reports and georeference them for this study. All wolf pack range data, dead wolves, and single wolf locations were created in ArcGIS using high resolution scanned images of the reports. These images were saved in the .jpeg format and brought into ArcMap. The Georeferencing Toolbar was used to match these images to a backdrop of the five counties and road networks. A second-order transformation was used for all four images with 9 – 10 points. All relevant information was digitized to newly created feature classes to be used in the study. Where there were questions about the ranges with too much overlapping data, Township and Range data from spreadsheets were used to narrow down the identification for the pack. Where there were too many questions about the ranges, they were left out of the final study to minimize misidentification.

All ranges were from actual pack locations and studies. The only issue with the wolf pack ranges may be with the naming of the pack and not in the location assigned to it. Because of the sensitive nature of the data and ethical issues, pack ranges were not shown. The following tables are a preview of the ranges used and all results were tabulated to create final analysis outcomes. Tables 1 and 2 show the estimated number of wolves in each pack, the county of the pack, calculated area of the range and the estimated year established.

Database Development

Data for this study and all subsequent analysis was stored in a Personal Geodatabase (PGDB) created in ArcCatalog 9.2. The PGDB was created with 8 different feature datasets

Table 1. Pack names with the county of habitation, and estimated count of wolves in the pack.

Pack Name	County	Wolf Count
Foley Creek	Gogebic	17
Clark Lake	Gogebic	12
South Boundary	Ontonagon	5
Tula	Gogebic	3
Moraine Lake	Gogebic	6
Lake Gogebic	Gogebic	6
Caddis Creek	Gogebic	14
Beatons Lake	Gogebic	9
North Ewen	Ontonagon	5
Gardner Road	Ontonagon	2
Langford	Gogebic	5
Kenton	Houghton	4
Golden Lake	Iron	4
Perch Lake	Iron	2
Smokey Lake	Iron	1
Block House	Iron	9
May Lake	Baraga	5
Limestone	Houghton	5
Baraga Plains	Baraga	8
Kirby Creek	Gogebic	8

Table 2. Pack names with estimated year of establishment and area of pack range.

Pack Name	Pack Year	Area (Square Miles)
Foley Creek	2005	35.87
Clark Lake	1999	109.88
South Boundary	2005	61.38
Tula	2005	87.68
Moraine Lake	1998	65.24
Lake Gogebic	1999	90.69
Caddis Creek	2005	100.60
Beatons Lake	2005	77.41
North Ewen	1998	36.12
Gardner Road	2005	36.22
Langford	2005	146.08
Kenton	2005	47.71
Golden Lake	2005	95.62
Perch Lake	2005	37.03
Smokey Lake	2005	60.18
Block House	2005	114.32
May Lake	2005	89.41
Limestone	2005	102.12
Baraga Plains	1999	34.87
Kirby Creek	2005	58.96

including: Baraga, Deer, Forest Service, Gogebic, Houghton, Iron, Ontonagon, and wolf packs. All feature datasets were created with projection of North American Datum (NAD) 1983 Universal Transverse Mercator (UTM) Zone 16N. This projection was chosen due to the common use among different agencies in the study area and for the constant relationship of area and distance on the map. Miscellaneous data and raster outputs were stored as standalone feature classes at the geodatabase level. Another PGDB was created to store the outputs of the model. The same coordinate system was used throughout to ensure data quality and reduce error.

Development of Raster Datasets

The raster datasets used in this study included population density, road density, prey density, and landuse/land cover and were created using data gathered from the Michigan Geographic Data Library (MiGDL), the Ottawa and Hiawatha National Forest and the Michigan DNR. Other relevant data for each county in the study area included 1995 TIGER Census base map features, 1978 landuse/land cover, and Township, Range and Section data downloaded from the MiGDL. The Ottawa and Hiawatha National Forest GIS personnel supplied forest boundaries, roads and lake/river features. The Michigan DNR provided the deer management units for prey density.

All data from the MiGDL were projected in a custom state projection called Michigan GeoRef. This projection needed to be defined for each data set downloaded from the website and converted to NAD 83 UTM Zone 16N to match the other data. The process of defining and converting the projections was completed using the ArcView 3.3 Projector Extension. The input for the Michigan GeoRef projection was as follows:

Spatial_Reference_Information: **Michigan GeoRef**
Horizontal_Coordinate_System_Definition:
Planar:
Map_Projection:
Map_Projection_Name: Oblique Mercator
Oblique_Mercator:
Scale_Factor_at_Center_Line: 0.999600
Oblique_Line_Azimuth:
Azimuthal_Angle: 337.255560
Azimuth_Measure_Point_Longitude: -86.000000
Latitude_of_Projection_Origin: 45.309167
False_Easting: 2546731.496000
False_Northing: -4354009.816000
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: coordinate pair
Coordinate_Representation:
Abscissa_Resolution: 0.001278
Ordinate_Resolution: 0.001278
Planar_Distance_Units: meters
Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1983
Ellipsoid_Name: Geodetic Reference System 80
Semi-major_Axis: 6378137.000000
Denominator_of_Flattening_Ratio: 298.257222

Population Density

Block group data from the United States Census Bureau were used for each county in the study area to calculate population densities. The attribute and line data contained in the block groups were from the 1994 U.S. Census Bureau based TIGER line files (MiGDL metadata). Block group was chosen as the basis of the population density analysis due to the fact that the study area is large and has a relatively low human population compared to other areas. Once each county block group was added to the PGDB, a new field was added to the attribute table (population per square kilometer). This field was calculated by multiplying the current field of population per square mile by 0.3861. This conversion was obtained from the U.S. Census Quick Facts website (n.d.). Once all five counties were modified, they were merged together into one feature class. Next, the Spatial Analyst toolbar in ArcMap was used to convert the newly merged feature class to a raster based on the new field calculation. The output cell size for the raster was 30 x 30 meters. The results of this conversion were then reclassified according to thresholds discussed later for the final output.

Road Density

Road data for this study were taken from the Census base map data from the MiGDL. TIGER road data represents paved roads and improved dirt/gravel roads determined from U.S. Geological Survey (USGS) quads at a scale of 1:100,000 (Census Bureau). The road data for the five counties in the study area were merged into one feature class. This feature class was then edited to include Ottawa National Forest roads that were classified as passable two-track roads not included in the TIGER data. This feature class was used as the basis for the calculation of road density. The Spatial Analyst Density tool was used to run a simple density on the feature class. The search radius was set to 3,000 or 3 km with an output grid size of 50 x 50 meters. Since some of the roads passed outside of the study area, the Spatial Analyst tool of Extract by Mask was used to clip the roads to the desired study area. The county polygon was used as the mask in the process. This output was reclassified according to the thresholds discussed in the next section for the final analysis.

Prey Density/Deer Management Units (DMU's)

Deer management units were used as the basis for the prey density in the analysis. DMU's are mapped polygons of relatively homogeneous deer density and habitat with a planned mean size of 681.3 km^2 (Michigan DNR, n.d.). The DMU's for 2007 for the state of Michigan were obtained from the Michigan DNR along with a spreadsheet of the white-tailed deer population projections for each unit as of October 1, 2006. The map of the DMU's was georeferenced in ArcMap using the Georeferencing Toolbar. Nine points were used along with the second-order polynomial transformation. The newly georeferenced image was then used to digitize in the seven relevant DMU's. Snapping was used to eliminate gaps in the data set. The county polygon and other digitized lines were used as the basis for the snapping. The next step was to add a field to the newly digitized feature class that would contain the population projections from the spreadsheet. The newly added field was used as the basis for the conversion to raster using the Spatial Analyst Tool. The output cell size was 50 x 50 meters. This output was then reclassified to give the final output for the analysis.

Landuse/Land Cover

The landuse/land cover data for the study area obtained from the MiGDL were data from 1978 and represented the most current landuse data available from the state of Michigan. This data represented a compilation of data from various county and regional planners. The data were intended for general planning purposes and had an accuracy of +/- 80 feet. The data contains forty-four different codes that corresponded to various land classifications. Data for the five county study area were merged into one feature class in the PGDB using the Data Management Tools in ArcCatalog. This feature class was then converted to a raster using the Spatial Analyst Toolbar with an output cell size of 30 x 30 meters. The conversion was based on the code field and then reclassified according to the stated thresholds in the next section.

Ordinal Ranking of Data

For this habitat suitability model, four rasters were considered to be relevant. These rasters were chosen based on suitability models of gray wolf habitat in the Great Lakes region and other parts of the country. Specifically, suitability models created by Mladenoff et al. (1999), Mladenoff et al. (1995) and thresholds in studies by Harrison and Chapin (n.d.) and the Wisconsin DNR (1999). The four most common components that were contained in the research were population density, road density, landuse/land cover, and prey density. All of the rasters were given a value on an ordinal scale of 1 – 3, with 3 being highly suitable habitat, 2 being moderately suitable habitat and 1 being low suitability.

Population Density

Population density thresholds were chosen based on the literature stated above. The first class suitability of 3 (high) was based on the < 4 people per square kilometer that was found in the Harrison and Chapin study (n.d.) and the Wisconsin DNR Management Plan of 1999. The next class of 2 (moderate) was chosen to be 4 – 8 people per square kilometer. This class was based on studies by Harrison and Chapin (n.d.) and Fuller et al. (1992). The third class of 1 (low suitability) contained all other values > 8.

Road Density

Road density and the affects on wolf habitat is something that has been widely studied in recent years. Class ranges for this category were based on studies by Mladenoff and Sickley (1998) and Harrison and Chapin (n.d.). The break down for classes were in kilometers of road per square kilometer and were as follows: Class 3 (high suitability) < 0.40 km/km^2, Class 2 (moderate suitability) 0.401 - 0.70 km/km^2, and Class 1 (low suitability) 0.701 km/km^2 and above.

Landuse/Land Cover Types

Since the gray wolf is highly adaptive and does not follow a specific habitat type consistently, it is hard to categorize the specific types of landcover a wolf pack will inhabit. However, Mladenoff and various Great Lakes DNR officials have come up with preferred types of habitat and habitat that is not conducive to wolf pack settlement. The consensus is that wolves prefer mixed forest types, large tracts of public land, and wooded wetlands. Habitat that is viewed as low suitability contains large agricultural tracts and livestock operations, urban development, large lake areas and intense recreational/industrial use. The classifications for the landuse/land cover types for this model are shown in Table 3. This classification has a higher level of subjectivity due to the lack of specific descriptions of habitat types. Personal contact with wolf trackers and biologists was used to try to refine the classification.

Prey Density

According to Mech and Boitani (2003), Fuller et al. (1992) and Mladenoff et al. (1995), prey density and the presence of available food is an important factor in the calculation of suitable wolf habitat. Western Upper Michigan supports large populations of white-tailed deer which account for roughly 55% of the diet for Great Lakes wolves (Wisconsin DNR, n.d.). Although other food sources such as beaver and snowshoe hare account for almost a quarter of wolf diets, they were not considered in this study.

The classification for the white-tailed deer density in the study was done by taking the total number of deer (does, bucks, and fawns) in each DMU and classifying them using the Natural Breaks (Jenks, 1967) method with 3 classes. The reason for this classification was due to the inadequate number of concrete thresholds for prey densities noted in the literature reviewed. This method was chosen to maximize the statistical differences that were inherent in the data gathered. This classification shows the different densities that exist between the various DMU's in the study area. The resulting classification consisted of the following ranges: Class 3 (high) 16,400.01 – 32,600 deer/DMU, Class 2 (moderate) 6,200.01 – 16,400 deer/DMU, and Class 1 (low) 5,400 – 6,200 deer/DMU.

Final Output Grids

Development of the final output raster datasets was completed to analyze the

Table 3. Landuse Reclassification Table.

Vegetation Code	Class	Value
421	Pine	1
422	Other Upland Conifer	1
612	Shrub/Scrub Wetland	1
413	Aspen/Birch	2
31	BareRock/Sand/Clay	1
411	Northern Hardwood	3
622	Emergent Wetland	1
146	Utilities/Waste Disposal	1
414	Lowland Hardwood	2
423	Lowland Conifer	2
51	Streams and Waterways	1
171	Open Pit	1
193	Outdoor Recreation	2
52	Lakes	1
611	Wooded Wetland	2
172	Underground Extractive	1
13	Industrial	1
12	Commercial Services and Institutional	1
113	Single Family, Duplex	1
623	Flats	1
72	Beaches and Riverbanks	1
21	Low Intensity Residential	1
22	High Intensity Residential	1
29	Other Agricultural Land	1
126	Institutional	1
53	Reservoirs	1
32	Quarries/Strip Mines/Gravel Pits	1
24	Permanent Pasture	1
74	Bare Exposed Rock	1
141	Air Transportation	1
194	Cemetaries	1
112	Multi-Family-Low Rise	1
121	Central Business District	1
124	Neighborhood Business	1
23	Commercial/Industrial/Transportation	1
111	Multi-Family-Medium to High Rise	1
143	Water Transportation	1
115	Mobile Home Park	1
142	Rail Transportation	1
41	Deciduous Forest	3
42	Evergreen Forest	2
621	Aquatic Bed Wetland	1
412	Central Hardwood	3
144	Road Transportation	1

preference of the wolf pack ranges in the study area against the final habitat suitability model and each of the four rasters (population density, road density, landuse/land cover, and prey density) separately.

The final habitat suitability raster was created by using the Single Output Map Algebra tool in the Spatial Analyst tools of ArcCatalog. The four elements of this study were added together with no weight or preference given to any of the datasets. This raster was reclassified to have three levels of suitability (low, moderate, and high). Final ranges of values in the output raster were 3 – 12. Values of 3 occurred due to the fact that some of the raster datasets have cell values of zero or no data. Values of 3 – 5 were given a final value of 1 (low suitability) in the final output, values of 6 – 8 were given a value of 2 (moderate suitability), and values of 9 – 12 were given a final output value of 3 (high suitability). The final output raster and each of the four rasters used were then clipped to only encompass the areas of wolf packs in the study area. From this, only the data within separate pack ranges were obtained and used to calculate the percentages of each habitat suitability class in that range. Figures 2 – 6 show each separate final reclassification of population density, road density, landuse/land cover, prey density and the final output.

Results

Twenty gray wolf pack ranges calculated using the Minimum Convex Polygon method were used to test the habitat suitability model created for this study. The make-up of each pack range was tabulated to show the percentage of the range that was ascribed to each of the three suitability types.

Habitat Selection

Evaluation of the habitat suitability model was performed by determining the percentage of each range that was comprised of low, moderate, and high suitability areas. A mean statistic was used to show the overall trend of wolf packs in the study area.

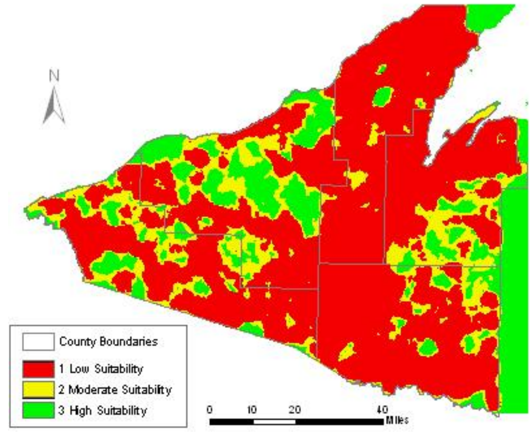

Figure 3. Road density in the study area (50 x 50 meter cell size).

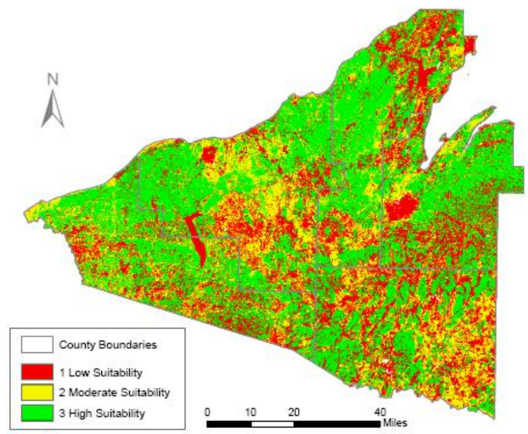

Figure 4. Landuse/Land Cover in the study area (30 x 30 meter cell size).

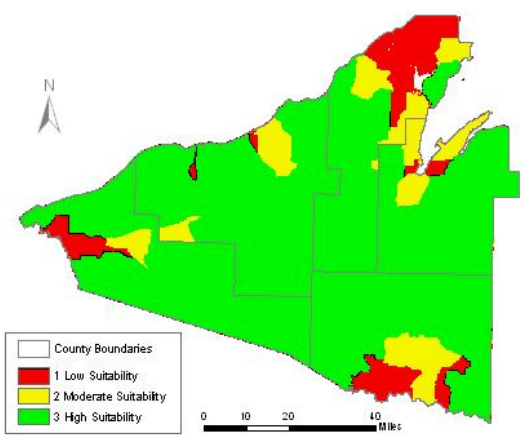

Figure 2. Population density in the study area (30 x 30 meter cell size).

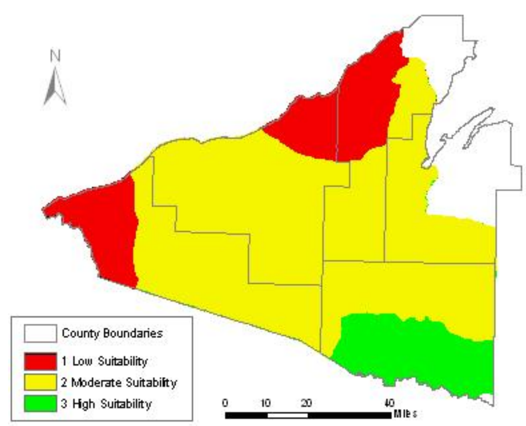

Figure 5. Prey density (white-tailed deer) in the study area (50 x 50 meter cell size).

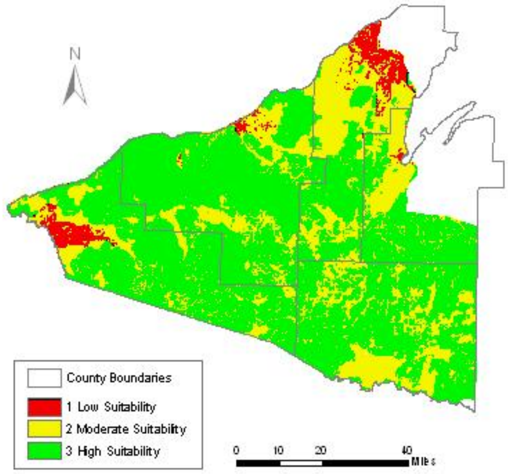

Figure 6. Final suitability analysis in the study area (50 x 50 meter cell size).

Human population density was the raster that showed the highest percentage of highly suitable habitat for the wolf pack ranges. The category of highly suitable habitat, according to the criteria used, made up 93.79% of all wolf pack ranges studied. This follows the idea that wolves are reclusive creatures and tend to stay away from high concentrations of human population. Moderately suitable habitat consisted of 4.03% and low suitability made up 2.18% of the wolf pack ranges.

Landuse/land cover was the next raster with the highest preponderance of high suitability habitat. 47.37% of all wolf pack ranges studied were made up of highly suitable habitat as classified in the study. Moderately suitable habitat accounted for 25.96% of all wolf pack areas and 26.67% of the ranges contained low suitability.

Prey density of white-tailed deer revealed that 6.88% of all wolf pack areas were made up of highly suitable habitat. 81.22% of all wolf pack areas contained moderately suitable habitat and 11.89% of low suitability. It should be noted that the moderately suitable habitat is still habitat that is adequate for the occupation of current and future wolf packs.

Road density in the study was one area that did not follow the literature that classified optimum habitat for gray wolves in the Great Lakes region. The mean statistic of the wolf pack ranges categorized as highly suitable habitat was 15.65%. 27.07% was classified as moderately suitable habitat and 57.28% was low suitability.

The final analysis of the overall habitat suitability showed a high percentage of all wolf pack range areas that were made up of either high or moderately suitable habitat. 57.51% of the twenty wolf pack ranges studied were made up of highly suitable habitat. 41.80% of all range areas consisted of moderately suitable habitat and 0.69% consisted of low suitability. The tables that follow (Tables 4 - 8) show the percentage of each separate wolf pack range that comprised each of the specific suitability classes (low, moderate, and high). The mean statistic along with the highest and lowest value in each category is shown in each table to give a better understanding of the data.

According to the final analysis, the Western Upper Peninsula contains large sections of land that are considered suitable habitat for gray wolf populations. This is important for the health of the population in the Western Upper Peninsula. Large areas of suitable habitat ensure that there will be sufficient land for new packs to form and allow for minimal conflict between humans and wolves as both populations rise.

Human population density, as classified in this study was low in most areas and thus resulted in large areas of suitable habitat being identified. This fact was anticipated knowing that the area is sparsely populated. There are 1,193.52 square miles of highly suitable habitat, 122.12 square miles of moderately suitable habitat, and 13.10 square miles of low suitability habitat.

Table 4. Wolf pack range areas and percentages of population density suitability.

Pack Name	Low Suitability (1) % of Range	Moderate Suitability (2) % of Range	High Suitability (3) % of Range
Foley Creek	41.62%	0.00%	58.38%
Clark Lake	0.00%	0.00%	100.00%
South Boundary	0.00%	0.00%	100.00%
Tula	0.00%	38.34%	61.66%
Moraine Lake	0.00%	0.00%	100.00%
Lake Gogebic	0.00%	6.65%	93.35%
Caddis Creek	0.00%	0.00%	100.00%
Beatons Lake	0.00%	0.00%	100.00%
North Ewen	0.00%	0.00%	100.00%
Gardner Road	0.00%	0.00%	100.00%
Lanford	0.00%	0.00%	100.00%
Kenton	0.00%	0.00%	100.00%
Golden Lake	0.03%	0.00%	99.97%
Perch Lake	0.00%	0.00%	100.00%
Smokey Lake	0.00%	0.00%	100.00%
Block House	0.00%	3.55%	96.45%
May Lake	0.00%	0.00%	100.00%
Limestone	0.00%	2.87%	97.13%
Baraga Plains	2.05%	28.30%	69.65%
Kirby Creek	0.00%	0.86%	99.14%
MEAN	2.18%	4.03%	93.79%
Highest Value	41.62%	38.34%	100.00%
Lowest Value	0.00%	0.00%	58.38%

Table 5. Wolf pack range areas and percentages of landuse/land cover suitability.

Pack Name	Low Suitability (1) % of Range	Moderate Suitability (2) % of Range	High Suitability (3) % of Range
Foley Creek	11.28%	34.71%	54.02%
Clark Lake	12.81%	6.33%	80.86%
South Boundary	15.66%	5.24%	79.11%
Tula	21.06%	19.69%	59.24%
Moraine Lake	35.21%	23.12%	41.67%
Lake Gogebic	17.08%	21.02%	61.89%
Caddis Creek	39.20%	41.31%	19.49%
Beatons Lake	27.83%	37.27%	34.90%
North Ewen	23.70%	62.84%	13.47%
Gardner Road	28.47%	40.64%	30.89%
Lanford	37.89%	15.81%	46.30%
Kenton	31.23%	41.39%	27.38%
Golden Lake	39.74%	20.68%	39.58%
Perch Lake	49.08%	22.69%	28.22%
Smokey Lake	21.56%	7.76%	70.68%
Block House	35.01%	23.03%	41.97%
May Lake	42.71%	12.76%	44.52%
Limestone	18.66%	16.54%	64.80%
Baraga Plains	16.83%	42.69%	40.47%
Kirby Creek	8.38%	23.70%	67.92%
MEAN	26.67%	25.96%	47.37%
Highest Value	49.08%	62.84%	80.86%
Lowest Value	8.38%	5.24%	13.47%

Table 6. Wolf pack range areas and percentages of prey density suitability.

Pack Name	Low Suitability (1) % of Range	Moderate Suitability (2) % of Range	High Suitability (3) % of Range
Foley Creek	41.62%	0.00%	58.38%
Clark Lake	0.00%	0.00%	100.00%
South Boundary	0.00%	0.00%	100.00%
Tula	0.00%	38.34%	61.66%
Moraine Lake	0.00%	0.00%	100.00%
Lake Gogebic	0.00%	6.65%	93.35%
Caddis Creek	0.00%	0.00%	100.00%
Beatons Lake	0.00%	0.00%	100.00%
North Ewen	0.00%	0.00%	100.00%
Gardner Road	0.00%	0.00%	100.00%
Lanford	0.00%	0.00%	100.00%
Kenton	0.00%	0.00%	100.00%
Golden Lake	0.03%	0.00%	99.97%
Perch Lake	0.00%	0.00%	100.00%
Smokey Lake	0.00%	0.00%	100.00%
Block House	0.00%	3.55%	96.45%
May Lake	0.00%	0.00%	100.00%
Limestone	0.00%	2.87%	97.13%
Baraga Plains	2.05%	28.30%	69.65%
Kirby Creek	0.00%	0.86%	99.14%
MEAN	2.18%	4.03%	93.79%
Highest Value	41.62%	38.34%	100.00%
Lowest Value	0.00%	0.00%	58.38%

Table 7. Wolf pack range areas and percentages of road density suitability.

Pack Name	Low Suitability (1) % of Range	Moderate Suitability (2) % of Range	High Suitability (3) % of Range
Foley Creek	59.33%	35.38%	5.285%
Clark Lake	75.25%	21.35%	3.402%
South Boundary	32.73%	22.10%	45.166%
Tula	27.67%	58.93%	13.391%
Moraine Lake	50.21%	30.44%	19.348%
Lake Gogebic	53.35%	41.32%	5.334%
Caddis Creek	34.15%	49.78%	16.072%
Beatons Lake	22.63%	61.06%	16.310%
North Ewen	3.27%	38.12%	58.612%
Gardner Road	0.75%	14.11%	85.146%
Lanford	77.77%	16.29%	5.943%
Kenton	100.00%	0.00%	0.000%
Golden Lake	98.94%	1.06%	0.000%
Perch Lake	100.00%	0.00%	0.000%
Smokey Lake	82.01%	17.84%	0.156%
Block House	64.51%	28.98%	6.515%
May Lake	43.18%	43.86%	12.959%
Limestone	88.63%	11.37%	0.000%
Baraga Plains	99.13%	0.87%	0.000%
Kirby Creek	32.06%	48.55%	19.383%
MEAN	57.28%	27.07%	15.65%
Highest Value	100.00%	61.06%	85.15%
Lowest Value	0.75%	0.00%	0.00%

Table 8. Wolf pack range areas and percentages of overall suitability.

Pack Name	Low Suitability (1) % of Range	Moderate Suitability (2) % of Range	High Suitability (3) % of Range
Foley Creek	13.22%	72.60%	14.18%
Clark Lake	0.00%	17.99%	82.01%
South Boundary	0.00%	10.45%	89.55%
Tula	0.03%	35.17%	64.80%
Moraine Lake	0.00%	41.29%	58.71%
Lake Gogebic	0.00%	33.04%	66.96%
Caddis Creek	0.01%	48.22%	51.77%
Beatons Lake	0.01%	29.55%	70.43%
North Ewen	0.00%	14.98%	85.02%
Gardner Road	0.00%	6.60%	93.40%
Lanford	0.00%	48.25%	51.75%
Kenton	0.04%	72.66%	27.31%
Golden Lake	0.00%	50.70%	49.30%
Perch Lake	0.00%	68.88%	31.12%
Smokey Lake	0.00%	20.28%	79.72%
Block House	0.00%	48.56%	51.44%
May Lake	0.05%	42.47%	57.48%
Limestone	0.02%	64.34%	35.64%
Baraga Plains	0.37%	67.11%	32.52%
Kirby Creek	0.01%	42.76%	57.22%
MEAN	0.69%	41.80%	57.51%
Highest Value	13.22%	72.66%	93.40%
Lowest Value	0.00%	6.60%	14.18%

The Western Upper Peninsula contains large tracts of public land and National Forest. This helps account for the identification of large areas of highly suitable landuse/land cover habitat for the wolves. There are 2,602.47 square miles of highly suitable habitat, 1,363.53 square miles of moderately suitable habitat, and 1,663.26 square miles of low suitability habitat.

The abundant population of white-tailed deer in the study area contributes to a suitable food environment for wolves. As stated earlier, white-tailed deer make up over half of the gray wolf diet. According to this analysis, 904.45 square miles of the study area contains highly suitable habitat. Moderately suitable habitat consisted of 3,952.11 square miles of area and 868.72 square miles of low suitability habitat. Although the largest concentration of the area was classified as moderately suitable habitat, this still constitutes area that can sustain wolf pack ranges. Also, it should be noted again that this food source makes up a large portion of the gray wolf diet, but is not their only food source.

The road densities in the study area were one raster of the study that had a higher affinity towards the lower end of the suitability scale. Only 1,008.01 square miles of area contained habitat classified as highly suitable for wolf pack ranges. The moderately suitable habitat classification contained 1,292.75 square miles and 3,737.97 square miles of low suitability habitat.

Overall, the study area contained large areas of habitat classified as high and moderately suitable according to the final suitability classification overlaying the four separate rasters. 2,343.36 square miles of land was classified as highly suitable habitat in the study area, with 2,502.64 square miles of moderately suitable habitat. Of all the available land in the study area, only 135.33 square miles was classified as low suitability for the gray wolf.

Conclusion

Estimating the habitat suitability for an animal that is not entirely dependent on a specific type of habitat can be a difficult process. Many factors were considered to be favorable and have been studied to show the positive and negative effects on wolf habitat. The gray wolf is a very adaptable creature and does not always follow the rules and thresholds set forth in research findings. However, this model shows that when all factors are considered together, the overall model can be a good indicator of suitable habitat and corresponds well with real world populations.

The habitat suitability model created for this study was prepared with the best available data for the study area and most recent attainable data for the wolf packs in the area. The final model showed that the wolf pack ranges studied contain large percentages of favorable habitat. On average, 57% of the wolf pack ranges studied contained highly suitable habitat, 42% contained moderately suitable habitat, and less than 1% of low suitability habitat. Although certain rasters considered separately do not correspond to the research findings of wolf pack habitat, it should be noted that the goal of this study was to consider all the rasters as a whole that can affect wolf pack settlement and see how closely they correspond. A visual inspection of the wolf mortality data from 2006 was compared to the road and population densities, but showed no visual correlation and was left out of the study discussion

Road density was one raster that did not follow the Mladenoff research findings about wolves avoiding high road densities. However, during the research for this study and the field work that was done, wolves do tend to use less traveled roads as a means of movement during the winter months due to the large amounts of snow in the area. One factor that could refine this study would be to look at road densities of only primary roads and acquire road usage data from the Michigan Department of Transportation.

Other elements that could refine the study would be to acquire actual telemetry data to compare various pack range calculation methods rather than range estimates obtained from the Minimum Convex Polygon as used in this study. More recent landuse/land cover data would also refine the study. However, the landuse/land cover has not changed significantly in the study area over the last 30 years due to large tracts of public and national forest land. It should also be noted that the ordinal ranking of the data in the study does not allow for quantifying the difference between the values. For example, there is no way to say how much better a suitability value of 3 (high) is than 1 (low).

Overall, GIS proved to be a good tool to study the habitats of these animals in the wild. Without the powerful tools and analysis available with certain GIS programs, it would take years for wildlife managers to analyze the data. The model created allows interested parties to change the data and thresholds as new research and better data become available (For further details or a copy of the ArcToolbox Model, please contact Cole Belongie at the email address of ccbelo06@ smumn.edu). With populations of humans and wolves alike on the rise, research and models like this one are important planning and educational tools to help minimize human – wolf conflicts and ensure protection of gray wolf habitat and successful proliferation of the species.

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