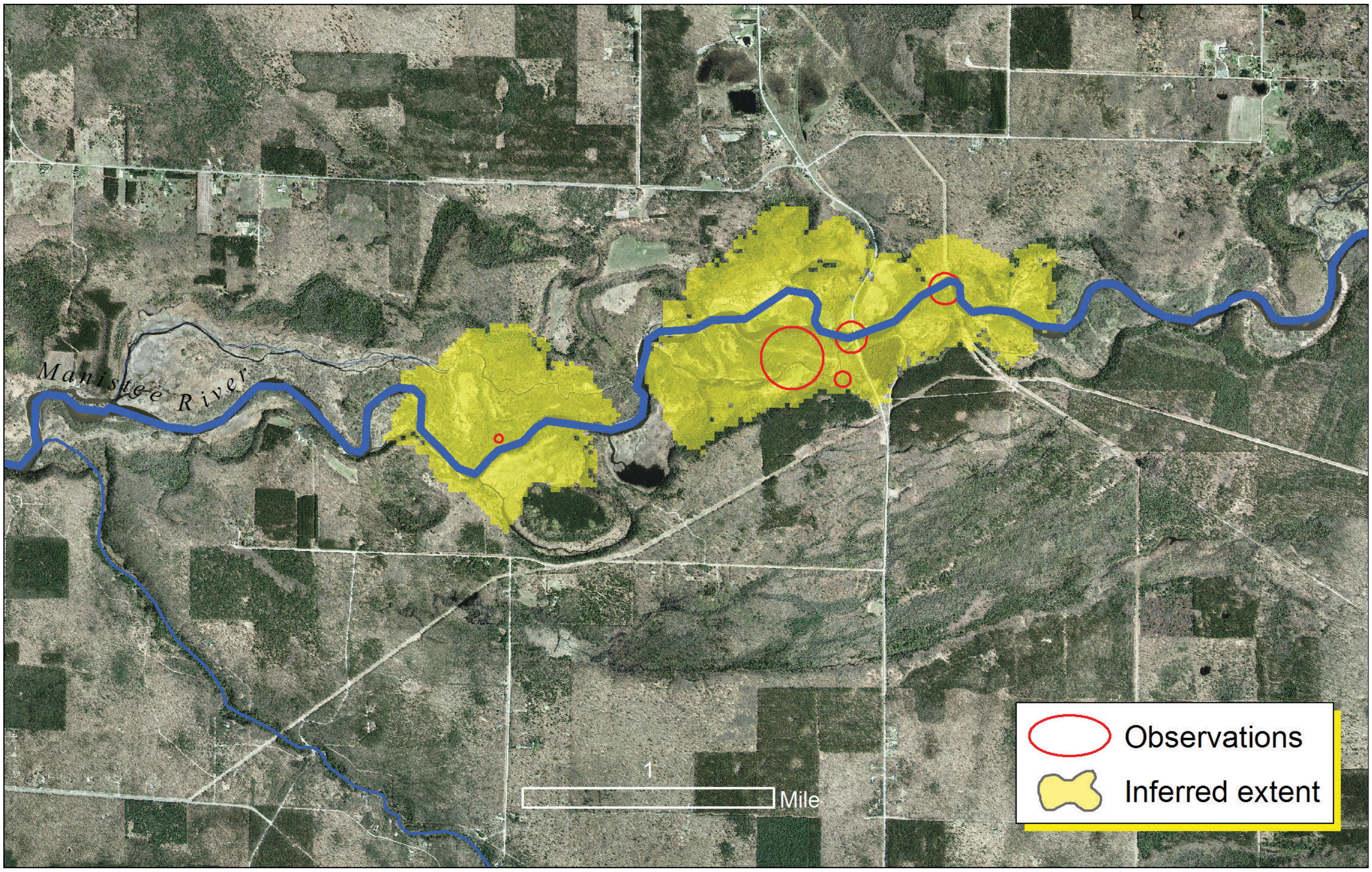
Modeling Inferred Extent of Endangered Animals for Conservation Decision-making



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Cover: A map of wood turtle source features and the resulting wood turtle inferred extent modeled in a small area of Manistee County Michigan.

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Abstract

Knowledge of where an animal exists on the landscape and the type and amount of habitat that is being utilized and/or required is necessary to manage for and protect the species. While known observations of species are valuable, incorporating those observations in a model of inferred extent provides additional information that is beneficial for conservation planning, management and decisionmaking.

Inferred Extent is a spatial product that is modeled from the Michigan Natural Features Inventory (MNFI) Natural Heritage Database (NHD). The NHD is the State's only comprehensive, single spatial database of occurrences of rare, threatened, and endangered plant and animal species and natural communities in Michigan. The spatial products/models available range from observation, element occurrence, Geographic Information Systems (GIS) models of inferred extent and populations, species distribution model (McCluskey 2016), to county range map (Figure 1). Observations are the core spatial feature, and are combined to create the element occurrence (EO), a group of single species observations combined within a specified separation distance, typically corresponding to a local population (NatureServe 2002). Inferred extent (IE) expands on the observation and EO data, which are based strictly on where an animal was actually observed, to include the surrounding area that is likely occupied based on home range size and habitat.

Inferred extent modeling augments the NHD species location data. The spatial requirements of a species are combined with expert knowledge and biological meaningful information including suitable/unsuitable habitat, barriers, reproductive and feeding behaviors, and other life history characteristics to more effectively delineate the boundary of the area used by the species, building a tool that supports planning, managing or prioritization. Inferred extent was modeled for 12 animals - nine federally listed, one state threatened, and two state special concern species.

Introduction

The Michigan Department of Natural Resources Wildlife Division (MDNR-WD) is engaged in conservation of federally listed species in collaboration with the U.S. Fish and Wildlife Service. Wildlife species that are added to the List of Endangered and Threatened Wildlife (50.CFR.11) are in greatest need of conservation. Animals that are newly listed usually lack information about their ecology, and current distribution. Knowledge of where these species occur and the extent of area likely utilized by the species is essential in order to protect these resources.

Michigan Natural Features Inventory (MNFI) maintains a comprehensive, statewide Natural Heritage Database (NHD) of element occurrences (EOs) of rare, threatened, and endangered animal and plant species and high quality examples of natural communities. Observations and element occurrences of rare animals mapped and included in the NHD are based on where animals were actually observed. However, animals are mobile, and generally occupy a larger area than the specific locations where the animals were observed. Inferred extent (IE) is a component of the MNFI mapping hierarchy (Figure 1) for rare species which expands on the locations derived from species observations and EOs to also include the surrounding area that is likely occupied based on the species' home range size and/

or available habitat. This adds a new level of biologically meaningful information to the species' location and EO data.

For this project we modeled the inferred extent for 12 animals, including nine federally listed, one state threatened, and two state special concern species. These include Blanding's turtle, copperbelly water snake, eastern massasauga, Indiana bat, Karner blue, Kirtland's warbler, Mitchell's satyr, northern long-eared bat, piping plover, Poweshiek skipperling, spotted turtle, and wood turtle. The specific objectives of this project include the following:

1. To provide the MDNR-WD with critical spatial information on listed species and suitable habitat so they can make well-informed decisions on the acquisition of land parcels below the Mason-Arenac County line, using the MNFI Natural Heritage Database and inferred extent GIS modeling for nine federally listed species and three state listed/special concern species.

2. To leverage existing spatial data products from previously funded projects such as the Preliminary Focal Area Network (Cohen et al. 2014), the Eastern Massasauga Rattlesnake Population Study (Lee and Enander, 2015), the Karner Blue Survey Project (Monfils and Cuthrell, 2015), and the Poweshiek Skipperling Survey Project (Cuthrell et al. 2015).

3. To rectify and interpret historical and current aerial imagery so that the probability for listed species in an area of potential land acquisition can be assessed.

4. To produce a report summarizing the modeling methods, and include metadata for the spatial data products.

Blanding's turtle (state special concern), spotted turtle (state threatened), and wood turtle (state special concern), were petitioned for federal listing in the recent past, and were added to this project. Inferred extent was modeled for each turtles' range in the State of Michigan.

This project relies solely on observed species locations, and should not be construed as mapping all the potential habitat for a particular animal. A number of species and/or habitats have declined so considerably in Michigan that even if the remaining sites are protected or conserved, it is not certain or even likely that the species will remain viable. Mapping inferred extent area will also not find new, suitable habitat that will be needed for re-introduction purposes.

Methods and Data

MNFI Natural Heritage Database

The primary source of location data was the Michigan Natural Features Inventory (MNFI) Natural Heritage Database (NHD) (MNFI 2016). The animal species, status codes, and state and global ranks that are included in this project are enumerated in Table 1 (Badra et al. 2014).

Using database queries, gaps were identified in the completeness of the data in the NHD for some species and temporal periods. Updating the database with data from ongoing MNFI projects, Huron-Manistee National Forest observations, Wildlife Division surveys, and the East Lansing Field Office of the U.S. Fish and Wildlife Service(USFWS) became the priority task.

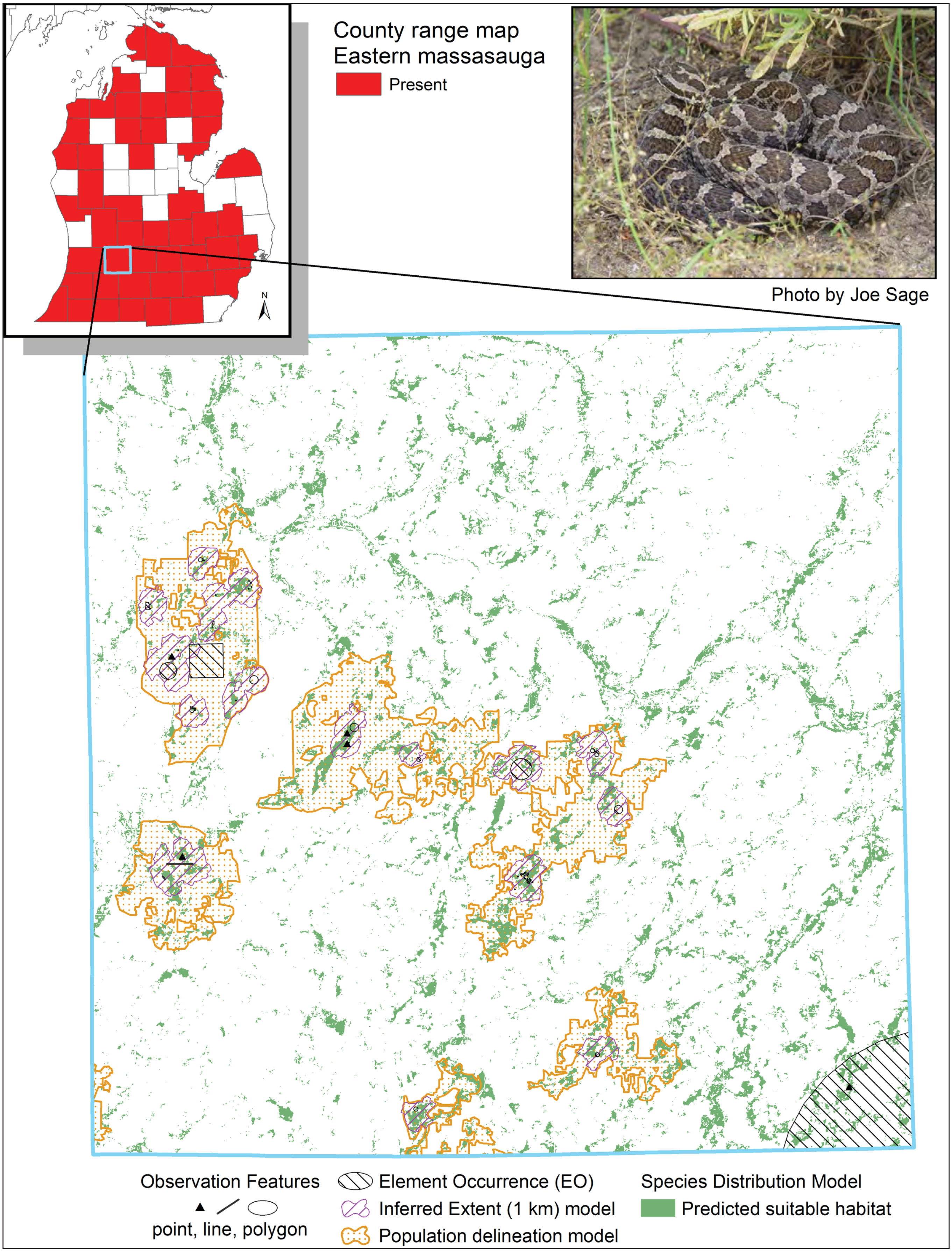

Figure 1. An illustration of the range of spatial products for eastern massasauga rattlesnake derived from the MNFI Natural Heritage Database (MNFI 2016). From observations, element occurrence, inferred extent model, population delineation model, species distribution model to county range map.

Table 1. Summary of species for this project with their current Global (G_rank), state (S_rank), federal (USESA) and state protection (Sprot) status.					
Scientific name	**Common name**	**G_rank**	**S_rank**	**USESA**	**Sprot**
Clemmys guttata	Spotted turtle	G5	S2		T
Glyptemys insculpta	Wood turtle	G4	S2		SC
Emydoidea blandingii	Blanding's turtle	G4	S2S3		SC
Myotis septentrionalis	Northern long-eared bat	G4	S1	LT	SC
Nerodia erythrogaster neglecta	Copperbelly water snake	G5T3	S1	LT	E
Charadrius melodus	Piping plover	G3	S2	LE	E
Dendroica kirtlandii	Kirtland's warbler	G1	S3	LE	E
Myotis sodalis	Indiana bat	G2	S1	LE	E
Oarisma poweshiek	Poweshiek skipperling	G2G3	S1	LE	T
Lycaeides melissa samuelis	Karner blue	G5T2	S2	LE	T
Neonympha mitchellii mitchellii	Mitchell's satyr	G1G2T1T2	S1	LE	E
Sistrurus catenatus catenatus	Eastern massasauga	G3G4T3T4Q	S3	C	SC

Species locations in the NHD are recorded based on heritage methodology developed by NatureServe (NatureServe 2002). The main database product, the element occurrence (EO) feature, defines known location(s) of an element (in this case, animal species), and is generated from one or more source features. Each source feature represents a location of an observation and incorporates local spatial uncertainty with the observation data/location. Observations recorded with a global positioning system (GPS) are mapped with a high representative accuracy, and low uncertainty distance, while other (usually older) observations are less precisely mapped and have a low representation accuracy with a high uncertainty distance. Source features within species-specific separation distances specified by NatureServe (NatureServe 2004) are combined by spatial union and are part of the same or one EO or population.

Element occurrences have a quality rank based on an overall ecological integrity score. Appendix 1 lists the domain of ranks and their definitions for heritage records. Records with a rank of "X" (extirpated) were eliminated from consideration for this project. Feature size selection criteria were set so that source features mapped with a general precision were removed, as their high locational uncertainty makes them undesirable for model input. Occurrences ranked 'H' (Historical) or 'F' (Failed to find) were included if they were below the maximum feature size criteria and if suitable habitat for the species of interest still appeared to occur within their boundary. Finally, if spatially precise locations were overlain by a feature of lower precision, the lower precision feature was removed (Figure 2a, 2b). This process ensures that the most spatially precise species location information that is available is retained

The three insects were exceptions to the previous criteria. Mitchell's satyr and Poweshiek skipperling sites have been in decline, and have been frequently surveyed. For these species, ranks of "F" or "H" were not included, since it is highly likely that the species is no longer found at these locations. Karner blue is also annually surveyed on state and federal land. Given the high number of historical records, two inferred extent models were produced for Karner blue; 1) by the original criteria of including H and F records that are mapped more precisely, and 2) without the inclusion of "H" records.

Inferred Extent

Inferred extent of habitat use refers to the surrounding area likely utilized or occupied by the species at that location, which may be useful for conservation planning purposes (NatureServe 2002). The inferred extent distance is an approximate spatial requirement for certain species, typically based on the average home range, or the distance from an initial location that would encompass the ultimate destination of 75-90% of the dispersing adult individuals (NatureServe 2002, 2013). The inferred extent distance generally does not exceed the maximum known single-year migration distance for the species (assuming flightless animal) or the EO separation distance (NatureServe 2002, 2004). The spatial requirements of a species are combined with expert knowledge and biological meaningful information including suitable/unsuitable habitat, barriers, reproductive and feeding behaviors, and other life history characteristics to more effectively delineate the boundary of the area used by the species. Inferred extent may vary by season, age, sex, and reproduction status, but those considerations are beyond the scope of this study.

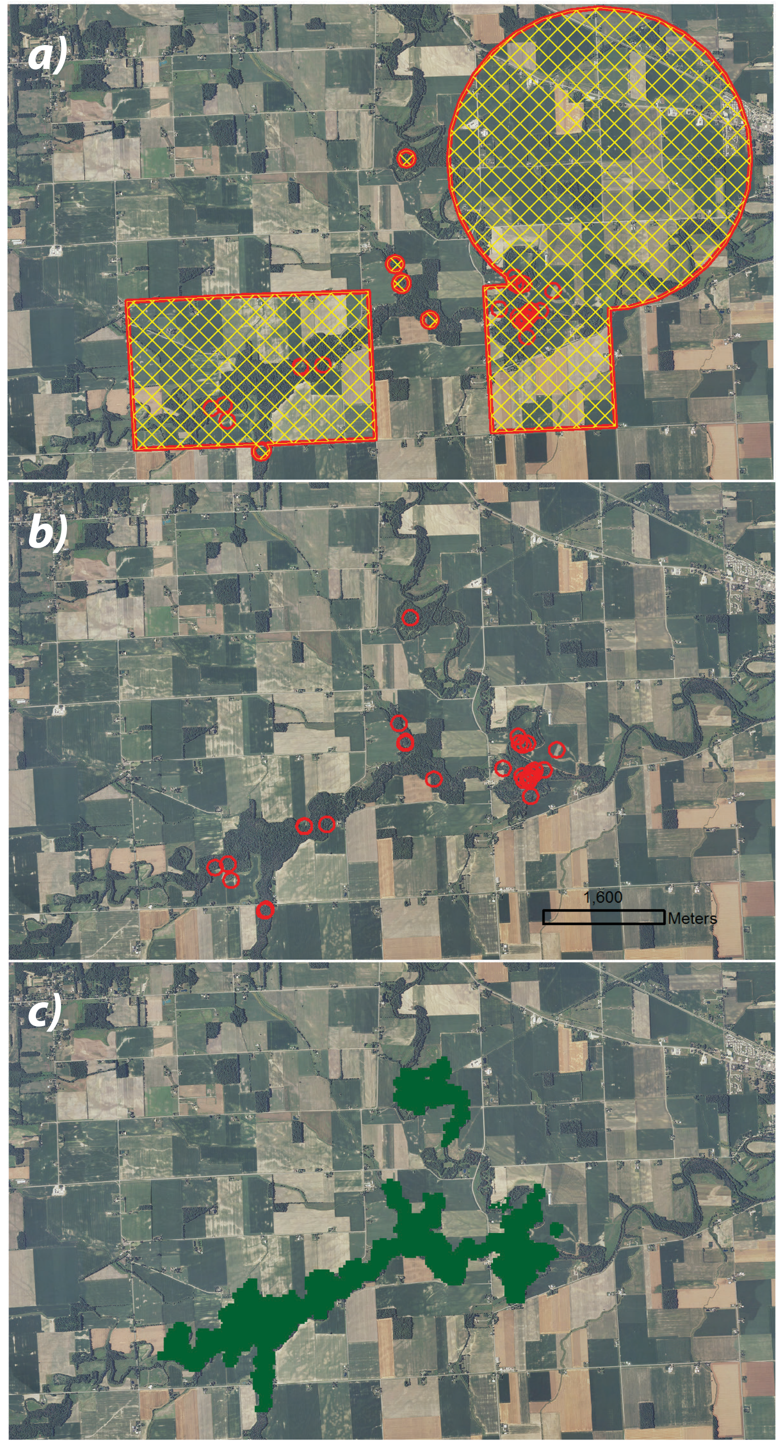

Figure 2. An example of a) the source features (red) that make up an EO feature (yellow hatch), and b) the subset of source features from that same EO that are mapped with higher precision and are acceptable for inferred extent modeling, and c) an example of the inferred extent layer (green) created from the source features in b.

NatureServe provides three possible values for determining inferred extent distance: 1) a specific inferred extent distance recommended by NatureServe, 2) a more generic value for species/species groups which don't have a lot of telemetry information, 3) EO separation distance, which is the distance of intervening suitable or unsuitable habitat that is great enough to effectively separate species occurrences by limiting the movement or dispersal of individuals between them. A literature search for information on habitat use, movement/dispersal distances, and home range size was conducted for each species modeled to compile data to compare the inferred extent distance value recommended by NatureServe. NatureServe recommended distances, literature review data, and expert opinion were combined to select the IE distance for each species in this study. Table 2 lists the NatureServe inferred extent if available, NatureServe separation distances, the selected IE distance for this project, and literature references if an alternate IE distance was selected. For an visual example of an IE, see Figure 2c, which illustrates the IE model output for the source features in Figure 2b.

The IE distances selected for each species are listed in Table 2. The recommended IE distances from NatureServe were utilized for copperbelly water snake, eastern massasauga, Karner blue, Mitchell's satyr, and piping plover. Eastern massasauga has two IE distances - the NatureServe-recommended distance of 1 km, and also at a IE distance of 2 km, as maximum movement in other states has been observed up to 2 km (from Lee and Enander 2016).

The Indiana and northern long-eared bat, and Kirtland's warbler did not have a designated inferred extent distance. The NatureServe separation distance of 5 km was selected as the IE for both bats. Kirtland's warbler also had a separation distance of 5 km, but movement and home range sizes summarized by the Kirtland's Warbler Recovery Team (Ennis 2002) suggested that a distance of 2.6 km is sufficient.

NatureServe's recommended inferred extent distance for Blanding's turtle is 1 km, but the studies in the literature reported movements of up to 2 km. (Gibbons 1968, Congdon et al. 1983, Rowe 1987, Piepgras and Lang 2000, Joyal et al. 2001, Congdon and Keinath 2006, Refsnider and Linck 2012, Anthonsamy et al. 2013), so we selected an IE distance for Blanding's turtle of 2 km. Spotted turtle and wood turtle have a generic IE of 5 km, but many studies report movement an order of magnitude lower. In Michigan, spotted turtle movement has been reported up to 662 meters (Harding 1997), so an IE of 1 km was selected. Wood turtles have been observed moving up to two miles in river corridors (Ewert et al. 1998, Parren 2013), however in a 20-year study in Michigan, Harding (1997) found all individuals within 500 feet (152.4 m), and most within 50 feet (15.2 m) of water throughout the year. An IE distance of 2 km was selected for the wood turtle.

The recommended IE distance for the Poweshiek skipperling is 1 km. However recent surveys and expert opinion suggest the distance is limited to the extent of the prairie fen natural community (Cuthrell 2012) in which the insect is found. Field surveys by MNFI, including GPS locations facilitated the manual delineation of the habitat used at the four remaining Poweshiek skipperling sites.

Cost Distance Modeling

Cost distance modeling is a raster-based function with the following requirements:

- **Inputs**:
  - source features
  - a cost (or impedence) surface
  - an optional maximum cost parameter
- **Output**:
  - cost distance – values indicate the least cost distance from the source features, up to the distance of the maximum cost parameter.

Cost distance functions are the primary algorithms of the inferred extent model. A "simple" or straight-line distance function takes the source features and calculates for each output cell, the nearest source based on straight-line distance alone. A cost distance function is similar, (think of "cost" here as impedance or friction) but requires a weighted raster called the cost surface (Figure 2). The "cost" is calculated as the straight-line distance multiplied by the weight of cells in the cost surface. For each cell in the cost distance output (Figure 3) the least accumulative cost to each of the source features is calculated. Setting the parameter of "maximum cost" controls how far (in cost units) from the source features that the function will continue to create output.

When applied to the modeling of IE, the cost surface represents habitat suitability, or the relative difficulty of traversing habitat classes. The cost surface is produced by assigning weights to land cover classes according to their probable habitat suitability for a particular species. A low weight of one equals potentially suitable habitat and as weights increase the suitability of habitat decreases (or the cost of traversing through the habitat is higher). An analogy is the choice of whether to climb directly over a mountain range, or to go around it. The shortest distance would be to climb straight over, but going around may be much easier, or less costly.

The maximum cost parameter is set to the IE distance value for the animal. This terminates the model at the actual IE distance if all pixels are suitable, or at the IE distance in cost units, if less suitable pixels are sometimes the only choice.

Species habitat requirements were summarized from the MNFI special animal abstracts (Cuthrell and Slaughter 2012; Hyde 1999, 2012; Lee 1999a, 1999b, 2000, 2010, 2013; Olson 2002; Rabe 2001, 2001b) and the NatureServe online species explorer (NatureServe 2015). An abstract has not been published for the northern long-eared bat, so habitat suitability was extracted from the NatureServe online species explorer (NatureServe 2015) and supplemented with expert opinion (B. Klatt, personal communication, June 2, 2016). The ensemble of data on habitat suitability by land cover class was reviewed and converted to cost surface layers for each species.

The most current land cover dataset for the study area is the National Oceanic and Atmospheric Administration (NOAA) Coastal Change Analysis Program (NOAA 2013) land cover dataset (circa 2010) which has a resolution of 30 meter pixels, and contains 18 land cover classes. It uses a standard classification scheme (Appendix 2) that identifies a greater number of wetland/coastal classes than a traditional (Anderson level II) land cover classification (Anderson et al. 1976). Land cover types that could provide suitable habitat for a species were given a low cost weight, while less suitable classes were given ever higher values, so that the most unsuitable habitat was assigned to the maximum weight.

For each species, the cost weights by land cover class that were used to create cost surfaces for the cost distance models are listed in Appendix 3. Land cover classes receiving a "NoData" weight serve as barriers to movement. Table 3 illustrates the cost weights for eastern massasauga, and the corresponding distance the snake could have moved through each land cover type. No movement is allowed through medium or high intensity developed land classes. All wetland types have a weight of 1, and are the preferred habitat for eastern massasaugas. Massasaugas are able to move in this habitat up to their IE distance of 1000 m. Upland forest and grassland types are often traversed by the snake, and have been assigned higher cost which will allow movement, but wetland habitat is preferred if available. Finally, the unsuitable land cover types (agriculture, open water, and residen-

Table 2. Summary of information on NatureServe-recommended inferred extent and separation distances, inferred extent distance selected for this project, and information on movement and home range size if the NatureServe-recommended IE was not selected.

Common Name	NatureServe Inferred Extent (m)	Separation distance Suitable habitat (m)	Separation distance Unsuitable habitat (m)	Inferred Extent selected (m)	Home range area \ Maximum movement
Northern long-eared bat	**NA**	5000	5000	5000	61.1 ha; 6 - 2800 m (Menzel et al. 1999, Foster and Kurta 1999, Menzel et al. 2002)
Indiana bat	**NA**	5000	5000	5000	52 - 335 ha; 1-8.4 km (Humphrey et al. 1977, Garner and Gardner 1992, Sparks et al. 2005)
Kirtland's warbler	**NA**	5000	5000	2600	6-30 acres (2.4-24 ha) (Ennis 2002)
Poweshiek skipperling	1000	10000	4000	Prairie fen	In MI, the extent of the Prairie fen (Cuthrell 2012)
Wood turtle	5000	5000	1000	2000	24-132 ha; 33 m-3200 km (Harding 1991, Quinn and Tate 1991, Ewert et al. 1998, Arvisais et al. 2002).
Blandings turtle	1000	10000	2000	2000	1.7 - 22 ha; < 100 m up to > 2 km (Gibbons 1968, Congdon et al. 1983, Rowe 1987, Piepgras and Lang 2000, Joyal et al. 2001, Refsnider and Linck 2012, Anthonsamy et al. 2013)
Spotted turtle	5000	3000	2000	1000	0.2-34.4 ha; 50- 662 meters (Harding 1997)
Eastern massasauga	1000	5000	1000	1000, 2000	20-95 ha; 300 m to 1 - 2 km (from Lee and Enander 2015)
Copperbelly water snake	5000	10000	1000	5000	
Karner blue	1000	8000	2000 - 4000	1000	
Mitchell's satyr	1000	2000	1000	1000	
Piping plover	1500	5000	5000	1500	

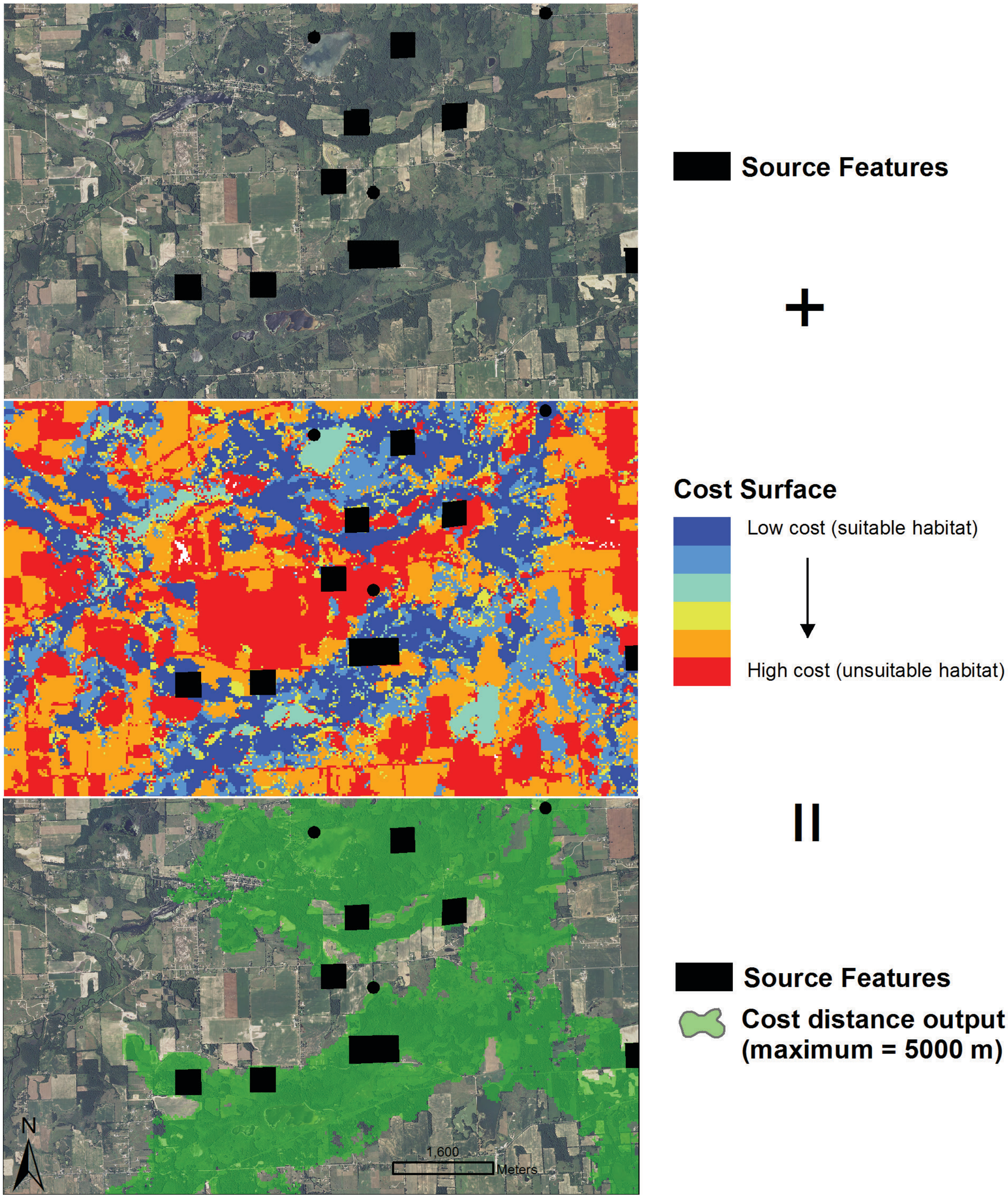

Figure 3. An example of the inputs to cost distance modeling (Source Features, Cost Surface, Maximum distance) and the successive model output (Cost Distance).

tial development) have been assigned a weight of 10. This allows the snake to move across a road, through a residential yard, or into a field for a short distance, but if other, lower cost habitat types are available, they will be chosen preferentially.

After consideration of previous work (Lee and Enander 2015, 2016; McCluskey 2016) showing that massasaugas in northern Michigan may have differing habitat preferences than massasaugas in the south, we adjusted the cost weights for massasauga in the north to include upland forest as suitable habitat, in addition to the wetland classes.

Historical Imagery

Historical imagery interpretation (Objective 3) was requested for parcels in the vicinity of Wigwam Bay State Game Area. Six aerial images from the earliest year available (1952) at the Michigan State University Aerial Imagery Archive were obtained, rectified, and merged into to an image called a mosaic dataset. A set of mosaicking rules dynamically blend and order the individual imagery to provide seamless, continuous data coverage. This dataset was provided to MNFI Botanist Bradford Slaughter for interpretation.

Table 3. For the eastern massasauga, cost weights ranged from one (highly suitable) to ten (unsuitable) and the medium to high intensity developed areas served as barriers.

Land cover class	Cost Weight	Maximum Distance (m)
Developed, High Intensity	*NoData*	0
Developed, Medium Intensity	*NoData*	0
Developed, Low Intensity	10	100
Developed, Open Space	10	100
Cultivated Crops	10	100
Pasture/Hay	10	100
Grassland/Herbaceous	3	600
Deciduous Forest	2	800
Evergreen Forest	2	800
Mixed Forest	2	800
Scrub/Shrub	2	800
Palustrine Forested Wetland	1	1000
Palustrine Scrub/Shrub Wetland	1	1000
Palustrine Emergent Wetland	1	1000
Palustrine Aquatic Bed	1	1000
Unconsolidated Shore	1	1000
Bare Land	10	100
Open Water	10	100

Results and Discussion

MNFI Natural Heritage Database

In an effort to ensure the NHD was as up-to-date as possible, the following data were obtained and entered into the database:

- Karner blue butterfly survey data from the Huron-Manistee National Forest had been received by MNFI for the years 2005 – 2013 and not all of the data had been entered. Approximately 351+ digital and paper records were entered into the database. Also field data collected from the Karner Blue Survey project (n=658 observations at 134 locations) (Monfils and Cuthrell, 2015) was entered into the database. All 189 Karner blue EOs were reviewed, and updated if newer spatial and or temporal data were available.

- Piping plover nesting locations from the early 1990s – 2015 were obtained from USFWS (n=959). Many of these locations collected before 2010 were already documented in the NHD, however seven new Piping plover EOs were added to the database from this source, and the remaining 36 EOs were reviewed and updated where indicated.

- Kirtland's warbler census data for 2011-2015 (n = 7133) was obtained from the Wildlife Division. All 43 Kirtland's warbler EOs were reviewed and updated where needed.

- A handful of eastern massasauga and Blanding's turtle observations from various sources were entered into the NHD.

A total of more than 9100 records from federal, state, and MNFI project sources were assessed, entered or updated in the NHD as a result of this project. After applying the the rank and size criteria, a total of 5336 source features from 1292 EOs were utilized in the IE models. (Table 4).

An additional outcome of this project resulted from an on-going discussion with USFWS personnel which identified the need to confer and develop a plan for a data-sharing mechanism that will keep the NHD more up to date with federally collected or held location records. A shared ArcGIS Online group has been established between MNFI and U.S. Fish and Wildlife Service East Lansing Field Office to advance this effort.

Inferred Extent

Inferred extent vector layers were created for each animal (Digital Appendix 4). The eastern massasauga was modeled at inferred extent distances of both one and two km. Two models of Karner

Table 4. A summary of the species location records in the NHD and the subset of features used in modeling

	NHD Totals				Modeling input totals				
Common Name	EOs	Source Points	Source Lines	Source Poly-gons	EOs	Source Points	Source Lines	Source Poly-gons	Total Features
Blanding's turtle	291	47	28	491	291	47	28	488	563
Copperbelly water snake	15	0	1	58	13	0	1	54	55
Eastern massasauga	284	16	29	1020	272	16	29	961	1006
Indiana bat	24	0	0	93	21	0	0	73	73
Karner blue (with historic)	189	2	2	664	186	2	2	657	661
Karner blue (wo historic)					161	2	2	552	556
Kirtland's warbler	24	0	0	10326	23	0	0	9980	23
Mitchell's satyr	24	489	0	523	9	489	0	303	792
Northern long-eared bat	33	0	0	148	30	0	0	109	109
Piping plover	40	151	0	593	27	151	0	569	720
Poweshiek skipperling	16	4	0	709	4	4	0	607	611
Spotted turtle	169	5	9	197	169	5	8	195	208
Wood turtle	253	15	60	460	247	15	60	440	515
Totals	1362				1292				5892

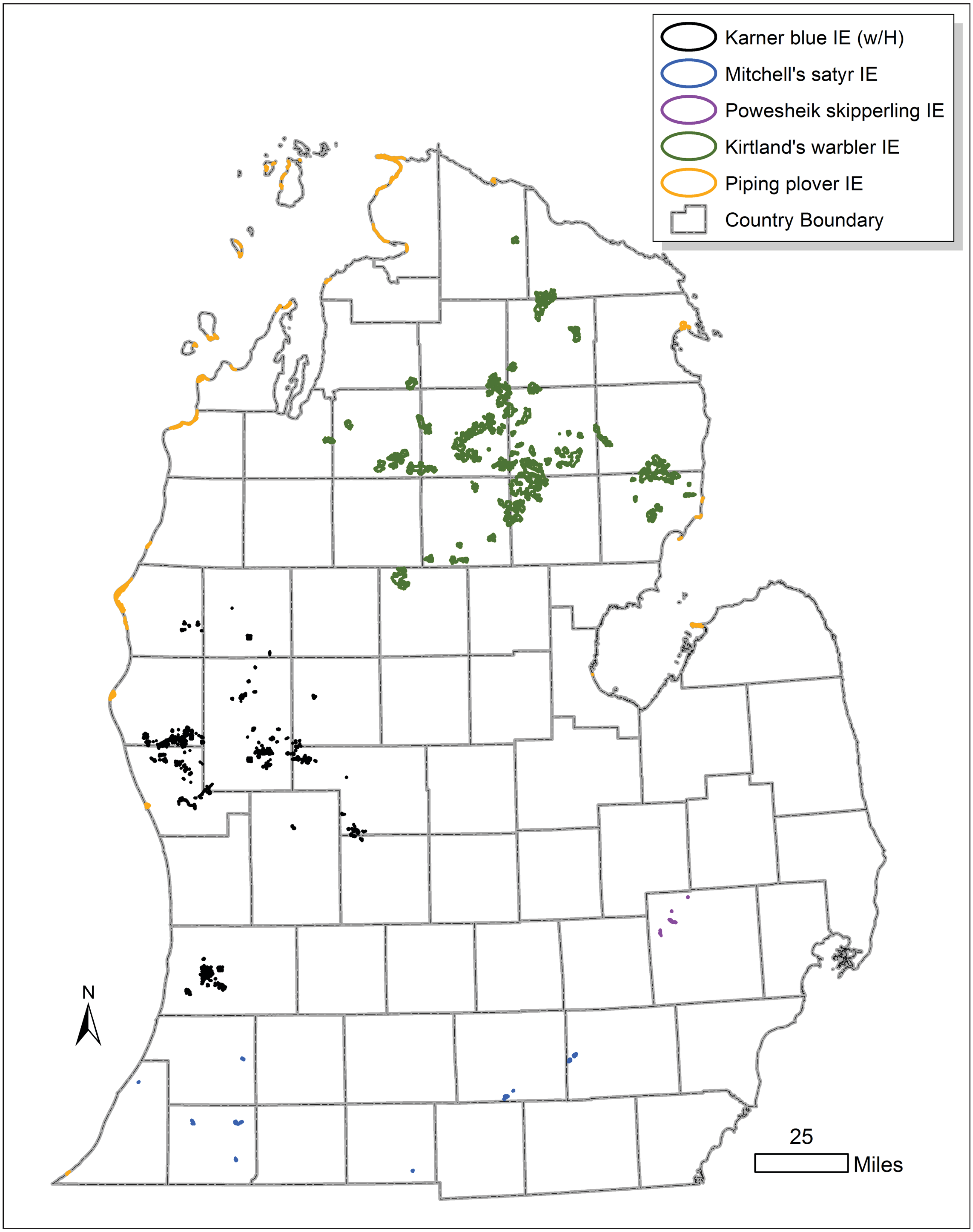

Figure 4. A map showing the inferred extent layers for piping plover, Kirtland's warbler, Karner blue, Mitchell's satyr and Poweshiek skipperling.

blue IE were also produced; 1) with historical locations, and 2) without historical locations. A total of 1,271,205 acres (514,438 ha) of inferred extent area was mapped for the nine federally listed animals in the Lower Peninsula of Michigan. The IE area mapped for the three turtles (in both Upper and Lower Peninsula) is 979,546 acres (396,408 ha).

A map of the bird and insect IE layers developed for this project in the Lower Peninsula of Michigan is shown in Figure 4. Piping plover habitat during nesting can be constrained by varying Great Lakes water levels, as all sites are on the Great Lakes shoreline. Thus the IE area mapped for piping plover may change over time depending on lake levels. Kirtland's warbler habitat requires intensive management, so land cover was only somewhat useful in selecting habitat. The NatureServe Terrestrial Ecological Systems of the U.S. (Sayre et al. 2009) ecological concept map contains attributes for "Managed Tree Plantation" and "Harvested forest-herbaceous regeneration", which were employed as a check for suitable habitat.

The range of Karner blue, Mitchell's satyr and Poweshiek skipperling is chiefly in the Southern Lower Peninsula, where habitat is generally more fragmented and less public land is available. These species have suffered significant decline in recent years. For example, Figure 5 illustrates the IE of the Karner blue with and without historical records. Inferred extent decreased from 18,469 acres (7,474 ha) with historic records to 13,242 acres (5,359 ha) currently thought to be occupied. By comparing the brown (current) IE that is overlain on the historic (turquoise) IE, dramatic spatial patterns of decline can be observed. Areas that are turquoise only are sites lost in the past few decades. A comparison of current to historical IE was not done for the two other butterflies, but we would expect similar dramatic declines. Historical IE layers could be useful in identifying remaining suitable habitat to help guide reintroduction efforts for these rare butterflies and other imperiled species.

The Indiana and northern long-eared bat inferred extent layers are mapped in Figure 6. Modeling inferred extent for bats was somewhat problematic, because groups of bats use different habitat and exhibit differing movements based on season and biology (bachelor colony, breeding, hibernaculum, maternity colony and non-breeding, as well as migrating). Modeling each of these somewhat dissimilar groups is beyond the scope of this project. Another obstacle regarding the use of known location data is that the East Lansing Field Office of the USFWS holds some additional northern long-eared bat locations that aren't available for the model because of data-sharing agreements. Additional location data would make the inferred extent layer more robust. Lastly, some current northern long-eared bat observations do not overlay suitable habitat according to the land cover data. One possible explanation could be that the observations were made from narrow tree-lines or other small habitat units that would not be represented on a 30-meter pixel land cover classification.

A map of the copperbelly water snake and eastern massasauga (IE at 1 km) inferred extent layers is shown in Figure 7. Eastern massasauga inferred extent areas extend into 49 of the 68 counties in the Lower Peninsula, while copperbelly water snake is on the northern limit of its range and occurs in only six counties in the south. A comparison of the two eastern massasauga inferred extent distance layers (1 km and 2 km) provides options for consideration of different management techniques and evaluation of potential threats as shown in Figure 8 from the recently completed endangered species modeling project to inform the Michigan Department of Transportation (MDOT) five year transportation plan (Lee and Enander 2016).

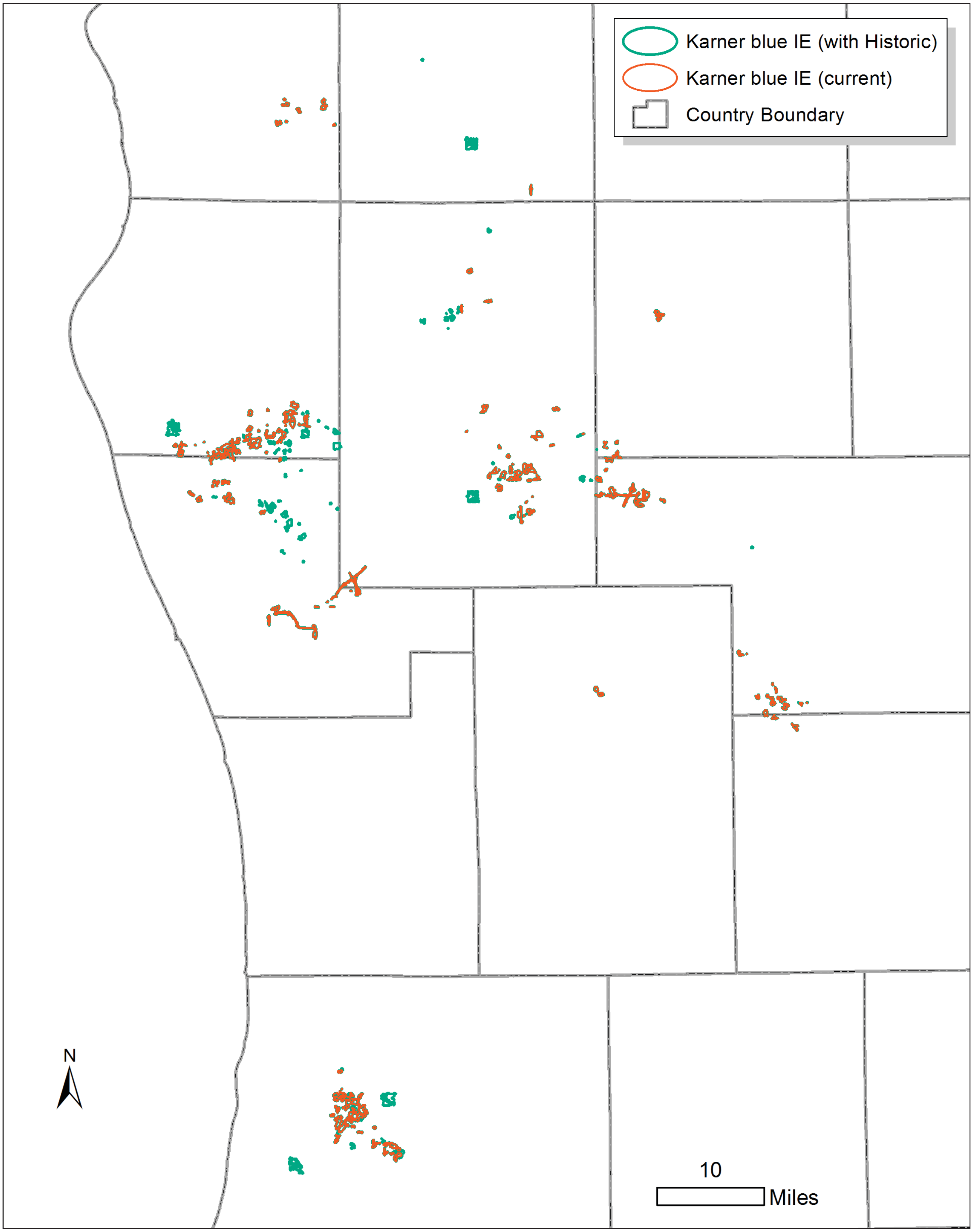

Figure 5. A comparison of Karner blue inferred extent modeled with (turquoise) and without (brown) historical records. Current IE is overlayed on the historical, so areas of only turquoise are sites lost in about the last 25 years..

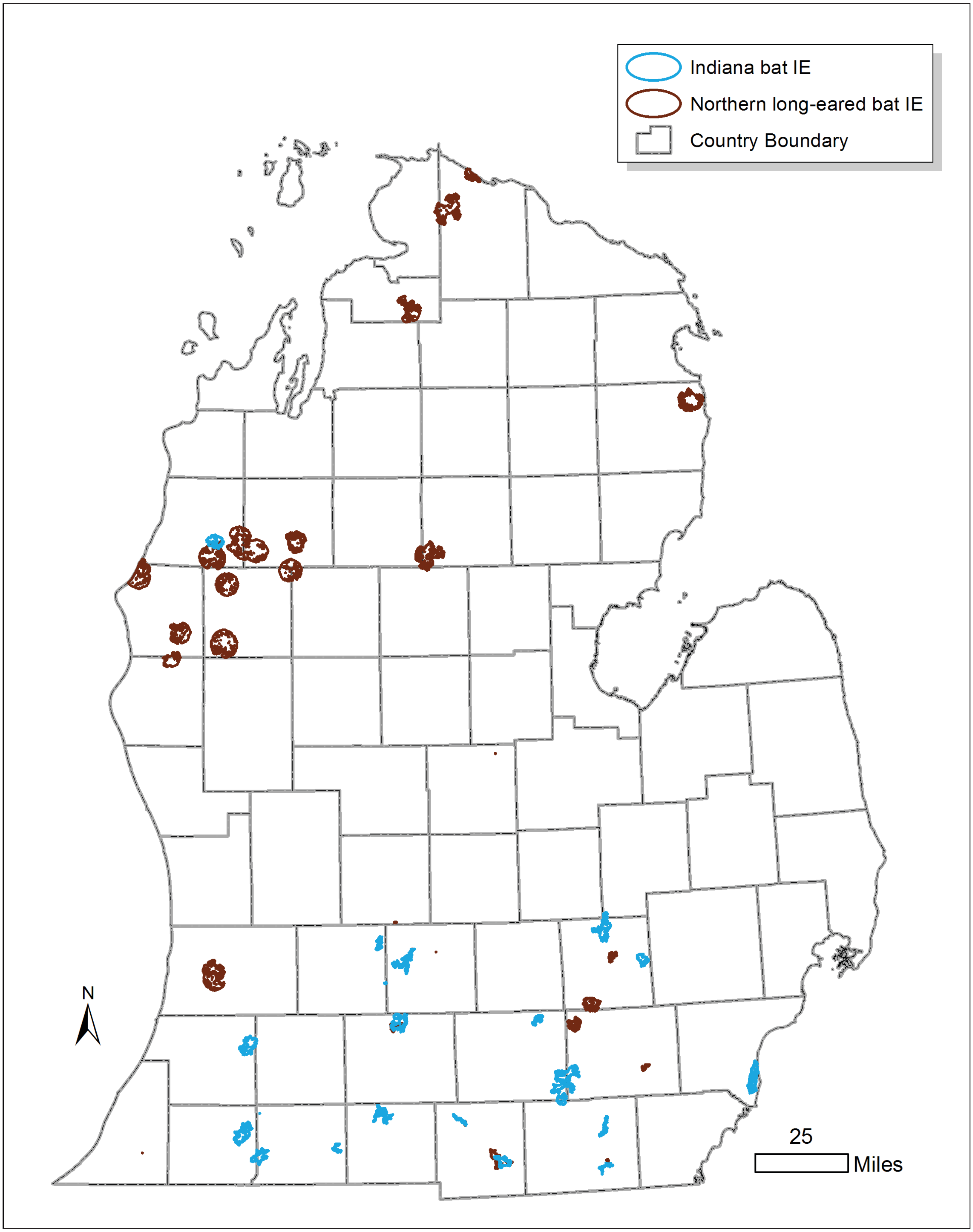

Figure 6. A map showing the inferred extent layers modeled for Indiana bat and northern long-eared bat.

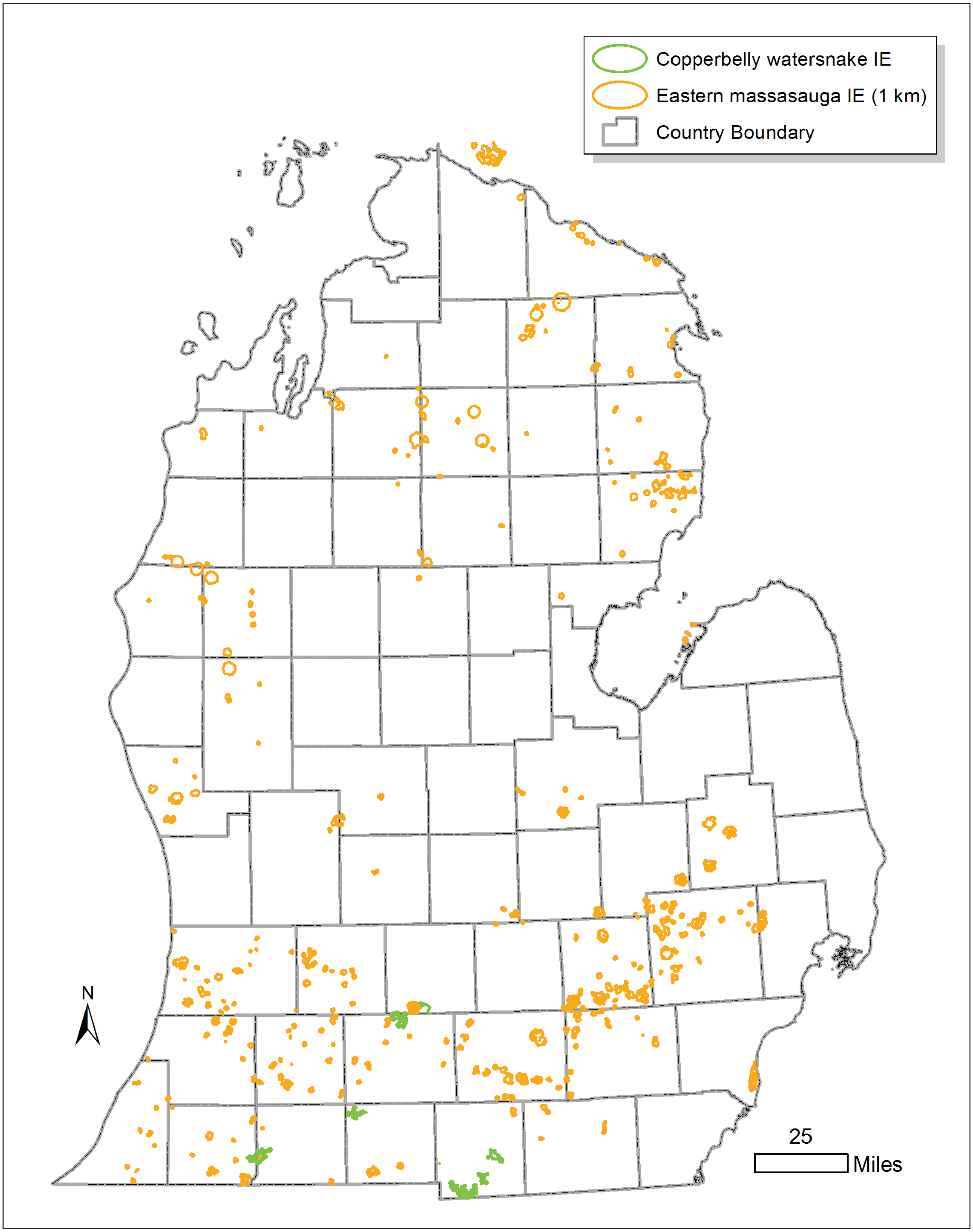

Figure 7. A map of the inferred extent layers modeled for eastern massasauga (at 1 km) and copperbelly water snake.

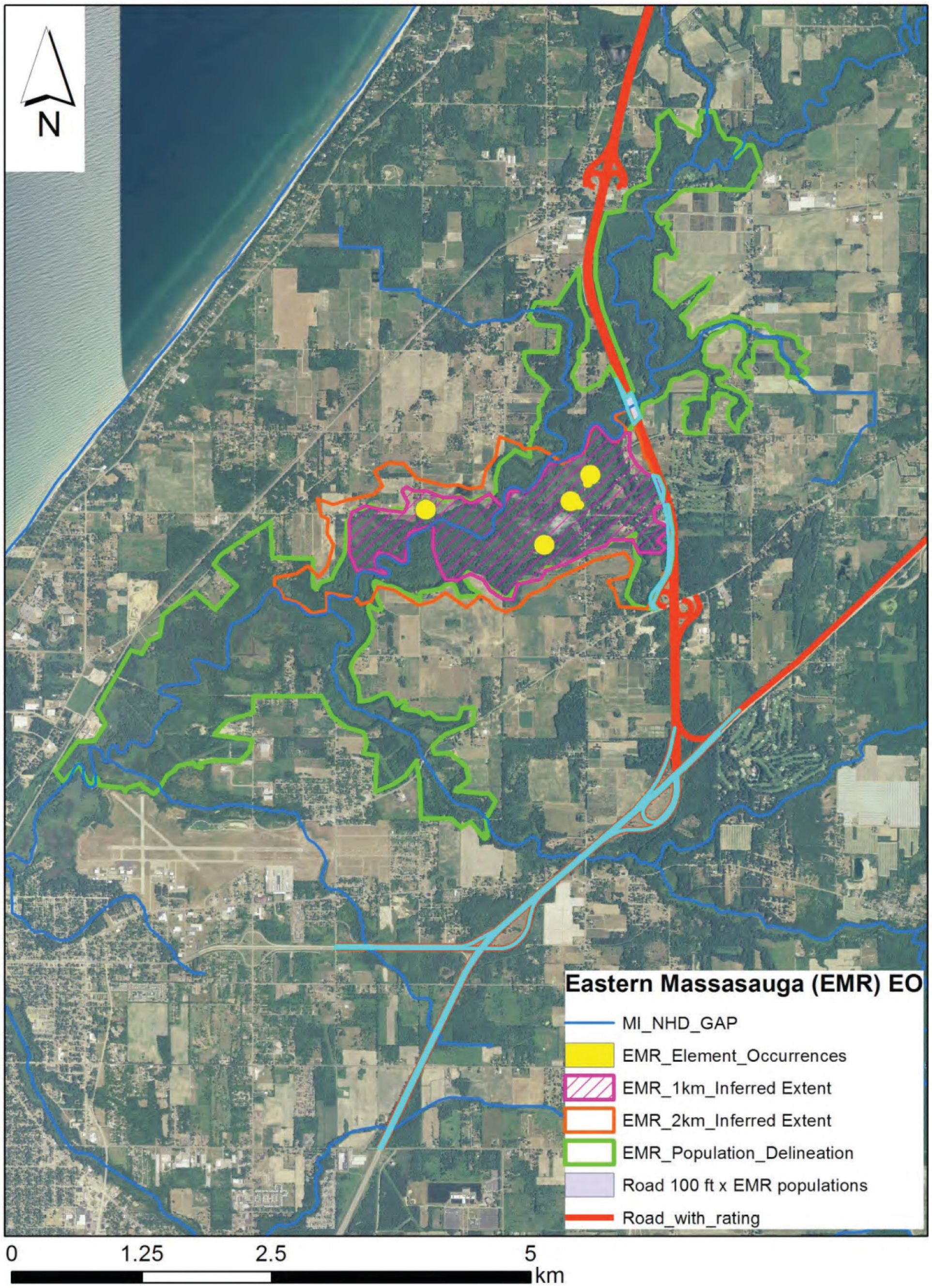

Figure 8. (Figure 6 from Lee and Enander 2016): Eastern massasauga element occurrence (EO) (yellow circles), 1-km inferred extent (pink), 2-km inferred extent (orange-red), and population delineation (green). MDOT road segments and future road projects are shown in red. Road segments highlighted in light blue are project sites that were located within 30.5 m (100 ft) or 0.8 km (0.5 mi) of massasauga inferred extent and/or population delineations.

Table 5. Summary of the Lower Peninsula species inferred extent area by land ownership class

	Copperbelly water snake		Eastern massasauga 1 km		Eastern massasauga 2 km		Indiana bat		Northern long-eared bat	
Ownership	**acres**	**%**	**acres**	**%**	**acres**	**%**	**acres**	**%**	**acres**	**%**
County	0	0%	2894	1%	4014	1%	20	0%	234	0%
Federal	0	0%	34391	10%	66219	10%	3968	5%	104543	40%
Local	423	2%	8731	3%	12816	2%	572	1%	307	0%
NGO	865	3%	4188	1%	5527	1%	1765	2%	8464	3%
State	3899	15%	91528	27%	167306	25%	10869	12%	43201	17%
Private/Unknown	20822	80%	196840	58%	420883	62%	70124	80%	104096	40%
Total	26010		338572		676765		87318		260844	

Table 5. cont.

	Karner blue + H		Karner blue - H		Kirtland's warbler		Mitchell's satyr		Piping plover		Poweshiek skipperling	
Ownership	**acres**	**%**	**acres**	**%**	**acres**	**%**	**acres**	**%**	**acres**	**%**	**acres**	**%**
County	82	0%	24	0%	0	0%	0	0%	0	0%	0	0%
Federal	4640	25%	3515	27%	50339	29%	0	0%	2893	19%	0	0%
Local	74	0%	71	1%	497	0%	31	2%	48	0%	0	0%
NGO	162	1%	162	1%	0	0%	389	26%	13	0%	62	17%
State	3930	21%	3156	24%	108105	63%	0	0%	4988	33%	40	11%
Private/Unknown	9581	52%	6313	48%	12759	7%	1100	72%	7034	47%	258	72%
Total	18469		13242		171700		1520		14976		360	

Table 6. Summary of inferred extent area by ownership class for three turtles in the Upper and Lower Peninsula of Michigan.

	Blanding's turtle		Spotted turtle		Wood turtle	
Ownership	**acres**	**%**	**acres**	**%**	**acres**	**%**
County	2,297	0%	765	1%	2,002	1%
Federal	84,722	16%	1,723	2%	68,163	20%
Local	4,451	1%	1,845	2%	1,228	0%
NGO	4,740	1%	4,184	4%	431	0%
State	120,538	23%	30,284	32%	76,369	22%
Private/Unknown	318,471	60%	56,783	59%	200,549	58%
Total	535,218		95,585		348,743	

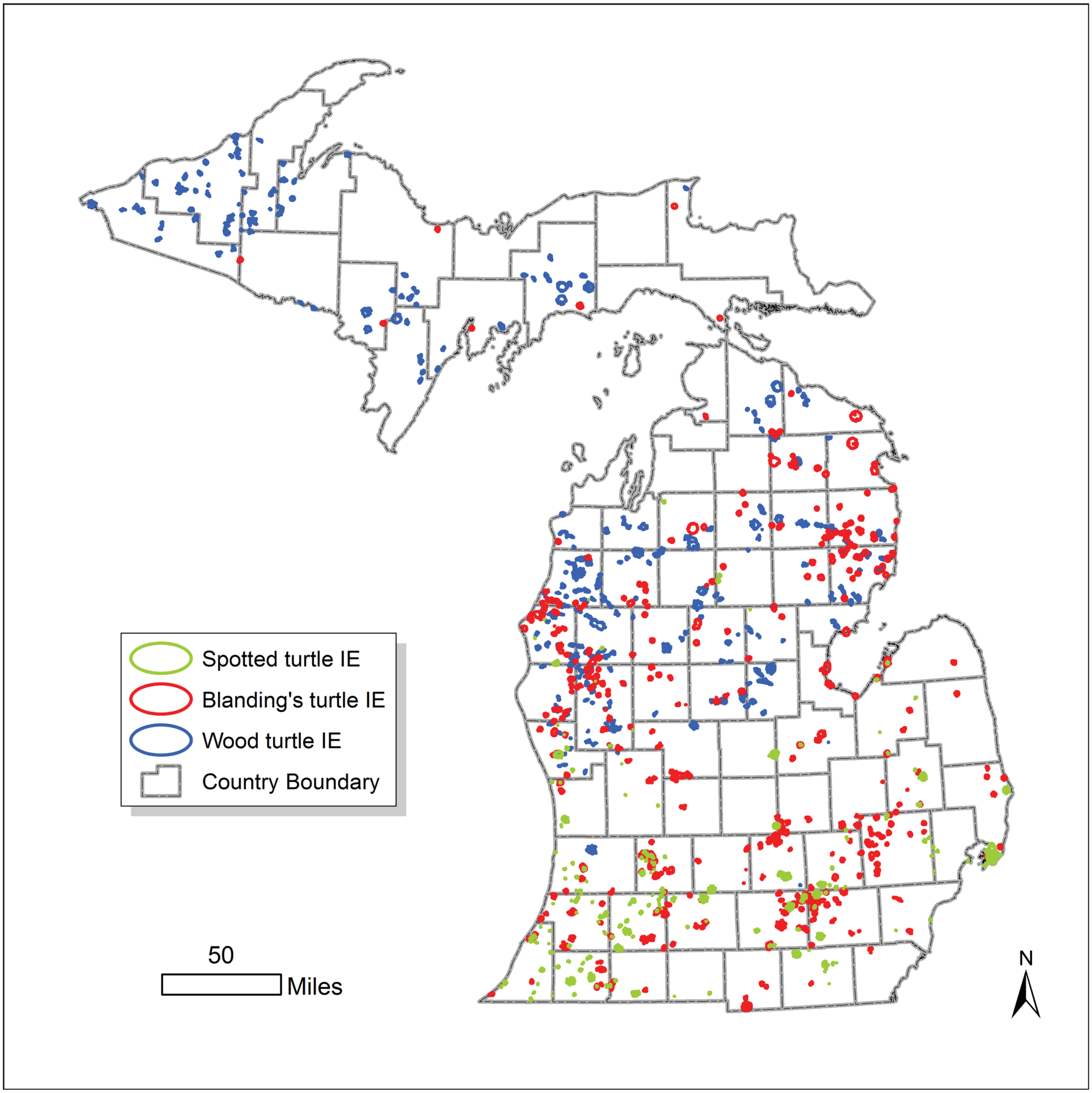

Figure 9. A map showing the inferred extent layers modeled for spotted turtle, Blanding's turtle and wood turtle in the Upper and Lower Peninsula of Michigan.

A map of the three turtle species' inferred extents for all of Michigan is shown in Figure 9. The range of Blanding's and wood turtle extends to both the Upper and Lower Peninsula, while spotted turtle is found in the Lower Peninsula only. A potential use of these data for maximizing management resources may be to find and prioritize coincident areas where all three turtles share habitat, such as the Muskegon State Game Area in Muskegon County (Figure 10).

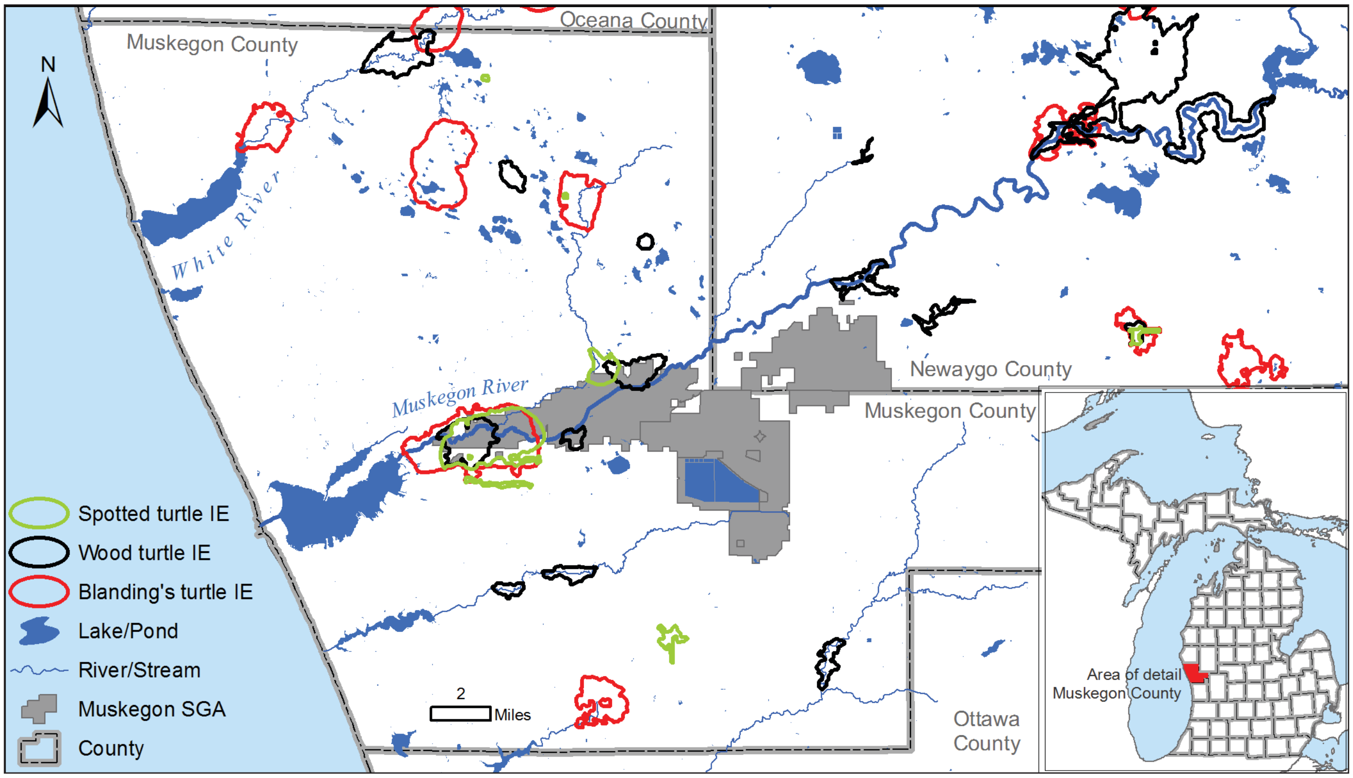

Figure 10. A map illustrating the inferred extent layers of the three turtle species in an area where they coincide on the Muskegon State Game Area on the Muskegon River.

Land Ownership

The IE layers produced in the Lower Peninsula were evaluated by land ownership category using the Conservation and Recreation Lands (CARL) layer (Ducks Unlimited 2008) (Table 5). Because both the Upper and Lower Peninsula served as the extent of the three turtle species' models, Table 6 lists the acreage by ownership class for their IE area separately. Comparing species by proportion of inferred extent area that is privately owned (Table 7) shows a wide range between Indiana bat (80% private) at maximum, to Kirtland's warbler (7% private) at the minimum. The majority of Kirtland's warbler observations come from surveys on state land, so there is clearly a survey bias effect, as well as the fact that habitat for Kirtland's warbler requires intensive management by state land managers. Northern long-eared bat IE proportion of area on private land (40%) may be reflecting the lack of survey effort on private land as well. Notable species with a high proportion of private land ownership include the Mitchell's satyr and the Poweshiek skipperling, both of which have seriously declined in number and sites in recent years. Protection of habitat for these species will require partnerships with private land owners or reintroduction of these species on public land.

Table 7. The proportion of inferred extent area on private land.

	% Private
Indiana bat	80%
Copperbelly water snake	80%
Mitchell's satyr	72%
Poweshiek skipperling	72%
Eastern massasauga (2 km)	62%
Blanding's turtle	60%
Spotted turtle	59%
Eastern massasauga (1 km)	58%
Wood turtle	58%
Karner blue + H	52%
Karner blue - H	48%
Piping plover	47%
Northern long-eared bat	40%
Kirtland's warbler	7%

Objectives

The 14 inferred extent layers for 12 animals will provide significant information for land acquisition prioritization, grant applications, impact assessment, and managing and conserving habitat. Historical aerial imagery in a location which is of acquisition interest (Wigwam Bay State Game Area) was also acquired, processed, and made available for interpretation. The historical imagery mosaic dataset (Digital Appendix 5) is provided, but its use and interpretation will be discussed via the MDNR WLD Land Acquisitions project.

Limitations and Future Work

The inferred extent modeling method accounts for known occupied habitat, however given the limited and biased sampling (survey effort tends to occur more often on public land, as well as closer to roads) in the state, potentially suitable habitat that has not been surveyed remains unaccounted for. Also, by relying on a single land cover classification at one point in time, error is possible through classification inaccuracies and potentially inappropriate temporal period. Finally, IE layers were requested for federally listed terrestrial animals the Lower Peninsula, however the range of piping plover and northern long-eared bat extends to the Upper Peninsula as well, so these models do not provide a complete picture of the species in Michigan.

It's important to point out that land cover class does not ensure high-quality or even suitable habitat. Local surveys of the modeled IE areas are necessary to ground truth the condition and quality of the habitat and to assess threats such as invasive species or pollution.

Assigning species habitat relationships for a large region like the Lower Peninsula can be problematic. Species habitat descriptions in the literature sometimes refer to a certain proximity distance or a minimum patch size. Wood turtle locations, for example, are characterized as virtually all within 150-300 of the large rivers/streams used by the turtles (Harding and Bloomer 1979, Arvisais et al. 2002). Remsberg et al. (2006) in Northern Michigan reported that of 955 turtle locations, 92.5% were within 200 m of the river. Parren (2013) in Vermont described a wood turtle friendly stream as "a large, low gradient stream (less than 1 degree slope)". When attempting to assign rules like these to a species habitat relationship for a State or large region as in this project, the rules don't often apply to all, or nearly all the actual data locations; e.g. of the 515 wood turtle locations for this project, only 366 of them were within 300 m of a large (3rd order or greater) river. Another example, Kirtland's warbler, has been described to require dense stands of 30 hectares or more (Mayfield 1960, 1993; Walkinshaw 1983). Using a 30 ha minimum patch size as a requirement for the Michigan data would result in about one third of the observations falling outside of habitat. Consequentally some generalization of the species habitat relationships defined for this project was necessary to fit the sample datasets.

Species distribution modeling (SDM) would be a valuable and substantial next step. Inferred extent modeling is restricted in usefulness, in that only locations where a species has been observed are modeled. An inductive, statistical modeling method, species distribution modeling (SDM) combines known species observation locations with a suite of environmental variables thought to be important for the species to predict habitat suitability across the range. SDMs quantify the correlation between environmental factors and the distribution of an animal or plant. This empirically derived 'environmental envelope' (not just land cover, but also data on topography, climate, soils, and geology) can be used to describe and measure the importance of specific factors and to predict species' distribution across unsampled areas (Elith and Leathwick 2009; Franklin 2010; Guisan and Thuiller 2005; Guisan and Zimmermann 2000). Methods to account for sampling bias have been confirmed (Barnhart and Gilliam 2014, Johnson and Gillingham 2008), and techniques such as crossvalidation and bootstrapping contribute to a robust accuracy assessment procedure.

With SDM, environmental change, such as climate change, and its ecological consequences can be examined, as well as predicting invasive species, modeling disease vectors, and identifying suitable areas for species re-introduction (Elith and Leathwick 2009, Engler et al. 2004, Peterson 2006). A species distribution model would deliver a greater latitude of applications for conservation decisions and contribute to the understanding of environmental factors that influence the suitability of habitat and the distribution of the species.

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Citations

Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 28 p.

Anthonsamy, W.J.B., M.J. Dreslik, and C.A. Phillips. 2013. Disruptive influences of drought on the activity of a freshwater turtle. Am. Midl. Nat. 169:322-332.

Arvisais, M., J.C. Bourgeois, E. Levesque, C. Daigle, D. Masse, and J. Jutras. 2002. Home range and movements of a wood turtle (*Clemmys insculpta*) population at the northern limits of its range. Canadian Journal of Zoology 80:402-408

Badra, P.J., D.L. Cuthrell, M.J. Monfils, J.P. Paskus, Y. Lee, and B.J. Klatt. 2014. Conservation Status Assessments of Michigan's Species of Greatest Conservation Need. Michigan Natural Features Inventory Report No. 2014-12. Report to the Michigan Dept. of Natural Resources, Wildlife Division, Lansing, MI. 29pp.

Barnhart, P.R. and E.H. Gilliam. 2014. The impact of sampling method on maximum entropy species distribution modeling for bats. Acta Chiropterologica, 16(1):241-248.

Cohen, J.G., D.L. Cuthrell, and H.D. Enander. 2014. Development of a Preliminary Focal Area Network for the Wildlife Action Plan. Michigan Natural Features Inventory Report Number 2014-26, Lansing, MI. 25 pp.

Congdon, J. D., D. W. Tinkle, G. L. Brettenbach, and R. C. van Loben Sels. 1983. Nesting ecology and hatching success in the turtle *Emydoidea blandingii*. Herpetologica 39(4):417-429.

Congdon J.D. and D.A.Keinath. 2006, July 20. Blanding's Turtle (*Emydoidea blandingii*): A technical conservation assessment. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5182075.pdf [Accessed 8/24/2016]. USDA Forest Service, Rocky Mountain Region.

Cuthrell, D.L. and B.S. Slaughter. 2012. Special animal abstract for *Oarisma poweshiek* (Poweshiek skipperling). Michigan Natural Features Inventory, Lansing, MI. 4 pp.

Cuthrell, D.L., M.J. Monfils, C.D. Pogue, and A.K. Monfils. 2015. Poweshiek Skipperling (*Oarisma poweshiek*) Surveys and Research in Michigan. Michigan Natural Features Inventory, Report No. 2015-04, Lansing, MI. 8 pp. + appendices

Ducks Unlimited. 2008. Conservation and Recreation Lands GIS Layer (CARL) for the Great Lakes. Great Lakes/Atlantic Region office. MI: Ann Arbor.

Elith, J. and J. Leathwick. 2009. Species distribution models: ecological explanation and prediction across space and time. Annual Review of Ecology, Evolution, and Systematics 40, pp. 677–697.

Engler, R., A. Guisan, and L. Rechsteiner. 2004. An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. Journal of Applied Ecology 41 (2), pp. 263–274.

Ennis, K. 2002. Kirtland's Warbler Recovery Team letter to the U.S. Fish and Wildlife Service dated January 12, 2002.

Ewert, M., D. Premo, J.H. Harding, and K. Premo. 1998. Wood turtles and their habitat in Michigan. Report by White Water Assoc., Inc. 11 pp. + cover.

Foster, R.W., and A. Kurta. 1999. Roosting ecology of the Northern Bat (*Myotis septentrionalis*) and comparisons with the endangered Indiana Bat (*Myotis sodalis*). Journal of Mammalogy 80(2):659-672.

Franklin, J. 2010. Mapping species distributions: spatial inference and prediction. Cambridge: Cambridge University Press.

Garner, J. D., and J. E. Gardner. 1992. Determination of summer distribution and habitat utilization of the Indiana bat (Myotis sodalis) in Illinois. Illinois Department of Conservation. Final Report, Project E-3. Springfield, IL, 23 pp.

Gibbons, J. W. 1968. Observations on the ecology and population dynamics of the Blanding's turtle *EMYDOIDEA BLANDINGII*. Canadian Journal of Zoology 46:288-290.

Guisan, A. and W. Thuiller. 2005. Predicting species distribution: offering more than simple habitat models. Ecology Letters 8, pp. 993–1009.

Guisan, A. and N. Zimmermann. 2000. Predictive habitat distribution models in ecology. Ecological

Modelling 135, pp. 147–186.

Harding, J.H. 1991. A twenty year wood turtle study in Michigan: Implications for conservation. In Beaman, K.R., F. Caporaso, S. McKeown, and M.D. Graff (eds.). Proceedings of the 1st International Symposium on Turtles and Tortoises: Conservation and Captive Husbandry - August 9-12, 1990. Chapman U., Orange, CA. pp. 31-35.

Harding, J. H. 1997. Amphibians and Reptiles of the Great Lakes region. The University of Michigan Press, Ann Arbor, MI. 378 pp.

Harding, J. H., and T. J. Bloomer. 1979. The Wood Turtle, Clemmys insculpta . . . a natural history. Bulletin of the New York Herpetological Society 15(1):9-26.

Humphrey, S.R., A.R. Richter and J.B. Cope. 1977. Summer habitat and ecology of the endangered Indiana bat. J. Mammal. 58:334-46.

Hyde, D.A. 1999. Special animal abstract for *Charadrius melodus* (piping plover). Michigan Natural Features Inventory, Lansing, MI. 4 pp.

Hyde, D. 2012. Update of Lee, Y. 2000. Special animal abstract for Mitchell's satyr butterfly (*Neonympha mitchellii mitchellii*). Michigan Natural Features Inventory, Lansing, MI. 7 pp.

Johnson, C.J. and M.P. Gillingham. 2008. Sensitivity of species-distribution models to error, bias, and model design: An application to resource selection functions for woodland caribou. Ecological Modelling 213:143-155.

Joyal, L. A., M. McCollough, and M. L. Hunter, Jr. 2001. Landscape ecology approaches to wetland species conservation: a case study of two turtle species in southern Maine. Conservation Biology 15:1755-1762.

Lee, Y. 1999a. Special animal abstract for *Emydoidea blandingii* (Blanding's turtle). Michigan Natural Features Inventory. Lansing, MI. 4 pp.

Lee, Y. 1999b. Special animal abstract for *Glyptemys insculpta* (wood turtle). Michigan Natural Features Inventory, Lansing, MI. 3 pp.

Lee, Y. 2000. Special animal abstract for *Clemmys guttata* (spotted turtle). Michigan Natural Features Inventory. Lansing, MI. 4 pp.

Lee, Y. 2010. Special animal abstract for *Nerodia erythrogaster neglecta* (Copperbelly Water Snake). Michigan Natural Features Inventory, Lansing, MI. 8 pp.

Lee, Y. and H. D. Enander. 2015. Developing an Eastern Massasauga Conservation Plan for Michigan – Phase I. Michigan Natural Features Inventory Report No. 2015-10, Lansing, MI. 51 pp.

Lee, Y. and H. D. Enander. 2016. Endangered Species Modelling and Analysis to Inform Michigan

Department of Transportation's Five-Year Transportation Plan. Michigan Natural Features Inventory Report No. 2016-16, Lansing, MI. 85 pp.

Lee 2013. Update of Lee, Y. and J. T. Legge. 2000. Special animal abstract for *Sistrurus catenatus catenatus* (Eastern massasauga). Michigan Natural Features Inventory, Lansing, MI. 8 pp.

Mayfield, H.F. 1960. The Kirtland's warbler. Cranbrook Institute of Sciences, Bloomfield Hills, MI 242 pp.

Mayfield 1993. Kirtland's warblers benefit from large forest tracts. Wilson Bulletin 105:351-353.

McCluskey, E. M. 2016. Landscape ecology approaches to Eastern Massasauga Rattlesnake conservation. PhD dissertation, Ohio State University. 128 pp.

Menzel, M. A., R. Odom, S. Owen, W. M. Ford, B. R. Chapman, K. V. Miller, J. Edwards, and P. Wood. 1999. Investigation of foraging habitat use by bats with a focus on Northern Long-eared Myotis (*Myotis septentrionalis*): a comparison of methods. IN M. K. Clark, editor. Abstracts from the 1999 Colloquium on the conservation of mammals in the Southeastern United States.

Menzel, M. A., S. F. Owen, W. M. Ford, J. W. Edwards, P. B. Wood, B. R. Chapman, and K. V. Miller. 2002. Roost tree selection by northern long-eared bat (*Myotis septentrionalis*) maternity colonies in an industrial forest of the central Appalachian Mountains. Forest Ecology and Management 155:107-114.

Michigan Natural Features Inventory. 2016. Michigan Natural Heritage Database. Lansing, MI.

Milam, J. C., and S. M. Melvin. 2001. Density, habitat use, movements, and conservation of spotted turtles (*Clemmys guttata*) in Massachusetts. Journal of Herpetology 35:418-427.

Monfils, M. J., and D. L. Cuthrell. 2015. Development and implementation of an occupancy survey for Karner blue butterflies. Michigan Natural Features Inventory, Report Number 2015-15, Lansing, USA.

NatureServe 2002. Element Occurrence Data Standard. Arlington, VA, 201 pp. http://help.natureserve.org/biotics/Content/Methodology/EO_DataStandard.pdf [Accessed 2016-02-19]

NatureServe, 2004. EO Specs: Separation Distance for Animals V. 1.0. Arlington, VA.

NatureServe, 2013. VISTA Decision Support Software for Land Use and Conservation Planning. User's Manual from Vista On-line Help version 3.0. http://www.natureserve.org/sites/default/files/vista_usermanual_102213_whole.pdf [Accessed 2016-07-07].

NatureServe. 2015. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1. NatureServe, Arlington, Virginia. Available http://explorer.natureserve.org. [Accessed: June 2, 2016].

NOAA Coastal Change Analysis Program (C-CAP) Regional Land Cover Database. 2013. Data collected 1995-present. Charleston, SC: National Oceanic and Atmospheric Administration (NOAA)

Office for Coastal Management. Data accessed at https://coast.noaa.gov/landcover.

NOAA C-CAP Regional Land Cover Classification Scheme. Online at https://coast.noaa.gov/data/digitalcoast/pdf/ccap-class-scheme-regional.pdf [accessed 6/2016].

Olson, J. A. 2002. Special animal abstract for *Dendroica kirtlandii* (Kirtland's warbler). Michigan Natural Features Inventory, Lansing, MI. 5 pp.

Parren, S.G. 2013. A Twenty-five year study of the Wood turtle (*Glyptemys insculpta*) in Vermont: Movements, Behavior, Injuries, and Death. Herpetological Conservation and Biology. 8(1):176-190.

Peterson, A. T. 2006. Ecological niche modeling and spatial patterns of disease transmission. Emerging Infectious Diseases 12 (12), pp. 1822–1826.

Piepgras, S. A., and J. W. Lang. 2000. Spatial ecology of Blanding's turtle in central Minnesota. Chelonian Conservation and Biology 3:589–601.

Quinn, N.W.S., and D.P. Tate. 1991. Seasonal movements and habitat of Wood Turtles (*Clemmys insculpta*) in Algonquin Park, Canada. Journal of Herpetology 25:217–220.

Rabe, M.L. 2001. Special animal abstract for *Lycaeides melissa samuelis* (Karner blue). Michigan Natural Features Inventory. Lansing, MI.6 pp.

Rabe, M.L. 2001b. Special animal abstract for *Myotis sodalis* (Indiana bat). Unpublished manuscript. Michigan Natural Features Inventory. Lansing, MI. 5 pp.

Refsnider, J.M. and M.H. Linck. 2012. Habitat use and movement patterns of Blanding's turtles (*Emydoidea blandingii*) in Minnesota, USA: A landscape approach to species conservation. Herpetological Conservation and Biology 7(2):185-195.

Rowe, J.W. 1987. Seasonal and daily activity in a population of Blanding's turtles (*Emydoidea blandingii*) in Northern Illinois. Unpubl. M.S. Thesis. Eastern Illinois Univ. Charleston. 86pp.

Sayre R., P. Comer, H. Warner and J. Cress. 2009. A new map of standardized terrestrial ecosystems of the conterminous United States: U.S. Geological Survey Professional Paper 1768, 17 p.

Sparks, D. W., C. M. Ritzi, J. E. Duchamp, and J. O. Whitaker, Jr. 2005. Foraging habitat of the Indiana bat (*Myotis sodalis*) at an urban-rural interface. Journal of Mammalogy 86:713-718.

Walkinshaw, L.H. 1983. Kirtland's warbler: The natural history of an endangered species. Cranbrook Institute of Science, Bloomfield Hills, MI. 207 pp.

Appendices

Appendix 1. The domain of EO rank in Heritage Methodology	
EO Rank	**Rank description**
A	Excellent estimated viability/ecological integrity
A?	Possibly excellent estimated viability/ecological integrity
AB	Excellent or good estimated viability/ecological integrity
AC	Excellent, good, or fair estimated viability/ecological integrity
B	Good estimated viability/ecological integrity
B?	Possibly good estimated viability/ecological integrity
BC	Good or fair estimated viability/ecological integrity
BD	Good, fair, or poor estimated viability/ecological integrity
C	Fair estimated viability/ecological integrity
C?	Possibly fair estimated viability/ecological integrity
CD	Fair or poor estimated viability/ecological integrity
D	Poor estimated viability/ecological integrity
D?	Possibly poor estimated viability/ecological integrity
E	Verified extant (viability/ecological integrity not assessed)
F	Failed to find
F?	Possibly failed to find
H	Historical
H?	Possibly historical
X	Extirpated
X?	Possibly extirpated
U	Unrankable
NR	Not ranked

Appendix 2. NOAA C-CAP Regional Land Cover Classification Scheme

Land cover class	Definition
Developed, High Intensity	Contains little or no vegetation. This subclass includes heavily built-up urban centers as well as large constructed surfaces in suburban and rural areas. Large buildings (such as multiple family housing, hangars, and large barns), interstate highways, and runways typically fall into this subclass. Impervious surfaces account for 80-100 percent of the total cover.
Developed, Medium Intensity	Contains substantial amounts of constructed surface mixed with substantial amounts of vegetated surface. Small buildings (such as single family housing, farm outbuildings, and large sheds), typically fall into this subclass. Impervious surfaces account for 50-79 percent of the total cover.
Developed, Low Intensity	Contains constructed surface mixed with vegetated surface. This class includes features seen class 3, with the addition of streets and roads with associated trees and grasses. Impervious surfaces account for 21-49 percent of the total cover.
Developed, Open Space	Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. This subclass includes parks, lawns, athletic fields, golf courses, and natural grasses occurring around airports and industrial sites. Impervious surfaces account for less than 20 percent of total cover.
Cultivated Crops	Includes herbaceous (cropland) and woody (e.g., orchards, nurseries, and vineyards) cultivated lands.
Pasture/Hay	Characterized by grasses, legumes or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops.
Grassland/ Herbaceous	Dominated by naturally occurring grasses and non-grasses (forbs) that are not fertilized, cut, tilled, or planted regularly.
Deciduous Forest	Includes areas dominated by single stemmed, woody vegetation unbranched 0.6 to 1 meter above the ground and having a height greater than 5 meters and cover more than 20% of land area. More than 75 percent of the tree species shed foliage simultaneous in response to seasonal change.
Evergreen Forest	Includes areas in which more than 67 percent of the trees remain green throughout the year. Both coniferous and broad-leaved evergreens are included in this category. Trees must be taller than 5 meters and more than 20% of the land cover.
Mixed Forest	Contains all forested areas in which both evergreen and deciduous trees are growing and neither predominate. Trees must be taller than 5 meters and more than 20% of the land cover.
Scrub/Shrub	Areas dominated by woody vegetation less than 5 meters in height. This class includes true shrubs,young trees, and trees or shrubs that are small or stunted because of environmental conditions. Includes both evergreen and deciduous scrub.
Palustrine Forested Wetland	Includes all non-tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 parts per thousand (ppt).
Palustrine Scrub/Shrub Wetland	Includes all non-tidal wetlands dominated by woody vegetation less than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 ppt.

Palustrine Emergent Wetland	Includes all non-tidal wetlands dominated by persistent emergents, emergent mosses, or lichens, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 ppt.
Palustrine Aquatic Bed	Includes wetlands and deepwater habitats dominated by plants that grow principally on or below the surface of the water for most of the growing season in most years. Salinity due to ocean-derived salts is below 0.5 ppt.
Unconsolidated Shore	Characterized by substrates lacking vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable. Erosion and deposition by waves and currents produce a number of landforms, such as beaches, bars, and flats, all of which are included in this class.
Bare Land	Composed of bare soil, rock, sand, silt, gravel, or other earthen material with little or no vegetation.
Open Water	Includes all areas of open water with less than 25 percent cover of vegetation or soil.

Appendix 3. Summary of cost weights by land cover class.

	Eastern massasauga	Piping plover	Copperbelly watersnake	Karner blue	Indiana Bat	Powesheik skipperling	Mitchell's satyr	Kirtland's warbler	Northern long-eared bat	Blanding's turtle	Spotted turtle	Wood turtle
Land cover class	Cost Weight	Cost Weight	Cost Weight	Cost Weight	Cost Weight	Cost Weight	Cost Weight	Cost Weight	Cost Weight	Cost Weight	Cost Weight	Cost Weight
Developed, High Intensity	NoData	NoData	NoData	NoData	NoData	NoData	NoData	NoData	NoData	NoData	NoData	NoData
Developed, Medium Intensity	NoData	NoData	NoData	NoData	NoData	NoData	NoData	NoData	NoData	NoData	NoData	NoData
Developed, Low Intensity	10	NoData	167	33	167	NoData	NoData	87	167	20	33	67
Developed, Open Space	10	NoData	NoData	NoData	167	NoData	NoData	87	167	20	33	67
Cultivated Crops	10	NoData	167	NoData	56	NoData	NoData	87	167	33	33	67
Pasture/Hay	10	NoData	167	33	56	33	33	87	167	33	33	67
Grassland/Herbaceous	3	50	5	1	56	10	33	1	167	1.3	4	7
Deciduous Forest	2	NoData	3	33	2	NoData	33	87	1*	2	17	7
Evergreen Forest	2	NoData	3	33	167	NoData	33	26	1*	2	17	7
Mixed Forest	2	NoData	3	33	10	NoData	33	26	1*	2	17	7
Scrub/Shrub	2	NoData	5	2	10	10	33	1	167	1.3	17	2
Palustrine Forested Wetland	1	NoData	1	NoData	1	NoData	17	NoData	1*	1.3	1	2
Palustrine Scrub/Shrub Wetland	1	25	1	NoData	1	1	1	NoData	167	1.3	1	2
Palustrine Emergent Wetland	1	25	1	NoData	10	1	1	NoData	167	1.3	1	4
Palustrine Aquatic Bed	1	25	1	NoData	10	1	1	NoData	167	1.3	1	4
Unconsolidated Shore	1	1	1	NoData	167	2	2	NoData	167	1.3	1	4
Bare Land	10	1	167	1	167	NoData	33	87	167	67	33	7
Open Water	10	50	167	NoData	5	33	10	87	167	1	1	1
Inferred extent (m)	***1000, 2000***	***1500***	***5000***	***1000***	***5000***	***1000***	***1000***	***2600***	***5000***	***2000***	***1000***	***2000***

* Forest restricted to a patch size of > one acre for northern long-eared bat.