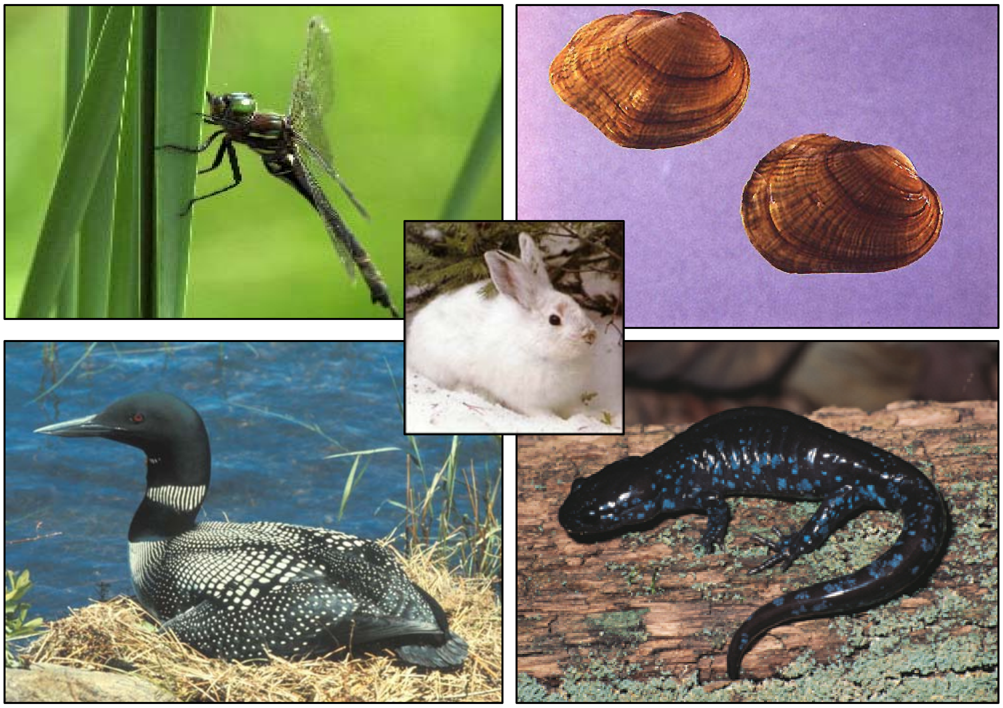
Climate Change Vulnerability Assessment of Natural Features in Michigan's Coastal Zone – Phase I: Assessing Rare Plants and Animals



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Cover photographs: Top left – Hine's emerald dragonfly, Photo by Carol Freeman
Top right – Northern riffleshell, Photo by USFWS,
Bottom left – Blue-spotted salamander
Bottom right – Common Loon, Photo by USFWS
Center – Snowshoe hare

Financial assistance for this project was provided, in part, by the Michigan Coastal Management Program (MCMP), Department of Environmental Quality (DEQ), through a grant from the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce. The statements, findings, conclusions, and recommendations provided in this report are those of the Michigan Natural Features Inventory and Michigan State University (MSU) and do not necessarily reflect the views of the DEQ and the NOAA.

EXECUTIVE SUMMARY

Michigan's coastal zone contains rare and ecologically significant natural communities including the globally unique freshwater dune systems, drowned river mouths, and coastal wetlands such as Great Lakes marshes and coastal fens. These and other natural communities in the coastal zone provide habitat for many rare and declining plants and animals, including several species found nowhere else on Earth. Predicted changes in climate will likely have profound effects on the disproportionally rich diversity of species and natural communities along Michigan's coastal zone. Recent climate change has been documented to cause many changes to ecological systems including range shifts, changes in abundance and phenology, disruption of ecological interrelationships, habitat loss and degradation, and extinction (Rosenzweig et al. 2007). Scientists, resource managers, planners, conservationists, and policymakers have emphasized the need to identify and implement strategies for adapting or dealing with impacts of climate change. Understanding which species and habitats are most vulnerable to climate change and why is key to developing effective adaptation strategies.

To assist in climate change adaptation efforts, the Michigan Natural Features Inventory (MNFI) in collaboration with the Michigan Coastal Management Program initiated a two-year project to assess the vulnerability of natural features in Michigan's coastal zone to climate change, focusing on rare plant and animal species and natural communities. This report summarizes the results of our vulnerability assessment of rare and declining plants and animals in Michigan's coastal zone. Based on information from the MNFI Natural Heritage Database and input from the MDNR Wildlife Division, we identified over 560 potential animal and plant species for the climate change vulnerability assessment. From these, we selected and assessed the vulnerability of a total of 157 species. These include 47 plants and 110 animals comprised of 10 amphibians, 23 birds, 12 fish, 18 insects, 12 mammals, 12 mussels, 12 reptiles, and 11 gastropods/snails (5 aquatic, 6 terrestrial). We used the Climate Change Vulnerability Index (CCVI) developed by NatureServe to assess the vulnerability of these species to climate change.

Overall, 116 (74%) of the 157 plant and animal species that we assessed were predicted to be vulnerable to climate change using the CCVI. Eighty of the 110 animal species and 36 of the 47 plant species that were assessed were predicted to be vulnerable. All amphibians, reptiles, and snails that were assessed were determined to be vulnerable. Fish, insects, and mussels also had over 70% of the species that were assessed rated as vulnerable. Much lower percentages of mammals and birds were ranked as vulnerable.

Several risk factors primarily caused or contributed to species vulnerability across all or most of the taxonomic groups. The main risk factor that was common across all animal plants was historical hydrological niche or exposure to past variations in precipitation across the species range within the assessment area. Physiological hydrological niche, natural barriers such as the Great Lakes, anthropogenic barriers, and dependence on a specific disturbance regime also contributed to species vulnerability. Additional vulnerability assessments and spatial analysis will be conducted during the second year of the project. Results from the vulnerability assessment will be used to help develop priorities and adaptation strategies for vulnerable species and systems.

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Introduction

Scientists, resource managers, planners, conservationists, and policymakers now recognize that climate change threatens biodiversity. They have emphasized the need to act and to identify and implement strategies for adapting or dealing with impacts of climate change. The MI-Great Lakes Plan, the Michigan Climate Action Plan, the Michigan Wildlife Action Plan (WAP), and the Association of Fish and Wildlife Agencies' Climate Change Committee have all recommended that Michigan incorporate climate change into planning and management efforts. To do this, further analyses are needed to identify, prepare for, and respond to the effects of climate change on natural resources including fish and wildlife and their habitats. Some species and habitats will be more vulnerable to climate change than others. Understanding which species and habitats are most vulnerable and why is key to developing effective adaptation strategies.

Climate change models predict dramatic changes in temperature and precipitation for the Great Lakes region in the coming century. The Great Lakes region, including Michigan, has already experienced the following changes in climate:

- Warmer temperatures - Temperatures in the northern Midwest increased by almost 4^{o}F (2^{o}C) during the 20th century (National Assessment Synthesis Team (NAST) 2000), and are projected to increase by 5 to 20^{o}F (3 to 11^{o}C) by the end of the current century according to some models (Kling et al. 2003). In Michigan, mean annual temperatures have increased by about 1^{o}F since 1895 (2^{o}F between 1980 and 2010), with increased temperatures particularly during the winter and at night (Andresen pers. comm.). Winters have been getting shorter, and spring has been arriving earlier (Kling et al. 2003, Andresen pers. comm.).
- Changes in the amount and timing of precipitation - The amount and seasonality of precipitation (i.e., rain and snow) are changing (NAST 2000, Kling et al. 2003), with predictions for more precipitation in the winter and spring and less during the height of the growing season (Kling et al. 2003). In Michigan, annual precipitation increased by 10-15% between 1895 and 2010, and precipitation was higher in all seasons (Andresen pers. comm.). Snowfall has increased in some places, primarily in areas that experience the lake effect, but has decreased in other places, typically further inland away from the lakes (Andresen pers. comm.).
- Increases in extreme weather events - The frequency of extreme heat and precipitation events has increased (NAST 2000, Kling et al. 2003, Andresen pers. comm.).
- The duration and extent of ice cover on the Great Lakes and inland lakes have decreased as air and water temperatures have increased (Kling et al. 2003, Dempsey et al. 2008).

Climate models predict these trends will likely continue and potentially accelerate during this century.

The effects of climate change will be particularly dramatic in the Great Lakes region along the shoreline or coastal zone. Most climate change models have predicted lower water levels in the Great Lakes due to higher summer air temperatures, reduced ice cover, and increased evaporation (Mortsch et al. 2000, NAST 2000, Kling et al. 2003, Field et al. 2007, Jensen et al. 2007). Great Lakes' water levels could drop from 1 to 5 ft (0.3 to 1.5 m) depending on the lake and climate change model (Lee et al. 1996, Lofgren et al. 2002, Dempsey et al. 2008). The impact of these declines on the shoreline could be dramatic. For example, because of its shallowness, Lake Erie's surface area could decrease by up to 15% by late this century, exposing nearly 1,500 square miles of additional land (US Environmental Protection Agency and Environment Canada 2006, Dempsey et al. 2008). However, one climate model suggests the potential for higher Great Lakes water levels in the future, although overall water level fluctuations are predicted to be within their normal range of variation (Lofgren et al. 2002). Increased evaporation and transpiration in a warmer climate, particularly in the summer (NAST 2000, Kling et al. 2003), also will likely affect shoreline, surface and groundwater levels, and decrease soil moisture as well (NAST 2000, Lofgren et al. 2002, Kling et al. 2003, Field et al. 2007).

Michigan's coastal zone is home to many rare and declining plants and animals, including several species found nowhere else on Earth. These include global endemics such as the Federal and state threatened Pitcher's thistle (*Cirsium pitcheri*), the Federal and state threatened dwarf lake iris (*Iris lacustris*), and the state threatened Lake Huron locust (*Trimerotropis huroniana*). Additional rare and declining species that occur along the shoreline include the Federal and state endangered Piping Plover (*Charadrius melodus*), the Federal candidate and state special concern Eastern Massasauga (*Sistrurus catenatus catenatus*), the Federal and state endangered Hine's emerald dragonfly (*Somatochlora hineana*), and the globally rare and state special concern Pleistocene catinella (*Catinella exile*) (i.e., a land snail known only from seven states and provinces globally and in Michigan only along the shoreline of Lakes Michigan and Huron). Habitats of particular interest in coastal areas include the globally unique freshwater dune systems, drowned river mouths, and coastal wetlands such as Great Lakes marshes and coastal fens. Over 25% of the documented natural features occurrences in Michigan's Natural Heritage Database occur within two miles of the shoreline (Michigan Natural Features Inventory 2011). Michigan's Wildlife Action Plan identifies 81 Species of Greatest Conservation Need (SGCN) and landscape features that are associated with the shoreline.

Predicted changes in climate will likely have profound effects on the disproportionally rich diversity of species and natural communities along Michigan's coastal zone, particularly those that are rare and declining and are already vulnerable or threatened due to other factors. Recent climate change has been documented to cause many changes to ecological systems. Future climate change will likely cause more range shifts, changes in abundance and phenology, disruption of ecological interrelationships, habitat loss and degradation, and extinction (Rosenzweig et al. 2007). Some species and habitats will be harmed by climate change, while others will be able to adapt and/or benefit from impacts of climate change. For example, coastal wetlands which provide critical habitat for migratory and breeding songbirds and waterfowl are expected to be significantly reduced due to climate change, at least in the short term (Price and Root 2000, Kling et al. 2003). Loss of wetlands would impact other wetland-dependent species such as frogs and salamanders. However, wetlands could increase over time as lake levels drop and new areas transition to wetlands (Kling et al. 2003). Non-native invasive species such as *Phragmites australis* could become more prevalent in coastal habitats (Wilcox et al. 2003). Species that have resistant or mobile life history stages and dune species may be able to better adapt to climate change.

Aquatic ecosystems of the Great Lakes region also are expected to be significantly impacted from climate changes. The ecosystem services, productivity, and biodiversity of aquatic systems will likely be altered by these impacts in a number of ways. These are summarized by Poff, Brinson, and Day (2002) and include the following expectations:

- Increases in water temperature will alter fundamental ecological processes and geographical distribution of aquatic species.
- Changes in seasonal patterns of precipitation and runoff will alter hydrologic characteristics of aquatic systems, affecting species composition and ecosystem productivity.
- Most specific ecological responses to climate change cannot be predicted, because new combinations of native and non-native species will interact in novel situations.
- Increases in water temperature and seasonally reduced stream flows will alter many ecosystem processes with potential direct society costs (e.g. warmer water increasing frequency and extent of nuisance algal blooms, reducing water quality and causing potential health problems).

The effect of climate change on the Great Lakes in particular may increase anoxic zones in the Great Lakes and inland lakes, interfere or eliminate lake turnover events, allow for greater expansion in the ranges of invasive species, such as zebra mussels (*Dreissena polymorpha)* and Asian carp, and increase algae growth, among other effects (Thorp et al. 1998, Hall and Stuntz 2007). Cold-water fish species such as lake trout, brook trout, and whitefish are expected to decline, while cool-water species such as muskie and walleye along with warm-water species such as bluegill and smallmouth bass may expand their ranges (Kling et al. 2003).

To assist in climate change adaptation efforts, the Michigan Natural Features Inventory (MNFI), in partnership with the Michigan Coastal Zone Management Program, Michigan Department of Natural Resources' (MDNR) Wildlife Division, NatureServe and The Nature Conservancy (TNC), initiated a two-year project to assess the vulnerability of natural features in Michigan's coastal zone to climate change. This project uses information from existing climate change models, natural features information and expertise at the MNFI, and climate change expertise and tools available through NatureServe and TNC. We addressed the following specific objectives during the first year of the project:

1) Identify and prioritize a subset of plant and animal species and natural communities associated with Michigan's coastal zone to assess for vulnerability to climate change, focusing on rare and declining species and natural communities, SGCN identified in Michigan's WAP, and species and communities that may be particularly vulnerable to climate change based on currently available information.

2) Assess the vulnerability of at least 150 select species to climate change by applying NatureServe's Climate Change Vulnerability Index.

3) Assess the vulnerability of natural communities found in Michigan's coastal zone to climate change by developing a general model or criteria for assessing vulnerability and using available climate change and natural community information and expertise.
4) Rank species and natural communities most vulnerable to climate change along Michigan's coastal zone. Determine which factors which most frequently contributed to high vulnerability scores based on vulnerability assessments conducted.

5) Share results broadly so that information and tools can be used and incorporated into climate change and other planning, management, conservation, and research efforts.

This report summarizes the results from the species vulnerability assessments conducted during the first year of the project. The natural community climate change vulnerability assessment is summarized in an accompanying report (see Kost and Lee 2011). Both these reports are meant to serve as preliminary assessments of the potential impacts of climate change on Michigan's species and natural communities.

A vulnerability assessment provides the scientific basis for developing climate adaptation strategies and helps managers anticipate how a species or system is likely to respond under the projected climate change conditions (Association of Fish and Wildlife Agencies [AFWA] 2009). Our assessment provides information on the relative vulnerability of species and natural communities occurring in Michigan's coastal zone and other parts of the state that may be most sensitive to predicted climate changes. This information can be used in conjunction with information on current status and threats to identify species and systems most in need of conservation actions due to climate change. Examining and identifying the key factors which contribute to vulnerability can provide insights and help tailor potential adaptation strategies for vulnerable species and habitats. The results from this project can be used to help develop and prioritize effective climate change adaptation strategies. Project results also will be shared with regional, state, and local conservation and planning efforts to foster collaboration and facilitate efficient use of resources.

Methods

Species Selection

For the species climate change vulnerability assessments, we focused primarily on rare and/or declining plant and animal species that are associated with Michigan's coastal zone. We identified potential species for the vulnerability assessment by querying the Michigan Natural Features Inventory's Natural Heritage Database for federally- and/or state-listed endangered, threatened, or special concern species that have been documented in the coastal zone. For this project, the coastal zone encompassed the area from the shoreline extending inland to the boundaries of the HUC 14 watersheds that occur along the shoreline. Species of Greatest Conservation Need (SGCN) identified in Michigan's Wildlife Action Plan (WAP) that are associated with Great Lakes coastal and nearshore habitats also were considered for the vulnerability assessment. Species were prioritized (i.e., High, Medium, Low) and selected for the vulnerability assessment based on the following factors: (1) their association with the coastal zone based on the species' ecology and association with coastal habitats or natural communities, and portion of the species' range or number of element occurrences in the coastal zone); (2) potential vulnerability to climate change based on the species' life history, ecology, and/or association with a natural community that is or may be vulnerable to climate change; and (3) amount of natural history and distribution information available on the species. For the plants, we augmented the species selected for this project with a set of species being similarly assessed as part of a concurrent, multi-state climate change project conducted with NatureServe. This project was part of a larger, multi-state, plants at-risk project to facilitate the incorporation of plants into State Wildlife Action Plans. This project primarily focused on globally critically imperiled to globally rare (G1-G3) plant species (see Appendix 1 for definition of codes). We also identified additional rare plant species associated with globally rare natural communities as well as ecologically significant and wide-ranging coastal community types for the assessment.

Species that are currently common in the state also may be vulnerable to climate change. We identified and included several common species within each taxonomic group in the vulnerability assessment. These included species that occur in Michigan's coastal zone and may be vulnerable to climate change based on their life history and ecology. These also included species that are of particular management interest (e.g., MDNR Wildlife Division Featured Species and invasive species).

Based on information from the MNFI Natural Heritage Database and input from the MDNR Wildlife Division, we identified over 560 potential animal and plant species for the climate change vulnerability assessment. From these, we selected and assessed the vulnerability of a total of 157 species. These include 47 plants and 110 animals comprised of 10 amphibians, 23 birds, 12 fish, 18 insects, 12 mammals, 12 mussels, 12 reptiles, and 11 gastropods/snails (5 aquatic, 6 terrestrial).

Climate Change Vulnerability Assessment

Vulnerability to climate change is the likelihood that climate-induced changes will have an adverse impact on a given species, habitat, or ecosystem (Glick et al. 2011). Vulnerability is a function of the ***sensitivity*** of a species or system to climate changes and ***exposure*** to those changes (Schneider et al. 2007, Williams et al. 2008). A species or system's ***capacity to adapt*** to climate changes also contributes to its vulnerability (Schneider et al. 2007, Williams et al. 2008). Sensitivity is a measure of whether and how a species or system is likely to be affected by a given change in climate (Schneider et al. 2007, Williams et al. 2008, Glick et al. 2011). Exposure is a measure of how much of a change in climate and associated impacts a species or system is likely to experience (Glick et al. 2011). Adaptive capacity refers to a species or system's ability to improve, minimize, or manage its sensitivity or exposure to climate changes (Williams et al. 2008, Glick et al. 2011).

We assessed the vulnerability of selected plant and animal species to climate change using the Climate Change Vulnerability Index (CCVI) recently developed by NatureServe (Young et al. 2011). The Climate Change Vulnerability Index provides a practical, easy-to-use tool for rapidly and scientifically assessing species vulnerability to climate change. The Index utilizes an Excel platform which allows users to enter numerical or categorical, weighted responses to a series of questions about risk factors related to a species exposure and sensitivity to climate change. The Index has been used in a number of states by a variety of agencies and organizations to conduct climate change vulnerability assessments including the natural resource departments and natural heritage programs in Nevada, West Virginia, Pennsylvania, New York, and Illinois (Byers and Norris 2011, Furedi et al. 2011, NatureServe 2011, Schlesinger et al. 2011). The Index is designed to complement, and not duplicate, information contained in the NatureServe conservation status ranks (Master et al. 2000l; see Appendix 1). Output from the Index should be used in conjunction with the conservation status ranks to identify priorities for adaptation efforts (Young et al. 2011). Output from the Index also may be used to update conservation status ranks to include the additional stressor of climate change (Byers and Norris 2011). Calculations were initially performed using the NatureServe CCVI version 2.01, with all results subsequently transferred to version 2.1 following its release in April 2011. The complete CCVI v2.1 tool and supporting guidance and documentation are available on NatureServe's website at the following link: http://www.natureserve.org/prodServices/climatechange/ccvi.jsp.

The Climate Change Vulnerability Index determines the vulnerability of a species to climate change by assessing its exposure to future projected climate change and its sensitivity to climate change. We provide a brief summary of the CCVI methods and data or issues specific to Michigan below (Table 1; Figure 1; Byers and Norris 2011, Furedi, et al. 2011. Schlesinger et al. 2011). Young et al. (2011) provides a more detailed summary and background on the Index.

Exposure to climate change is subdivided into direct exposure and indirect exposure (Table 1; Figure 1). Direct exposure is measured by examining the magnitude of predicted changes in temperature and moisture across the range of the species within the assessment area (Young et al. 2011). It is scored based on the percentage of the species' range within the assessment area that falls into categories of projected changes in temperature or moisture (Table 1; Figure 1). Projections for average annual temperature changes in Michigan for the year 2050 were downloaded from The Nature Conservancy's Climate Wizard (www.climatewizard.org) (Girvetz et al. 2009) and displayed in a GIS format (Figure 2). Projections for changes in moisture by 2050 were downloaded from NatureServe (Figure 2). These climate models or predictions represented a median of an ensemble of 16 global circulation models (GCMs) based on a "middle of the road" emissions scenario. Indirect exposure examines the species distribution relative to sea level rise, natural and anthropogenic barriers to dispersal, and new land uses aiming to mitigate climate change (Table 1).

Sensitivity to climate change is based on a variety of factors, including dispersal capability; past climate regime (Figure 3) and reliance on specific thermal and hydrological conditions; dependence on disturbance; dependence on snow or ice cover; restriction to certain geological types; reliance on interspecific interactions (e.g., herbivory and predator/prey relationships); genetic variation; and climate-related changes in phenology (Table 1). Each species is scored for each sensitivity factor from "decrease vulnerability" to "greatly increase vulnerability" (or a subset range of these categories), with three to six of these categories available for each factor (Figure 1). Some factors are optional, but certain numbers of factors in each group must be filled out to obtain a vulnerability score. Documented or modeled responses to climate change from the peer-reviewed literature are incorporated as a final factor (Table 1). These were rarely available for our selected species.

The assessment area, or area over which the species were assessed, was the entire state of Michigan. We had originally intended to use the coastal zone as the assessment area, but the available climate data or

models were not at a fine enough resolution or spatial scale to do this. We did focus our species selection on species that are strongly associated with the coastal zone which allowed us to apply or evaluate the risk factors mainly on the coastal zone. For the listed or special concern species, we utilized the MNFI Natural Heritage Database, MNFI species abstracts, MNFI Rare Species Explorer, NatureServe Explorer, and other relevant literature and references (e.g., Michigan Breeding Bird Atlas, Michigan Fish Atlas) for species range, distribution and life history information for the vulnerability assessment. For listed species with few or no element occurrences in the MNFI database and for common or non-listed species, we had to rely on the NatureServe Explorer and other references and published literature for distribution information (e.g., Baker 1983, Kurta 1995, Michigan Breeding Bird Atlas 1991, and Michigan Fish Atlas). These references also were consulted for general habitat and life history descriptions.
Ranges of terrestrial gastropod species in Michigan were obtained from Hubricht (1985) and occurrence records in the Natural Heritage Database. Additional taxa specific information for terrestial and aquatic gastropods, including habitat preferences, was obtained from published literature (Burch 1988, Burch and Jung 1988, Burch and Jung 1993, and Nekola 1998). Ranges of unionid mussels and aquatic gastropod species in Michigan were estimated using a GIS layer of occurrence records in the Natural Heritage Database. Species ranges or distributions were overlaid on the projected temperature and moisture maps/data layers and the historical precipitation variation data layer to rank the factors related to direct exposure and predicted sensitivity to temperature and moisture changes/niches. We also consulted with additional sources of information for the vulnerability assessment including webinars (e.g, S. Ludsin 2011), theses and dissertations.

The Index produces a climate change vulnerability score for each species along with a measure of confidence or uncertainty around the score. Young et al. (2011) provides a summary of how the vulnerability score is generated. Vulnerability scores, definitions, and abbreviations are provided below. Confidence scores range from low to very high (VH) (see Appendix 1).

- **Extremely Vulnerable (EV):** Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050.
- **Highly Vulnerable (HV):** Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050.
- **Moderately Vulnerable (MV):** Abundance and/or range extent within geographical area assessed likely to decrease by 2050.
- **Not Vulnerable/Presumed Stable (PS):** Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change.
- **Not Vulnerable/Increase Likely (IL):** Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050.
- **Insufficient Evidence (IE):** Available information about a species' vulnerability is inadequate to calculate an Index score.

Table 1. Variables or factors assessed in the Climate Change Vulnerability Index (from Byers and Norris 2011). See Young et al. (2011) for more details.

Direct exposure

- Temperature change: predicted change in annual temperature by 2050, calculated over the range of the species in Michigan, ranged from 4.5 to >5.5°F increase.
- Moisture change: predicted net change in moisture based on the Hamon AET:PET Moisture Metric, calculated over the range of the species in Michigan, net drying ranging from -0.028 to -0.096.

Indirect Exposure

- Exposure to sea level rise: not a factor in Michigan.
- Distribution relative to natural and anthropogenic barriers: The geographical features of the landscape where a species occurs may naturally restrict it from dispersing to inhabit new areas. Similarly, dispersal may be hindered by intervening anthropogenically altered landscapes such as urban or agricultural areas for terrestrial species and dams or culverts for aquatic species. The Great Lakes was a natural barrier for some species.
- Predicted impact of land use changes resulting from human responses to climate change: strategies designed to mitigate greenhouse gases, such as creating large wind farms, plowing new cropland for biofuel production, or planting trees as carbon sinks, have the potential to affect large tracts of land and the species that use these areas in both positive and negative ways.

Sensitivity

- Dispersal and movements: Species with poor dispersal abilities may not be able to track shifting favorable climate envelopes.
- Predicted sensitivity to temperature and moisture changes: Species requiring specific moisture and temperature regimes may be less likely to find similar areas as climates change and previously-associated temperature and precipitation patterns uncouple.
    - Predicted sensitivity to changes in temperature, based on current/recent past temperature tolerance.
        - Historic thermal niche: exposure to past variations in temperature.
        - Current physiological thermal niche
    - Predicted sensitivity to changes in precipitation, hydrology, or moisture regime.
        - Historical hydrological niche: exposure to past variations in precipitation.
        - Current physiological hydrologic niche.
    - Dependence on a specific disturbance regime likely to be impacted by climate change: Species dependent on habitats such as longleaf pine forests, floodplain forests, and riparian corridors that are maintained by regular disturbances (*e.g.*, fires or flooding) are vulnerable to changes in the frequency and intensity of these disturbances caused by climate change.
    - Dependence on ice, ice-edge, or snow-cover habitats: the extent of oceanic ice sheets and mountain snow fields are decreasing as temperatures increase, imperiling species dependent on these habitats.
- Restriction to uncommon geological features or derivatives: species requiring specific substrates, soils, or physical features such as caves, cliffs, or sand dunes may become vulnerable to climate change if their favored climate conditions shift to areas without these physical elements.
- Reliance on interspecific interactions: because species will react idiosyncratically to climate change, those with tight relationships with other species may be threatened.
    - Dependence on other species to generate habitat.
    - Dietary versatility (animals only).

    - Pollinator versatility (plants only).
    - Dependence on other species for propagule dispersal.
    - Forms part of an interspecific interaction not covered above.
- Genetic factors: a species' ability to evolve adaptations to environmental conditions brought about by climate change is largely dependent on its existing genetic variation.
    - Measured genetic variation.
    - Occurrence of bottlenecks in recent evolutionary history.
- Phenological response to changing seasonal temperature and precipitation dynamics. Recent research suggests that some phylogenetic groups are declining due to lack of response to changing annual temperature dynamics (*e.g.*, earlier onset of spring, longer growing season), including some bird species that have not advanced their migration times, and some temperate zone plants that are not moving their flowering times.

<u>Documented or Modeled Response to Climate Change (optional, if available)</u>

- Documented response to recent climate change: Although conclusively linking species declines to climate change is difficult, convincing evidence relating declines to recent climate patterns has begun to accumulate in a variety of species groups. This criterion incorporates the results of these studies when available. Rarely used for assessment.
- Modeled future change in range or population size: The change in area of the predicted future range relative to the current range is a useful indicator of vulnerability to climate change.
- Overlap of modeled future range with current range. A spatially disjunct predicted future range indicates that the species will need to disperse in order to occupy the newly favored area, and geographical barriers or slow dispersal rates could prevent the species from getting there.
- Occurrence of protected areas in modeled future distribution. For many species, future ranges may fall entirely outside of protected areas and therefore compromise their long-term viability.

The NatureServe Climate Change Vulnerability Index

Release 2.1 *7 April 2011; Bruce Young, Elizabeth Byers, Kelly Gravuer, Kim Hall, Geoff Hammerson, Alan Redder*

With input from: *Jay Cordeiro, Kristin Szabo*

Funding for Release 2.0 generously provided by the Duke Energy Corporation.

NatureServe

** = Required field*

Geographic Area Assessed: Michigan *

Assessor: Yu Man Lee

Species Scientific Name: Lithobates pipiens * **English Name:** Northern Leopard Frog

Major Taxonomic Group: Amphibian *

G-Rank: G5

S-Rank: S5

Relation of Species' Range to Assessment Area: Center of range *

Check if species is an obligate of caves or groundwater aquatic systems: *(Must be marked with an "X" for accurate scoring of these species.)*

Assessment Notes (to document special methods and data sources)

NatureServe Explorer, Harding 1997. Increased flooding could potentially increase habitat for species.

Section A: Exposure to Local Climate Change *(Calculate for species' range within assessment area)*

Temperature *

Severity	**Scope** (percent of range)
>5.5° F (3.1° C) warmer	2
5.1-5.5° F (2.8-3.1° C) warmer	97
4.5-5.0° F (2.5-2.7° C) warmer	1
3.9-4.4° F (2.2-2.4° C) warmer	
< 3.9° F (2.2° C) warmer	
Total:	100 *(Must sum to 100)*

Hamon AET:PET Moisture Metric *

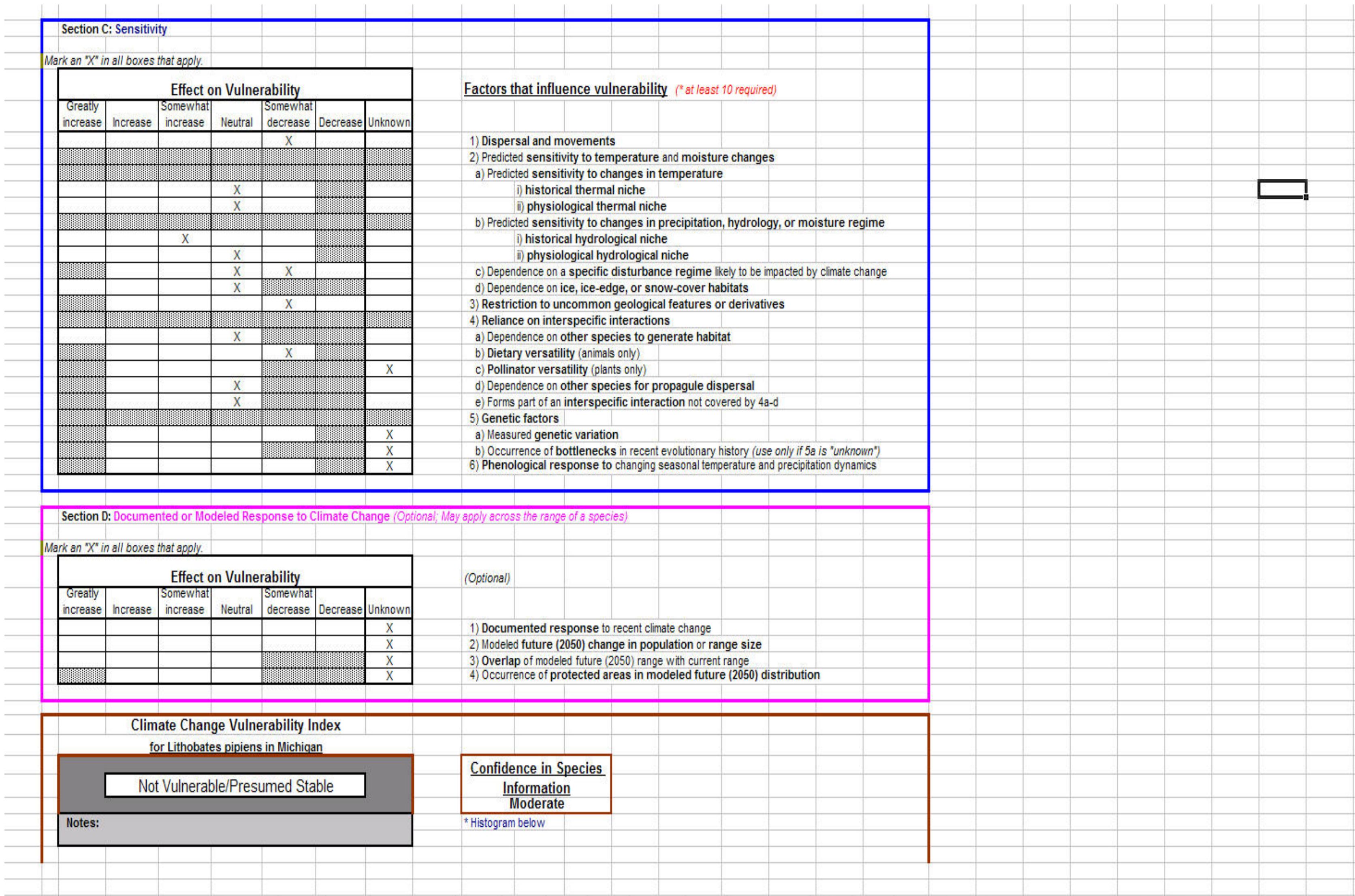
Severity	**Scope** (percent of range)
< -0.119	
-0.097 - -0.119	
-0.074 - -0.096	37
-0.051 - -0.073	46
-0.028 - -0.050	17
>-0.028	
Total:	100 *(Must sum to 100)*

Section B: Indirect Exposure to Climate Change *(Evaluate for specific geographical area under consideration)*

Mark an "X" in all boxes that apply.

Greatly increase	Increase	Somewhat increase	Neutral	Somewhat decrease	Decrease	Unknown	**Factors that influence vulnerability** *(* at least three required)*
			X				1) Exposure to **sea level rise**
							2) Distribution relative to **barriers**
		X					a) **Natural barriers**
		X	X				b) **Anthropogenic barriers**
			X				3) Predicted **impact of land use changes resulting from human responses** to climate change

Figure 1. A screen shot of the Climate Change Vulnerability Index form.



Section C: Sensitivity

Mark an "X" in all boxes that apply.

Factors that influence vulnerability *(* at least 10 required)*

Greatly increase	Increase	Somewhat increase	Neutral	Somewhat decrease	Decrease	Unknown	Factors that influence vulnerability
				X			1) **Dispersal and movements**
							2) Predicted **sensitivity to temperature** and **moisture changes**
							a) Predicted **sensitivity to changes in temperature**
			X				i) **historical thermal niche**
			X				ii) **physiological thermal niche**
							b) Predicted **sensitivity to changes in precipitation, hydrology, or moisture regime**
		X					i) **historical hydrological niche**
			X				ii) **physiological hydrological niche**
			X	X			c) Dependence on a **specific disturbance regime** likely to be impacted by climate change
			X				d) Dependence on **ice, ice-edge, or snow-cover habitats**
				X			3) **Restriction to uncommon geological features or derivatives**
							4) **Reliance on interspecific interactions**
			X				a) Dependence on **other species to generate habitat**
				X			b) **Dietary versatility** (animals only)
						X	c) **Pollinator versatility** (plants only)
			X				d) Dependence on **other species for propagule dispersal**
			X				e) Forms part of an **interspecific interaction** not covered by 4a-d
							5) **Genetic factors**
						X	a) Measured **genetic variation**
						X	b) Occurrence of **bottlenecks** in recent evolutionary history *(use only if 5a is "unknown")*
						X	6) **Phenological response to** changing seasonal temperature and precipitation dynamics

Section D: Documented or Modeled Response to Climate Change *(Optional; May apply across the range of a species)*

Mark an "X" in all boxes that apply.

(Optional)

Greatly increase	Increase	Somewhat increase	Neutral	Somewhat decrease	Decrease	Unknown	
						X	1) **Documented response** to recent climate change
						X	2) Modeled **future (2050) change in population** or **range size**
						X	3) **Overlap** of modeled future (2050) range with current range
						X	4) Occurrence of **protected areas in modeled future (2050) distribution**

Climate Change Vulnerability Index

for Lithobates pipiens in Michigan

Not Vulnerable/Presumed Stable

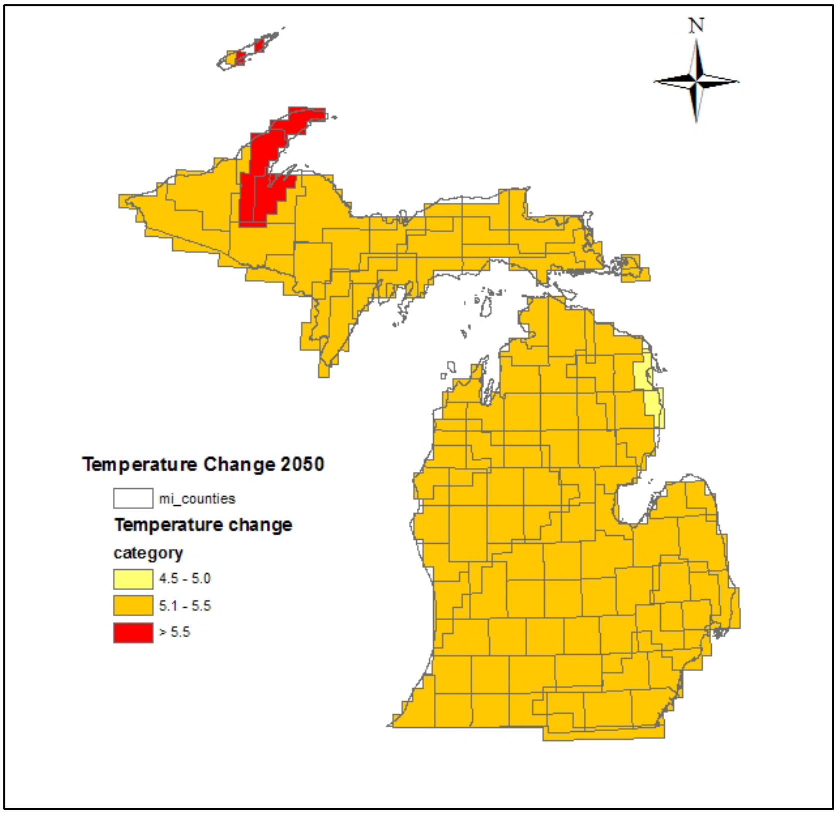
Notes:

Confidence in Species Information

Moderate

* Histogram below

Figure 1. A screen shot of the Climate Change Vulnerability Index form (continued).



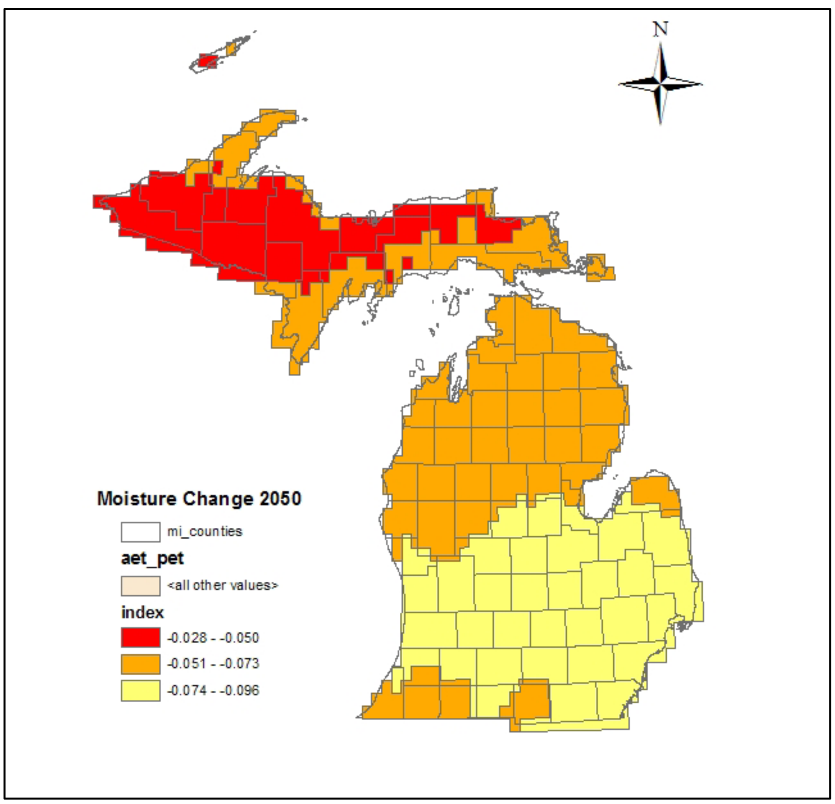


Figure 2. (Top) Projected temperature increase for Michigan by 2050, increasing from yellow (4.5°F) to red (>5.5°F). (Bottom) Projected decreases in moisture availability for Michigan by 2050, from yellow (most drying, -0.074 - -0.096) to red (least drying, -0.028 - -0.050). Data from www.climatewizard.org and www.natureserve.org

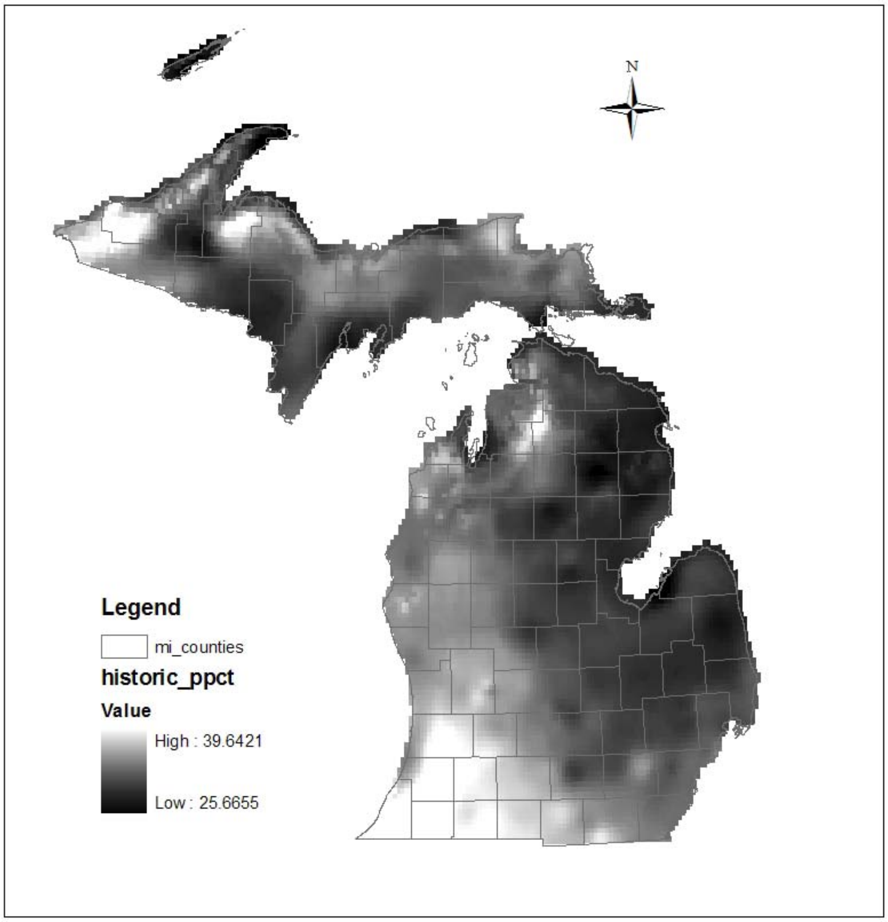


Figure 3. Climate regime in Michigan over the past 50 years: historical precipitation shown here (increasing precipitation from black to white, units in inches). Historical temperature variation not shown here because was the same for most of the state (57.1 – 77°F). Data from www.climatewizard.org.

Results

Animals

Eighty (73%) of the 110 animal species assessed were determined to be vulnerable (Extremely Vulnerable (EV), Highly Vulnerable (HV), or Moderately Vulnerable (MV)) to climate change (Figure 4). Assessment scores for all the species are provided in Appendices 2, 3 and 4. One species, the round hickorynut (mussel) (*Obovaria subrotunda*) was determined to have "Insufficient Evidence" for assessing vulnerability because of a lack of information (host fish are not known).

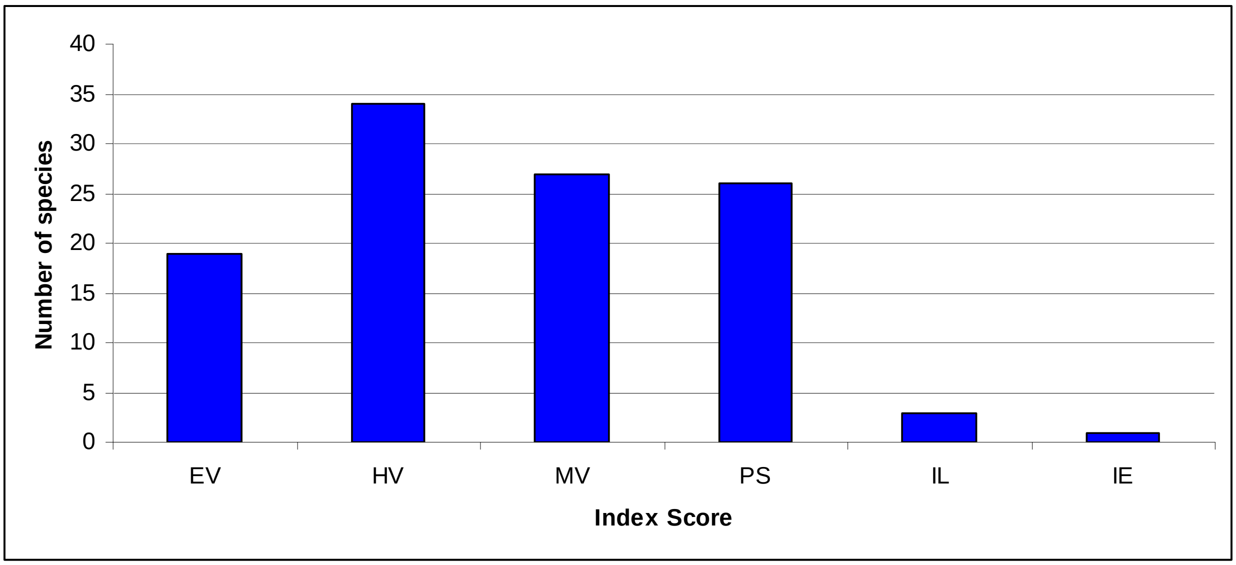


Figure 4. Number of animal species in each category of vulnerability. See page 7 for index abbreviations.

Species rated as "Extremely Vulnerable" or "Highly Vulnerable"

Nineteen species were rated as "Extremely Vulnerable" (Table 2) and 34 species as "Highly Vulnerable" (Table 3). All but three or four of the species rated as "Extremely Vulnerable" are very rare and listed as endangered or threatened at the state level, and have highly restricted or limited distributions in the state (i.e., state ranks of S1 or S2). Most of these species also are aquatic or are associated with aquatic and seasonally wet habitats. The same trend holds true for the most part for the species rated as "Highly Vulnerable." Twenty (59%) of the 34 species rated as "Highly Vulnerable" have state ranks of S1 or S2. Many of the "Highly Vulnerable" species also are aquatic or are closely associated with aquatic or seasonal wet habitats.

Table 2. Species assessed as "Extremely Vulnerable" across taxonomic groups. Codes are defined in Appendix 1.

Taxonomic Group	Scientific Name	Common Name	Global Rank	State Rank	State Listing	US Listing
Amphibian	*Acris crepitans blanchardi/ Acris blanchardi*	Blanchard's cricket frog	G5	S2S3	T	
Amphibian	*Amybstoma laterale*	Blue-spotted salamander	G5	S5		
Amphibian	*Amybstoma texanum*	Smallmouth salamander	G5	S1	E	
Amphibian	*Hemidactylium scutatum*	Four-toed salamander	G5	S5		
Amphibian	*Lithobates sylvaticus*	Wood frog	G5	S5		
Amphibian	*Pseudacris maculata*	Boreal chorus frog	G5	S1	SC	
Fish	*Clinostomus elongatus*	Redside dace	G3G4	S1S2	E	
Fish	*Noturus stigmosus*	Northern madtom	G3	S1	E	
Insect	*Neonympha mitchellii mitchellii*	Mitchell's satyr	G2T2	S1	E	LE
Insect	*Somatochlora hineana*	Hine's emerald dragonfly	G2G3	S1	E	LE
Mussel	*Alasmidonta viridis*	Slippershell	G4G5	S2S3	T	
Mussel	*Epioblasma torulosa rangiana*	Northern riffleshell	G2T2	S1	E	LE
Mussel	*Obliquaria reflexa*	Threehorn wartyback	G5	SNR	E	
Mussel	*Pleurobema clava*	Northern clubshell	G1G2	S1	E	LE
Mussel	*Simpsonaias ambigua*	Salamander mussel	G3	S1	E	C
Snail	*Fontigens nickliniana*	Watercress snail	G5	SU	SC	
Snail	*Gastrocopta holzingeri*	Lambda snaggletooth	G5	S1	E	
Snail	*Hendersonia occulta*	Cherrystone drop	G4	S1	T	
Snail	*Vertigo nylanderi*	Deep-throat vertigo	G3G4	S1	E	

Table 3. Species assessed as "Highly Vulnerable." Codes are defined in Appendix 1.

Taxonomic Group	Scientific Name	Common Name	Global Rank	State Rank	State Listing	US Listing
Amphibian	*Lithobates pipiens*	Northern leopard frog	G5	S5		
Amphibian	*Plethodon cinereus*	Redback salamander	G5	S5		
Bird	*Gavia immer*	Common loon	G5	S3S4	T	
Fish	*Acipenser fulvescens*	Lake sturgeon	G3G4	S2	T	
Fish	*Lepisosteus oculatus*	Spotted gar	G5	S2S3	SC	
Fish	*Notropis anogenus*	Pugnose shiner	G3	S3	E	
Fish	*Notropis photogenis*	Silver shiner	G5	S1	E	
Fish	*Opsopoeodus emiliae*	Pugnose minnow	G5	S1	E	
Fish	*Percina copelandi*	Channel darter	G4	S1S2	E	
Fish	*Sander canadensis*	Sauger	G5	S1	T	
Insect	*Boloria freija*	Freija fritillary	G5	S3S4	SC	
Insect	*Boloria frigga*	Frigga fritillary	G5	S3S4	SC	
Insect	*Brychius hungerfordi*	Hungerford's crawling water beetle	G1	S1	E	LE
Insect	*Calephelis mutica*	Swamp metalmark	G3	S1S2	SC	
Insect	*Dorydiella kansana*	Leafhopper	GNR	S1S2	SC	
Insect	*Lycaeides idas nabokovi*	Northern blue	G5TU	S2	T	
Insect	*Lycaeides melissa samuelis*	Karner blue	G5T2	S2	T	
Mammal	*Alces americanus*	Moose	G5	S4	SC	
Mammal	*Lepus americanus*	Snowshoe hare	G5	S5		
Mammal	*Lynx canadensis*	Lynx	G5	S1		
Mammal	*Sorex fumeus*	Smoky shrew	G5	S1	T	
Mussel	*Epioblasma triquetra*	Snuffbox	G3	S1	E	C*
Mussel	*Lasmigona compressa*	Creek heelsplitter	G5	SNR		
Mussel	*Obovaria olivaria*	Hickorynut	G4	S2	E	
Mussel	*Villosa fabalis*	Rayed bean	G2	S1	E	C*
Reptile	*Diadophis punctatus edwardsii*	Northern ring-necked snake	G5	S5		
Reptile	*Emydoidea blandingii*	Blanding's turtle	G4	S3	SC	
Reptile	*Pantherophis gloydi*	Eastern fox snake	G3	S2	T	
Reptile	*Sistrurus catenatus catenatus*	Eastern massasauga	G3G4 T3Q	S3S4	SC	C
Snail	*Mesodon elevatus*	Proud globe	G5	SU	T	
Snail	*Pomatiopsis cincinnatiensis*	Brown walker	G4	SU	SC	
Snail	*Stagnicola contracta*	Deepwater pondsnail	G1	S1	E	
Snail	*Vallonia gracilicosta albula*	terrestrial snail	G4Q	S1	E	
Snail	*Vertigo bollesiana*	Delicate vertigo	G4	S2	T	

*Species were listed as Federally Endangered, effective March 15, 2012 (Federal Rule FWS–R3–ES–2010–0019).

Species rated as "Moderately Vulnerable"

Twenty-seven (25%) of the 110 animal species that were assessed were determined to be "Moderately Vulnerable" to climate change (Table 4).

Table 4. Species assessed as "Moderately Vulnerable." Codes are defined in Appendix 1.

Taxonomic Group	Scientific Name	Common Name	Global Rank	State Rank	State Listing	US Listing
Amphibian	*Anaxyrus fowleri/ Bufo fowleri*	Fowler's toad	G5	S5		
Amphibian	*Necturus maculosus*	Mudpuppy	G5	S5		
Bird	*Botaurus lentiginosus*	American bittern	G4	S3S4	SC	
Bird	*Charadrius melodus*	Piping plover	G3	S1	E	LE
Bird	*Chilodonias niger*	Black tern	G4	S3	SC	
Bird	*Coturnicops noveboracensis*	Yellow rail	G4	S1S2	T	
Bird	*Falco columbarius*	Merlin	G5	S1S2	T	
Bird	*Ixobrychus exilis*	Least bittern	G5	S2	T	
Bird	*Sterna forsteri*	Forster's tern	G5	S2	T	
Bird	*Sternia caspia*	Caspian tern	G5	S2	T	
Bird	*Sternia hirundo*	Common tern	G5	S2	T	
Fish	*Coregonus artedi*	Lake herring	G5	S3	T	
Fish	*Esox americanus*	Grass pickerel (redfin pickerel)	G5	S5		
Insect	*Appalachia arcana*	Secretive locust	G2G3	S2S3	SC	
Insect	*Erebia discoidalis*	Red-disked alpine	G5	S2S3	SC	
Insect	*Papaipema aweme*	Aweme borer	G1	SH	SC	
Insect	*Somatochlora incurvata*	Incurvate emerald	G4	S1S2	SC	
Insect	*Trimerotropis huroniana*	Lake Huron locust	G2G3	S2S3	T	
Mammal	*Martes americana*	American marten	G5	S3		
Mussel	*Ligumia nasuta*	Eastern pondmussel	G4	SNR		
Reptile	*Clemmys guttata*	Spotted turtle	G5	S2	T	
Reptile	*Clonophis kirtlandi*	Kirtland's snake	G2	S1	E	
Reptile	*Glyptemys insculpta*	Wood turtle	G3	S2S3	SC	
Reptile	*Heterodon platirhinos*	Eastern hognose snake	G5	S3S4		
Reptile	*Terrapene carolina carolina*	Eastern box turtle	G5	S2S3	SC	
Snail	*Helisoma anceps*	Two-ridge rams-horn	G5	SU		
Snail	*Potamopyrgus antipodarum**	New Zealand mudsnail*	G5	SU		

*This species was run as a hypothetical resident of the assessment area. It has not been documented in Michigan but is present in the Great Lakes.

Species rated as "Presumed Stable" or "Increase Likely"

Twenty-six species (24%) were rated as "Presumed Stable" and three species were rated as "Increase Likely." Many of these species have either wide or large ranges or distributions in the state and/or are associated with more open, early successional wetland and upland habitats.

Table 5. **Species assessed as "Presumed Stable", "Increase Likely" or "Insufficient Evidence." Codes are defined in Appendix 1.**

Taxonomic Group	Scientific Name	Common Name	Global Rank	State Rank	State Listing	US Listing
Presumed Stable						
Bird	*Ammodramus savannarum*	Grasshopper sparrow	G5	S3S4	SC	
Bird	*Ardea herodias*	Great blue heron	G5	S5		
Bird	*Buteo lineatus*	Red-shouldered hawk	G5	S3S4	T	
Bird	*Cistothorus palustris*	Marsh wren	G5	S3S4	SC	
Bird	*Haliaeetus leucocephalis*	Bald eagle	G5	S4	SC	
Bird	*Meleagris gallopavo*	Wild turkey	G5	S5		
Bird	*Nycticorax nycticorax*	Black-crowned night-heron	G5	S2S3	SC	
Bird	*Pandion haliaetus*	Osprey	G5	S4	SC	
Bird	*Phasianus colchicus*	Ring-necked pheasant	G5	SNA		
Bird	*Rallus elegans*	King rail	G4	S1	E	
Bird	*Tympanuchus phasianellus*	Sharp-tailed grouse	G4	S3S4	SC	
Fish	*Hypopthalmichthys nobilis*	Big head carp	G5	SNA		
Insect	*Euxoa aurulenta*	Dune cutworm	G5	S1S2	SC	
Insect	*Flexamia delongi*	Leafhopper	GNR	S1S2	SC	
Insect	*Flexamia reflexus*	Leafhopper	GNR	S1	SC	
Mammal	*Canis lupus*	Gray wolf	G4	S3	T	LE
Mammal	*Microtus orchrogaster*	Prairie vole	G5	S1	E	
Mammal	*Microtus pinetorum*	Woodland vole	G5	S3S4	SC	
Mammal	*Myotis sodalis*	Indiana bat	G2	S1	E	
Mammal	*Nycticeius humeralis*	Evening bat	G5	SNR	T	
Mammal	*Odocoileus virginianus*	White-tailed deer	G5	S5		
Mammal	*Ursus americanus*	Black bear	G5	S5		
Mussel	*Dreissena polymorpha*	Zebra mussel	G5	SNA		
Reptile	*Chelydra serpentina serpentina*	Snapping turtle	G5	S5		
Reptile	*Chrysemys picta*	Painted turtle	G5	S5		
Reptile	*Pantherophis spiloides*	Gray ratsnake	G5T5	S3	SC	

Increase Likely/Insufficient Evidence						
Bird	*Dendroica discolor*	Prairie warbler	G5	S1	E	
Bird	*Dendroica kirtlandii*	Kirtland's warbler	G1	S1	E	LE
Insect	*Aeshna canadensis*	Canada darner	G5	SNR		
Mussel*	*Obovaria subrotunda**	Round hickorynut*	G4	S1	E	

*This species had insufficient evidence because its host fish are not known.

Taxonomic groups and vulnerability

Some taxonomic groups were assessed as more vulnerable to climate change than others (Figure 5). All amphibians, reptiles, and snails were determined to be vulnerable (EV, HV, MV), and fish, insects, and mussels also had over 70% of the species rated as vulnerable. Much lower percentages of mammals and birds were rated as vulnerable. Taxonomic groups that generally contain species with lower dispersal/movement capabilities and/or were closely associated with aquatic or wet habitats, especially seasonally wet habitats, appear to be more vulnerable. For example, amphibians are closely associated with aquatic, wet, or moist habitats and also generally have lower dispersal distances compared to birds, mammals, and even some insects which have longer dispersal distances and can fly or travel around barriers.

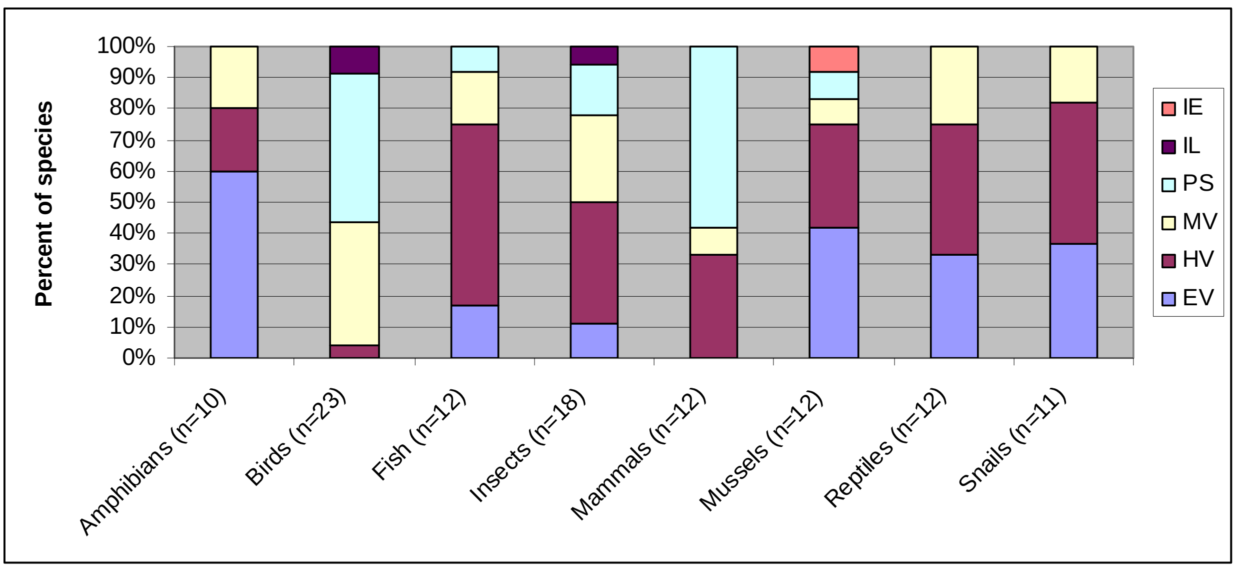


Figure 5. Percent of species within eight taxonomic groups in each vulnerability category. See page 7 and Appendix 1 for abbreviations.

Amphibians

All ten of the amphibian species that were included in the vulnerability assessment were assessed as vulnerable to climate change, with eight of the species assessed as “Extremely Vulnerable” and “Highly vulnerable” (Table 6). Natural barriers and anthropogenic barriers contributed to species vulnerability for most of the amphibians that were assessed. Historical and physiological hydrological niche also were factors that contributed to climate change vulnerability for all the amphibian species. Most amphibians require or are closely associated with specific hydrological regimes and require moist or wet habitat conditions, which makes them vulnerable to climate change given current predictions for reduced moisture and drier conditions. Dependence on a disturbance regime also was a key factor that contributed to vulnerability for most of the amphibians. This was mostly due to the potential for increased flooding which can increase runoff, erosion, and sedimentation and impact and reduce habitat for amphibians. Some of these amphibians, such as the Four-toed salamander, prefer specific habitat and moisture conditions.

Table 6. CCVI results for amphibians. Codes are defined in Appendix 1.

Scientific Name	Common Name	Global Rank	State Rank	Index Score
Pseudacris maculata	Boreal Chorus Frog	G5	S1	Extremely Vulnerable
Amybstoma texanum	Smallmouth Salamander	G5	S1	Extremely Vulnerable
Lithobates sylvaticus	Wood Frog	G5	S5	Extremely Vulnerable
Amybstoma laterale	Blue-spotted Salamander	G5	S5	Extremely Vulnerable
Hemidactylium scutatum	Four-toed Salamander	G5	S5	Extremely Vulnerable
Acris crepitans blanchardi/ Acris blanchardi	Blanchard's Cricket Frog	G5	S2S3	Extremely Vulnerable
Lithobates pipiens	Northern Leopard Frog	G5	S5	Highly Vulnerable
Plethodon cinereus	Redback Salamander	G5	S5	Highly Vulnerable
Necturus maculosus	Mudpuppy	G5	S5	Moderately Vulnerable
Anaxyrus fowleri/ Bufo fowleri	Fowler's Toad	G5	S5	Moderately Vulnerable

Birds

As other vulnerability assessments have found, a smaller percentage of the birds that were assessed were ranked as vulnerable to climate change, especially extremely or highly vulnerable, compared to other taxonomic groups. Of the 23 bird species that were assessed, only 1 species was assessed as highly vulnerable, which is the Common Loon, and 9 other species were assessed as moderately vulnerable (Table 7). Almost half the bird species that were assessed were ranked as presumed stable, and two species were actually predicted to likely increase. The factors that primarily contributed to species vulnerability to climate change for many of the birds were historical hydrological niche and physiological hydrological niche. Most of the birds that were assessed as moderately vulnerable occur primarily along the shoreline and primarily utilize or are associated with wetland habitats (e.g., Great Lakes marshes, emergent marshes) which are vulnerable to climate change (e.g., wetland loss, water level decrease, increased flooding and water level fluctuations). Some of these birds are vulnerable to flooding and water level flucations associated with increased frequency of extreme precipitation events and other disturbance. Dependence on disturbance regime also was a significant contributing factor for many of the birds assessed as vulnerable. Increase in storm events, flooding, and severe winds could reduce water quality, reduce habitat, or impact nesting success for some of these species..

Table 7. CCVI results for birds. Codes are defined in Appendix 1.

Scientific Name	Common Name	Global Rank	State Rank	Index Score
Gavia immer	Common Loon	G5	S3S4	Highly Vulnerable
Charadrius melodus	Piping Plover	G3	S1	Moderately Vulnerable
Coturnicops noveboracensis	Yellow rail	G4	S1S2	Moderately Vulnerable
Chilodonias niger	Black tern	G4	S3	Moderately Vulnerable
Botaurus lentiginosus	American Bittern	G4	S3S4	Moderately Vulnerable
Falco columbarius	Merlin	G5	S1S2	Moderately Vulnerable
Ixobrychus exilis	Least Bittern	G5	S2	Moderately Vulnerable
Sternia caspia	Caspian Tern	G5	S2	Moderately Vulnerable
Sternia hirundo	Common Tern	G5	S2	Moderately Vulnerable
Sterna forsteri	Forster's Tern	G5	S2	Moderately Vulnerable
Rallus elegans	King Rail	G4	S1	Presumed Stable
Tympanuchus phasianellus	Sharp-tailed Grouse	G4	S3S4	Presumed Stable
Nycticorax nycticorax	Black-crowned Night-heron	G5	S2S3	Presumed Stable
Buteo lineatus	Red-shouldered Hawk	G5	S3S4	Presumed Stable
Cistothorus palustris	Marsh Wren	G5	S3S4	Presumed Stable
Ammodramus savannarum	Grasshopper Sparrow	G5	S3S4	Presumed Stable
Pandion haliaetus	Osprey	G5	S4	Presumed Stable
Haliaeetus leucocephalis	Bald Eagle	G5	S4	Presumed Stable
Ardea herodias	Great Blue Heron	G5	S5	Presumed Stable
Meleagris gallopavo	Wild Turkey	G5	S5	Presumed Stable
Phasianus colchicus	Ring-necked Pheasant	G5	SNA	Presumed Stable
Dendroica kirtlandii	Kirtland's Warbler	G1	S1	Increase Likely
Dendroica discolor	Prairie Warbler	G5	S1	Increase Likely

Fish

Ten listed fish species were chosen for the assessment based on inclusion of both lake and river species. One additional species (Grass pickerel, *Esox americanus*) was scored in order to include a common species with a wide range in Michigan, and one exotic species (Big head carp, *Hypopthalmicthys nobilis*) was scored as a hypothetical resident of Michigan.

Two of the twelve assessed fish species scored "Extremely Vulnerable." Redside dace (*Clinostomus elongatus*) scored "Extremely Vulnerable" with "High" confidence and northern madtom (*Noturus stigmosus*) with "Moderate" confidence. These scores were driven in part by the fact that these are cool/cold water and headwater species which are more vulnerable due to natural barriers, anthropogenic barriers, and physiological thermal niche. The main factor that contributed to vulnerability of the fish species that were assessed was historical hydrological niche followed closely by physiological hydrological niche and dependence on a specific disturbance regime. Big head carp scored as "Presumed Stable." Changes in climate were expected to "slightly decrease" its vulnerability in terms of physiological thermal niche since its northern range is thought to be somewhat limited by cooler temperatures. Fish scored less vulnerable to dispersal/movement than both mussels and gastropods.

Table 8. CCVI results for fish species. Codes are defined in Appendix 1.

Scientific Name	Common Name	Global Rank	State Rank	Index Score
Noturus stigmosus	Northern madtom	G3	S1	Extremely Vulnerable
Clinostomus elongatus	Redside dace	G3G4	S1S2	Extremely Vulnerable
Notropis anogenus	Pugnose shiner	G3	S3	Highly Vulnerable
Acipenser fulvescens	Lake sturgeon	G3G4	S2	Highly Vulnerable
Percina copelandi	Channel darter	G4	S1S2	Highly Vulnerable
Notropis photogenis	Silver shiner	G5	S1	Highly Vulnerable
Opsopoeodus emiliae	Pugnose minnow	G5	S1	Highly Vulnerable
Sander canadensis	Sauger	G5	S1	Highly Vulnerable
Lepisosteus oculatus	Spotted gar	G5	S2S3	Highly Vulnerable
Coregonus artedi	Lake herring	G5	S3	Moderately Vulnerable
Esox americanus	Grass pickerel (redfin pickerel)	G5	S5	Moderately Vulnerable
Hypopthalmichthys nobilis	Big head carp	G5	SNA	Presumed Stable

Insects

Of the 18 insect species that were assessed, 14 species (78%) were determined to be vulnerable (EV, HV, MV), with nine (50%) rated as either “Extremely Vulnerable” or “Highly Vulnerable” to climate change. An additional five species were rated as “Moderately Vulnerable.” The most common factor contributing to vulnerability for the insects was historical hydrological niche followed by physiological hydrological niche, physiological thermal niche, natural barriers, artificial barriers, and diet. At least six of the nine vulnerable species are strongly associated with seasonally wet habitats or wetlands. Several of the vulnerable species also had reportedly experienced genetic bottlenecks. Interestingly, the CCVI results indicate that the two species rated as “Extremely Vulnerable,” the Mitchell’s satyr (*Neonympha mitchellii mitchellii*) and Hine’s emerald dragonfly (*Somatochlora hineana*), may expand its range in the assessment area.

Table 9. CCVI results for insect species. Codes are defined in Appendix 1.

Scientific Name	Common Name	Global Rank	State Rank	Index Score
Neonympha mitchellii mitchellii	Mitchell's satyr	G2T2	S1	Extremely Vulnerable
Somatochlora hineana	Hine's Emerald Dragonfly	G2G3	S1	Extremely Vulnerable
Brychius hungerfordi	Hungerford's crawling water beetle	G1	S1	Highly Vulnerable
Calephelis mutica	Swamp metalmark	G3	S1S2	Highly Vulnerable
Lycaeides melissa samuelis	Karner blue	G5T2	S2	Highly Vulnerable
Lycaeides idas nabokovi	Northern blue	G5TU	S2	Highly Vulnerable
Dorydiella kansana	Leafhopper	GNR	S1S2	Highly Vulnerable
Boloria freija	Freija fritillary	G5	S3S4	Highly Vulnerable
Boloria frigga	Frigga fritillary	G5	S3S4	Highly Vulnerable
Papaipema aweme	Aweme borer	G1	SH	Moderately Vulnerable
Appalachia arcana	Secretive locust	G2G3	S2S3	Moderately Vulnerable
Trimerotropis huroniana	Lake Huron locust	G2G3	S2S3	Moderately Vulnerable
Somatochlora incurvata	Incurvate emerald	G4	S1S2	Moderately Vulnerable
Erebia discoidalis	Red-disked alpine	G5	S2S3	Moderately Vulnerable
Euxoa aurulenta	Dune cutworm	G5	S1S2	Presumed Stable
Flexamia delongi	Leafhopper	GNR	S1S2	Presumed Stable
Flexamia reflexus	Leafhopper	GNR	S1	Presumed Stable
Aeshna canadensis	Canada darner	G5	SNR	Increase Likely

Mammals

Mammals represent perhaps the most diverse group of vertebrates in Michigan with respect to range of habitats occupied, dispersal ability, and body size. Michigan mammals occupy both aquatic and terrestrial habitats; while only the bats are volant, none of the mammal species are restricted with respect to inherent dispersal ability as defined by the index; and body size varies from a few grams for the bats and shrews, up to several hundred kilograms for bear and moose. Not surprisingly then, the result of applying the CCVI resulted in a variety of predictions, with most of those predictions of increased vulnerability being the result of a fairly specific life-history trait of the given species. The characteristics of mammals also mean that many of the most often suggested adaptation strategies for addressing climate change related risk, such as providing dispersal corridors, may have limited to no conservation value for mammals. Overall, 6 (50%) of the 12 species evaluated resulted in a prediction of increased vulnerability based on the CCVI, and the other 6 species resulted in predictions of not vulnerable or populations may, in fact, be benefited from predicted climate change (Table 10). All five of the species that were predicted to be vulnerable to climate change are associated with cold/cool habitats and/or snow, particularly the snowshoe hare (*Lepus americanus*) which appears to be the most vulnerable of the common mammal species that were assessed). Historical hydrological niche, physiological hydrological niche, and natural barriers were the most common or key factors contributing to vulnerability of the mammals that were assessed. Diet, association with snow/ice, dependence on interactions with other species, and modeled response to climate change also contributed to species vulnerability. Several species were predicted to perhaps shift their range out of the assessment area as well. Specific predictions for each species are discussed here and in Appendix 5. Specific model factor scores are provided in Appendices 2, 3, and 4.

Table 10. CCVI results for mammal species. Codes are defined in Appendix 1.

Scientific Name	Common Name	Global Rank	State Rank	Index Score
Lynx canadensis	Lynx	G5	S1	Highly Vulnerable
Sorex fumeus	Smoky shrew	G5	S1	Highly Vulnerable
Alces americanus	Moose	G5	S4	Highly Vulnerable
Lepus americanus	Snowshoe hare	G5	S5	Highly Vulnerable
Martes americana	American marten	G5	S3	Moderately Vulnerable
Myotis sodalis	Indiana bat	G2	S1	Presumed Stable
Canis lupus	Gray wolf	G4	S3	Presumed Stable
Microtus orchrogaster	Prairie vole	G5	S1	Presumed Stable
Microtus pinetorum	Woodland vole	G5	S3S4	Presumed Stable
Ursus americanus	Black bear	G5	S5	Presumed Stable
Odocoileus virginianus	White-tailed deer	G5	S5	Presumed Stable
Nycticeius humeralis	Evening bat	G5	SNR	Presumed Stable

Mussels

Ten of the 12 mussel species that were assessed were predicted to be vulnerable to climate change (Table 11), with 5 species rated as "Extremely Vulnerable," 4 species rated as "Highly Vulnerable," and 1 species rated as "Moderately Vulnerable." Historical hydrological niche was the primary factor contributing to species vulnerability for the mussels followed by physiological hydrological niche, dependence on specific disturbance (e.g., increased flooding could reduce water quality which could adversely impact the species), natural and anthropogenic barriers, and climate change mitigation activities. Limitations on mussel migration due to natural pathways of waterbodies and waterways were taken into account. Many of Michigan's rivers and lakes also are isolated by dams and impoundments. These anthropogenic barriers were accounted for under Section B.2.b. (Watters, Hoggarth, and Stansbery 2009).

Dependence on other species for propagule dispersal also was a key contributing factor to vulnerability of mussel species. The mobility of host fish for each unionid species was factored in under Section C., and the host specificity (based on number of known hosts occurring in Michigan for each unionid species) was factored in under Section C.4.d. This was scored "unknown" if suitable hosts were not known for a unionid species. Unionids with unknown hosts have "insufficient evidence" to be scored in the CCVI. The accuracy of CCVI score for unionid mussels is greatly influenced by the knowledge of each unionid species' suitable hosts (e.g. which fish species and actual host use within the assessment area).

Zebra mussels (*Dreissena polymorpha*) have free swimming larvae that do not utilize fish hosts. Due to this characteristic, rivers (with current) were considered a natural barrier for this species. The migration of zebra mussels upstream and to isolated lakes and impoundments is facilitated by boating and other anthropogenic activities (Johnson, Olden, and Vander Zanden 2008). Reduced seasonal ice cover and increased temperature are expected to increase recreational boating and further facilitate migration of zebra mussels. Unionid mussels scored more vulnerable to dependence on other species for propagule dispersal than both fish and gastropods, and less vulnerable to physiological thermal niche.

Table 11. CCVI results for mussel species. Codes are defined in Appendix 1.

Scientific Name	Common Name	Global Rank	State Rank	Index Score
Pleurobema clava	Northern clubshell	G1G2	S1	Extremely Vulnerable
Epioblasma torulosa rangiana	Northern riffleshell	G2T2	S1	Extremely Vulnerable
Simpsonaias ambigua	Salamander mussel	G3	S1	Extremely Vulnerable
Alasmidonta viridis	Slippershell	G4G5	S2S3	Extremely Vulnerable
Obliquaria reflexa	Threehorn wartyback	G5	SNR	Extremely Vulnerable
Villosa fabalis	Rayed bean	G2	S1	Highly Vulnerable
Epioblasma triquetra	Snuffbox	G3	S1	Highly Vulnerable
Obovaria olivaria	Hickorynut	G4	S2	Highly Vulnerable
Lasmigona compressa	Creek heelsplitter	G5	SNR	Highly Vulnerable
Ligumia nasuta	Eastern pondmussel	G4	SNR	Moderately Vulnerable
Dreissena polymorpha	Zebra mussel	G5	SNA	Presumed Stable
Obovaria subrotunda	Round hickorynut	G4	S1	Insufficient Evidence*

*This species had insufficient evidence because its host fish are not known.

Reptiles

Nine (75%) of the 12 reptile species that were assessed were rated as vulnerable with 4 species rated as "Highly Vulnerable" and 5 species rated as "Moderately Vulnerable." Historical hydrological niche, physiological hydrological niche, and barriers, both natural and anthropogenic, were the main factors contributing to vulnerability of reptile species. Dependence on a specific disturbance regime likely to be impacted by climate change also was a key contributing factor. Many of the species that were assessed are associated with specific wetland habitats/seasonally wet habitats, and/or localized moisture regimes. Since climate change is predicted to lead to a drier climate, these species may be vulnerable. Natural barriers were mainly the Great Lakes for species whose distributions extended to the shoreline/coastal zone. Anthropogenic barriers mainly consisted of intensive urban and agricultural areas and busy roads/highways for at least part of the range for some species. Dependence on specific disturbance regime contributed to vulnerability in terms of increased fire or increased flooding which could adversely impact some species in parts of their range.

Table 12. CCVI results for reptile species. Codes are defined in Appendix 1.

Scientific Name	Common Name	Global Rank	State Rank	Index Score
Pantherophis gloydi	Eastern Fox Snake	G3	S2	Highly Vulnerable
Sistrurus catenatus catenatus	Eastern Massasauga	G3G4T3Q	S3S4	Highly Vulnerable
Emydoidea blandingii	Blanding's Turtle	G4	S3	Highly Vulnerable
Diadophis punctatus edwardsii	Northern Ring-necked Snake	G5	S5	Highly Vulnerable
Clonophis kirtlandi	Kirtland's Snake	G2	S1	Moderately Vulnerable
Glyptemys insculpta	Wood Turtle	G3	S2S3	Moderately Vulnerable
Clemmys guttata	Spotted Turtle	G5	S2	Moderately Vulnerable
Terrapene carolina carolina	Eastern Box Turtle	G5	S2S3	Moderately Vulnerable
Heterodon platirhinos	Eastern Hognose Snake	G5	S3S4	Moderately Vulnerable
Chrysemys picta	Painted Turtle	G5	S5	Presumed Stable
Chelydra serpentina serpentina	Snapping Turtle	G5	S5	Presumed Stable
Pantherophis spiloides	Gray Ratsnake	G5T5	S3	Presumed Stable

Snails/Gastropods

Nine of the 11 species that were assessed were rated as vulnerable to climate change, with 4 species rated as “Extremely Vulnerable” and 5 species rated as “Highly Vulnerable.” Historical hydrological niche and natural barriers were the most common and key contributing factors to species vulnerability followed by physiological hydrological niche, anthropogenic barriers, and dispersal to movement. Aquatic snails or gastropods that occur in both rivers and lakes were considered less vulnerable to natural and anthropogenic barriers. Compared to fish and mussels, the gastropods scored more vulnerable to natural and anthropogenic barriers, dispersal/movements, and restriction to uncommon geological features (C3). Snails generally are sedentary and have very limited dispersal distances, which may make them more vulnerable to climate change if they can’t move to follow their climate envelope if it shifts in response to climate change. The gastropods also were less vulnerable to climate change mitigation than fish and mussels. Terrestrial gastropods were rated more vulnerable to physiological thermal niche than aquatic gastropods.

Table 13. CCVI results for snail species. Codes are defined in Appendix 1.

Scientific Name	Common Name	Global Rank	State Rank	Index Score
Vertigo nylanderi	Deep-throat vertigo	G3G4	S1	Extremely Vulnerable
Hendersonia occulta	Cherrystone drop	G4	S1	Extremely Vulnerable
Gastrocopta holzingeri	Lambda snaggletooth	G5	S1	Extremely Vulnerable
Fontigens nickliniana	Watercress snail	G5	SU	Extremely Vulnerable
Stagnicola contracta	Deepwater pondsnail	G1	S1	Highly Vulnerable
Vertigo bollesiana	Delicate vertigo	G4	S2	Highly Vulnerable
Pomatiopsis cincinnatiensis	Brown walker	G4	SU	Highly Vulnerable
Vallonia gracilicosta albula	Terrestrial snail	G4Q	S1	Highly Vulnerable
Mesodon elevatus	Proud globe	G5	SU	Highly Vulnerable
Helisoma anceps	Two-ridge rams-horn	G5	SU	Moderately Vulnerable
*Potamopyrgus antipodarum**	New Zealand mudsnail*	G5	SU	Moderately Vulnerable

*This species was run as a hypothetical resident of the assessment area. It has not been documented in Michigan but is present in the Great Lakes.

Plants

The 47 plant species that were selected for the vulnerability assessment were taxonomically diverse (e.g. several pteridophytes (ferns and fern allies), orchids, sedges, grasses, and numerous dicots were included), and also were diverse in terms of distribution, ecology, and life history. The group also represents associations with several natural community types known throughout the state, and included one saprophyte (fascicled broomrape) and two insectivorous species (butterwort and English sundew).

The majority of the vascular plant species assessed were determined to be moderately, highly, or extremely vulnerable to climate change, as summarized in Table 14. Of the 47 species scored, 36 species (77%) were predicted to be vulnerable to climate change of which 9 species were found to be "Extremely Vulnerable," 19 were found to be "Highly Vulnerable," and 8 were found to be "Moderately Vulnerable." Of the 11 species not found to be vulnerable, 10 were scored as "presumed stable" whereas one species was scored as "Not Vulnerable/Increase Likely" (Table 15).

Table 14. Plant species assessed as "Extremely Vulnerable," "Highly Vulnerable" or "Moderately Vulnerable." Codes are defined in Appendix 1.

Scientific Name	Common Name	Global Rank	State Rank	State Status	US Status
Extremely Vulnerable					
Isotria medeoloides	Lesser whorled pogonia or smaller whorled pogonia	G2	SX	X	LT
Schoenoplectus hallii	Hall's bulrush	G2G3	S2	T	
Poa paludigena	Bog bluegrass	G3	S2	T	
Listera auriculata	Auricled twayblade	G3	S2S3	SC	
Agalinis skinneriana	Skinner's agalinis or Skinner's gerardia	G3G4	S1	E	
Panax quinquefolius	Ginseng	G3G4	S2S3	T	
Bromus nottowayanus	Satin brome	G3G5	S3	SC	
Amerorchis rotundifolia	Small round-leaved orchis	G5	S1	E	
Mimulus michiganensis	Michigan monkey-flower	G5T1	S1	E	LE
Highly Vulnerable					
Lycopodiella margueritae	Northern prostrate clubmoss	G2	S2	T	
Lycopodiella subappressa	Northern appressed clubmoss	G2	S2	SC	
Aster furcatus	Forked aster	G3	S1	T	
Hymenoxys herbacea	Lakeside daisy	G3	S1	E	LT
Platanthera leucophaea	Eastern prairie fringed-orchid or prairie white fringed-orchid	G3	S1	E	LT
Potamogeton hillii	Hill's pondweed	G3	S2	T	
Cypripedium arietinum	Ram's head lady's-slipper	G3	S3	SC	
Iris lacustris	Dwarf lake iris	G3	S3	T	LT
Solidago houghtonii	Houghton's goldenrod	G3	S3	T	LT
Triphora trianthophora	Nodding pogonia or three birds orchid	G3G4	S1	T	
Valerianella umbilicata	Corn salad	G3G5	S2	T	
Orobanche fasciculata	Broomrape or fascicled broom-rape	G4	S2	T	

Cacalia plantaginea	Prairie indian-plantain	G4G5	S3	SC	
Asplenium scolopendrium	American hart's tongue fern	G4T3	S1	E	LT
Asclepias hirtella	Tall green milkweed	G5	S2	T	
Asclepias sullivantii	Sullivant's milkweed	G5	S2	T	
Calypso bulbosa	Calypso orchid	G5	S2	T	
Drosera anglica	English sundew	G5	S3	SC	
Pinguicula vulgaris	Butterwort	G5	S3	SC	
Moderately Vulnerable					
Cirsium pitcheri	Pitcher's thistle	G3	S3	T	LT
Botrychium campestre	Prairie moonwort, dunewort	G3G4	S2	T	
Utricularia subulata	Bladderwort	G5	S1	T	
Carex scirpoidea	Bulrush sedge	G5	S2	T	
Stellaria longipes	Stitchwort or long-stalked stitchwort	G5	S2	SC	
Bromus pumpellianus	Pumpelly's bromegrass	G5T4	S2	T	
Tanacetum huronense	Lake Huron tansy	G5T4T5	S3	T	
Zizania aquatica var. aquatica	Wild rice	G5T5	S2S3	T	

Table 15. Plants species assessed as "Presumed Stable" or "Increase Likely." Codes are defined in Appendix 1.

Scientific Name	Common Name	Global Rank	State Rank	State Status	US Status
Presumed Stable					
Botrychium acuminatum	Moonwort	G1	S1	E	
Cystopteris laurentiana	Laurentian fragile fern	G3	S1S2	SC	
Botrychium mormo	Goblin fern	G3	S2	T	
Botrychium spathulatum	Spatulate moonwort	G3	S2	T	
Calamagrostis lacustris	Northern reedgrass	G3Q	S1	T	
Botrychium hesperium	Western moonwort	G4	S2	T	
Nelumbo lutea	American lotus	G4	S2	T	
Adlumia fungosa	Climbing fumitory	G4	S3	SC	
Sagittaria montevidensis	Arrowhead	G4G5	S1S2	T	
Leymus mollis	American dune wild-rye	G5	S3	SC	
Increase Likely					
Cirsium hillii	Hill's thistle	G3	S3	SC	

Factors contributing to plant vulnerability

One of the principal risk factors contributing to the determination of climate change vulnerability for plants was historical hydrological regime, which was scored as "greatly increase" for about 50% of the species assessed. For all but one of the remaining species (which was scored as "somewhat increase") this factor was scored as "increase", and in no case did historical hydrological regime score as low as "neutral", thus it is clearly a significant factor. One of the other prominent risk factors for plants was the allied category of physiological hydrological niche, which indicates that several of the taxa included have a strong wetland affinity, particularly those species that inhabit ecotones and/or depend on seasonal flooding and drawdown cycles, although in general most wetland related species would be expected to experience more adverse and disrupted conditions owing to the projected drier, warmer conditions for 2050. Approximately 50% of the species assessed for this factor were scored from "slightly increase" or higher, with more than half of those scored as "greatly increase".

Other prominent risk factors included the category of natural barriers and dispersal/movement, as in both of these categories well over 50% of the species assessed were scored above neutral (i.e. as "increase" or higher). For natural barriers, many of the shoreline species will be impeded by the inability to migrate northward over the portions of the Great Lakes, particularly, for example, for species along the southern shore of Lake Superior. Although it is expected that several species would migrate lakeward as basins (ostensibly) retract, and thus continue to occupy available habitat, long-distance dispersal will be problematical. In addition, plant species in southern Michigan may have formidable barriers with regard to dispersing north over the largely agricultural interior in the southern Lower Peninsula, where there is extensive unsuitable habitat. For the category of dispersal/movement, the scores largely indicate the relatively limited short-dispersal distances that many plants have, particularly those species that have few or no animal vectors and thus can only scatter seeds very locally (i.e. less then about 100 meters).

Other notable risk factors included physical habitat (restriction to uncommon geological features or derivatives) and reliance on interspecific interactions. For the former category, about 50% of the species assessed were scored as "increase" or higher, indicating the dependence several of the assessed species have on such habitats as dunes, certain wetland types, and specialized substrates such as those that are found on bedrock shorelines (e.g. limestone/alvar, volcanic, etc.). With regard to interspecific interactions, 9 species were scored as "increase" or "slightly increase", indicating such taxa as the several orchids and the one saprophyte assessed, which have obligate relationships with fungi, and thus due to this dependence such species have a greater vulnerability to climate change.

Discussion

Overall, 116 (74%) of the 157 total animal and plant species that were assessed were predicted to be vulnerable (EV, HV, MV). Figure 6 provides a summary of the number of plant and animal species in each vulnerability category. Overall vulnerability assessment results or general trends appear to be similar to what other assessment efforts have found. Other assessment efforts also found that amphibians, fish, mussels, and insects may be more vulnerable to climate change than reptiles, mammals and birds (Byers and Norris 2011, Furedi et al. 2011, Schlesinger et al. 2011). However, this study scored a higher percentage of reptiles as vulnerable to climate change than other assessments (Byers and Norris 2011, Furedi et al. 2011, Schlesinger et al. 2011). Additional analysis is needed to compare vulnerability assessment results for individual species.

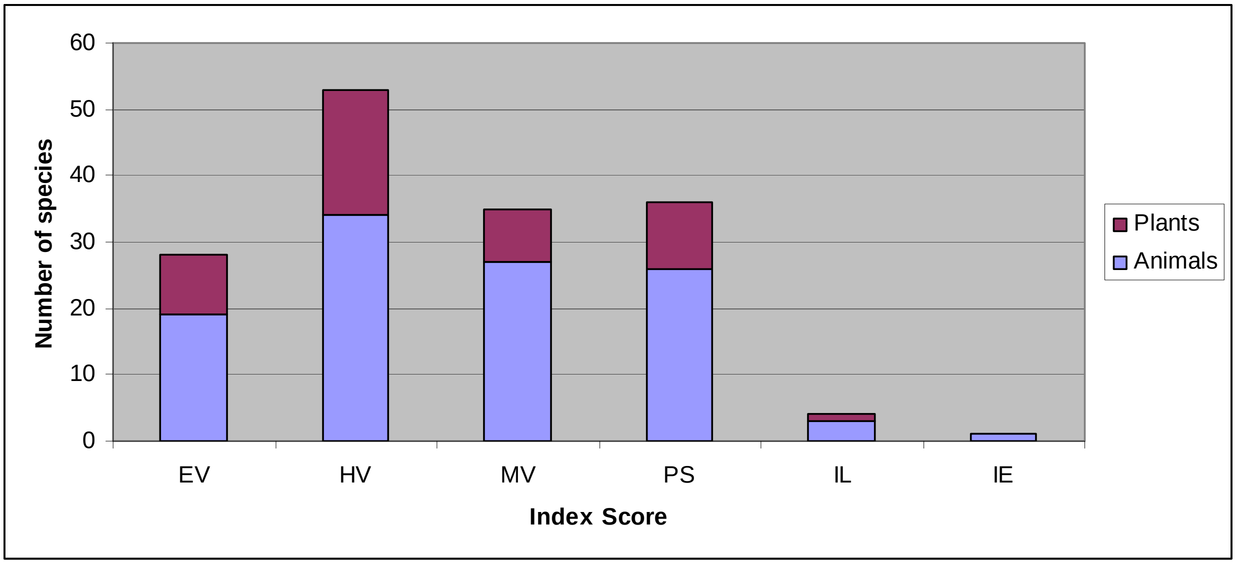


Figure 6. Summary of plant and animal species in each vulnerability category. See page 7 and Appendix 1 for abbreviations.

The number and percentage of species predicted to be vulnerable to climate change with this assessment were quite high. The high number and percentage of species that were predicted to be vulnerable to climate change could be due to the focus on rare and declining species and/or species associated with the coastal zone. Assessor bias or misinterpretation of the factors also may have contributed to overestimation or inflation of species vulnerability leading to high rates of vulnerability. Further analyses of our assessment results are warranted to investigate this further.

Combining vulnerability with conservation status

Because the CCVI does incorporate factors used in evaluating species status and because species face other ongoing threats in addition to climate change, vulnerability rankings and conservation status ranks should be combined or compared before setting priorities for adaptation. NatureServe recommends examining conservation ranks for species within each vulnerable category (i.e., EV, HV, and MV), and species with more imperiled conservation status (i.e., lower G- or S-rank) would represent higher priorities. This can be done by sorting or ranking the species first on their climate change vulnerability and then by their conservation status within each category. Table 16 provides a summary of animal species within the “Extremely Vulnerable,” “Highly Vulnerable,” and “Moderately Vulnerable” categories sorted first by global rank and then by state rank. An initial approach for prioritizing species for adaptation efforts could entail prioritizing globally rare species (G1-G3) first (highlighted in green in Table 16) followed by species that are rare in the state (S1-S3) (highlighted in yellow in Table 16). Additional factors also could be considered such as species with small populations, small ranges, and long generation times (Young et al. 2011). Further analyses of these species and assessment results should be conducted to examine and identify potential priorities for adaptation efforts. A similar analysis could be conducted with the plant species that were identified as vulnerable.

Table 16. Potential prioritization of animals identified as vulnerable to climate change based on CCVI results and conservation status ranks (e.g., G1-G3 highlighted in green, S1-S3 in yellow). Codes are defined in Appendix 1.

Taxonomic Group	Scientific Name	Common Name	Global Rank	State Rank	State Listing	US Listing
Extremely Vulnerable						
Mussel	*Pleurobema clava*	Northern clubshell	G1G2	S1	E	LE
Insect	*Somatochlora hineana*	Hine's emerald dragonfly	G2G3	S1	E	LE
Insect	*Neonympha mitchellii mitchellii*	Mitchell's satyr	G2T2	S1	E	LE
Mussel	*Epioblasma torulosa rangiana*	Northern riffleshell	G2T2	S1	E	LE
Fish	*Noturus stigmosus*	Northern madtom	G3	S1	E	
Mussel	*Simpsonaias ambigua*	Salamander mussel	G3	S1	E	C
Snail	*Vertigo nylanderi*	Deep-throat vertigo	G3G4	S1	E	
Fish	*Clinostomus elongatus*	Redside dace	G3G4	S1S2	E	
Snail	*Hendersonia occulta*	Cherrystone drop	G4	S1	T	
Mussel	*Alasmidonta viridis*	Slippershell	G4G5	S2S3	T	
Amphibian	*Amybstoma texanum*	Smallmouth salamander	G5	S1	E	
Amphibian	*Pseudacris maculata*	Boreal chorus frog	G5	S1	SC	
Snail	*Gastrocopta holzingeri*	Lambda snaggletooth	G5	S1	E	
Amphibian	*Acris crepitans blanchardi/ Acris blanchardi*	Blanchard's cricket frog	G5	S2S3	T	
Amphibian	*Amybstoma laterale*	Blue-spotted salamander	G5	S5		
Amphibian	*Hemidactylium scutatum*	Four-toed salamander	G5	S5		
Amphibian	*Lithobates sylvaticus*	Wood frog	G5	S5		
Mussel	*Obliquaria reflexa*	Threehorn wartyback	G5	SNR	E	
Snail	*Fontigens nickliniana*	Watercress snail	G5	SU	SC	
Highly Vulnerable						
Insect	*Brychius hungerfordi*	Hungerford's crawling water beetle	G1	S1	E	LE
Snail	*Stagnicola contracta*	Deepwater pondsnail	G1	S1	E	
Mussel	*Villosa fabalis*	Rayed bean	G2	S1	E	C*
Mussel	*Epioblasma triquetra*	Snuffbox	G3	S1	E	C*
Insect	*Calephelis mutica*	Swamp metalmark	G3	S1S2	SC	
Reptile	*Pantherophis gloydi*	Eastern fox snake	G3	S2	T	
Fish	*Notropis anogenus*	Pugnose shiner	G3	S3	E	
Fish	*Acipenser fulvescens*	Lake sturgeon	G3G4	S2	T	
Reptile	*Sistrurus catenatus catenatus*	Eastern nassasauga	G3G4T3Q	S3S4	SC	C
Fish	*Percina copelandi*	Channel darter	G4	S1S2	E	

Mussel	*Obovaria olivaria*	Hickorynut	G4	S2	E	
Snail	*Vertigo bollesiana*	Delicate vertigo	G4	S2	T	
Reptile	*Emydoidea blandingii*	Blanding's turtle	G4	S3	SC	
Snail	*Pomatiopsis cincinnatiensis*	Brown walker	G4	SU	SC	
Snail	*Vallonia gracilicosta albula*	terrestrial snail	G4Q	S1	E	
Fish	*Notropis photogenis*	Silver shiner	G5	S1	E	
Fish	*Opsopoeodus emiliae*	Pugnose minnow	G5	S1	E	
Fish	*Sander canadensis*	Sauger	G5	S1	T	
Mammal	*Lynx canadensis*	Lynx	G5	S1		
Mammal	*Sorex fumeus*	Smoky shrew	G5	S1	T	
Fish	*Lepisosteus oculatus*	Spotted gar	G5	S2S3	SC	
Bird	*Gavia immer*	Common loon	G5	S3S4	T	
Insect	*Boloria freija*	Freija fritillary	G5	S3S4	SC	
Insect	*Boloria frigga*	Frigga fritillary	G5	S3S4	SC	
Mammal	*Alces americanus*	Moose	G5	S4	SC	
Amphibian	*Lithobates pipiens*	Northern leopard frog	G5	S5		
Amphibian	*Plethodon cinereus*	Redback salamander	G5	S5		
Mammal	*Lepus americanus*	Snowshoe hare	G5	S5		
Reptile	*Diadophis punctatus edwardsii*	Northern ring-necked snake	G5	S5		
Mussel	*Lasmigona compressa*	Creek heelsplitter	G5	SNR		
Snail	*Mesodon elevatus*	Proud globe	G5	SU	T	
Insect	*Lycaeides melissa samuelis*	Karner blue	G5T2	S2	T	
Insect	*Lycaeides idas nabokovi*	Northern blue	G5TU	S2	T	
Insect	*Dorydiella kansana*	Leafhopper	GNR	S1S2	SC	
Moderately Vulnerable						
Insect	*Papaipema aweme*	Aweme borer	G1	SH	SC	
Reptile	*Clonophis kirtlandi*	Kirtland's snake	G2	S1	E	
Insect	*Appalachia arcana*	Secretive locust	G2G3	S2S3	SC	
Insect	*Trimerotropis huroniana*	Lake Huron locust	G2G3	S2S3	T	
Bird	*Charadrius melodus*	Piping plover	G3	S1	E	LE
Reptile	*Glyptemys insculpta*	Wood turtle	G3	S2S3	SC	
Bird	*Coturnicops noveboracensis*	Yellow rail	G4	S1S2	T	
Insect	*Somatochlora incurvata*	Incurvate emerald	G4	S1S2	SC	
Bird	*Chilodonias niger*	Black tern	G4	S3	SC	
Bird	*Botaurus lentiginosus*	American bittern	G4	S3S4	SC	
Mussel	*Ligumia nasuta*	Eastern pondmussel	G4	SNR		
Bird	*Falco columbarius*	Merlin	G5	S1S2	T	
Bird	*Ixobrychus exilis*	Least bittern	G5	S2	T	

Bird	*Sterna forsteri*	Forster's tern	G5	S2	T
Bird	*Sternia caspia*	Caspian tern	G5	S2	T
Bird	*Sternia hirundo*	Common tern	G5	S2	T
Reptile	*Clemmys guttata*	Spotted turtle	G5	S2	T
Insect	*Erebia discoidalis*	Red-disked alpine	G5	S2S3	SC
Reptile	*Terrapene carolina carolina*	Eastern box turtle	G5	S2S3	SC
Fish	*Coregonus artedi*	Lake herring	G5	S3	T
Mammal	*Martes americana*	American marten	G5	S3	
Reptile	*Heterodon platirhinos*	Eastern hognose snake	G5	S3S4	
Amphibian	*Anaxyrus fowleri/ Bufo fowleri*	Fowler's toad	G5	S5	
Amphibian	*Necturus maculosus*	Mudpuppy	G5	S5	
Fish	*Esox americanus*	Grass pickerel (redfin pickerel)	G5	S5	
Snail	*Helisoma anceps*	Two-ridge rams-horn	G5	SU	
Snail	*Potamopyrgus antipodarum**	New Zealand mudsnail*	G5	SU	

*Species were listed as Federally Endangered, effective March 15, 2012 (Final Rule FWS–R3–ES–2010–0019).

Factors causing vulnerability across taxa

Historical hydrological niche

Several factors that caused or contributed to species vulnerability to climate change were common across all or many of the animals and plants. The main factor that was common across all animal groups and plants was historical hydrological niche or exposure to past variations in precipitation across the species range within the assessment area. The maximum range of historical precipitation (mean annual precipitation) across Michigan over the last 50 years was about 14 inches. The variation in mean annual precipitation across occupied cells for most species was ranked either < 4 inches (very small) or between 4 and 10 inches. These ranges resulted in a score of "increase vulnerability" or "greatly increase vulnerability" for most species. This factor contributed to the vulnerability of many animal and plant species as discussed above in the plant section. Twenty-seven out of the 33 species fish, mussel, and snail species assessed had this as its highest rated factor. No other factor scored "greatly increase" and there were only two other scores of "GI-Inc." Historical hydrological niche scored "greatly increase" for 12 out of 33 species, with an additional 15 species scoring "increase." This factor indicates that most species in Michigan have experienced fairly small variations in mean annual precipitation. Increase in mean annual precipitation and increase in extreme precipitation events due to climate change could expose species in Michigan to a greater variation in precipitation than they have experienced in the past and associated impacts which could adversely impact some species and benefit others.

Physiological hydrological niche

A second factor that contributed frequently to species vulnerabil niche. Many species that were assessed were associated with aquatic and/or wetlands habitats, particularly seasonal wetlands, and specific hydrological regimes. This might have been due to the fact that many of our rare and declining species are associated with wetlands given the rate of wetland loss that has occurred in Michigan. However, this does emphasize the importance of protecting and restoring wetlands and maintaining or restoring the hydrologic regime as an important strategy for adaptation and conservation in general.

Natural and anthropogenic barriers

An additional factor that contributed quite frequently and significantly for many species was barriers and particularly natural barriers in terms of the Great Lakes. Because Michigan is surrounded by the Great Lakes, this factor could pose a significant barrier to dispersal for many species. This could prevent species from being able to shift their range to follow potential shifts in their climate envelope or habitats. This issue is exacerbated by the reduction in ice cover on the Great Lakes. Climate change adaptation efforts may need to consider strategies for addressing this factor (e.g., translocation).

Dependence on a specific disturbance regime

Dependence on a specific disturbance regime likely to be impacted by climate change such as fires, floods, severe winds, pathogen outbreaks, or similar events was frequently scored as a factor for causing vulnerability among amphibians, reptiles, fish, mussels, and birds. Increase in flooding was a concern for many species. Further analysis and adaptation efforts to address this factor may be needed.

Species moving into or out of the Assessment Area

Species scored as "Not Vulnerable/Presumed Stable" may shift their range with climate changes and potentially move out of the assessment area (Young et al. 2011). Vulnerable species also may disperse out of the assessment area or move into the assessment area. The Index indicates species with characteristics that might make them more likely to move out of or expand in the assessment area. This information should be examined and considered in developing adaptation strategies. We will further investigate this issue during the second year of the project.

Additional considerations

Additional factors might have biased or affected our results. In general, the western Upper Peninsula and northern Lower Peninsula have not been surveyed as completely as the rest of the state. This may skew results of "temperature scope" away from >5.5, and the "moisture metric scope" away from the -0.028 to -0.050 and -0.051 to 0.073 categories for species that actually occur in the western UP but have not been recorded there. Limited available information or information gaps also could impact our assessment ratings and results. For example, information is fairly limited on the fish hosts for freshwater mussels. This is a critical factor for mussels and for accurately assessing their vulnerability and developing appropriate adaptation strategies. Also, genetic studies and climate modeling efforts are increasing and could provide additional insights and information for vulnerability assessments in the future. The effect of climate change on algae and zooplankton in the Great Lakes, inland lakes, and rivers could have implications to these ecosystems and the services and biodiversity they support. The amount and type of information available for these taxa should be evaluated to determine if they could be effectively scored in the CCVI.

The Great Lakes are known to affect local and regional climate/weather patterns. These effects will likely be altered as temperature, ice cover duration, and various large scale weather patterns respond to global climate change. A regional model for climate change accounting for the influence of the Great Lakes would allow for a more accurate assessment of the potential impacts to species occurring in the Coastal Zone of Michigan. It would be beneficial to recalculate the Climate Change Vulnerability Index (CCVI) when finer-scale or better downscaled climate models are available for Michigan.

Next steps

We will share results from this year's project with our current partners and other planning, management, and conservation organizations. We have already presented some initial results from this project at a couple of professional meetings/conferences. We will work with our partners to share our findings. We also are considering submitting our vulnerability assessment results to the National Climate Assessment.

During the second year of the project, we will conduct further review of our initial vulnerability assessments to refine results and identify potential priorities. We also will conduct additional species vulnerability assessments, add a spatial component to our vulnerability assessments, and develop recommendations for adaptation strategies during the second year of the project. Specifically, we will address the following objectives during the second year of the project:

1) Conduct and complete additional species climate change vulnerability assessments.

2) Identify species and natural communities most vulnerable to climate change along Michigan's coastal zone and factors which most frequently contributed to high vulnerability scores based on completed vulnerability assessments.

3) Conduct spatial analysis to identify geographic areas along Michigan's coastal zone that might be impacted by climate change as well as other stressors such as areas of high development, agricultural use, increased runoff/pollution, etc. The output will be a map of high, moderate, and low stress areas based on climate change and other stressors along the coastal zone.

4) Conduct spatial analysis to identify geographic areas along the coastal zone where species and natural communities sensitive to climate change may be particularly vulnerable to climate change based on known occurrences and identification of high, moderate, or low stress areas identified above.

5) Identify potential adaptation strategies and potential areas in which some of these strategies could be applied by utilizing information and results from vulnerability assessments and conducting a spatial analysis of locations/occurrence of vulnerable species and areas suitable for implementing adaptation strategy (e.g., areas with opportunities for dispersal corridors or connectivity if this is factor causing species' vulnerability).

6) Share results broadly so that information and tools can be used and incorporated into climate change and other planning, management, conservation, and research efforts.

Finally, as mentioned earlier, these vulnerability assessments should be viewed as a first step and as part of an iterative process. Vulnerability assessments should be revisited and reassessed as better and more information about climate changes and species distribution, life history, ecology, genetics, and responses to climate change become available. Tools for assessing vulnerability such as the CCVI also continue to be developed and enhanced. Vulnerability assessment also should be incorporated into adaptive planning, management, and monitoring efforts.

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References

Association of Fish and Wildlife Agencies (AFWA). 2009. Voluntary guidance for states to incorporate climate change into state wildlife action plans and other management plans. AFWA, Washington, D.C. Available: http://www.fishwildlife.org/pdfs/ClimateChangeGuidance%20Document_Final_reduced%20size.pdf

Baker, R. H. 1983. *Michigan Mammals*. Michigan State University Press, East Lansing, MI. 642pp.

Beyer Jr., D. E., S. R. Winterstein, P. E. Lederle, and J. J. Maskey. 2001. Moose in Michigan: History, Biology and Considerations for Hunting. Michigan Department of Natural Resources, Lansing, MI.

Brack Jr., V, C. W. Stihler, R. J. Reynolds, C. M. Butchkoski, and C. S. Hobson. 2002. Effect of climate and elevation on distribution and abundance in the mideastern United States. In: *The Indiana Bat: Biology and Management of an Endangered Species.* Kurta, A. and J. Kennedy, eds. Bat Conservation International. Austin, TX.

Burch, J.B. 1988. North American freshwater snails. Introduction, systematics, nomenclature, identification, morphology, habitats, distribution. Walkerana. 2(6):1-80.

Burch, J.B., Y. Jung. 1988. Land snails of the University of Michigan Biological Station area. Walkerana. 3(9):1-177.

Burch, J.B., Y. Jung. 1993. Freshwater snails of the University of Michigan Biological Station area. Walkerana. 6(15):1-218

Byers, E. and S. Norris. 2011. Climate Change Vulnerability Assessment of Species of Concern in West Virginia. Project Report, Elkins, WV. 69 pp.

Clawson, R. L. 2002. Trends in population size and current status. In: *The Indiana Bat: Biology and Management of an Endangered Species.* Kurta, A. and J. Kennedy, eds. Bat Conservation International. Austin, TX.

Dempsey, D., J. Elder, and D. Scavia. 2008. Great Lakes restoration and the threat of global warming. Report for the Healing Our Waters-Great Lakes Coalition. 33 pp.

Eagle, A.C., E.M. Hay-Chmielewski, K.T. Cleveland, A.L. Derosier, M.E. Herbert, and R.A. Rustem, eds. 2005. Michigan's Wildlife Action Plan. Michigan Department of Natural Resources. Lansing, Michigan. 1592 pp. http://www.michigan.gov/dnrwildlifeactionplan

Field, C.B., L.D. Mortsch, M. Brklacich, D.L. Forbes, P. Kovacs, J.A. Patz, S.W. Running, and M.J. Scott. 2007. North America. *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M. L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds. Cambridge University Press, Cambridge, UK, 617-652.

Furedi, M., B. Leppo, M. Kowalski, T. Davis, and B. Eichelberger. 2011. Identifying species in Pennsylvania potentially vulnerable to climate change. Pennsylvania Natural Heritage Program, Western Pennsylvania Conservancy, Pittsburgh, PA.

Gardner, J. E. and E. A. Cook. 2002. Seasonal and geographic distribution and quantification of potential summer habitat. In: *The Indiana Bat: Biology and Management of an Endangered Species.* Kurta, A. and J. Kennedy, eds. Bat Conservation International. Austin, TX.

Girvetz, E. H., C. Zganjar, G. T. Raber, E. P. Maurer, P. Kareiva, and J. J. Lawler. 2009. Applied climate-change analysis: the climate wizrd tool. PLoS ONE 4: r8320. doi:10.1371/journal.pone.0008320.

Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. *Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment.* National Wildlife Federation, Washington, D.C.

Gough, G.A., Sauer, J.R., Iliff, M. *Patuxent Bird Identification Infocenter.* 1998. Version 97.1. Patuxent Wildlife Research Center, Laurel, MD. http://www.mbrpwrc.usgs.gov/id/framlst/infocenter.html

Hall, N.D. and B.B. Stuntz. 2007. "Climate Change and Great Lakes Water Resources" Prepared for the National Wildlife Federation. 44pgs.

Hoving, C. L. 2001. Historical Occurrence and Habitat Ecology of Canada Lynx (*Lynx canadensis*) in Eastern North America. M.S. Thesis, University of Maine

Hubricht, L. 1985. The distributions of the native land mollusks of the Eastern United States. Fieldiana, Zoology New Ser: 24. 191 pp.

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds. Cambridge University Press, Cambridge, UK, 976 pp.

Jensen, O. P., B. J. Benson, J.J. Magnuson, V.M. Card, M.N. Futter, P.A. Soranno, K.M. Stewart. 2007. Spatial analysis of ice phenology trends across the Laurentian Great Lakes region during a recent warming period." Limnology and Oceanography **52**(5): 2013-2026.

Johnson, P.T.J., J.D. Olden, M.J. Vander Zanden. 2008. Dam invaders: impoundments facilitate biological invasions into freshwaters. Fronteries in Ecology and the Environment 6:357-363.

Klatt, B. J. 1986. Factor Affecting the Distribution and Abundance of *Microtus ochrogaster* and *M. pennsylvanicus* in East-Central Illinois. Ph.D. Thesis. University of Illinois, Urbana-Champaign, Illinois. 108 pp.

Klatt, B.J. and L.L. Getz. 1986. Vegetation Characteristics of *Microtus ochrogaster* and *M. pennsylvanicus* Habitats in East-Central Illinois. Journal of Mammalogy 68:569-577.

Kling, G.W., K. Hayhoe, L.B. Johnson, J.J. Magnuson, S. Polasky, S.K. Robinson, B.J. Shuter, M.M. Wander, D.J. Wuebbles, D.R. Zak, R.L. Lindroth, S.C. Moser, and M.L. Wilson. 2003. *Confronting Climate Change in the Great Lakes Region: Impacts on our Communities and Ecosystems*. Union of Concerned Scientists, Cambridge, Massasachusetts, and Ecological Society of America, Washington, D.C.

Kling, G. W. and D. J. Wuebbles 2005. *Confronting Climate Change in the Great Lakes Region: Impacts on our Communities and Ecosystems.* Executive Summary, Updated Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, D.C.

Kuhn, A., J. Copeland, J. Cooley, H. Vogel, K. Taylor, D. Nacci, and P. August. 2011. Modeling habitat associations for the Common Loon (*Gavia immer*) at multiple scales in northeastern North America. *Avian Conservation and Ecology* 6(1): 4. [online] URL: http://www.ace-eco.org/vol6/iss1/art4/http://dx.doi.org/10.5751/ACE-00451-060104

Kurta, A. 1995. *Mammals of the Great Lakes Region*. University of Michigan Press, Ann Arbor, MI. 376pp.

Kurta, A. 2008. *Bats of Michigan.* Publication No. 2, Indiana State University Center for North American Bat Research and Conservation.

Kurta, A., R. Foster, E. Hough, L. Winhold. 2005. The Evening Bat (*Nycticeius humeralis*) on the Northern Edge of Its Range—a Maternity Colony in Michigan. *Am. Midl. Nat.* 154:264–267

Lee. D.H., R. Moulton, and B.A. Hibner. 1996. Climate change impacts on western Lake Erie, Detroit River, and Lake St. Clair water levels. Great Lakes-St. Lawrence Basin Project Report, Ann Arbor, MI. 51 pp.

Lofgren, B.M., F.H. Quinn, A.H. Clites, R.A. Assel, A.J. Eberhardt, and C.L. Luukkonen. 2002. Evaluation of potential impacts on Great Lakes water resources based on climate scenarios of two GCM's. Journal of Great Lakes Research 28(4):537-554.

Ludsin, S. 2011. Ohio State Univeristy Webinar, "Climate Change Impacts on Great Lakes Fishes". www.changingclimate.osu.edu

Matthews, S.N., R. J. O'Connor, L. R. Iverson, and A. M. Prasad. 2004. Atlas of climate change effects in 150 bird species of the eastern United States. United States Department of Agriculture Forest Service Northeastern Research Station General Technical Report NE-318. 341 pp.

Matthews, S.N., L. R. Iverson, A.M. Prasad, A. M., and M.P. Peters. 2007-ongoing. A Climate Change Atlas for 147 Bird Species of the Eastern United States [database]. http://www.nrs.fs.fed.us/atlas/bird, Northern Research Station, USDA Forest Service, Delaware, Ohio.

Matthews, S. N., Iverson, L. R., Prasad, A. M. and Peters, M. P. 2011. Changes in potential habitat of 147 North American breeding bird species in response to redistribution of trees and climate following predicted climate change. Ecography, 34: no. doi: 10.1111/j.1600-0587.2010.06803.x Published online: http://onlinelibrary.wiley.com/doi/10.1111/j.1600-0587.2010.06803.x/full

Michigan Climate Action Council. 2009. Michigan Climate Action Plan. Final report to Governor Jennifer M. Granholm, Michigan Department of Environmental Quality. 111 pp + appendices. http://www.miclimatechange.us/ewebeditpro/items/O46F21226.pdf

Michigan Department of Environmental Quality, Office of Great Lakes. 2009. MI-Great Lakes Plan: Our Path to Protect, Restore, and Sustain Michigan's Natural Treasures. 79 pp. http://www.michigan.gov/documents/deq/MI-GLPlan_262388_7.pdf

Michigan Fish Atlas. Available at http://www.michigan.gov/dnr/0,1607,7-153-10364-30538--,00.html

Michigan Natural Features Inventory (MNFI). 2011. Biotics Database. Michigan Natural Features Inventory, Lansing, MI.

Miller, M.P., Haig, S.M., Gratto-Trevor, C.L., and T.D. Mullins, 2009, Molecular population genetic structure in the Piping Plover: U.S. Geological Survey Open-File Report 2009-1032, 30 p.

Mortsch, L., H. Hengeveld, M. Lister, B. Lofgren, F. Quinn, M. Silvitzky, and L. Wenger. 2000. Climate change impacts on the hydrology of the Great Lakes-St. Lawrence system. Canadian Water Resources Journal 25:153-179.

Munzer, O. M. 2008. *Ecology of The Evening Bat (Nycticeius humeralis) At The Northern Edge Of Its Range.* M.S. Thesis, Eastern Michigan University.

National Assessment Synthesis Team (NAST). 2000. *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*. US Climate Change Science Program/US Global Change Research Program, Washington, D.C. www.usgcrp.gov/usgcrp/nacc/.

Nekola, J.C. 1998. Terrestrial gastropod inventory of the Niagaran Escarpment and Keweenaw Volcanic Belt in Michigan's Upper Peninsula. Final Report, Michigan Department of Natural Resources Small Grants Program, Lansing. 133 pages.

Poff, N.L., M.M. Brinson, J.W. Day Jr. 2002. "Aquatic Ecosystems and Global Climate Change: Potential impacts on inland freshwater and coastal wetland ecosystems in the United States." Prepared for the Pew Center on Global Climate Change.

Prasad, A. M., L. R. Iverson, and A. Liaw. 2006. Newer classification and regression tree techniques: bagging and random forests for ecological prediction. Ecosystems 9:181-199. http://www.treesearch.fs.fed.us/pubs/22432

Price, J.T. and T.L. Root. 2000. Focus: Effects of climate change on bird distributions and migration patterns. In: *Preparing for a Changing Climate The Potential Consequences of Climate Variability and Change Great Lakes Overview*, P. J. Sousounis and J. M. Bisanz, eds., A report of the Great Lakes Regional Assessment Group for the U.S. Global Change Research Program, 65-68.

Rosenzweig, C., G. Casassa, D.J. Karoly, A. Imeson, C. Liu, A. Menzel, S. Rawlins, T.L. Root, B. Seguin, and P. Tryjanowski. 2007. Assessment of observed changes and responses in natural and unmanaged systems. *Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M. L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds. Cambridge University Press, Cambridge, UK, 79-131.

Schlesinger, M.D., J.D. Corser, K.A. Perkins, and E.L. White. 2011. Vulnerability of at-risk species to climate change in New York. New York Natural Heritage Program, Albany, NY.

Thorp, J.H, J.E. Alexander, B.L. Bukaveckas, G.A. Cobbs, and K.L. Bresko. 1998. Responses of Ohio River and Lake Erie dreissinid mollusks to changes in temperature and turbidity. Canadian Journal of Fisheries and Aquatic Sciences. 55(1):220-229.

Trautman, M. B. 1981. The Fishes of Ohio. 2nd Ed., Ohio State University Press, Columbus, 782 p.

U. S. Environmental Protection Agency and Environment Canada. 2006. Lake Erie Lakewide Management Plan Report.

Watters, G.T., Hoggarth, M.A. & D.H. Stansbery. 2009. *The Freshwater Mussels of Ohio*. The Ohio State University Press, Columbus. 421 pp.

Wilcox, K.L., S.A. Petrie, L.A. Maynard, and S.W. Meyer. 2003. Historical distribution and abundance of *Phragmites australis* at Long Point, Lake Erie, Ontario. Journal of Great Lakes Research 29(4):664-680.

Wilson, W. H. Jr., D. Kipervaser, and S. A. Lilley. 2000. Spring Arrival Dates of Maine Migratory Breeding Birds: 1994-1997 vs. 1899-1911. Northeastern Naturalist, Vol. 7, No. 1 (2000), pp. 1-6

Wisconsin's Changing Climate: Impacts and Adaptation. 2011. Wisconsin Initiative on Climate Change Impacts. Nelson Institute for Environmental Studies, University of Wisconsin-Madison and the Wisconsin Department of Natural Resources, Madison, Wisconsin.

Young, B., E. Byers, K. Gravuer, K. Hall. G. Hammerson, and A. Redder. 2011. Guidelines for using the NatureServe Climate Change Vulnerability Index. Release 2.1. Arlington, VA.

Appendix 1. Key to codes and definitions for global, state, and CCVI ranks used in the document and tables.

NatureServe Conservation Status Ranks

G1, S1	Critically imperiled globally or in the state because of extreme rarity (often 5 or fewer occurrences) or because of some factor(s) such as a steep population decline making it especially vulnerable to extirpation.
G2, S2	Imperiled globally or in the state because of rarity due to very restricted range, very few populations (often 20 or less), steep population declines, or other factors making it very vulnerable to extirpation.
G3, S3	Vulnerable globally or in the state due to restricted range, relatively few populations (often 80 or less), recent and widespread declines, or other factors making it vulnerable to extinction.
G4, S4	Apparently secure species are uncommon but not rare but there is some cause for concern due to declines or other factors.
G5, S5	Secure species are common, widespread, and abundant globally or in the state.

GH, SH	Only known historically rangewide (global) or not reported in NY the last 20 years
GX, SX	Apparently extinct (global) or extirpated from NY (state)
GU, SU	Lack of information or substantial conflicting information about status or trends makes ranking infeasible at this time
SNA	A visitor to the state but not a regular occupant (such as a bird or insect migrating through the state), or a species that is predicted to occur in NY but that has not been found.
SNR	No effort has yet been made to rank the species.

Vulnerability Index Scores

EV	Extremely Vulnerable – Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050.
HV	Highly Vulnerable – Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050.
MV	Moderately Vulnerable – Abundance and/or range extent within geographical area assessed likely to decrease by 2050.
PS	Not Vulnerable/Presumed Stable – Available evidence does not suggest that abundance and/or range extent within geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change.
IL	Not Vulnerable/Increase Likely – Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050.
IE	Insufficient Evidence – Available information about a species' vulnerability is inadequate to calculate an Index score.

Individual Risk Factor Scores

GI	Greatly Increase Vulnerability
Inc	Increase Vulnerability
SI	Somewhat Increase Vulnerability
N	Neutral
SD	Somewhat Decrease Vulnerability
Dec	Decrease Vulnerability
N/A	Not Applicable
U	Unknown

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Amphibians							
Acris crepitans blanchardi/ Acris blanchardi	Blanchard's Cricket Frog	G5	S2S3	EV	VH		MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Harding 1997, Beauclerc 2010 - genetic variation. Natural barriers - upland areas without suitable wetland habitats. Anthropogenic barriers - intense agricultural and Predicted increase in ppt in winter and spring which could lead to increased flooding; increased flooding in the winter can be catastrophic for overwintering cricket frogs although if temperatures are warmer but may not be as bad. Prefer alkaline waters.
Amybstoma laterale	Blue-spotted Salamander	G5	S5	EV	VH		NatureServe Explorer and Harding 1997. Natural barriers - Great Lakes (Lakes Michigan, Huron, and Superior) act as natural barriers for a northern portion of the population in the state. Section C: C2c: Dependence on specific disturbance regime likely to be impacted by climate change - increased flooding of rivers/streams could lead to potential for fish to enter breeding pools and decrease eggs/larvae or wash them away; C3 - Restriction to uncommon geological features or derivatives - Harding 1997 - species most abundant in moist woodlands with sandy soils but turn up in variety of habitats including open fields and suburban backyards. Demastes et al 2007 - genetic variation.
Amybstoma texanum	Smallmouth Salamander	G5	S1	EV	VH	Species may expand range in assessment area.	MNFI Database, NatureServe Explorer, MNFI Species Abstract, MNFI Rare Species Explorer, and Harding 1997. Section B - Anthropogenic barriers - statewide - increase vulnerability due to agricultural development and urbanization; if just along coastal zone - greatly increase vulnerability, so tried both ways; Section C: C2c: Dependence on specific disturbance regime likely to be impacted by climate change - increased flooding of rivers/streams could lead to potential for fish to enter breeding pools and decrease eggs/larvae or wash them away; C3 - Restriction to uncommon geological features or derivatives - Associated with vernal pools/shallow water systems that range from pH 6-10 but 6-8 optimal so either neutral or somewhat decrease vulnerability/somewhat flexible but not highly generalized - found on a subset of dominant water chemistry types within its range but not sure if pH 6-8 common at occupied sites.
Anaxyrus fowleri/ Bufo fowleri	Fowler's Toad	G5	S5	MV	Mod	Species may expand range in assessment area.	Harding 1997, NatureServe Explorer. Natural barriers - primarily Lake Michigan. Closely associated with sandy soils, particularly along shorelines.

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Hemidactylium scutatum	Four-toed Salamander	G5	S5	EV	Mod		NatureServe Explorer and Harding 1997. Natural barriers - Great Lakes (Lakes Michigan, Huron, and Superior) act as natural barriers for a northern portion of the population in the state. Adults live under objects or among mosses in swamps, boggy streams, and wet, wooded or open areas near ponds or quiet, mossy or grassy/sedgy pools (the larval habitat). Sphagnum moss is commonly abundant in suitable habitat. Flooding may adversely impact species. Herman 2009 - genetic variation info.
Lithobates pipiens	Northern Leopard Frog	G5	S5	HV	Mod		Harding 1997, NatureServe Explorer. Natural barriers - primarily Lakes Michigan, Huron, and Superior. Hoffman and Blouin 2004 - genetic variation. Increased flooding could potentially increase habitat for species but also could increase runoff, sedimentation and pollution/contamination in wetland/aquatic habitats.
Lithobates sylvaticus	Wood Frog	G5	S5	EV	High		NatureServe Explorer, Harding 1997 - general info. Gibbs and Breisch 2001 - phenological response
Necturus maculosus	Mudpuppy	G5	S5	MV	Mod	Species may expand range in assessment area.	NatureServe Explorer, Harding 1997.
Plethodon cinereus	Redback Salamander	G5	S5	HV	Mod		NatureServe Explorer, Harding 1997, Welsh and Droege 2001, Highton and Webster 1976 and Larson et al. 1984 - genetic variation. Natural barriers - Lake Michigan, Lake Huron and Lake Superior.
Pseudacris maculata	Boreal Chorus Frog	G5	S1	EV	VH		MNFI Natural Heritage Database, MNFI Rare Species Explorer, NatureServe Explorer, Harding 1997. Natural barrier - Lake Superior. Increased flooding could lead to some increased habitat but also could lead to increased runoff, sedimentation and reduced water quality.
Birds							
Ammodramus savannarum	Grasshopper Sparrow	G5	S3S4	PS	VH	Species may expand range in assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, USDA USFS Northern Research Station Matthews et al. 2004 and 2007 and ongoing - Climate Change Bird Atlas http://nrs.fs.fed.us/atlas/bird/bird_atlas.html# - modelled future change in range or population size. Kuvlesky et al. 2007 and Stewart et al. 2007 - wind development impacts. Habitat - grasslands, prairie, old fields, cultivated fields, pastures, and savannas. Increase in disturbance like fire could increase habitat for the species but burning during the breeding season in the summer could negatively impact species.

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Ardea herodias	Great Blue Heron	G5	S5	PS	Mod		MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, USDA USFS Northern Research Station Matthews et al. 2004 and 2007 and ongoing - Climate Change Bird Atlas http://nrs.fs.fed.us/atlas/bird/bird_atlas.html# - modelled change in range and population size, Wilson et al 2000 - phenological response in ME. Increased disturbance (e.g., flooding) could increase habitat but also could lead to decreased water quality. Increased storm events and severe winds could knock down nest trees and decrease habitat and nesting success.
Botaurus lentiginosus	American Bittern	G4	S3S4	MV	High		MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, Cornell Lab of Ornithology Bird Guide, Distribution info from North American Breeding Bird Survey Data on USGS Patuxent Bird Identification InforCenter, USFS Northern Research Station Matthews et al. 2007 and ongoing - Climate Change Bird Atlas http://nrs.fs.fed.us/atlas/bird/bird_atlas.html#, Wilson et al 2000 for phenological response in ME. Increased flooding could potentially increase habitat for this species but flooding also could increase runoff, siltation, and pollution in wetlands. Typically found in large, shallow wetlands (area-dependent species).
Buteo lineatus	Red-shouldered Hawk	G5	S3S4	PS	VH	Species may expand range in assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, Cornell Lab of Ornithology Bird Guide, Distribution info from North American Breeding Bird Survey Data on USGS Patuxent Bird Identification InforCenter, USFS Northern Research Station Matthews et al. 2007 and ongoing - Climate Change Bird Atlas http://nrs.fs.fed.us/atlas/bird/bird_atlas.html#, Kuvlesky et al. 2007 - Wind energy development impacts on wildlife - wind turbines can cause significant mortality of raptors if placed in inappropriate locations but otherwise may not cause significant mortality.

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Charadrius melodus	Piping Plover	G3	S1	MV	VH		MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, Cornell Lab of Ornithology Bird Guide. Center of range longitudinally, northern part of range latitudinally. Ideal habitat consists of wide, flat, open, sandy beach with sparse vegetation and scattered cobble - may increase with reduced GL levels. Nesting territories often include small creeks, seeps or interdunal wetlands - specific aquatic/wetland habitats that are highly vulnerable to loss or reduction with climate change. Miller et al. 2009 (genetics data) - Comparable genetic diversity to Snowy Plover - similar listed taxon, and evidence of recent bottleneck and population expansion in Great Lakes population. Although reduced GL water levels could increase habitat for species, increased variation in lake levels, increased storm/extreme precipitation events, increased wind along shoreline will lead to increased waves, increased erosion, and increased flooding along shoreline which could reduce species' abundance and habitat quality.
Chilodonias niger	Black tern	G4	S3	MV	VH	Species range may shift and perhaps leave the assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, Cornell Lab of Ornithology Bird Guide, Distribution info from North American Breeding Bird Survey Data on USGS Patuxent Bird Identification InfoCenter, Kuvlesky et al. 2007 - wind energy development impacts, Matthews et al 2004 - modeled future change in range. Southern edge of breeding range in the Midwest. Black terns nest on floating plant matter. The instability of their nests leaves them vulnerable to storms, wave action, and rapid water level changes such as occur in floods. Their reproductive success fluctuates widely from year to year, depending on weather and water levels. Although reduced GL water levels could increase habitat for species, increased variation in lake levels, increased storm/extreme precipitation events, increased wind along shoreline will lead to increased waves, increased erosion, and increased flooding along shoreline which could reduce species' abundance and habitat quality.

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Cistothorus palustris	Marsh Wren	G5	S3S4	PS	VH	Species may expand range in assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, Cornell Lab of Ornithology Bird Guide, Distribution info from North American Breeding Bird Survey Data on USGS Patuxent Bird Identification InfoCenter, Stewart et al 2007 and Kuvlesky et al. 2007 - wind energy development impacts. Along northern edge of breeding range in the Midwest, but range extends further north to the west. Although reduced GL water levels could increase habitat for species, increased variation in lake levels, increased storm/extreme precipitation events, increased wind along shoreline will lead to increased waves, increased erosion, and increased flooding which could reduce species' abundance and habitat quality, along with reduced water levels in inland marshes. In Michigan, marsh wrens usually nest over water in cattail and bulrush stands.
Coturnicops noveboracensis	Yellow rail	G4	S1S2	MV	Low	Species range may shift and perhaps leave the assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, Cornell Lab of Ornithology Bird Guide, Distribution info from North American Breeding Bird Survey Data on USGS Patuxent Bird Identification InfoCenter, Alvo, R. and M. Robert. 1999. COSEWIC status report on the yellow rail. Disturbance - flooding would adversely impact species but fire could increase or maintain habitat and benefit species.
Dendroica discolor	Prairie Warbler	G5	S1	IL	Mod	Species may expand range in assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, USDA USFS Northern Research Station Matthews et al. 204 and 2007 and ongoing - Climate Change Bird Atlas http://nrs.fs.fed.us/atlas/bird/bird_atlas.html# - modelled change in range and population size, Duvlesky et al. 2007 and Stewart et al. 2007 - wind development impacts. Has use early successional stages of GL dunelands, jack-pine plains burnt a decade ago, and recently burnt areas of former pineries now dominated by deciduous shrubs and small trees for habitat in Michigan (Michigan BBA).
Dendroica kirtlandii	Kirtland's Warbler	G1	S1	IL	Mod	Species range may shift and perhaps leave the assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991. Increased fires would benefit this species. USFWS Kirtland's Warbler Wildlife Management Area/Comprehensive Conservation Plan - reported that climate change modelling of jack pine indicates jack pine may remain in similar abundance but shift distribution a little within or around KW range but did not model KW distribution, range, or abundance.

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Falco columbarius	Merlin	G5	S1S2	MV	Mod	Species range may shift and perhaps leave the assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, Cornell Lab of Ornithology Bird Guide, Distribution info from North American Breeding Bird Survey Data on USGS Patuxent Bird Identification InfoCenter. Southern edge of breeding range. Circumboreal species. Breeds mostly along lakeshores/shoreline and on islands in boreal forest and other forests. Utilizes nests of other birds, mostly crows and ravens.
Gavia immer	Common Loon	G5	S3S4	HV	VH	Species range may shift and perhaps leave the assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, Cornell Lab of Ornithology Bird Guide, Distribution info from North American Breeding Bird Survey Data on USGS Patuxent Bird Identification InforCenter, USFS Northern Research Station Matthews et al. 2007 and ongoing - Climate Change Bird Atlas http://nrs.fs.fed.us/atlas/bird/bird_atlas.html#, Kuhn et al 2011 (habitat info), Wilson et al 2000 for phenological response in ME at least.
Haliaeetus leucocephalis	Bald Eagle	G5	S4	PS	High	Species range may shift and perhaps leave the assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, Cornell Lab of Ornithology Bird Guide, Distribution info from North American Breeding Bird Survey Data on USGS Patuxent Bird Identification InforCenter. Assessment area in Michigan represents southern edge of breeding range. Best and Bowerman 2011 - Bald eagles along Michigan shoreline nesting significantly earlier but not nesting earlier in the interior (http://www.fws.gov/news/blog/index.cfm/2011/6/10/Michigan-Nesting-Behavior-May-Provide-Clues-to-Climate-Change-Effects-in-Bald-Eagles).
Ixobrychus exilis	Least Bittern	G5	S2	MV	VH	Species may expand range in assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breed Bird Atlas 1991. Lower Great Lakes water levels might increase nesting habitat for this species. But decreased water levels and wetlands inland would negatively impact species. Utilizes deeper water marshes, freshwater to brackish, and marsh size, cover type and ratio may be important. Increased flooding could adversely impact species by increasing runoff, siltation, and chemical contaminants/pollution in wetlands.

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Meleagris gallopavo	Wild Turkey	G5	S5	PS	VH	Species may expand range in assessment area.	NatureServe Explorer, Michigan Breeding Bird Atlas 1991, Kuvlesky et al. 2007 and Stewart et al. 2007 - wind development impacts. Habitat - wide variety of forests with mast-producing trees, openings of herbaceous growth, and protection from disturbance. Mature oak, beech, and hickory are important food for turkey. Forages in grasslands or forest clearings in the summer. Winter range - upland hardwood, mixed hardwood-conifer, conifer and lowland forests. Natural barrier - Great Lakes. Fleming and Porter 2007 - turkey dispersal and barriers. Increased fire could lead to increased habitat (openings, grasslands, old fields) but fire during the growing season also could adversely affect species since nests on the ground.
Nycticorax nycticorax	Black-crowned Night-heron	G5	S2S3	PS	VH	Species may expand range in assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, Cornell Lab of Ornithology Bird Guide, Distribution info from North American Breeding Bird Survey Data on USGS Patuxent Bird Identification InforCenter. Species primarily utilizes Great Lakes/coastal marshes, swamps, and islands (for nesting) in Michigan. Predicted drop in Great Lakes water levels could lead to expansion of GL coastal wetland and island habitats for this species. Species associated with mid-successional habitat/vegetation nesting in shrubs and small/young trees. Ice and wind along the shoreline help to maintain mid-successional habitat.
Pandion haliaetus	Osprey	G5	S4	PS	VH	Species range may shift and perhaps leave the assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, Cornell Lab of Ornithology Bird Guide, Distribution info from North American Breeding Bird Survey Data on USGS Patuxent Bird Identification InforCenter, USFS Northern Research Station Matthews et al. 2007 and ongoing - Climate Change Bird Atlas http://nrs.fs.fed.us/atlas/bird/bird_atlas.html#, Wilson et al 2000 for phenological response.
Phasianus colchicus	Ring-necked Pheasant	G5	SNA	PS	High		NatureServe Explorer, Michigan Breeding Bird Atlas 1991; Wilson et al. 1992, Leif 2005, Homan et al. 2000 - dispersal/movement distances; Kuvlesky et al. 2007 and Stewart et al. 2007 - wind development impacts. USDA USFS Northern Research Station Matthews et al. 2004 and 2007 and ongoing - Climate Change Bird Atlas http://nrs.fs.fed.us/atlas/bird/bird_atlas.html# - modelled change in range and population size. Habitat - Row crops, old fields, hay fields, occasional nesting in old fields, grassy/shrubby fence rows, marshes. Winter range - . Natural barriers - Forest and Great Lakes. Increased disturbance fire could lead to increased habitat (openings, grasslands, old fields) but fire during the growing season also could adversely affect species since it nests on the ground.

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Rallus elegans	King Rail	G4	S1	PS	VH	Species may expand range in assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, Cornell Lab of Ornithology Bird Guide, Distribution info from North American Breeding Bird Survey Data on USGS Patuxent Bird Identification InfoCenter.
Sterna forsteri	Forster's Tern	G5	S2	MV	Mod		MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, Cornell Lab of Ornithology Bird Guide, Distribution info from North American Breeding Bird Survey Data on USGS Patuxent Bird Identification InfoCenter, Stewart et al. 2007 - windfarm impacts on birds. Species nests in freshwater marshes along shoreline, frequently in open water away from the shoreline, and along also inland lakes. Minnesota DNR Species Profile 2011 http://www.dnr.state.mn.us/rsg/profile.html?action=elementDetail&selectedElement=ABNNM08090, Dulin 1990, Fraser 1994 - impacts of disturbance like flooding and water level fluctation. Although reduced GL water levels could increase habitat for species, increased variation in lake levels, increased storm/extreme precipitation events, increased wind along shoreline will lead to increased waves, increased erosion, and increased flooding along shoreline which could reduce species' abundance and habitat quality.
Sternia caspia	Caspian Tern	G5	S2	MV	VH		MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, Cornell Lab of Ornithology Bird Guide, Distribution info from North American Breeding Bird Survey Data on USGS Patuxent Bird Identification InfoCenter. Although reduced GL water levels could increase habitat for species, increased variation in lake levels, increased storm/extreme precipitation events, increased wind along shoreline will lead to increased waves, increased erosion, and increased flooding along shoreline which could reduce species' abundance and habitat quality.
Sternia hirundo	Common Tern	G5	S2	MV	VH	Species range may shift and perhaps leave the assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, Cornell Lab of Ornithology Bird Guide, Distribution info from North American Breeding Bird Survey Data on USGS Patuxent Bird Identification InfoCenter, Wilson et al 2000 for phenological response in ME. Southern edge of breeding range in the Midwest, extends further south along the Atlantic Coast. Nest mainly on bare sandy, gravelly parts of islamds or peninsulas or along shoreline. Habitat would likely increase if GL water levels drop as currently predicted.

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Tympanuchus phasianellus	Sharp-tailed grouse	G4	S3S4	PS	VH	Species range may shift and perhaps leave the assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Michigan Breeding Bird Atlas 1991, Cornell Lab of Ornithology Bird Guide, Distribution info from North American Breeding Bird Survey Data on USGS Patuxent Bird Identification InfoCenter, Sjogren and Corace 2006 - Conservation Assessment for Sharp-tailed Grouse in the Great Lakes Region.
Fish							
Acipenser fulvescens	Lake sturgeon	G3G4	S2	HV	Mod	Species may expand range in assessment area.	
Clinostomus elongatus	Redside dace	G3G4	S1S2	EV	High		
Coregonus artedi	Lake herring	G5	S3	MV	Low		
Esox americanus	Grass pickerel (redfin pickerel)	G5	S5	MV	Low		
Hypopthalmichthys nobilis	Big head carp	G5		PS	VH	Species may expand range in assessment area.	This invasive species has not been recorded in Michigan but was calculated as a hypothetical resident of Lake Michigan.
Lepisosteus oculatus	Spotted gar	G5	S2S3	HV	Mod	Species may expand range in assessment area.	
Notropis anogenus	Pugnose shiner	G3	S3	HV	Mod		
Notropis photogenis	Silver shiner	G5	S1	HV	Low	Species may expand range in assessment area.	
Noturus stigmosus	Northern madtom	G3	S1	EV	Mod	Species may expand range in assessment area.	
Opsopoeodus emiliae	Pugnose minnow	G5	S1	HV	Low	Species may expand range in assessment area.	
Percina copelandi	Channel darter	G4	S1S2	HV	Mod		
Sander canadensis	Sauger	G5	S1	HV	Low		
Insects							
Aeshna canadensis	Canada darner	G5	SNR	IL	VH	Species range may shift and perhaps leave the assessment area.	Dragonflies through Binoculars: A field guide to Dragonflies of North America, NatureServe Explorer, MNFI Rare Species Explorer, http://insects.ummz.lsa.umich.edu/MICHODO/michodolist.html

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Appalachia arcana	Secretive locust	G2G3	S2S3	MV	VH		MNFI Rare Species Explorer, MNFI Animal Abstract, Nature Serve Explorer
Boloria freija	Freija fritillary	G5	S3S4	HV	Low		MNFI Rare Species Explorer, MNFI Animal Abstract, Nature Serve Explorer, Michigan Butterflies and Skippers
Boloria frigga	Frigga fritillary	G5	S3S4	HV	Low		MNFI Rare Species Explorer, MNFI Animal Abstract, Nature Serve Explorer, Michigan Butterflies and Skippers
Brychius hungerfordi	Hungerford's crawling water beetle	G1	S1	HV	VH		MNFI Rare Species Explorer, MNFI Animal Abstract, Nature Serve Explorer
Calephelis mutica	Swamp metalmark	G3	S1S2	HV	Mod	Species may expand range in assessment area.	MNFI Rare Species Explorer, MNFI Animal Abstract, Nature Serve Explorer, Michigan Butterflies and Skippers
Dorydiella kansana	Leafhopper	GNR	S1S2	HV	VH		MNFI Rare Species Explorer, Nature Serve Explorer, www.fs.fed.us/r9/wildlife/tes/ca-overview/docs/.../Dorydiella_Kansana.pdf
Erebia discoidalis	Red-disked alpine	G5	S2S3	MV	Low	Species range may shift and perhaps leave the assessment area.	MNFI Rare Species Explorer, MNFI Animal Abstract, Nature Serve Explorer, The Butterflies of Canada
Euxoa aurulenta	Dune cutworm	G5	S1S2	PS	VH		MNFI Rare Species Explorer, MNFI Animal Abstract, Nature Serve Explorer
Flexamia delongi	Leafhopper	GNR	S1S2	PS	VH		MNFI Rare Species Explorer, Nature Serve Explorer, http://spot.colorado.edu/~hicks/delongi.html
Flexamia reflexus	Leafhopper	GNR	S1	PS	VH		MNFI Rare Species Explorer, Nature Serve Explorer,http://www.fs.fed.us/r9/wildlife/tes/ca-overview/docs/insects/Flexamia_Reflexa.pdf
Lycaeides idas nabokovi	Northern blue	G5TU	S2	HV	VH		MNFI Rare Species Explorer, MNFI Animal Abstract, Nature Serve Explorer, Michigan Butterflies and Skippers
Lycaeides melissa samuelis	Karner blue	G5T2	S2	HV	VH		MNFI Rare Species Explorer, MNFI Animal Abstract, Nature Serve Explorer, Michigan Butterflies and Skippers
Neonympha mitchellii mitchellii	Mitchell's satyr	G2T2	S1	EV	VH	Species may expand range in assessment area.	MNFI Rare Species Explorer, MNFI Animal Abstract, Nature Serve Explorer, Michigan Butterflies and Skippers
Papaipema aweme	Aweme borer	G1	SH	MV	Mod	Species range may shift and perhaps leave the assessment area.	MNFI Rare Species Explorer, MNFI Animal Abstract, Nature Serve Explorer
Somatochlora hineana	Hine's Emerald Dragonfly	G2G3	S1	EV	VH	Species may expand range in assessment area.	Nature Serve Explorer, MNFI Rare Species Explorer

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Somatochlora incurvata	Incurvate emerald	G4	S1S2	MV	VH		Dragonflies through Binoculars: A field guide to Dragonflies of North America, NatureServe Explorer, MNFI Rare Species Explorer
Trimerotropis huroniana	Lake Huron locust	G2G3	S2S3	MV	VH		MNFI Rare Species Explorer, MNFI Animal Abstract, Nature Serve Explorer
Mammals							
Alces americanus	Moose	5	4	HV	VH		While moose can disperse to the west, dispersal in that direction would also be against the climate gradient. Lake Superior constitutes a barrier, but also defines the northern edge of our are of geographic consideration. For the moose, an increase in temperatures may result in greater exposure to two parasites (brain worm and a liver fluke), which adversely affect survival. An increase in temperatures may also result in their thermal niche being completely absent from the state.
Canis lupus	gray wolf	4	3	PS	VH	Species range may shift and perhaps leave the assessment area.	
Lepus americanus	Snowshoe hare	5	5	HV	VH		Historical hydrological niche: 38.97 - 29.14 = 9.83
Lynx canadensis	Lynx	5	1	HV	VH	Species range may shift and perhaps leave the assessment area.	While lynx are dependent on large scale fires, and fires may increase with climate change, we do not expect an increase in large scale fires as human fire suppression efforts will continue. Therefore, we rated the effect of changes in disturbance regimes as neutral. For interspecific interactions, lynx may be more vulnerable to interspecific aggression by fishers, increased competition with coyotes and bobcats, and suffer a decrease in snowshoe hare, their preferred prey item.
Martes americana	American marten	5	3	MV	Low		Historical hydrological niche: 37.82 - 28.42 = 9.4
Microtus orchrogaster	Prairie vole	5	1	PS	VH	Species may expand range in assessment area.	Historical hydrological niche: 37.9 - 33.85 = 4.05
Microtus pinetorum	Woodland vole	5	3/4	PS	VH	Species may expand range in assessment area.	While this species is currently limited to the lower peninsula, its overall range includes populations well into norther Wisconsin and it is presumed that those populations could well serve as sources for colonization of the upper peninsula; historical hydrological niche: 39.64 - 25.67 = 13.97

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Myotis sodalis	Indiana bat	2	1	PS	Mod	Species may expand range in assessment area.	Historic ppt range: 38.29 - 30.52 = 7.71 inches; cave-hibernating bats are NOT considered cave-obligate species (per discussion with Kim Hall and NatureServe staff, the cave-hibernating habit of this species seems analogous to island nesting birds, and the Indiana bat is considered moderately to highly dependent on a specific geologic feature, ergo it is considered "Somewhat susceptible" to climate change. However, a warming trend in Michigan may actually make caves and mines in Michigan, which are currently considered too cold for hibernation, more amenable as hibernacula.
Nycticeius humeralis	Evening bat	5	NA	PS	VH	Species may expand range in assessment area.	Historic ppt range: 37.97 - 31.97 = 6.00 inches; The evening bat is not a cave hibernating bat, but rather spends both its summers and winters roosting in trees. The colony located near Palymyra in Lenawee County is the northern most recorded colony in the US. Evening bats perform long distance migration between their summer and winter habitats, with their winter range located primarily south of a line between South Carolina and Arkansas. With warming temperatures, evening bat populations in Michigan may actually expand. The colony near Palmyra was only first discovered in the early 2000s and may represent a northern expansion already.
Odocoileus virginianus	White-tailed deer	5	5	PS	VH		Historical hydrological niche: 39.64 - 25.67 = 13.97
Sorex fumeus	Smoky shrew	5	1	HV	VH		For historical ppt range, used rastors from east end of upper peninsula: 35.23-29.72 = 5.51 inches
Ursus americanus	Black bear	5	5	PS	VH	Species range may shift and perhaps leave the assessment area.	Historical hydrological niche: 38.97 - 29.14 = 9.83
Mussels							
Alasmidonta viridis	Slippershell	G4G5	S2S3	EV	VH	Species may expand range in assessment area.	
Dreissena polymorpha	Zebra mussel	G5	SNA	PS	VH		
Epioblasma torulosa rangiana	Norther riffleshell	G2T2	S1	EV	High	Species may expand range in assessment area.	
Epioblasma triquetra	Snuffbox	G3	S1	HV	Low		
Lasmigona compressa	Creek heelsplitter	G5	SNR	HV	Mod		
Ligumia nasuta	Eastern pondmussel	G4	NSR	MV	Low		
Obliquaria reflexa	Threehorn wartyback	G5	NSR	EV	High		

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Obovaria olivaria	Hickorynut	G4	S2	HV	Low	Species may expand range in assessment area.	
Obovaria subrotunda	Round hickorynut	G4	S1	IE	—-		This species had insuficient evidence because its host fish are not known.
Pleurobema clava	Northern clubshell	G1G2	S1	EV	VH	Species may expand range in assessment area.	This species is not present within the coastal zone but was run to provide contrast to the other species as it is a very rare species that occurs in small streams
Simpsonaias ambigua	Salamander mussel	G3	S1	EV	High		
Villosa fabalis	Rayed bean	G2	S1	HV	Low	Species may expand range in assessment area.	
Reptiles							
Chelydra serpentina serpentina	Snapping Turtle	G5	S5	PS	VH		NatureServe Explorer and Harding 1997. Natural barriers - Great Lakes to some degree.
Chrysemys picta	Painted Turtle	G5	S5	PS	VH		NatureServe Explorer and Harding 1997. Natural barriers - Lakes Michigan, Huron, and Superior.
Clemmys guttata	Spotted Turtle	G5	S2	MV	Mod	Species may expand range in assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Harding 1997. Western edge of range too. Extensive forest - natural barrier.
Clonophis kirtlandi	Kirtland's Snake	G2	S1	MV	VH	Species may expand range in assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, and Harding 1997. Michigan represents part of the northern edge of species range. Anthropogenic barriers - busy highways primarily within range - e.g., US-94, I-96, urbanization and agricultural development. Depends on crayfish burrows. Feeds mainly on earthworms, slugs and leeches, occasionally insects and crayfish. Ray 2009 - genetic variation info and modelled future change in range and population size.
Diadophis punctatus edwardsii	Northern Ring-necked Snake	G5	S5	HV	Mod		Harding 1997 and NatureServe Explorer; Natural barriers - Great Lakes - Lake Michigan, Lake Huron, and Lake Superior. Used distribution in Harding and NatureServe Explorer for section A. Feeds heavilly on amphibians, esp. toads, but also feed on salamanders, reptiles, small mammals, birds and insects. Regularly occurs in moist, shady woodlands, although floodprone bottomlands are avoided. Also will use more open habitats close to woods such as clearcuts, old fields, grassy dunes, and beaches and trash dumps. Rarely seen on surface - largely nocturnal except for during heavy rains. Fontanella et al. 2008 for genetic variation information, compared to estimates in Ray 2009.

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Emydoidea blandingii	Blanding's Turtle	G4	S3	HV	Mod	Species may expand range in assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Harding 1997. Northern edge of species range and center of range longitudinally. Very limited range centered around Michigan. Natural barriers - Great Lakes - Lakes Michigan, Huron, and Superior. Anthropogenic barriers - busy highways, urbanization and agricultural development. Increase in flooding can impact turtle hibernacula and nesting habitat/success. May lose seasonal shallow wetland habitats but if flooding increases, may increase backwater habitats so ended up with increase/somewhat increase vulnerability.
Glyptemys insculpta	Wood Turtle	G3	S2S3	MV	Mod		MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, and Harding 1997. Also represents southern edge of range in the Midwest but extends farther south along the East Coast so selected northern edge of range instead. AET:PET exposure based on distribution in Rare Species Explorer. Natural barriers - Great Lakes - Lakes Michigan, Huron, and Superior. Increase in flooding can impact turtle hibernacula and nesting habitat/success and increase runoff/pollution.
Heterodon platirhinos	Eastern Hognose Snake	G5	S3S4	MV	Low		Harding 1997 and NatureServe Explorer; Natural barriers - Great Lakes - Lake Michigan, Lake Huron. Feeds heavilly on amphibians, esp. toads, but also feed on salamanders, reptiles, small mammals, birds and insects.
Pantherophis gloydi	Eastern Fox Snake	G3	S2	HV	Mod		MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, and Harding 1997. Artificial barriers - heavily urbanized areas, seawalls, agricultural areas, busy highways. Row et al 2010 - genetic variation and natural barrier info.
Pantherophis spiloides	Gray Ratsnake	G5T5	S3	PS	High	Species may expand range in assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Burbrink 2001 - for species range. Anthropogenic barriers - Current distribution in southern Michigan surrounded by large areas of agricultural development and some urban development and couple major highways but there are still some forests on the landscape so not greatly or completely impaired. Species also can use open habitats or edge of forest and open habitats. Historical hydrological niche - 38.5 - 30.2 = 8.3. Disturbance - increase in forest fires could impact/decrease habitat for this species.
Sistrurus catenatus catenatus	Eastern Massasauga	G3G4T3Q	S3S4	HV	Mod	Species may expand range in assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, and Harding 1997. Natural barrier - Lake Michigan and Lake Huron and areas with extensive, closed canopy forests. Require crayfish burrows for hibernacula at some sites. Chiucchi 2011 and Anderson et al. 2009 - genetic variation info. Ray 2009 - genetic info and modelled change in range.

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Terrapene carolina carolina	Eastern Box Turtle	G5	S2S3	MV	Mod	Species may expand range in assessment area.	MNFI Natural Heritage Database, MNFI Rare Species Explorer, MNFI Species Abstract, NatureServe Explorer, Harding 1997. Anthropogenic barriers - busy highways primarily within range - e.g., US-94, I-96, urbanization and agricultural development. Increase in flooding can impact turtle hibernacula and nesting habitat/success.
Snail							
Fontigens nickliniana	Watercress snail	G5	SU	EV	VH		
Gastrocopta holzingeri	Lambda snaggletooth	G5	S1	EV	VH		
Helisoma anceps	Two-ridge rams-horn	G5	SU	MV	Mod		
Hendersonia occulta	Cherrystone drop	G4	S1	EV	Low		
Mesodon elevatus	Proud globe	G5	SU	HV	Mod		
Pomatiopsis cincinnatiensis	Brown walker	G4	SU	HV	Low		
Potamopyrgus antipodarum	New Zealand mudsnail	G5	SU	MV	Low		This species was run as a hypothetical resident of the Assessment Area. It has not been documented in Michigan but is present in the Great Lakes.
Stagnicola contracta	Deepwater pondsnail	G1	S1	HV	VH		
Vallonia gracilicosta albula	terrestrial snail	G4Q	S1	HV	Mod		
Vertigo bollesiana	Delicate vertigo	G4	S2	HV	Mod		
Vertigo nylanderi	Deep-throat vertigo	G3G4	S1	EV	Mod		
Plants							
Adlumia fungosa	climbing fumitory	G4	S3	PS	Mod		
Agalinis skinneriana	Skinner's agalinis	G3G4	S1	EV	VH		Good information on seed dispersal is drawn from NatureServe explorer, citing the extensive work of Canne-Hilliker on the genus.
Amerorchis rotundifolia	small round-leaved orchis	G5	S1	EV	VH	Species range may shift and perhaps leave the assessment area.	
Asclepias hirtella	tall green milkweed	G5	S2	HV	Low		
Asclepias sullivantii	Sullivant's milkweed	G5	S2	HV	Low		
Asplenium scolopendrium	American hart's tongue fern	G4T3	S1	HV	VH	Species may expand range in assessment area.	Some dependence on snow cover per information in NatureServe Explorer, although too much snow cover or persistence can be detrimental. Neutral with regard to geological substrate, because it is common to dominant within the range (Niagara Escaprment). Some dependence on bryophyte cover for creation of habitat, or helping to maintain moisture conditions for spore germination and development of sporelings.
Aster furcatus	forked aster	G3	S1	HV	VH		
Besseya bullii	kitten-tails	G3	S1	EV	VH		

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Betula murrayana	Murray birdh	G1Q	S1	EV	VH		Only one site known globally; taxon
Botrychium acuminatum	moonwort	G1	S1	PS	VH	Species range may shift and perhaps leave the assessment area.	
Botrychium campestre	prairie moonwort, dunewort	G3G4	S2	MV	VH		
Botrychium hesperium	Western moonwort	G4	S2	PS	Low		
Botrychium mormo	goblin fern	G3	S2	PS	Mod		Midwest endemic species
Botrychium spathulatum	spatulate moonwort	G3	S2	PS	Low		
Bromus nottowayanus	satin brome	G3G5	S3	EV	Mod	Species may expand range in assessment area.	Obtained paper by McKenzie and Ladd (1995), which provided detailed information on habitat, flowering period, and ecology for Missouri.
Bromus pumpellianus	Pumpelly's bromegrass	G5T4	S2	MV	VH		
Cacalia plantaginea	prairie Indian-plantain	G4G5	S3	HV	Low	Species may expand range in assessment area.	
Calamagrostis lacustris	northern reedgrass	G3Q	S1	PS	Low	Species range may shift and perhaps leave the assessment area.	Species is now subsumed under the broad concept of C. stricta ssp. inexpansa
Calypso bulbosa	calypso orchid	G5	S2	HV	Low		
Carex scirpoidea	bulrush sedge	G5	S2	MV	VH		
Cirsium hillii	Hill's thistle	G3	S3	IL	VH		
Cirsium pitcheri	Pitcher's thistle	G3	S3	MV	VH		
Cypripedium arietinum	ram's head lady's-slipper	G3	S3	HV	VH		Genetic variation has been assessed (M. Case 1994, Am. J. Bot.), but although the variation is low it is also low in several related taxa (C. candidum, acaule, and reginae), although it is high in C. calceolus).
Cystopteris laurentiana	Laurentian fragile fern	G3	S1S2	PS	VH	Species range may shift and perhaps leave the assessment area.	

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Drosera anglica	English sundew	G5	S3	HV	High	Species range may shift and perhaps leave the assessment area.	
Hymenoxys herbacea	lakeside daisy	G3	S1	HV	VH		
Hypericum adpressum	creeping St. John's-wort	G3	S1	MV	VH	Species may expand range in assessment area.	Known from only two Michigan occurrences in Newaygo County
Iris lacustris	dwarf lake iris	G3	S3	HV	VH		
Isotria medeoloides	lesser whorled pogonia	G2	SX	EV	VH		
Leymus mollis	American dune wild-rye	G5	S3	PS	VH	Species range may shift and perhaps leave the assessment area.	
Listera auriculata	auricled twayblade	G3	S2S3	EV	VH		Much relevant habitat information available from NatureServe Explorer; extensive information that demonstrates dependence on cool microsites, ice scouring, and seasonal flooding for creation of habitat as well as aiding in dispersal
Lycopodiella margueritae	Northern prostrate clubmoss	G2	S2	HV	VH	Species may expand range in assessment area.	
Lycopodiella subappressa	Northern appressed clubmoss	G2	S2	HV	VH	Species may expand range in assessment area.	
Mimulus michiganensis	Michigan monkey-flower	G5T1	S1	EV	VH		
Nelumbo lutea	American lotus	G4	S2	PS	Low	Species may expand range in assessment area.	
Orobanche fasciculata	fasciled broom-rape	G4	S2	HV	VH		Obligate host plant in Michigan is observed to be a single species, Artemisia campestre, whereas several species of Artemisia are hosts in the western portion of the range.
Panax quinquefolius	ginseng	G3G4	S2S3	EV	Mod	Species may expand range in assessment area.	Genetic information available (Cruse-Sanders and Hamrick) but not applicable to full range of species; genetic structure is high relative to life history type per Cruse-Sanders but this may not be the full picture
Pinguicula vulgaris	butterwort	G5	S3	HV	VH		

Appendix 2. Vulnerability Index Scores

Scientific name	Common name	GRank	SRank	Index	Confidence	Index Notes	Assessment Sources and Notes
Platanthera leucophaea	Eastern prairie fringed orchid	F3	S1	HV	Mod	Species may expand range in assessment area.	Dependent, as thus far known, on only a few species of hawk moths for pollination. Only 4 species documented as known pollinators.
Poa paludigena	bog bluegrass	G3	S2	EV	VH		
Potamogeton hillii	Hill's pondweed	G3	S2	HV	Mod		
Prosartes maculata	nodding mandarin	G3G4	SX	EV	VH	Species may expand range in assessment area.	
Sagittaria montevidensis	arrowhead	G4G5	S1S2	PS	VH	Species may expand range in assessment area.	
Schoenoplectus hallii	Hall's bulrush	G2G3	S2	EV	Low	Species may expand range in assessment area.	
Sisyrinchium strictum	blue-eyed-grass	G2Q	S2	MV	VH		
Solidago houghtonii	Houghton's goldenrod	G3	S3	HV	VH		
Stellaria longipes	American dune wild-rye	G5	S2	MV	VH		
Tanacetum huronense	Lake Huron tansy	G5T4T5	S3	MV	VH		
Tomanthera auriculata	eared foxglove	G3	SX	MV	Mod		
Triphora trianthophora	noding pogonia or three birds orchid	G3G4	S1	HV	Low	Species may expand range in assessment area.	Very little ecological and life history information available; consulted Case (Orchids of the Western Great Lakes Region) for natural history desciption. As for most orchids, very little information for assessing seed dispersal
Utricularia subulata	bladderwort	G5	S1	MV	VH		Scored as neutral for physiological hydrological niche instead of "somewhat increase' because listed as a C3/C4 taxon in Freeman's alternative photosynthetic pathways list.
Valerianella umbilicata	corn salad	G3G5	S2	HV	Mod	Species may expand range in assessment area.	
Zizania aquatica var. aquatica	wild rice	G5T5	S2S3	MV	VH		Zizana aquatica sensu lato noted in Freeman list as C3

Appendix 3. Intrinsic and modeled risk factor scores for the CCVI assessment. Scores are defined in Appendix 1.

Scientific name	Common name	Dispersal/Movement	historical thermal niche	physiological thermal niche	historical hydrological niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	Modeled overlap
Amphibians																			
Acris crepitans blanchardi/ Acris blanchardi	Blanchard's Cricket Frog	SI	N	N	Inc	SI	SI	N	N	N	N	N	N	SI	N/A	U	U	U	U
Amybstoma laterale	Blue-spotted Salamander	N	N	SI-N	SI	Inc	SI	N	N-SD	N	N	N	N	SI	N/A	U	U	U	U
Amybstoma texanum	Smallmouth Salamander	N	N	SI-N	GI	Inc	SI	N	N	N	N	N	N	U	U	U	U	U	U
Anaxyrus fowleri/ Bufo fowleri	Fowler's Toad	N	N	N-SD	Inc	N	SD	N	SI-N	N	N	N	N	U	U	U	U	U	U
Hemidactylium scutatum	Four-toed Salamander	SI	N	N	Inc	GI-Inc	SI	N	N-SD	N	N	N	N	N	N/A	U	U	U	U
Lithobates pipiens	Northern Leopard Frog	SD	N	SI-N	SI	Inc	SI	N	N	N	SD	N	N	N	N/A	U	U	U	U
Lithobates sylvaticus	Wood Frog	N-SD	N	Inc-SI	SI	Inc	SI	N	N	N	N	N	N	U	U	N	U	U	U
Necturus maculosus	Mudpuppy	SD	N	N	SI	SI-N	Inc-SI	N	SD	N	N	N	N	U	U	U	U	U	U
Plethodon cinereus	Redback Salamander	SI	N	N	SI	Inc	SI	N	SD	N	N	N	N	SI-N	N/A	U	U	U	U
Pseudacris maculata	Boreal Chorus Frog	SI-N	N	GI	GI	Inc	SI-SD	N	N-SD	N	N	N	N	U	U	U	U	U	U
Birds																			
Ammodramus savannarum	Grasshopper Sparrow	Dec	N	N	Inc	N-SD	SI	N	SD	N	N	N	N	U	U	U	U	SD	N
Ardea herodias	Great Blue Heron	Dec	N	N	SI	Inc	SI-N-SD	N	SD	N	N	N	N	U	U	N	U	SI-N	N
Botaurus lentiginosus	American Bittern	Dec	N	N	Inc	Inc	Inc	N	N-SD	N	N	N	N	U	U	U	U	Inc	Inc-SI
Buteo lineatus	Red-shouldered Hawk	Dec	N	N	Inc	Inc	SI-N	N	SD	N	N	N	N	U	U	U	U	N-SD	SI-N
Charadrius melodus	Piping Plover	Dec	N	N	Inc	Inc	Inc-SI	N	SI	N	N	N	N	N	N/A	U	U	U	U
Chilodonias niger	Black tern	Dec	N	N	Inc	Inc	Inc	N	SD	N	N	N	N	U	U	U	U	GI-Inc	U
Cistothorus palustris	Marsh Wren	Dec	N	N	Inc	Inc	Inc-SI	N	SD	N	N	N	N	U	U	U	U	U	U
Coturnicops noveboracensis	Yellow rail	Dec	N	SI-N	GI	Inc	SI	N	N	SI	SD	N	N	U	U	U	U	U	U
Dendroica discolor	Prairie Warbler	Dec	N	N	Inc	N-SD	SD-Dec	N	SI	N	N	N	N	U	U	U	U	SD-Dec	N
Dendroica kirtlandii	Kirtland's Warbler	Dec	N	SI-N	Inc	N-SD	SD-Dec	N	SD	SI	N	N	N	U	U	U	U	U	U

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Scientific name	Common name	Dispersal/Movement	historical thermal niche	physiological thermal niche	historical hydrological niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	Modeled overlap
Falco columbarius	Merlin	Dec	N	Inc	GI	SI-N	N	N	SD	SI	N	N	N	U	U	U	U	U	U
Gavia immer	Common Loon	Dec	N	Inc-SI	Inc	Inc-SI	Inc	N	SI-N	N	N	N	N	U	U	N	U	Inc	Inc
Haliaeetus leucocephalis	Bald Eagle	Dec	N	SI-N	Inc	SI-N	SI	N	SD	N	N	N	N	U	U	SD	U	U	U
Ixobrychus exilis	Least Bittern	Dec	N	N	Inc	Inc	Inc	N	N	N	N	N	N	U	U	U	U	U	U
Meleagris gallopavo	Wild Turkey	SD	N	N	Inc	N	SD	N	SD	N	SD	N	N	U	U	U	U	U	U
Nycticorax nycticorax	Black-crowned Night-heron	Dec	N	N	Inc	SI-N	N	SI	SI	N	SD	N	N	U	U	U	U	U	U
Pandion haliaetus	Osprey	Dec	N	N	Inc	N	SI	N	SD	N	N	N	N	U	U	U	U	U	U
Phasianus colchicus	Ring-necked Pheasant	N-SD	N	N	Inc-SI	SI	SI-SD	N	SD-Dec	N	SD	N	N	U	U	U	U	N-SD	N
Rallus elegans	King Rail	Dec	N	N	SI	Inc-SI	SI	N	N	N	N	N	N	U	U	U	U	U	U
Sterna forsteri	Forster's Tern	Dec	N	N	GI	SI-N	Inc	N	U	N	N	N	N	U	U	U	U	U	U
Sternia caspia	Caspian Tern	Dec	N	N	GI	N	Inc-SI	N	SI	N	N	N	N	U	U	U	U	U	U
Sternia hirundo	Common Tern	Dec	N	N	GI	N	Inc-SI	N	SI	N	N	N	N	U	U	U	U	U	U
Tympanuchus phasianellus	Sharp-tailed grouse	SD	N	Inc	Inc	N	SD-Dec	SI	N	N	SD	N	N	U	U	U	U	U	U
Fish																			
Acipenser fulvescens	Lake sturgeon	N	N	N	GI	SI-N	SI-N	N	N	N	N	N	N	SI-N	N/A	SI-N	U	U	U
Clinostomus elongatus	Redside dace	N	N	Inc-SI	Inc	SI-N	SI-N	N	N	N	N	N	N	U	U	U	U	U	U
Coregonus artedi	Lake herring	N	N	Inc-SI	SI	SI-N	SI-N	N	N	N	N	N	N	U	U	U	U	U	U
Esox americanus	Grass pickerel (redfin pickerel)	N	N	N	SI	SI-N	SI-N	N	N	N	N	N	N	U	U	U	U	U	U
Hypopthalmichthys nobilis	Big head carp	N	N	SD	N	N	N	N	N	N	N	N	N	U	U	U	U	U	U
Lepisosteus oculatus	Spotted gar	N	N	SI-N	GI	N	SI-N	N	N	N	N	N	N	U	U	U	U	U	U
Notropis anogenus	Pugnose shiner	N	N	SI-N	Inc	N	Inc-SI	N	N	N	N	N	N	U	U	U	U	U	U
Notropis photogenis	Silver shiner	N	N	SI-N	Inc	SI-N	SI-N	N	N	N	N	N	N	U	U	U	U	U	U
Noturus stigmosus	Northern madtom	N	N	SI	GI	SI-N	SI-N	N	N	N	N	N	N	U	U	U	U	U	U

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Scientific name	Common name	Dispersal/Movement	historical thermal niche	physiological thermal niche	historical hydrological niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	Modeled overlap
Opsopoeodus emiliae	Pugnose minnow	N	N	SI-N	GI	SI-N	SI-N	N	N	N	N	N	N	U	U	U	U	U	U
Percina copelandi	Channel darter	N	N	SI-N	GI	SI-N	SI-N	N	N	N	N	N	N	U	U	U	U	U	U
Sander canadensis	Sauger	N	N	SI-N	Inc	SI-N	SI-N	N	N	N	N	N	N	U	U	U	U	U	U
Insects																			
Aeshna canadensis	Canada darner	Dec	N	N	Inc	N	N	N	SD	U	N	U	U	U	N	U	U	U	U
Appalachia arcana	Secretive locust	SI	N	N	Inc	N	N	N	N	U	N	U	U	U	N	U	U	U	U
Boloria freija	Freija fritillary	SI	N	SI	Inc	Inc-SI	N	N	N	U	SI-N	U	U	U	N	U	U	U	U
Boloria frigga	Frigga fritillary	N	N	SI	Inc	Inc-SI	N	N	N	U	SI	U	U	U	N	U	U	U	U
Brychius hungerfordi	Hungerford's crawling water beetle	N	N	N	GI	N	SI	N	N	SI	N	U	U	U	N	U	U	U	U
Calephelis mutica	Swamp metalmark	SI-N	N	N	Inc	N	N	N	SI	N	SI	U	U	U	N	U	U	U	U
Dorydiella kansana	Leafhopper	SI	N	N	Inc	N	N	U	N	N	SI	U	U	U	N	U	U	U	U
Erebia discoidalis	Red-disked alpine	N	N	SI-N	Inc	N	N	N	N	U	SI	U	U	U	N	U	U	U	U
Euxoa aurulenta	Dune cutworm	Dec	N	SD	Inc	N	N	N	Inc	N	N	U	U	U	U	U	U	U	U
Flexamia delongi	Leafhopper	SI	N	SD	Inc	SD	N-SD	U	N	N	SI	U	U	U	N	U	U	U	U
Flexamia reflexus	Leafhopper	SI	N	SD	Inc	SD	SD	U	N	N	SI	U	U	U	N	U	U	U	U
Lycaeides idas nabokovi	Northern blue	N	N	N	Inc	N	N	N	N	N	Inc	U	U	U	SI-N	U	U	U	U
Lycaeides melissa samuelis	Karner blue	SD	N	N	Inc	N	SD	N	N	N	Inc	U	U	U	N	U	U	U	U
Neonympha mitchellii mitchellii	Mitchell's satyr	N	N	SI	Inc	GI	N	N	SI	SI	SI	U	U	U	SI-N	U	U	U	U
Papaipema aweme	Aweme borer	SD	N	N-SD	GI	N	N	N	Inc-SI	N	U	U	U	U	SI	U	U	U	U
Somatochlora hineana	Hine's Emerald Dragonfly	SD	N	GI	GI	GI	N	SI	SI	Inc	N	N	U	U	U	U	U	U	U
Somatochlora incurvata	Incurvate emerald	SD	N	N	Inc	Inc	N	SI	SI	N	N	U	U	U	U	U	U	U	U
Trimerotropis huroniana	Lake Huron locust	N	N	SD	Inc	SI	N	N	Inc	U	N	U	U	U	N	U	U	U	U
Mammals																			
Alces americanus	Moose	N	N	N	SI	SI	N	N	N	N	N	N	Inc	U	N	N	U	U	U
Canis lupus	gray wolf	N	N	N	SI	N	N	N	N	N	N	N	N	N	N/A	N	U	U	U

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Lepus americanus	Snowshoe hare	SD	N	N	Inc	SI	N	GI	N	N	N	N	U	U	U	U	U	U	U
Lynx canadensis	Lynx	N	N	N	SI	SI	N	Inc	N	N	SI	N	SI	N	N/A	N	N	GI	N
Martes americana	American marten	SD	N	N	Inc	SI	N	N	N	N	N	N	U	U	U	U	U	U	U
Microtus orchrogaster	Prairie vole	N	N	N	Inc	SD	N	N	N	N	N	N	U	U	U	N	U	U	U
Microtus pinetorum	Woodland vole	N	N	N	SI	N	N	N	N	N	N	N	U	U	U	N	U	U	U
Myotis sodalis	Indiana bat	N	N	N	Inc	N	N	N	SI-N-SD	N	N	U	U	U	U	U	U	U	U
Nycticeius humeralis	Evening bat	N	N	N	Inc	N	N	N	N	N	N	N	U	U	U	U	U	U	U
Odocoileus virginianus	White-tailed deer	SD	N	N	SI	N	N	N	N	N	N	N	U	U	U	U	U	U	U
Sorex fumeus	Smoky shrew	N	N	N	Inc	Inc	N	N	N	N	N	U	U	U	U	U	U	U	U
Ursus americanus	Black bear	SD	N	N	Inc	N	N	N	N	N	N	N	U	U	U	U	U	U	U
Mussels																			
Alasmidonta viridis	Slippershell	SI-N	N	SI	GI	SI-N	SI-N	N	N	N	U	SI	U	U	U	U	U	U	U
Dreissena polymorpha	Zebra mussel	Dec	N	N	SI	N	N	N	N	N	N	N	U	U	U	U	U	U	U
Epioblasma torulosa rangiana	Norther riffleshell	SI-N	N	N	GI	SI-N	SI-N	N	N	N	U	SI	U	U	SI	U	U	U	U
Epioblasma triquetra	Snuffbox	SI	N	N	Inc	SI-N	SI-N	N	N	N	U	SI	U	U	U	U	U	U	U
Lasmigona compressa	Creek heelsplitter	N	N	N	SI	SI-N	SI-N	N	N	N	U	N	U	U	U	U	U	U	U
Ligumia nasuta	Eastern pondmussel	N-SD	N	N	Inc	SI-N	SI-N	N	N	N	U	N	U	U	U	U	U	U	U
Obliquaria reflexa	Threehorn wartyback	Inc-SI	N	N	Inc	SI-N	SI-N	N	N	N	U	Inc-SI	U	U	U	U	U	U	U
Obovaria olivaria	Hickorynut	SI-N	N	N	GI	SI-N	SI-N	N	N	N	U	SI-N	U	U	U	U	U	U	U
Obovaria subrotunda	Round hickorynut	U	N	N	GI	SI-N	SI-N	N	N	N	U	U	U	U	U	U	U	U	U
Pleurobema clava	Northern clubshell	SI-N	N	N	GI	SI-N	SI-N	N	N	N	U	SI-N	U	U	Inc-SI	U	U	U	U
Simpsonaias ambigua	Salamander mussel	Inc-SI	N	N	Inc	SI-N	SI-N	N	N	N	U	Inc-SI	U	U	U	U	U	U	U

Appendix 3. Intrinsic and modeled risk factor scores for the CCVI assessment. Scores are defined in Appendix 1.

Scientific name	Common name	Dispersal/Movement	historical thermal niche	physiological thermal niche	historical hydrological niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	Modeled overlap
Villosa fabalis	Rayed bean	SI-N	N	N	Inc	SI-N	SI-N	N	N	N	U	SI-N	U	U	U	U	U	U	U
Reptiles																			
Chelydra serpentina serpentina	Snapping Turtle	SD	N	N	SI	N	SI-N	N	N	N	SD	N	N	U	U	U	U	U	U
Chrysemys picta	Painted Turtle	N	N	N	SI	N	N	N	N	N	SD	N	N	U	U	U	U	U	U
Clemmys guttata	Spotted Turtle	N	N	N	Inc	Inc	SI-N	N	SD	N	SD	N	N	U	U	U	U	U	U
Clonophis kirtlandi	Kirtland's Snake	N	N	N	Inc	Inc	N-SD	N	SD	SI	SI-N	N	N	SI	N/A	U	U	N	N
Diadophis punctatus edwardsii	Northern Ring-necked Snake	SI-N	N	N	Inc	Inc-SI	SI	N	SD	N	N	N	N	N	N/A	U	U	U	U
Emydoidea blandingii	Blanding's Turtle	N	N	N	Inc	Inc	SI	N	N	N	SD	N	N	U	U	U	U	U	U
Glyptemys insculpta	Wood Turtle	N	N	N	Inc	N	SI-N	N	N	N	SD	N	N	U	U	U	U	U	U
Heterodon platirhinos	Eastern Hognose Snake	N	N	N	Inc	N	N-SD	N	N	N	N	N	N	U	U	U	U	U	U
Pantherophis gloydi	Eastern Fox Snake	SD	N	N	GI	SI-N	SI-N	N	SI-N	N	N	N	N	SI-N	N/A	U	U	U	U
Pantherophis spiloides	Gray Ratsnake	N	N	N	Inc	N-SD	SI-N	N	SD	N	N	N	N	U	U	U	U	U	U
Sistrurus catenatus catenatus	Eastern Massasauga	N-SD	N	SI-N	Inc	Inc	SI	SI-N	SD	SI-N	N	N	N	SI-N	N/A	U	U	N	N
Terrapene carolina carolina	Eastern Box Turtle	N	N	N	Inc	SI-N	Inc-SI	N	N	N	SD	N	N	U	U	U	U	U	U
Snails																			
Fontigens nickliniana	Watercress snail	SI	N	N	Inc	SI	N	N	N	SI-N	N	N	N	U	U	U	U	U	U
Gastrocopta holzingeri	Lambda snaggletooth	SI	N	SI-N	GI	Inc-SI	N	N	SI	N	N	N	N	U	U	U	U	U	U
Helisoma anceps	Two-ridge rams-horn	SI	N	N	SI	SI-N	N	N	N	N	N	N	N	U	U	U	U	U	U
Hendersonia occulta	Cherrystone drop	SI	N	SI-N	GI	Inc-SI	N	N	N	N	N	N	N	U	U	U	U	U	U
Mesodon elevatus	Proud globe	SI	N	SI-N	Inc	SI-N	N	N	N	N	N	N	N	U	U	U	U	U	U
Pomatiopsis cincinnatiensis	Brown walker	SI	N	N	Inc	SI	N	N	N	N	N	N	N	U	U	U	U	U	U
Potamopyrgus antipodarum	New Zealand mudsnail	SI	N	N	SI	SI-N	N	N	N	N	N	N	N	U	U	U	U	U	U
Stagnicola contracta	Deepwater pondsnail	SI	N	N	Inc	SI-N	N	N	N	N	N	N	N	U	U	U	U	U	U
Vallonia gracilicosta albula	terrestrial snail	SI	N	SI-N	Inc	SI-N	N	N	SI	N	N	N	N	U	U	U	U	U	U
Vertigo bollesiana	Delicate vertigo	SI	N	Inc-SI	SI	SI-N	N	N	SI-N	N	N	N	N	U	U	U	U	U	U

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Scientific name	Common name	Dispersal/Movement	historical thermal niche	physiological thermal niche	historical hydrological niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	Modeled overlap
Vertigo nylanderi	Deep-throat vertigo	SI	N	Inc-SI	Inc	SI-N	N	N	SI-N	N	N	N	N	U	U	U	U	U	U
Plants																			
Adlumia fungosa	climbing fumitory	SI-N	N	N	Inc	N	N-SD	N	N	N	N/A	N	N	U	U	U	U	U	U
Agalinis skinneriana	Skinner's agalinis	Inc	N	N	GI	GI-Inc	SD-Dec	N	N	N	N/A	N	SI	U	U	U	U	U	U
Amerorchis rotundifolia	small round-leaved orchis	SI-N	N	GI	GI	GI	N	N	N	N	N/A	N	SI	U	U	U	U	U	U
Asclepias hirtella	tall green milkweed	N	N	N	Inc	N-SD	SD	N	SI	N	N/A	N	N	U	U	U	U	U	U
Asclepias sullivantii	Sullivant's milkweed	N	N	SD	GI	N-SD	SD	N	SI-N	N	N/A	N	N	U	U	U	U	U	U
Asplenium scolopendrium	American hart's tongue fern	N	N	Inc	GI	N	N	SI-N	N	SI	N/A	N	N	U	U	U	U	U	U
Aster furcatus	forked aster	SI	N	N	GI	SI	SI	N	N	N	N/A	N	N	U	U	U	U	U	U
Besseya bullii	kitten-tails	Inc	N	N	Inc	N	SD	N	SI	N	N/A	N	N	U	U	U	U	U	U
Betula murrayana	Murray birdh	SI	N	SI	GI	SI	N	N	N	N	N/A	N	N	U	U	U	U	U	U
Botrychium acuminatum	moonwort	N	N	N	GI	N	N	N	SI	N	N/A	N	N	U	U	U	U	U	U
Botrychium campestre	prairie moonwort, dunewort	N	N	N	GI	N	N	N	SI	N	N/A	N	N	U	U	U	U	U	U
Botrychium hesperium	Western moonwort	N	N	N	GI	N	N	N	SI-N	N	N/A	N	N	U	U	U	U	U	U
Botrychium mormo	goblin fern	N	N	N	Inc	N	SI-N	N	N	N	N/A	N	N	U	U	U	U	U	U
Botrychium spathulatum	spatulate moonwort	N	N	N	GI	N	N	N	SI-N	N	N/A	N	N	U	U	U	U	U	U
Bromus nottowayanus	satin brome	N	N	N	GI	GI-Inc	Inc-SI	N	N	N	N/A	N	N	U	U	U	U	U	U
Bromus pumpellianus	Pumpelly's bromegrass	SI	N	N	GI	N	N	N	SI	N	N/A	N	N	U	U	U	U	U	U
Cacalia plantaginea	prairie Indian-plantain	N	N	N	Inc	Inc-SI	SD	N	Inc	N	N/A	N	N	U	U	U	U	U	U

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Calamagrostis lacustris	northern reedgrass	N	N	SI-N	Inc	SI-N	N-SD	N	SI	N	N/A	N	N	U	U	U	U	U	U
Calypso bulbosa	calypso orchid	SI	N	SI	Inc	N	SI-N	N	N	N	N/A	N	SI	U	U	U	U	U	U
Carex scirpoidea	bulrush sedge	SI	N	N	GI	SI-N	N	N	N	N	N/A	N	N	U	U	U	U	U	U
Cirsium hillii	Hill's thistle	N	N	SD	Inc	SD	Dec	N	N	N	N/A	N	N	U	U	U	U	U	U
Cirsium pitcheri	Pitcher's thistle	SI	N	N	Inc	N	N	N	SI	N	N/A	N	N	SI	N/A	U	U	U	U
Cypripedium arietinum	ram's head lady's-slipper	SI	N	SI	Inc	SI	SI	N	N	N	N/A	N	SI	N	N/A	U	U	U	U
Cystopteris laurentiana	Laurentian fragile fern	N	N	N	Inc	N	N	N	SI	N	N/A	N	N	U	U	U	U	U	U
Drosera anglica	English sundew	Inc-SI-N	N	N	Inc	SI	N	N	Inc	N	N/A	N	N	U	U	U	U	U	U
Hymenoxys herbacea	lakeside daisy	Inc	N	N	GI	N	N	N	SI	N	N/A	N	N	SI	N/A	N	U	U	U
Hypericum adpressum	creeping St. John's-wort	N	N	N	GI	GI	N	N	N	N	N/A	N	N	U	U	U	U	U	U
Iris lacustris	dwarf lake iris	Inc	N	N	GI	N	N	SI	N	N	N/A	N	N	SI	N/A	N	U	U	U
Isotria medeoloides	lesser whorled pogonia	SI	N	N	GI	GI	N	N	N	N	N/A	U	SI	U	U	U	U	U	U
Leymus mollis	American dune wild-rye	N	N	N	Inc	N	N	N	SI	N	N/A	N	N	U	U	U	U	U	U
Listera auriculata	auricled twayblade	N	N	GI	GI	GI	Inc	SI-N	N	N	N/A	N	SI	U	U	U	U	U	U
Lycopodiella margueritae	Northern prostrate clubmoss	N	N	N	GI	GI	N	N	N	N	N/A	N	N	U	U	U	U	U	U
Lycopodiella subappressa	Northern appressed clubmoss	N	N	N	Inc	GI	N	N	N	N	N/A	N	N	U	U	U	U	U	U
Mimulus michiganensis	Michigan monkey-flower	Inc-SI	N	GI	GI	GI	N	N	SI	N	N/A	N	N	U	U	U	U	U	U
Nelumbo lutea	American lotus	N	N	N	Inc	N	N	N	N	N	N/A	N	N	U	U	U	U	U	U
Orobanche fasciculata	fasciled broom-rape	SI	N	N	GI	N	N	N	SI	N	N/A	N	Inc	U	U	U	U	U	U

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Scientific name	Common name	Dispersal/Movement	historical thermal niche	physiological thermal niche	historical hydrological niche	physiological hydrological niche	Disturbance	Ice/snow	Phys habitat	Other spp for hab	Diet	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenol response	Doc response	Modeled change	Modeled overlap
Panax quinquefolius	ginseng	N	N	SI	Inc	N	SI	N	N	N	N/A	N	N	U	U	U	U	U	U
Pinguicula vulgaris	butterwort	SI	N	N	GI	Inc	N	N	N	N	N/A	N	N	U	U	U	U	U	U
Platanthera leucophaea	Eastern prairie fringed orchid	N	N	N	SI	N	N-SD	N	N	N	N/A	N	U	SI	N/A	U	U	U	U
Poa paludigena	bog bluegrass	Inc-SI	N	GI	Inc	GI-Inc	N	N	N	N	N/A	N	U	U	U	U	U	U	U
Potamogeton hillii	Hill's pondweed	N	N	GI-Inc	GI	GI-Inc	N	N	N	N	N/A	N	N	U	U	U	U	U	U
Prosartes maculata	nodding mandarin	N	N	Inc-SI	GI	N	SI	N	N	N	N/A	N	N	U	U	U	U	U	U
Sagittaria montevidensis	arrowhead	N	N	N	GI	N	N	N	N	N	N/A	N	N	U	U	U	U	U	U
Schoenoplectus hallii	Hall's bulrush	SI-N	N	N	GI	GI	N	N	N	N	N/A	N	N	U	U	U	U	U	U
Sisyrinchium strictum	blue-eyed-grass	Inc	N	N	Inc	Inc-SI	N	N	N	N	N/A	N	N	U	U	U	U	U	U
Solidago houghtonii	Houghton's goldenrod	SI	N	N	GI	N	SI	N	SI	N	N/A	N	N	U	U	U	U	U	U
Stellaria longipes	American dune wild-rye	SI	N	N	GI	N	N	N	SI	N	N/A	N	U	U	U	U	U	U	U
Tanacetum huronense	Lake Huron tansy	SI	N	N	GI	N	SI	N	N	N	N/A	N	N	U	U	U	U	U	U
Tomanthera auriculata	eared foxglove	SI	N	SD	GI	SD	SD	N	N	N	N/A	N	SI	U	U	U	U	U	U
Triphora trianthophora	noding pogonia or three birds orchid	SI-N	N	SI	Inc	N	SI	N	N	N	N/A	N	SI	U	U	U	U	U	U
Utricularia subulata	bladderwort	Inc-SI	N	N	Inc	N	N	N	SI	N	N/A	N	N	U	U	U	U	U	U
Valerianella umbilicata	corn salad	N	N	N	GI	SI	SI	N	N	N	N/A	N	N	U	U	U	U	U	U
Zizania aquatica var. aquatica	wild rice	N	N	N	Inc	SI	SI	N	N	N	N/A	N	N	U	U	U	U	U	U

Appendix 4. Exposure and geography risk factor scores for CCVI assessment. Scores are defined in Appendix 1.

Scientific name	Common name	Mich Range Relative to Global Range	Percent range warmest (>5.5^{o}F)	Percent range warmer (5.1-5.5^{o}F)	Percent range warm (4.5-5.0^{o}F)	Percent range driest (-0.074 - -0.096)	Percent range drier (-0.051 - -0.073)	Percent range dry (-0.028 - -0.050)	Sea level	Natl barriers	Anth barriers	CC mitigation
Amphibians												
Acris crepitans blanchardi/ Acris blanchardi	Blanchard's Cricket Frog	Northern edge of range		100		85	15		N	N	SI	N
Amybstoma laterale	Blue-spotted Salamander	Southern edge of range		100		80	20		N	GI-Inc	SI	N
Amybstoma texanum	Smallmouth Salamander	Northern edge of range		100		80	20		N	N	GI-Inc	N
Anaxyrus fowleri/ Bufo fowleri	Fowler's Toad	Northern edge of range		100		50	50		N	Inc-SI	SI-N	N
Hemidactylium scutatum	Four-toed Salamander	Northern edge of range	10	85	5	30	45	25	N	Inc	SI	N
Lithobates pipiens	Northern Leopard Frog	Center of range	2	97	1	37	46	17	N	GI-Inc	SI	N
Lithobates sylvaticus	Wood Frog	Center of range	3	96	1	37	46	17	N	GI-Inc	SI	N
Necturus maculosus	Mudpuppy	Northern edge of range	3	96	1	37	46	17	N	Inc-SI	Inc-SI	U
Plethodon cinereus	Redback Salamander	Center of range	3	96	1	37	46	17	N	GI-Inc	SI	N
Pseudacris maculata	Boreal Chorus Frog	Center of range	50	50				100	N	GI	N	N
Birds												
Ammodramus savannarum	Grasshopper Sparrow	Northern edge of range		100		49	50	1	N	N	N	N
Ardea herodias	Great Blue Heron	Center of range	5	94	1	30	40	30	N	N	N	U
Botaurus lentiginosus	American Bittern	Center of range	5	90	5	30	45	25	N	N	N	SI-N
Buteo lineatus	Red-shouldered Hawk	Northern edge of range	1	95	4	10	80	10	N	N	N	SI-N
Charadrius melodus	Piping Plover	Center of range		98	2	5	85	10	N	N	N	SI
Chilodonias niger	Black tern	Southern edge of range		95	5	40	60		N	N	N	SI
Cistothorus palustris	Marsh Wren	Northern edge of range		98	2	65	30	5	N	N	N	N
Coturnicops noveboracensis	Yellow rail	Southern edge of range		100			80	20	N	N	N	N
Dendroica discolor	Prairie Warbler	Northern edge of range		100		30	70		N	N	N	N
Dendroica kirtlandii	Kirtland's Warbler	Entire range	5	95			55	45	N	N	N	N
Falco columbarius	Merlin	Southern edge of range	60	30	10		50	50	N	N	N	SI-N
Gavia immer	Common Loon	Southern edge of range	10	90		2	58	40	N	N	N	SI

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Haliaeetus leucocephalis	Bald Eagle	Southern edge of range	5	93	2	10	50	40	N	N	N	SI-N
Ixobrychus exilis	Least Bittern	Northern edge of range	2	96	2	50	45	5	N	N	N	SI-N
Meleagris gallopavo	Wild Turkey	Northern edge of range		97	3	15	84	1	N	Inc-SI	SI	SI-N
Nycticorax nycticorax	Black-crowned Night-heron	Northern edge of range		85	15	40	60		N	N	N	SI
Pandion haliaetus	Osprey	Southern edge of range	10	90		5	50	45	N	N	N	SI-N
Phasianus colchicus	Ring-necked Pheasant	Northern edge of range		100		75	25		N	Inc	N	N
Rallus elegans	King Rail	Northern edge of range		100		10	85	5	N	N	N	SI-N
Sterna forsteri	Forster's Tern	Center of range		100		80	20		N	N	N	SI-N
Sternia caspia	Caspian Tern	Center of range		100		15	85		N	N	N	SI
Sternia hirundo	Common Tern	Southern edge of range		90	10	20	80		N	N	N	SI
Tympanuchus phasianellus	Sharp-tailed grouse	Southern edge of range	15	85			50	50	N	N	N	SI-N
Fish												
Acipenser fulvescens	Lake sturgeon	Northern edge of range	5	91	4	36	46	18	N	N	Inc-SI	SI-N
Clinostomus elongatus	Redside dace	Center of range		100		65	5	30	N	Inc-SI	Inc-SI	SI-N
Coregonus artedi	Lake herring	Center of range	10	85	5	30	50	20	N	SI-N	SI-N	SI-N
Esox americanus	Grass pickerel (redfin pickerel)	Center of range		100		85	15		N	SI-N	Inc-SI	SI-N
Hypopthalmichthys nobilis	Big head carp	Northern edge of range		100		20	80		N	N	N	N
Lepisosteus oculatus	Spotted gar	Northern edge of range		100		80	20		N	N	SI-N	SI-N
Notropis anogenus	Pugnose shiner	Center of range		100		80	20		N	SI-N	SI-N	SI-N
Notropis photogenis	Silver shiner	Northern edge of range		100		75	25		N	SI-N	Inc-SI	SI-N
Noturus stigmosus	Northern madtom	Northern edge of range		100		100			N	SI-N	Inc-SI	SI-N
Opsopoeodus emiliae	Pugnose minnow	Northern edge of range		100		100			N	SI-N	Inc-SI	SI-N
Percina copelandi	Channel darter	Center of range		95	5	40	60		N	SI-N	Inc-SI	SI-N
Sander canadensis	Sauger	Center of range	30	70		25	75		N	SI-N	Inc-SI	SI-N
Insects												
Aeshna canadensis	Canada darner	Southern edge of range	3	95	2	37	45	18	N	N	N	N
Appalachia arcana	Secretive locust	Entire range		100			100		N	SI	N	N

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Boloria freija	Freija fritillary	Southern edge of range	10	90			20	80	N	GI	N	N
Boloria frigga	Frigga fritillary	Southern edge of range	20	80			50	50	N	GI-Inc	N	N
Brychius hungerfordi	Hungerford's crawling water beetle	Center of range		100			100		N	SI	Inc	N
Calephelis mutica	Swamp metalmark	Northern edge of range		100		80	20		N	N	Inc-SI	N
Dorydiella kansana	Leafhopper	Northern edge of range		90	10	70	30		N	N	Inc	U
Erebia discoidalis	Red-disked alpine	Southern edge of range	25	75				100	N	SI	N	N
Euxoa aurulenta	Dune cutworm	Center of range		100		10	90		N	N	N	U
Flexamia delongi	Leafhopper	Center of range		90	10	40	60		N	N	N	U
Flexamia reflexus	Leafhopper	Northern edge of range		100		100			N	N	SI	U
Lycaeides idas nabokovi	Northern blue	Southern edge of range	30	70			30	70	N	GI	N	N
Lycaeides melissa samuelis	Karner blue	Center of range		100		50	50		N	N	Inc	SI
Neonympha mitchellii mitchellii	Mitchell's satyr	Northern edge of range		100		50	50		N	N	Inc	N
Papaipema aweme	Aweme borer	Southern edge of range		100			100		N	N	N	N
Somatochlora hineana	Hine's Emerald Dragonfly	Northern edge of range		80	20		100		N	N	N	U
Somatochlora incurvata	Incurvate emerald	East/west edge of range	6	94			77	23	N	N	N	N
Trimerotropis huroniana	Lake Huron locust	Center of range		95	5		90	10	N	N	N	N
Mammals												
Alces americanus	Moose	Southern edge of range	11	89			41	59	N	GI-Inc	N	N
Canis lupus	gray wolf	Southern edge of range	11	89			41	59	N	SI-N	N	SI
Lepus americanus	Snowshoe hare	Southern edge of range	10	85	5		50	50	N	Inc	N	SI
Lynx canadensis	Lynx	Southern edge of range	11	89			41	59	N	Inc	N	N
Martes americana	American marten	Southern edge of range	11	89			41	59	N	GI-Inc	N	SI
Microtus orchrogaster	Prairie vole	Northern edge of range		100		25	75		N	N	N	N
Microtus pinetorum	Woodland vole	Northern edge of range	11	89		52	48		N	N	N	N
Myotis sodalis	Indiana bat	Northern edge of range		100		66	34		N	N	N	N
Nycticeius humeralis	Evening bat	Northern edge of range		100		50	50		N	N	N	N
Odocoileus virginianus	White-tailed deer	Center of range	3	96	1	36	46	18	N	N	N	N

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Scientific name	Common name	Mich Range Relative to Global Range	Percent range warmest (>5.5°F)	Percent range warmer (5.1-5.5°F)	Percent range warm (4.5-5.0°F)	Percent range driest (-0.074 - -0.096)	Percent range drier (-0.051 - -0.073)	Percent range dry (-0.028 - -0.050)	Sea level	Natl barriers	Anth barriers	CC mitigation
Sorex fumeus	Smoky shrew	East/west edge of range		100			100		N	GI	N	U
Ursus americanus	Black bear	Southern edge of range	10	85	5		50	50	N	SI	N	N
Mussels												
Alasmidonta viridis	Slippershell	Northern edge of range	5	95		55	40	5	N	SI	SI	SI
Dreissena polymorpha	Zebra mussel	Center of range	2	96	2	37	46	17	N	SI-N	N	N
Epioblasma torulosa rangiana	Norther riffleshell	Northern edge of range		100		100			N	N	SI	SI-N
Epioblasma triquetra	Snuffbox	Northern edge of range		100		90	10		N	N	SI	SI-N
Lasmigona compressa	Creek heelsplitter	Center of range		100		95	5		N	Inc-SI	Inc-SI	SI-N
Ligumia nasuta	Eastern pondmussel	East/west edge of range		100		50	45	5	N	SI-N	SI	SI-N
Obliquaria reflexa	Threehorn wartyback	Northern edge of range		100		90	10		N	SI-N	SI	SI-N
Obovaria olivaria	Hickorynut	Northern edge of range		100		50	50		N	SI-N	SI	SI-N
Obovaria subrotunda	Round hickorynut	Northern edge of range		100		100			N	SI-N	SI	SI-N
Pleurobema clava	Northern clubshell	Northern edge of range		100		50	50		N	SI-N	Inc-SI	SI-N
Simpsonaias ambigua	Salamander mussel	Northern edge of range		100		100			N	SI-N	SI	SI-N
Villosa fabalis	Rayed bean	Northern edge of range		100		95	5		N	SI-N	SI	SI-N
Reptiles												
Chelydra serpentina serpentina	Snapping Turtle	Center of range	2	97	1	37	46	17	N	Inc	N	N
Chrysemys picta	Painted Turtle	Center of range	2	97	1	37	46	17	N	GI-Inc	N	N
Clemmys guttata	Spotted Turtle	Northern edge of range		100		90	10		N	SI-N	Inc-SI	N
Clonophis kirtlandi	Kirtland's Snake	Northern edge of range		100		50	50		N	N	SI	N
Diadophis punctatus edwardsii	Northern Ring-necked Snake	Northern edge of range	3	95	2	37	46	17	N	GI-Inc	N	N
Emydoidea blandingii	Blanding's Turtle	Northern edge of range		98	2	55	44	1	N	Inc-SI	SI	SI-N
Glyptemys insculpta	Wood Turtle	Northern edge of range	5	93	2	10	70	20	N	GI-Inc	N	N
Heterodon platirhinos	Eastern Hognose Snake	Northern edge of range		99	1	50	50		N	Inc	SI	N
Pantherophis gloydi	Eastern Fox Snake	East/west edge of range		100		90	10		N	SI	Inc-SI	U
Pantherophis spiloides	Gray Ratsnake	Northern edge of range		100		60	40		N	N	SI-N	N

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Sistrurus catenatus catenatus	Eastern Massasauga	Northern edge of range		95	5	70	30		N	Inc-SI	SI	N
Terrapene carolina carolina	Eastern Box Turtle	Northern edge of range		100		65	35		N	N	SI	U
Snails												
Fontigens nickliniana	Watercress snail	Northern edge of range		100		66	34		N	GI-Inc	Inc	N
Gastrocopta holzingeri	Lambda snaggletooth	Center of range		100			90	10	N	GI-Inc	SI	N
Helisoma anceps	Two-ridge rams-horn	Center of range	3	96	1	25	50	25	N	SI	Inc-SI	N
Hendersonia occulta	Cherrystone drop	Northern edge of range		100			90	10	N	Inc-SI	SI	N
Mesodon elevatus	Proud globe	Northern edge of range		100			15	85	N	Inc-SI	Inc-SI	N
Pomatiopsis cincinnatiensis	Brown walker	Northern edge of range		100		66	34		N	Inc-SI	SI	N
Potamopyrgus antipodarum	New Zealand mudsnail	Center of range	3	96	1	25	50	25	N	SI-N	SI-N	N
Stagnicola contracta	Deepwater pondsnail	Entire range		100			100		N	Inc	Inc	N
Vallonia gracilicosta albula	terrestrial snail	Center of range		100			80	20	N	Inc-SI	SI	N
Vertigo bollesiana	Delicate vertigo	Center of range	5	95			75	25	N	Inc-SI	SI	N
Vertigo nylanderi	Deep-throat vertigo	Center of range		100			90	10	N	Inc-SI	SI	N
Plants												
Adlumia fungosa	climbing fumitory	Center of range	4	92	4	25	64	11	N	SI-N	SI-N	N
Agalinis skinneriana	Skinner's agalinis	Northern edge of range		100		100			N	Inc-SI	Inc-SI	N
Amerorchis rotundifolia	small round-leaved orchis	Southern edge of range		100			80	20	N	SI	N	N
Asclepias hirtella	tall green milkweed	Northern edge of range		100		91	9		N	GI-Inc	GI-Inc-SI	N
Asclepias sullivantii	Sullivant's milkweed	East/west edge of range		100		100			N	Inc	Inc	N

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Asplenium scolopendrium	American hart's tongue fern	Northern edge of range		100			100		N	N	N	N
Aster furcatus	forked aster	Northern edge of range		100		100			N	N	N	N
Besseya bullii	kitten-tails	East/west edge of range		100		71	29		N	Inc	Inc	N
Betula murrayana	Murray birdh	Entire range		100		100			N	GI	GI	N
Botrychium acuminatum	moonwort	Southern edge of range		100				100	N	N	N	N
Botrychium campestre	prairie moonwort, dunewort	East/west edge of range		100			91	9	N	N	N	N
Botrychium hesperium	Western moonwort	East/west edge of range		100			67	33	N	N	N	N
Botrychium mormo	goblin fern	East/west edge of range		100			50	50	N	SI-N	N	N
Botrychium spathulatum	spatulate moonwort	East/west edge of range		83	17		83	17	N	N	N	N
Bromus nottowayanus	satin brome	Northern edge of range		100		61	33	6	N	SI-N	SI-N	N
Bromus pumpellianus	Pumpelly's bromegrass	Southern edge of range		100			100		N	N	N	N
Cacalia plantaginea	prairie Indian-plantain	Northern edge of range		98	2	52	48		N	Inc-SI	SI	N
Calamagrostis lacustris	northern reedgrass	Southern edge of range	6	88	6	11	67	22	N	N	N	N
Calypso bulbosa	calypso orchid	Southern edge of range	26	72	2		92	8	N	N	N	N
Carex scirpoidea	bulrush sedge	Southern edge of range	6	88	6		100		N	N	N	N
Cirsium hillii	Hill's thistle	East/west edge of range		100		2	98		N	N	N	N
Cirsium pitcheri	Pitcher's thistle	Center of range		95	5	4	95	1	N	N	N	N
Cypripedium arietinum	ram's head lady's-slipper	Southern edge of range	2	96	2	4	88	8	N	N	N	N
Cystopteris laurentiana	Laurentian fragile fern	Southern edge of range	20	80			80	20	N	N	N	N
Drosera anglica	English sundew	Southern edge of range	25	75		8	80	12	N	SI-N	N	U
Hymenoxys herbacea	lakeside daisy	Center of range		100			100		N	SI	N	N
Hypericum adpressum	creeping St. John's-wort	Northern edge of range		100			100		N	N	N	N
Iris lacustris	dwarf lake iris	Center of range		85	15		100		N	N	N	N
Isotria medeoloides	lesser whorled pogonia	East/west edge of range		100			100		N	SI	N	N
Leymus mollis	American dune wild-rye	Southern edge of range		100			19	81	N	N	N	N
Listera auriculata	auricled twayblade	Southern edge of range	29	71			52	48	N	Inc	N	N
Lycopodiella margueritae	Northern prostrate clubmoss	Northern edge of range		100		100			N	SI	N	N

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Lycopodiella subappressa	Northern appressed clubmoss	Northern edge of range		100		67	22	11	N	SI	N	N
Mimulus michiganensis	Michigan monkey-flower	Entire range		100			100		N	Inc	N	N
Nelumbo lutea	American lotus	Northern edge of range		100		91	9		N	N	N	SI-N
Orobanche fasciculata	fasciled broom-rape	East/west edge of range		100			100		N	N	N	U
Panax quinquefolius	ginseng	Northern edge of range		99	1	50	46	4	N	Inc-SI	Inc-SI	N
Pinguicula vulgaris	butterwort	Southern edge of range	36	61	3		86	14	N	SI	N	N
Platanthera leucophaea	Eastern prairie fringed orchid	Northern edge of range		100		90	10		N	SI-N	SI	SI
Poa paludigena	bog bluegrass	Northern edge of range	10	90		58	42		N	SI	SI	N
Potamogeton hillii	Hill's pondweed	East/west edge of range		100			100		N	N	N	N
Prosartes maculata	nodding mandarin	Northern edge of range		100		100			N	SI	SI	N
Sagittaria montevidensis	arrowhead	Northern edge of range		100		100			N	N	N	N
Schoenoplectus hallii	Hall's bulrush	Northern edge of range		100		100			N	SI	N	N
Sisyrinchium strictum	blue-eyed-grass	East/west edge of range	10	90		40	40	20	N	N	N	N
Solidago houghtonii	Houghton's goldenrod	East/west edge of range		100			100		N	N	SI-N	N
Stellaria longipes	American dune wild-rye	Southern edge of range		100			79	21	N	N	N	N
Tanacetum huronense	Lake Huron tansy	Southern edge of range		99	1		98	2	N	N	N	N
Tomanthera auriculata	eared foxglove	Northern edge of range		100			100		N	Inc-SI	SI-N	N
Triphora trianthophora	noding pogonia or three birds orchid	Northern edge of range		100		21	79		N	SI	SI	U
Utricularia subulata	bladderwort	Northern edge of range		100		33	67		N	N	N	N
Valerianella umbilicata	corn salad	Northern edge of range		100		100			N	SI-N	SI-N	N
Zizania aquatica var. aquatica	wild rice	Center of range		100		72	28		N	N	N	N

Appendix 5. Discussion of Individual Mammal CCVI Results.

Smoky shrew (*Sorex fumeus*) G5/S1 – Highly vulnerable, very high confidence. This species occurs in cool, moist forests throughout the Appalachian Mountains and in the eastern portion of the Great Lakes basin. In Michigan, it is known only from Sugar Island, at the eastern tip of the upper peninsula. Due to predicted increased temperatures and drier conditions, expansion of its preferred habitat, maple-hemlock forest, is unlikely. With expected loss of its relatively specialized habitat, mitigation measures are unlikely to be helpful. However, it should be noted that this species is considered globally secure.

Indiana bat (*Myotis sodalis*) G2/S1 – Moderately vulnerable, very high confidence. The Indiana bat is one of the “cave bats” that occur in Michigan (Kurta 2008). Cave bats hibernate in caves and mines over winter, but spend their summers away from these hibernacula. In the case of the Indiana bat, only one hibernaculum is known in Michigan and is located at Tippy Dam near Manistee. The majority of Indiana bats, approximately 90%, in Michigan are females and are found in the southern tier of counties where they form “maternity colonies”; in general, male Indiana bats do not travel far from their hibernacula. These females migrate to Michigan from hibernacula in southern Indiana and northern Kentucky (Gardner and Cook 2002). Curiously, it is not known at present where the bats from the Tippy Dam hibernaculum spend their summers. The bats spend the daylight hours primarily under the peeling bark of dead trees, emerging at dusk to feed. Indiana bats use a wide variety of tree species for roost trees and, at present, roost trees are not thought to be a limiting resource with respect to their northward distribution. On the other hand, the requirements for hibernacula are quite specific, especially with respect to temperature. Indiana bats occupy the portions of caves and mines that have winter temperatures of 37-43^{o}F. It is thought that this requirement is one reason there are so few hibernacula in Michigan; the mines of northern Michigan are too cold, especially due to the “chimney effect” caused by multiple openings to the mines (Kurta 2008). Interestingly, the chimney effect may be essential for cooling mines to the appropriate temperature in the southern states.

The CCVI predicts moderate vulnerability of this species to climate change due to changes in hydrologic cycle and dependence on an unusual geologic structure for part of their life history. It is indeed conceivable that changes in hydrologic cycle could result in changes to winter humidity levels in caves and mines and cave bats are quite selective with respect to humidity levels. However, with respect to their dependence on mines and caves, shifts in climate could be positive or negative. While Michigan does not have the abundance of karst formations that areas such as Missouri, Kentucky and Indiana have, Michigan does have some karst formations as well as abandoned mines that are used by various bat species. As noted above, it is thought that Michigan caves and mines are currently too cold to serve as hibernacula, but long-term climate change could make them more suitable. In his review of population trends, Clawson (2002) noted that during the period of 1960-2001, southern populations of the Indiana bat, i.e. those in Alabama, Arkansas, Kentucky, Missouri, Tennessee and Virginia, underwent substantial decreases, while populations in northern areas, i.e. Illinois, Indiana, New York, Ohio, Pennsylvania, and West Virginia, actually increased in the same period by 30%. Clawson invokes a number of factors that may have contributed to the decrease in the southern states, including increased levels of disruption to hibernating bats by humans, changes in cave and mine temperatures due to human actions at the mines (e.g. opening or sealing of entrances, improper gating, etc.). However, Clawson also points out that increase in populations in the north may be related to temperature and Brack, et al. (2002) provides analysis of suitable summer and winter temperature ranges consistent with Clawson's argument and Clawson urges additional research on the subject. The relationship between winter cave and mine temperatures and suitability for hibernation suggests a possible conservation management practice that could mitigate climate change, namely actively managing the temperature regime of Michigan mines by controlling the number and degree of openings, thereby altering the chimney effect.

<u>Evening bat (*Nycticeius humeralis*) G5/SNA – Not vulnerable, very high confidence.</u> Unlike the Indiana bat, the evening bat is not a regionally-migrating, cave or mine hibernating bat, but is a long-distance migratory species. The evening bat spends winters in the southern United States and migrates north for the summers, roosting primarily in trees throughout the year. The evening bat is considered a southern species and historically was only an infrequent visitor to Michigan; known only from a handful of reports. However, in the mid-2000s, Kurta and his students at Eastern Michigan University discovered a maternity colony of evening bats along the Raisin River near Palmyra in Lenawee County. The colony reported by Kurta, et al. (2005), and further studied by Munzer (2008), appears to be persistent and is the northernmost colony on the continent. Finding of this colony prompted addition of the evening bat to the list of state threatened species. It may be possible that the evening bat's historic northern range limit was established due to energetic limitations of migration between summer and winter ranges. If so, a warming trend in the northern US may actually allow this species to further expand into Michigan and establishment of the Lenawee County colony may possibly be a reflection of this.

<u>Prairie vole (*Microtus ochrogaster*) G5/S1 – Not vulnerable, very high confidence</u>. While the prairie vole can be found well into the Province of Alberta, it reaches the northeastern limit of its range in Michigan. Not surprisingly, its range coincides well with the former distribution of prairies in the central plains and its occurrence in Michigan is limited to the "prairie peninsula" area of southwest Michigan. It lives primarily in family groups in burrows which the members dig. Its life history and habits are well adapted to relatively dry conditions where fires were frequent in the past and snow cover may be variable or non-existent in winter. If climate changes to a hotter, drier regime as predicted, the changed conditions may favor populations of the prairie vole. However, biotic interactions with competitors, such as the meadow vole (*Microtus pennsylvanicus*), may provide countervailing forces to any expansion. In central Illinois, where both species now occur following a range expansion by the meadow vole (Klatt and Getz, 1986), the two species appear to compete, resulting in habitat segregation, with prairie voles occupying grassy areas of relatively sparse cover and meadow voles occupying grassy areas with more dense cover (Klatt 1986). Regardless of the biotic interactions, the prairie vole as a species is, if anything, likely to benefit from predicted climate change trends in Michigan.

Woodland vole (*Microtus pinetorum*) G5/S3/S4 – Not vulnerable, very high confidence. Consistent with its name, the woodland vole is very much a forest-dwelling species and occupies a wide range of forest types, including deciduous, coniferous and mixed forests. Its range outside of Michigan extends throughout the eastern US, south almost to the Gulf of Mexico, and westward into the central plains. Thus, like the prairie vole and the evening bat, the woodland vole in Michigan is more toward the northern limit of its range. Due to its generalized habitat preferences, its tolerance to temperature extremes in other parts of its range well above the range of change predicted for Michigan, the woodland vole, like the prairie vole and evening bat is likely to benefit from predicted climate change.

Snowshoe hare (*Lepus americana*) – Highly vulnerable, very high confidence. While not currently considered a rare species, the snowshoe hare may be the currently common mammal species most vulnerable related to climate change in Michigan. Its range in Michigan includes those areas with greatest predicted change in temperatures and moisture conditions. The well-known aspect of the snowshoe hare, namely that its coat color changes from brown to white in winter, occurs in September and is triggered by decreasing daylength; thus this change comes about regardless of the presence or absence of snow. Thus, lower levels of snow or shorter snow-cover periods will vastly increase the vulnerability of this species to predation. Additionally, Hoving (2001) has shown that snowshoe hare abundance is positively associated with forested wetlands and negatively associated with mature deciduous forest. Thus, a shift toward more deciduous forest as the state warms will also contribute to the vulnerability of this species, as its optimal habitat is reduced.

Gray wolf (*Canis lupus*) G4/S3 – Not vulnerable, very high confidence. The range of climate tolerance for this species is very broad and the historic range of the gray wolf included most of North America. Predicted climate change with respect to temperature and rainfall is well within the historic ranges experienced by this species throughout its range. The resurgence of the wolf in North America has been possible because it has occurred in areas of relative little human population. Nevertheless, human-wolf conflict does occur regularly in areas where wolves are once again common. If the wolf in Michigan is at all vulnerable to climate change it will be likely be through land use changes in the upper peninsula that increase the level of human-wolf conflict.

Lynx (*Lynx canadensis*) G5/S1 – Highly vulnerable, very high confidence. Lynx are usually described as being associated with coniferous forest and areas with high snowshoe hare populations. Additionally, lynx are morphologically well adapted to deep snow and are thought to have a competitive edge over other predators, such as bobcat (*Lynx rufus*), under such conditions. Giving additional scientific rigor to these common assertions, Hoving (2001), through a combination of historical records, tracking data and modeling, was able to show that the historic and current distribution of lynx in Maine is dependent primarily on two factors: 1) the occurrence of heavy snowfall (>268 cm per year); and 2) a low presence of deciduous forest. In his analyses, Hoving (2001) showed that the distribution of lynx over long periods of time (1833-1999) was associated with forest composition, with lynx being widespread during peaks of coniferous forest development at the end of the little ice age in the early to mid- 1800s and a decrease in occurrence as forest composition has shifted to a greater representation of deciduous forest types in Maine. Thus, he was able to demonstrate that Canada lynx are strongly affected both directly and indirectly by changes in climate; directly through depth of snowfall and indirectly through changes of forest composition.

While uncertainty exists with respect to predicted snowfall patterns, depth of annual snowfall and forest composition are both factors expected to change in Michigan under current climate change scenarios. Expectations in general are that annual snowfall amounts may decrease, or at least fallen snow may melt faster, and that there will be a shift of current coniferous forests to include a greater proportion of deciduous forest types. Both of these changes would be detrimental to lynx populations in Michigan. Currently, lynx are exceedingly rare in Michigan and it seems likely that climate change toward less snow and higher temperatures, resulting in a long-term shift in forest composition, in combination with a relatively specialized diet and strong competitors, such as bobcat and coyote (*Canis latrans*) under lower snowfall scenarios, will almost certainly affect lynx in Michigan adversely.

American marten (*Martes americana*) – Moderately vulnerable, low confidence. Though not currently considered threatened, endangered, or special concern, the American marten was essentially extirpated from the state through a combination of habitat destruction and over harvesting. However, beginning in the 1950s, a reintroduction effort has been conducted in Michigan and the species now occurs in both the upper and lower peninsulas. The habitat of the American marten varies somewhat across its range in North America with western populations showing a very distinct preference for cool, closed canopy, coniferous forests. However, in the eastern portion of its range, including Michigan, the American marten can also be found in mixed or deciduous forests. While a shift from coniferous forest to deciduous forest in the upper peninsula may result in reduced preferred habitat, sufficient mixed forest areas may remain abundant enough to support this species. What may be more key to their conservation is the maintenance of extended forest tracks and the coarse woody debris in which they prefer to hunt.

Black bear (*Ursus americanus*) – Not vulnerable, very high confidence. Like the wolf, black bear were ubiquitous in eastern North America during presettlement times and their range extends into Florida. Currently, the Michigan Department of Natural Resources indicates that black bear may be encountered in any county in Michigan, though populations are much higher above the tension line. The biology of black bears varies across their North American range. In Michigan, black bears enter a period of winter dormancy, though not a true hibernation, but bears in more southern states may become dormant for only short times, or not at all. Presumably, these differences are related to availability of food. As growing seasons have already expanded in the Midwest, food availability for black bears may be increasing and energetic challenges due to long dormancy periods may be decreasing. Thus, a higher temperature regime is not likely to physiologically stress black bears and their populations may be favored under changed climate conditions.

White-tailed deer (*Odocoileus virginiana*) – Not vulnerable, very high confidence. Like the black bear, the white-tailed deer may be a beneficiary of a slightly warmer climate regime. Deer populations in the upper peninsula are frequently stressed during the winter due to limited food supplies and ability of the deer to move to find food. Shorter winters, longer growing seasons and a shift toward more deciduous forest may all combine to provide a larger and more reliable food supply for deer in Michigan. Additionally, warmer climates and extended growing seasons may result in expanded row crop agriculture in more northern parts of the state, providing even a more abundant food supply.

Moose (*Alces americana*) G5/S4 – Highly vulnerable, very high confidence. Beyer, et al. (2011) recently summarized a number of considerations with respect to moose in Michigan and the outlook for moose under current trends of climate change is bleak. Moose occur in northern climes around the world and while they are well adapted to cold climates they are poorly adapted to warm climates. In fact, the southern limit of moose worldwide coincides closely with the 68^{o}F July isotherm, placing Michigan at the southern end of moose range in North America, except for areas of higher elevation. In summer, moose must actively thermoregulate at temperatures above 57^{o}F. The 430 moose that currently live in Michigan are located in the upper peninsula where temperatures are expected to increase by 5.1^{o}F, or more, within the next 50 years. Beyer, et al. (2011) estimate that temperatures in the upper peninsula will exceed the limits for moose by the end of this century.

The intolerance of moose to warm temperatures can be traced to a number of mechanisms and interacting factors. For example, one method of thermoregulation employed by moose is inactivity. This inactivity includes reduced feeding and an associated decrease in caloric intake, which is difficult for moose to make up. This decreased feeding can weaken moose and further exacerbate their ability to deal with warm temperatures. Additionally, their weakened state may make them more susceptible to diseases and pathogens, such as the brainworm parasite (*Parelaphostrongylus tenuis*), which is carried by white-tailed deer. A liver fluke (*Fascioloides magna*) carried by deer is also a significant cause of mortality in moose and was invoked as the primary cause of death in 16% of mortality cases investigated. As noted above, climate change may result in increased populations of white-tailed deer, increasing the parasitic threat to moose under climate change scenarios. In summary, the combination of heat stress, reduced diet, and increased incidence of disease pose serious threats for moose in response to climate change in Michigan. While it may be impossible to directly affect temperatures, one possible mitigation measure may be to control deer populations in moose areas, as it is thought that keeping deer populations to levels of 10 deer/square mile or below, largely eliminates the threat of parasite transfer.

REFERENCES

Baker, R. H. 1983. *Michigan Mammals*. Michigan State University Press, East Lansing, MI. 642pp.

Beyer Jr., D. E., S. R. Winterstein, P. E. Lederle, and J. J. Maskey. 2001. Moose in Michigan: History, Biology and Considerations for Hunting. Michigan Department of Natural Resources, Lansing, MI.

Brack Jr., V, C. W. Stihler, R. J. Reynolds, C. M. Butchkoski, and C. S. Hobson. 2002. Effect of climate and elevation on distribution and abundance in the mideastern United States. In: *The Indiana Bat: Biology and Management of an Endangered Species.* Kurta, A. and J. Kennedy, eds. Bat Conservation International. Austin, TX.

Clawson, R. L. 2002. Trends in population size and current status. In: *The Indiana Bat: Biology and Management of an Endangered Species.* Kurta, A. and J. Kennedy, eds. Bat Conservation International. Austin, TX.

Gardner, J. E. and E. A. Cook. 2002. Seasonal and geographic distribution and quantification of potential summer habitat. In: *The Indiana Bat: Biology and Management of an Endangered Species.* Kurta, A. and J. Kennedy, eds. Bat Conservation International. Austin, TX.

Hoving, C. L. 2001. Historical Occurrence and Habitat Ecology of Canada Lynx (*Lynx canadensis*) in Eastern North America. M.S. Thesis, University of Maine.

Klatt, B. J. 1986. Factor Affecting the Distribution and Abundance of *Microtus ochrogaster* and *M. pennsylvanicus* in East-Central Illinois. Ph.D. Thesis. University of Illinois, Urbana-Champaign, Illinois. 108 pp.

Klatt, B.J. and L.L. Getz. 1986. Vegetation Characteristics of *Microtus ochrogaster* and *M. pennsylvanicus* Habitats in East-Central Illinois. Journal of Mammalogy 68:569-577.

Kurta, A. 1995. *Mammals of the Great Lakes Region*. University of Michigan Press, Ann Arbor, MI. 376pp.

Kurta, A. 2008. *Bats of Michigan.* Publication No. 2, Indiana State University Center for North American Bat Research and Conservation.

Kurta, A., R. Foster, E. Hough, L. Winhold. 2005. The Evening Bat (*Nycticeius humeralis*) on the Northern Edge of Its Range—a Maternity Colony in Michigan. *Am. Midl. Nat.* 154:264–267

Munzer, O. M. 2008. *Ecology of The Evening Bat (Nycticeius humeralis) At The Northern Edge Of Its Range.* M.S. Thesis, Eastern Michigan University.