Climate Change Vulnerability Assessment and Adaptation Strategies for Natural Communities in Michigan, Focusing on the Coastal Zone

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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. Climate change can significantly impact the biodiversity in Michigan and the Great Lakes region. 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 and why is key to developing effective adaptation strategies.

To assist in climate change adaptation efforts, we conducted a two-year project to assess the vulnerability of natural features in Michigan's coastal zone to climate change, including plant and animal species and natural communities. We also conducted a spatial analysis to identify where species and natural communities may be particularly vulnerable due to climate change and other stressors on the landscape. Potential strategies and areas for adaptation efforts also were identified. This report summarizes our analysis and results for natural communities in Michigan, particularly those in the coastal zone. We selected eleven variables on which to assess the impacts of climate change on each of the 76 natural communities described for Michigan (Kost et al. 2007). Each variable was scored for vulnerability and confidence. Average vulnerability and confidence scores were calculated for each variable, natural community, and natural community group (e.g., upland forests, wetland forests, etc.). For the natural communities that occur in the coastal zone and are likely vulnerable to climate change, we examined their potential exposure to climate change and associated impacts as well as existing non-climate stressors on the landscape to identify areas where they may be particularly vulnerable.

Overall, results indicate that many wetland communities will be negatively impacted by climate change. Forested wetlands are predicted to be most impacted, with the greatest changes expected in the communities that support a significant conifer component such as poor conifer swamp, rich conifer swamp, rich tamarack swamp, and hardwood-conifer swamp. Fens and bogs are also likely to be negatively impacted. A number of wetland communities that occur in the coastal zone are likely vulnerable to climate change. These include lakeplain systems such as lakeplain wet prairie, lakeplain wet-mesic prairie, lakeplain oak openings, and wet-mesic flatwoods; forested wetlands such as rich conifer swamp, northern hardwood swamp, southern hardwood swamp, and floodplain forest; open coastal wetlands such as coastal plain marsh, interdunal wetland, coastal fen, and Great Lakes marsh; and wooded dune and swale complexes. In addition to wetlands, several upland forest communities with significant conifer components are likely vulnerable to climate change, especially boreal forest and mesic northern forest.

Unlike most wetlands, many upland community types have the potential to benefit through increased acreage resulting from colonization of former mesic to wet habitats. Upland natural communities that have the potential to benefit from a warmer and drier climate include prairies, savannas, open dunes, sand and gravel beach, Great Lakes cobble shores, bedrock grasslands and glades, and bedrock shorelines.

As climate changes, the assemblages of species that currently comprise Michigan's natural communities will also change. It is unlikely that whole communities will migrate northward along with climate. Instead, species will respond independently to the changes according to their ability to thrive or decline under the altered climate regime and associated stressors. In many cases, new species assemblages will arise to reflect the new environmental conditions.

The spatial analysis identified watersheds along the coastal zone in which natural communities that are sensitive to climate change may be more vulnerable due to potential exposure to climate change impacts and other stressors on the landscape. Potential adaptation strategies were identified for natural communities that are likely vulnerable to climate change. These include reducing current stressors to natural communities (e.g., controlling invasive species, restoring hydrology, reducing deer densities/deer browse pressure, and/or implementing prescribed fire); focusing conservation and restoration efforts on numerous high quality occurrences in different ecological regions of the state and large, intact natural complexes or landscapes to enhance resilience; and identifying and protecting climate refugia (i.e., areas that are expected to retain more stable climates and where species and natural communities can persist under changing climate conditions). Because many of the natural communities that are likely vulnerable to climate change are wetlands communities, adaptation strategies related to restoring natural hydrological regimes/functions, reducing stressors that alter hydrology and impact water availability and quality, and protecting water resources (e.g., groundwater) are particularly relevant. Potential areas for some of these strategies were identified in the coastal zone based on the results of the spatial analysis and known occurrences of natural communities.

This project represents a significant step toward assessing potential impacts of climate change on natural features in Michigan, particularly in the coastal zone, and developing and implementing appropriate and effective adaptation strategies for natural features that are vulnerable to climate change. This effort represents the first and an initial attempt to systematically assess the vulnerability of the range of natural communities in Michigan to climate change, and utilize results from the assessment to identify potential strategies and areas for adaptation efforts. Although this report attempts to shed light on how different natural communities may respond to climate change and potential associated stressors, it is important to understand that, at the level of a natural community, many of the ecological changes resulting from climate change are difficult to predict, and observable changes will often lag considerably behind the current climate regime. In addition, this analysis is meant to only address potential changes resulting from a warmer and drier climate. The results of this analysis would have been significantly different with a different set of climate projections (e.g., warmer and wetter, cooler and drier, cooler and wetter, etc.).

This effort also provides an example of an adaptation planning framework and approach that can be utilized in Michigan, which includes identifying conservation targets (e.g., natural communities), assessing vulnerability of conservation targets, identifying where conservation targets may be particularly vulnerable or resilient, and identifying potential strategies and areas where adaptation efforts may be implemented. This framework and specific components and approaches should be further developed and refined, particularly as new and improved data on potential climate change impacts, existing non-climate stressors, and natural communities in Michigan and new tools and approaches become available.

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

- Warmer temperatures - Temperatures in the northern portion of the Midwest, including the upper Great Lakes, increased by almost 4^{o}F (2^{o}C) over the 20th century (National Assessment Synthesis Team (NAST) 2000). In Michigan and the Great Lakes region, mean annual temperatures have increased by about 1^{o}F (0.6^{o}C) since 1895, and about 2^{o}F (1.3^{o}C) between 1980 and 2010 (Andresen 2012). Mean annual temperatures in the Great Lakes region are projected to increase by 1.8 to 5.4^{o}F (1 to 3^{o}C) by 2050, and 3.6 to 11.2^{o}F (2 to 6.2^{o}C) by 2100 according to various climate models (NAST 2000, Kling et al. 2003, Christensen et al. 2007, Hayhoe et al. 2010a and 2010b, Great Lakes Integrated Sciences and Assessments (GLISA) 2012, Kunkel et al. 2012, Winkler et al. 2012). Additionally, increased temperatures have occurred primarily during the winter and spring seasons, and at night (i.e., warmer nighttime or minimum temperatures) (Andresen 2012, Andresen et al. 2012). Winters have been getting shorter, and spring has been arriving earlier (Kling et al. 2003, Andresen 2012).

- 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 and the Great Lakes region, annual precipitation, in general, has increased by 2.5 to 5.5 inches (5-15%) since 1895 (Andresen et al. 2012). Projections of future precipitation vary widely; annual precipitation may increase significantly, decrease significantly, or remain the same (GLISA 2012, Winkler et al. 2012). Winter and spring precipitation may increase more significantly, with little change or even a slight decrease in summer precipitation (GLISA 2012, Winkler et al. 2012). Snowfall has increased in some places, particularly in areas that experience lake effect, but has decreased in other places, typically further inland away from the lakes (Andresen 2012). This trend may continue, and warmer temperatures will likely lead to less precipitation falling as snow, and more falling as rain (GLISA 2012).

- Increases in extreme weather events - The frequency and intensity of extreme heat and precipitation events have increased, and current models suggest this trend will likely continue (NAST 2000, Kling et al. 2003, Andresen 2012, GLISA 2012).

- Decreased snow and ice cover - The duration and extent of snow and ice cover on land and on the Great Lakes and inland lakes have decreased as air and water temperatures have increased; snow and ice cover will likely continue to decrease (Kling et al. 2003, Dempsey et al. 2008, GLISA 2012).

- Overall drier conditions potentially – Despite increases in precipitation, the Great Lakes region may become drier overall due to increasing temperatures and evaporation rates (NAST 2000, GLISA 2012). Increased evaporation and transpiration in a warmer climate, particularly in the summer, could lead to more frequent drought conditions, which would reduce soil moisture, surface water and groundwater supplies, and lake and river/stream levels (NAST 2000, Lofgren et al. 2002, Kling et al. 2003, Field et al. 2007, GLISA 2012).

The effects of climate change will be particularly dramatic in the Great Lakes region along the coastal zone. Water levels in the Great Lakes have been decreasing since record highs in 1980 (GLISA 2012). Climate change projections for Great Lakes water levels vary, but 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 (Croley 1990, Mortsch et al. 2000, NAST 2000, Kling et al. 2003, Field et al. 2007, Jensen et al. 2007, Angel and Kunkel 2010, Hayhoe et al. 2010a). 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, Hayhoe et al. 2010a, Lofgren et al. 2011). The impact of these declines on the shoreline would 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 (U.S. Environmental Protection Agency and Environment Canada 2006, Dempsey et al. 2008). However, some more recent models indicate Great Lakes water levels may remain near long-term mean and/or present-day levels, or may increase in the future (by 0.4 to 1.4 ft/0.1 to 0.4 m depending on the lake) (Lofgren et al. 2002, Lofgren et al. 2011, IUGLS 2012, Mackey 2012). The annual range or variability around mean water levels also may increase according to some models (Mackey 2012).

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*). 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 (MNFI) 2012). 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 (Root et al. 2003, 2005; Parmesan and Yohe 2003, Parmesan 2006, Rosenzweig et al. 2007). 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). 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. While some species and habitats will be harmed by climate change, others will be able to adapt and/or benefit from impacts of climate change. 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.

Climate change adaptation refers to actions designed to reduce the vulnerability of species, natural systems, and human communities to actual or expected climate change effects, and help them better cope with changing conditions (Intergovernmental Panel on Climate Change (IPCC) 2007, Comer et al. 2012). Developing and implementing effective adaptation strategies first requires an understanding of the potential impacts of climate change. ***Vulnerability assessments*** are a key tool for informing adaptation planning, and provide the scientific basis for developing adaptation strategies. Climate change vulnerability assessments help identify which species or systems are likely to be most strongly affected by projected changes, and why these resources are likely to be vulnerable, including the interaction between climate shifts and existing stressors (Glick et al. 2011). This information helps managers anticipate how a species or system is likely to respond under the projected climate change conditions, set priorities for conservation action, and develop appropriate management and conservation responses (Association of Fish and Wildlife Agencies (AFWA) 2009, Glick et al. 2011).

To inform and 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), conducted 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. The following objectives were addressed as part of this 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 180 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) Identify and rank species and natural communities most vulnerable to climate change along Michigan's coastal zone. Identify factors which most frequently contributed to high vulnerability scores based on vulnerability assessments conducted.

5) Conduct spatial analysis to identify geographic areas along Michigan's coastal zone that may be particularly vulnerable to or impacted by climate change as well as other stressors (e.g., areas of high development, agricultural use, increased runoff/pollution, etc.). Areas that may be less vulnerable or more resilient to climate change and other stressors also will be identified. The output will be a map of areas predicted to have high, moderate, or low stress due to climate change and other stressors along the coastal zone.

6) 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. Areas where species and natural communities may be less vulnerable or more resilient to climate change impacts and other stressors also will be identified.

7) 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 spatial analyses (e.g. conservation or management of areas that provide opportunities for dispersal corridors or connectivity if this is factor causing species' vulnerability).

8) 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 for the natural community vulnerability assessment and spatial analysis that were conducted as part of this project. The results for the vulnerability assessment and spatial analyses that were conducted for animal and plant species are summarized in an accompanying report (see Lee et al. 2012). Our assessments provide 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 climate change. 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. Identifying the key factors which contribute to vulnerability can 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 will be shared with regional, state, and local conservation and planning efforts to foster collaboration and facilitate more effective and efficient use of resources for climate change adaptation efforts.

It is important to emphasize that a natural community is an assemblage of interacting plants, animals, and other organisms that repeatedly occurs under similar environmental conditions across the landscape, and is predominantly structured by natural processes rather than modern anthropogenic disturbances (Kost et al. 2007). Although soils, geology, and hydrology are critical factors for structuring the distribution of natural communities, climate is the primary driver. As environmental conditions change, individual species respond with increased or decreased growth, fecundity, and survival; new niches are carved out and others are vacated; competitive relationships are altered, new ones arise, and old ones die out; symbiotic relationships are broken, forged, or changed. In summary, as climate changes, the assemblages of species that currently comprise Michigan’s natural communities will also change. It is unlikely that whole communities will migrate northward along with climate. Instead, species will respond independently to the changes according to their ability to thrive or decline under the altered climate regime and associated stressors (e.g., changes in canopy cover, soil mycorrhizal associations, competitive relationships, natural disturbances, invasive species, etc.). These new species assemblages may not be easy to predict. The relatively slow pace of community change likely further complicates matters for biologists and land managers. For example, broad changes in plant species composition for most natural communities is likely to be a relatively slow process when compared to the average person’s ability to notice these changes (e.g., longer than several decades, a career, a lifetime). Many of the dominant trees in our present forests have life spans of 200 to 300 years and some much longer. Although some species and natural communities may be slow in responding to climate change, planning for potential changes now will provide greater flexibility and increase chances of maintaining biodiversity in the future.

This report is meant to serve as an initial assessment of the potential impacts of climate change on Michigan’s natural communities. Although this report attempts to shed light on how different natural communities may respond to climate change and potential associated stressors, it is important to understand that, at the level of a natural community, many of the ecological changes resulting from climate change are difficult to predict, and observable changes will often lag considerably behind the current climate regime. In addition, this analysis is meant to only address potential changes resulting from a warmer and drier climate. The results of this analysis would have been significantly different with a different set of climate projections (e.g., warmer and wetter, cooler and drier, cooler and wetter, etc.).

Methods

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), or the degree to which a system is susceptible to and unable to cope with adverse effects of climate change (IPCC 2007). Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed (i.e., ***exposure***), its ***sensitivity***, and its ***adaptive capacity*** (IPCC 2007). Exposure is a measure of how much of a change in climate or degree of climate stress a species or system is likely to experience, in terms of long-term change in climate conditions or changes in climate variability (IPCC 2007, Glick et al. 2011). 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). Adaptive capacity refers to a species or system's ability to accommodate or cope with potential climate change impacts with minimal disruption (Williams et al. 2008, Glick et al. 2011).

Climate change vulnerability assessments can utilize different approaches. There is no single right approach to vulnerability assessment that applies to all situations; the approach depends on the user's needs, the decision processes into which it will feed, and the availability of resources such as time, money, data, and expertise (Glick et al. 2011). For this project, the Climate Change Vulnerability Index (CCVI) tool developed by NatureServe was utilized for assessing the vulnerability of animal and plant species to climate change (see Lee et al. 2012). However, a similar tool for assessing the vulnerability of natural communities was not available during this project. We examined habitat or ecosystem vulnerability assessments that had been conducted in other states (e.g., North Carolina - DeWan et al. 2010, Massasachusetts - Manomet Center for Conservation Sciences (MCCC) and Massachusetts Division of Fisheries and Wildlife (MDFW) 2010, Four Corners Region and Pacific Northwest – Glick et al. 2011), considered available resources, and developed an approach for this project.

We developed and utilized an expert-based approach for assessing the vulnerability of natural communities to climate change in Michigan. Our approach was primarily based on the habitat vulnerability assessment that was conducted in Massachusetts (MCCC and MDFW 2010). This assessment consisted of identifying 10 habitat variables that are likely to affect the vulnerability of habitats to climate change, and convening a panel of experts to score the habitat variables for different habitat types under high and low emissions scenarios (MCCC and MDFW 2010). An overall vulnerability score and confidence level were generated for each habitat type. The habitat variables were based on climate change impacts, non-climate stressors, and adaptive capacity, including vulnerability to increasing temperature, vulnerability to increased frequency or intensity of extreme events, current rate of loss, and intrinsic dispersive rate (see MCCC and MDFW 2010 for detailed information regarding variables and assessment).

Although this project was focused on the coastal zone, we assessed potential impacts of climate change on each of the 76 natural communities described for Michigan (Table 1, Kost et al. 2007). Fifty-nine of these natural communities have occurrences documented in the coastal zone based on information in Michigan's Natural Heritage Database (MNFI 2012), including 29 natural communities that occur primarily in the coastal zone. We selected eleven variables upon which to assess a natural community's vulnerability to climate change (Table 2). The variables were drawn from our current understanding of potential climate changes and associated impacts that could affect natural communities in Michigan, and the habitat vulnerability assessment that was conducted in Massachusetts (MCCC and MDFW 2010).

For each natural community, we scored its vulnerability to each variable (i.e., whether and how the community is likely to be affected by that variable). Vulnerability was scored with the following scale: +5, +3, +1, 0, -1, -3, -5. Positive numbers indicate the community is likely to benefit. Negative numbers indicate the community is likely to be negatively impacted. Zero indicates the effect of the variable is neutral overall. Larger numbers, positive or negative, indicate greater impact (positive or negative). The scoring range of 1, 3, and 5 was used to provide greater separation among composite scores. We also scored our confidence associated with each vulnerability score. Confidence was scored using a scale of 1, 2, and 3, with higher numbers indicating greater confidence in the assignment of a vulnerability score. Average vulnerability and confidence scores were calculated for each variable, natural community, and natural community group (e.g., upland forests, wetland forests, etc.).

The natural community vulnerability assessment was conducted by two of MNFI's ecologists. Each ecologist first scored the variables for each natural community individually. After this was completed, the ecologists met and reviewed their scores and rationale. Discrepancies in vulnerability scores were discussed and reconciled. In addition to the vulnerability and confidence scores, detailed summaries of how each natural community group and some specific natural communities may be impacted by climate change also were produced.

To get some peer review of our natural community vulnerability assessment, we organized and convened a half-day meeting of local experts on climate change and/or natural communities in Michigan in 2012. Ten experts were invited and attended the meeting in addition to three MNFI staff. The experts included resource managers, biologists, and academic researchers from the Michigan Department of Natural Resources, Michigan Department of Environmental Quality, Michigan State University, Wayne State University, and The Nature Conservancy. The purpose of this meeting was to obtain feedback on the approach and criteria we used for our natural community vulnerability assessment, some of our initial results, and other potential approaches and/or criteria that could be used to assess the vulnerability of natural communities to climate change. The meeting agenda and list of participants are provided in Appendix 2.

Table 1. List of the 76 natural communities in Michigan that were assessed for vulnerability to climate change and their global and state conservation status ranks. Codes for global and state ranks are defined in Appendix 1.

NATURAL COMMUNITY GROUPS	**GLOBAL RANK**	**STATE RANK**
Natural Communities		
MARSH COMMUNITIES		
Submergent Marsh	GU	S4
Emergent Marsh	GU	S4
Great Lakes Marsh	G2	S3
Northern Wet Meadow	G4G5	S4
Southern Wet Meadow*	G4?	S3
Inland Salt Marsh*	G1	S1
Intermittent Wetland	G2	S3
Coastal Plain Marsh	G2	S2
Interdunal Wetland	G2?	S2
WET PRAIRIE COMMUNITIES		
Wet Prairie*	G3	S2
Wet-mesic Prairie*	G2	S2
Wet-mesic Sand Prairie*	G2G3	S2

Lakeplain Wet Prairie	G2	S1
Lakeplain Wet-mesic Prairie	G1?	S1
FEN COMMUNITIES		
Prairie Fen	G3	S3
Northern Fen	G3	S3
Coastal Fen	G1G2	S2
Patterned Fen	GU	S2
Poor Fen	G3	S3
BOG COMMUNITIES		
Bog	G3G5	S4
Muskeg	G4G5	S3
SHRUB WETLAND COMMUNITIES		
Northern Shrub Thicket	G4	S5
Southern Shrub-carr*	GU	S5
Inundated Shrub Swamp*	G4	S3
FORESTED WETLAND COMMUNITIES		
Poor Conifer Swamp	G4	S4
Rich Conifer Swamp	G4	S3
Rich Tamarack Swamp*	G4	S3
Hardwood-Conifer Swamp	G4	S3
Northern Hardwood Swamp	G4	S3?
Southern Hardwood Swamp	G3	S3
Floodplain Forest	G3?	S3
Wet-mesic Flatwoods	G2G3	S2
PALUSTRINE/TERRESTRIAL		
Wooded Dune and Swale Complex	G3	S3
TERRESTRIAL COMMUNITIES		
PRAIRIE COMMUNITIES		
Dry Sand Prairie	G3	S2
Dry-mesic Prairie*	G3	S1
Mesic Sand Prairie	G2	S1
Mesic Prairie*	G2	S1
Hillside Prairie*	G3	S1
SAVANNA COMMUNITIES		
Pine Barrens	G3	S2
Oak-Pine Barrens	G3	S2
Oak Barrens*	G2?	S1
Oak Openings*	G1	S1
Bur Oak Plains*	G1	S1
Lakeplain Oak Openings	G2?	S1
FOREST COMMUNITIES		
Dry Northern Forest	G3?	S3
Dry-mesic Northern Forest	G4	S3
Mesic Northern Forest	G4	S3

Dry Southern Forest*	G4	S3
Dry-mesic Southern Forest	G4	S3
Mesic Southern Forest	G2G3	S3
Boreal Forest	GU	S3
PRIMARY COMMUNITIES		
COASTAL SAND COMMUNITIES		
Sand and Gravel Beach	G3?	S3
Open Dunes	G3	S3
Great Lakes Barrens	G3	S2
BEDROCK GRASSLAND AND GLADE		
Alvar	G2?	S1
Limestone Bedrock Glade	G2G4	S2
Granite Bedrock Glade	G3G5	S2
Volcanic Bedrock Glade	GU	S2
Northern Bald	GU	S1
COBBLE SHORE COMMUNITIES		
Limestone Cobble Shore	G2G3	S3
Sandstone Cobble Shore	G2G3	S2
Volcanic Cobble Shore	G4G5	S3
BEDROCK LAKESHORE COMMUNITIES		
Limestone Bedrock Lakeshore	G3	S2
Sandstone Bedrock Lakeshore	G4G5	S2
Granite Bedrock Lakeshore	G4G5	S2
Volcanic Bedrock Lakeshore	G4G5	S3
LAKESHORE CLIFF COMMUNITIES		
Limestone Lakeshore Cliff	G4G5	S2
Sandstone Lakeshore Cliff	G3	S2
Granite Lakeshore Cliff*	GU	S1
Volcanic Lakeshore Cliff	GU	S1
INLAND CLIFF COMMUNITIES		
Limestone Cliff	G4G5	S2
Sandstone Cliff	G4G5	S2
Granite Cliff	G4G5	S2
Volcanic Cliff	G4G5	S2
SUBTERRANEAN/SINK COMMUNITIES		
Cave*	G4?	S1
Sinkhole	G3G5	S2

*Natural communities that did not have any documented occurrences in the coastal zone based on the MNFI Natural Heritage Database (2012) at the time of the assessment. Some of these natural communities may occur in the coastal zone but do not have documented occurrences in the database yet.

Table 2. Climate Change Variables Assessed for Natural Communities (i.e., vulnerability to these variables).

1. Increased Air and Surface Temperatures
2. Longer Growing Season
3. Phenological Changes
4. Latitude Range Expansion or Contraction
5. Intrinsic Ability to Disperse
6. Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)
7. Great Lakes Lower Water Levels
8. Reduction in Regional Groundwater and Surface Water Levels
9. Wetter Winters and Springs and Drier Summers and Falls
10. Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
11. Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers

Spatial Analysis to Identify Vulnerable Areas Due to Climate Change and Other Stressors

A spatial analysis was conducted to identify geographic areas along Michigan's coastal zone where natural communities sensitive to climate change may be particularly vulnerable due to climate change and other stressors on the landscape. Michigan's coastal zone and natural communities within the coastal zone are already impacted by other serious stressors in addition to climate change including habitat loss, degradation, and fragmentation due to urban, agricultural, commercial and/or industrial development; altered ecological processes (e.g., fire suppression, altered hydrologic regimes); point and non-point source pollution; and invasive species. The effects of climate change in coastal areas will be exacerbated by these other stressors (Mackey 2012). As a result, natural communities that are sensitive to climate change may be more vulnerable in areas that experience greater impacts from these other stressors.

To identify geographic areas along Michigan's coastal zone where natural communities sensitive to climate change may be more vulnerable, a spatial analysis was first conducted to identify areas along the coastal zone that might be impacted by climate change as well as other stressors. Stressors that can significantly impact natural communities are those that affect landscape fragmentation, moisture availability, and invasive species. The geographic extent of the spatial analysis was the entire coastal zone in Michigan, primarily comprised of the HUC14 watersheds along the shoreline, although we developed and/or compiled data for the entire state for most stressors. The geographic scale or unit used for the spatial analysis was the HUC14 watershed.

Six variables or stressors related to climate change impacts and nine non-climate related stressors were identified for the spatial analysis (Table 3). To assess and map where these stressors occur or might occur on the landscape and to what degree, fifteen spatial data layers representing or indicating these stressors were compiled and/or developed (Table 3 and Appendices 3 and 4). For some of the stressors, spatial data were not available or could not be compiled given available resources. In these cases, other accessible data were used as surrogates or indicators of these stressors. For example, two of the climate change-related stressors (i.e., decreased water levels in rivers, streams, inland lakes, and wetlands, and increased flooding) did not have spatial data available on where these stressors might occur in Michigan due to climate change. We used percentage of natural land cover and percentage of impervious surface in watersheds as indicators of areas that may be more vulnerable to decreased water levels or increased flooding due to climate change. Urbanization is characterized by increased percentages of impervious surface cover, which leads to increased surface runoff, reduced infiltration of water into the soil, reduced groundwater recharge, lower water tables, and increased flooding or flashiness of peak flow events (Environmental Protection Agency 1993, Arnold and Gibbons 1996, Wissmar et al. 2004, Hogan and Walbridge 2007). Agricultural land use also has been found to accelerate runoff and increase flooding (Knox 2001). Percent natural cover and percent impervious surface also were used as indicators of non-point source pollution because urban and agricultural land use and impervious surface cover have been found to increase surface runoff, increase erosion and sedimentation, and increase nutrient loading and other sources of non-point source pollution into aquatic or wetland systems (Watson et al. 1981, Environmental Protection Agency 1993, Arnold and Gibbons 1996, Reinelt et al. 1998, Knox 2001, Wissmar et al. 2004, Hogan and Walbridge 2007). Stream and wetland health can become impacted when impervious surface coverage in a watershed exceeds 10% (Schueler 1994, Hicks 1995, Arnold and Gibbons 1996). Percentage of natural riparian cover in a watershed also was used to indicate areas that may be more vulnerable to decreased water levels, and increased flooding and non-point source pollution because loss of riparian vegetation reduces water infiltration, increases runoff, and increases sedimentation and nutrients (Gregory et al. 1991, Pinay et al. 1992, Naiman et al. 1993).

To identify watersheds along the coastal zone that may be particularly impacted by other stressors on the landscape, we examined the spatial data layers that were compiled or developed for each non-climate stressor separately and cumulatively. To assess and identify high, medium and low stress areas for each non-climate stressor, we used the ArcGIS Fisher-Jenks natural breaks algorithm (Slocum 1999, de Smith 2009) to group the HUC14 watersheds into five categories, based on the range of values in each dataset, except for *Phragmites* locations and boat access sites. The highest or lowest category within each stressor or data layer was considered high stress depending on the stressor/data layer. For example, the lowest category of percent natural cover was considered high stress, whereas the highest category for road density was considered high stress. The middle two categories were considered medium stress, and the lowest or highest two categories, depending on the data layer, were considered low stress.

Table 3. Summary of climate change impacts and other stressors on the landscape that were included in the spatial analysis to identify geographic areas along Michigan's coastal zone where natural communities sensitive to climate change may be more vulnerable. Sources of data for these stressors are summarized in Appendix 3.

Stressor	**Description of Stressor and Available Data**
Climate Change	
Change in average annual air temperature	Projections for change in average annual air temperature in Michigan by 2050s were downloaded from Climate Wizard (Girvetz et al. 2009). Projections were based on a median of an ensemble of 16 global circulation models (GCMs) using a medium emissions scenario (A1B).
Change in annual precipitation	Projections for percent change in annual precipitation in Michigan by 2050s were downloaded from Climate Wizard (Girvetz et al. 2009). Projections were based on an ensemble of 16 GCMs using a medium emissions scenario (A1B).
Change in moisture availability	Projections for change in moisture availability by 2050 using the Hamon Moisture Metric were downloaded from NatureServe. Projections were based on an ensemble of 16 GCMs using a medium emissions scenario.
Climate Change Associated Impacts/Stressors	
Change in Great Lakes water levels	Great Lakes water levels could decrease by 1 to 5 ft (0.3 to 1.5 m) or increase by 0.4 to 1.4 ft (0.1 to 0.4 m) depending on the lake and climate change model (Lee et al. 1996, Lofgren et al. 2002, Dempsey et al. 2008, Hayhoe et al. 2010a, Lofgren et al. 2011). Impacts of these changes on natural communities in the coastal zone will vary and depend in part on the bathymetry of the shoreline. Bathymetry data were available only for the Lake Erie shoreline, and were visually examined to assess where natural communities may be more vulnerable due to potential changes in lake levels.
Decreased water levels in rivers, streams, inland lakes, and wetlands - Percent natural land cover and percent impervious surface	Base flow in rivers and streams and water levels in inland lakes and wetlands are predicted to decrease due to potential for drier conditions, and reduced surface and ground water levels (NAST 2000, Lofgren et al. 2002, Kling et al. 2003, Field et al. 2007, GLISA 2012). Data layer indicating where water levels will likely decrease due to climate change was not available. We used data layers for percent natural cover and percent impervious surface as surrogates to indicate areas that may be more vulnerable to decreased water levels. The percent of natural land cover in each HUC was calculated as the amount of natural cover types divided by the total of both natural and non-natural cover types (urban & agricultural cover). The percent of impervious surface was calculated as the amount of impervious types divided by the total of both pervious & impervious cover types.

Increased flooding (increased frequency and/or magnitude of peak flows) - Percent natural land cover, percent impervious surface, and percent natural riparian land cover	Climate change is predicted to increase flooding/peak flow events (Knox 2000) due to increase in extreme precipitation/storm events, potential increase in annual precipitation, and other factors. Increased flooding can cause increased erosion and runoff/non-point source pollution and can negatively impact some species and natural communities. Data on where extreme events and increased flooding due to climate change will likely occur in Michigan are currently not available. We examined data layers for percent natural cover, percent impervious surface, percent riparian cover, and percent agricultural cover to indicate areas that may be more vulnerable to increased flooding (i.e., lower percentage of natural cover (and higher urban/agricultural cover), higher percentage of impervious surface, lower percentage of natural riparian cover). The percent of natural riparian land cover within a 60 meter buffer of streams in each HUC was calculated as the amount of natural cover types divided by the total of both natural and non-natural cover types.
Non-Climate Related Stressors	
Landscape/habitat fragmentation due to development - Percent natural land cover	Percent natural cover was used to indicate level of fragmentation due to urban and agricultural development (i.e., higher percentage of natural cover – less development, less fragmentation; lower percentage of natural cover – higher development, greater fragmentation). The percent of natural land cover in each HUC was calculated as the amount of natural cover types divided by the total of both natural and non-natural cover types (including urban & agricultural cover).
Landscape/habitat fragmentation due to roads - Road density	Road density was used to indicate level of fragmentation (i.e., higher road density, landscape more fragmented).
Invasive species (terrestrial) - *Phragmites* locations	Data on the presence/locations of invasive species that affect terrestrial systems were available for only one species - common reed (*Phragmites australis)*. Although data on the presence/distribution of other terrestrial/wetland invasive species were not available, areas experiencing greater fragmentation may be more vulnerable to invasive species.
Invasive species (aquatic) - Boat access sites	For aquatic invasives, spatial data on the presence/locations of aquatic invasives are not readily available. We used presence/locations of boat access sites as a surrogate or indication of areas that may contain or are vulnerable to aquatic invasives (e.g., zebra mussels).
Water withdrawal - Non-agricultural groundwater withdrawal and percent agricultural land cover	Location and density of non-agricultural groundwater withdrawals and percentage of agricultural land cover. Presence and higher number or density of groundwater withdrawals in an area would add more stress to climate change impacts on groundwater/moisture availability, which would impact some species and natural communities. Percent agricultural land cover was examined to indicate areas that may experience greater stress from water/groundwater withdrawal due to agricultural use. Percent of agricultural land cover in each HUC was calculated as the amount of agricultural land divided by the total of both agricultural and non-agricultural land.
Pollution - Point source pollution	Location and number/density of point source pollution discharge sites. Presence or higher density of discharge sites indicates greater stress.

Pollution - Non-point source pollution - Percent impervious surface, percent natural land cover, and percent natural riparian land cover	Spatial data on locations and levels of non-point source pollution were not readily available. Percent impervious surface, percent natural cover, and percent riparian cover were used to indicate areas that may be experiencing greater stress from non-point source pollution (i.e., higher percentage of impervious surface, lower percentage of natural cover (higher urban/agricultural land cover), and lower natural riparian cover - greater stress).
Anthropogenic barriers for aquatic animal species - Dams and stream-road intersections	Spatial data on the location and density of dams and the number of stream-road intersections per mile of stream in a watershed were used to indicate areas that may contain more barriers to dispersal of aquatic animal species (fish and mussels). Anthropogenic barriers were identified as a factor that contributed to the vulnerability of some aquatic species to climate change.
Anthropogenic barriers for terrestrial animal species- Road density	Anthropogenic barriers such as roads were identified as a factor that contributed to vulnerability of some terrestrial animal species (e.g., amphibians and reptiles). Road density was used as an indicator of areas in which species may experience greater stress and may be more vulnerable to climate change.

To combine and assess stressors cumulatively, we identified the watersheds that were in the highest stress category for each stressor/data layer included in the analysis, and gave them a score of “1” for that stressor/data layer. If the watershed contained a boat access site or a *Phragmites* location, it was also given a score of “1” for these data layers. If the watershed was not in the highest stress category for a particular data layer or did not contain a boat access site or a *Phragmites* location, it was given a score of “0.” We then summed the scores for each watershed across all the stressors or data layers included in the analysis to generate an overall combined stressor score for each watershed. The overall combined stressor score indicates the number of non-climate related stressors or data layers in which the watershed was in the highest stress category. Watersheds with higher combined stressor scores were considered high stress areas, and watersheds with lower combined scores were considered medium or low stress areas. A map and data layer showing the high stress and low/moderate stress areas or watersheds along the coastal zone based on the combined scores for the non-climate stressors was produced.

For the cumulative analysis of non-climate stressors, we only included a subset of the data layers in the analysis because several of them were correlated or conveyed the same information. The eight stressors or data layers that were included in the cumulative analysis were percent natural cover, percent natural riparian cover, road density, non-agricultural water withdrawal, point source pollution, *Phragmites* locations, boat access sites, and dams. Percent agricultural cover was not included in the cumulative analysis because these data were already included in the percent natural cover data layer. The watersheds that were considered high and/or medium stress for percent agricultural cover were already included in the high or medium stress areas for percent natural cover so including this layer did not add any new data to the analysis. Percent impervious surface was not included because it was correlated with percent natural cover, and the percent impervious surface results were basically captured by combining the percent natural cover and road density data layers. Stream-road intersections also were not included in the cumulative spatial analysis because the road density layer provided basically the same results.

For the spatial analysis, we identified 17 natural communities that occur in the coastal zone and are likely vulnerable to climate change based on our vulnerability assessment. These natural communities were grouped into the following five groups: lakeplain systems, open coastal wetlands, forested wetlands, upland forest, and wooded dune and swale complex. To identify geographic areas or watersheds along the coastal zone where each of these natural community groups may be particularly vulnerable due to climate change, we overlaid known occurrences of the natural communities within each group onto climate change projection maps and the maps of high, moderate, and low stress areas based on the cumulative stressor analysis and individual stressors. We used element occurrence data from Michigan's Natural Heritage Database (MNFI 2012) to map the distribution of each natural community group in the coastal zone by watershed. For each natural community group, we identified watersheds within their distribution that were considered high stress areas due to other stressors on the landscape. We used this information along with climate change information to identify areas along the coastal zone where each natural community group may be particularly vulnerable to climate change.

Identification of Potential Adaptation Strategies and Areas

Potential adaptation strategies were identified for natural communities that are more likely to be vulnerable to climate change and for all natural community groups. Adaptation efforts or strategies generally fall under one or more of the following categories:

1) building *resistance* to climate-related stressors to tolerate, withstand, or prevent direct effects of climate change (e.g., building seawalls to address rising water levels, measures to prevent the introduction or spread of invasive species or large-scale fires);
2) enhancing *resilience* to cope with or recover from climate change and associated impacts without significant loss of function or structure (e.g., maintaining large, contiguous, natural landscapes; maintaining or enhancing connectivity; restoring natural communities, removing invasive species, maintaining diversity); and
3) *facilitating ecological transitions or transformations* that fit with changing environmental conditions, while minimizing ecological disruption (e.g., assisted migration) (Glick et al. 2011, Comer et al. 2012).

Potential strategies were identified based on expert knowledge of the communities and factors contributing to their vulnerability to climate change, information in the literature, and other vulnerability assessment and adaptation efforts. Areas or watersheds in the coastal zone that were identified as less vulnerable to climate change and other stressors based on our spatial analysis were examined to identify potential areas for adaptation efforts.

Sharing project results broadly

Methods for sharing project results broadly include presenting at meetings and conferences, distributing project report or results to partners and other interested individuals and organizations (e.g., Michigan Climate Coalition), direct discussions with individuals, posting results on various websites, sharing information through webinars, and working with partners and the media to identify other opportunities to share project results.

Results

Climate Change Vulnerability Assessment

Each climate change variable and the average vulnerability and confidence scores are discussed below. The vulnerability and confidence scores for each variable, natural community, and natural community group are included in Appendices 5 and 6. Detailed summaries of the vulnerability assessments for all natural community groups and specific natural communities along the coastal zone that are sensitive to climate change are provided in Appendices 7-38.

Overall, results indicate that many wetland communities will be negatively impacted by climate change (Table 4). Forested wetlands are predicted to be most impacted, with the greatest changes expected in the communities that support a significant conifer component such as poor conifer swamp, rich conifer swamp, rich tamarack swamp, and hardwood-conifer swamp. Fens and bogs are also likely to be negatively impacted. A number of wetland communities that occur in the coastal zone are likely vulnerable to climate change. These include the following wetland communities, in order of decreasing vulnerability: (1) lakeplain systems such as lakeplain wet prairie, lakeplain wet-mesic prairie, lakeplain oak openings, and wet-mesic flatwoods; (2) forested wetlands such as rich conifer swamp, northern hardwood swamp, southern hardwood swamp, and floodplain forest; (3) open coastal wetlands such as coastal plain marsh, interdunal wetland, coastal fen, and Great Lakes marsh; and (4) wooded dune and swale complexes. In addition to wetlands, several upland forest communities with significant conifer components are likely vulnerable to climate change, especially boreal forest and mesic northern forest.

Unlike most wetlands, many upland community types have the potential to benefit through increased acreage resulting from colonization of former mesic to wet habitats. Upland natural communities that have the potential to benefit from a warmer and drier climate include prairies, savannas, open dunes, sand and gravel beach, Great Lakes cobble shores, bedrock grasslands and glades, and bedrock shorelines.

<u>**Explanation of Variables Assessed**</u>

1. Increased Air and Surface Temperatures

The effect of increased air and surface temperatures is likely to vary among natural community types. Community types comprised primarily of species that are most competitive in full sunlight or are well-adapted to hot, dry conditions are likely to benefit. This includes community types such as marshes, wet prairies, upland prairies and savannas, dry pine and oak forests, open dunes, and bedrock communities. An exception to this general trend may be open community types that are strongly dependent on cold groundwater such as fens. Unlike the other open wetland types, it is possible that fens may be negatively impacted by warmer surface temperatures. Community types comprised of species well-adapted to moist, cool conditions such as mesic forests and those with mesic or wetland conifers may be negatively impacted by warmer air and surface temperatures. Negatively impacted community types may include mesic southern forest, mesic northern forest, poor conifer swamp, rich conifer swamp, rich tamarack swamp, hardwood conifer swamp, muskeg, and bog. This variable was consistently scored with a low level of confidence (1.1).

Table 4. Summary of overall climate change vulnerability assessment results for natural community groups in Michigan. Please refer to Table 1 for list of natural communities within each group.

NATURAL COMMUNITY GROUP	OVERALL CLIMATE CHANGE VULNERABILITY ASSESSMENT
PALUSTRINE/WETLAND COMMUNITIES	
Marsh Communities	Open wetlands will likely be moderately to highly vulnerable to climate change. The degree of vulnerability of open wetlands will vary depending on the region of the state with open wetlands in the southern Lower Peninsula being most vulnerable due to high levels of fragmentation and invasive species competition. In other words, where these systems are currently stressed, open wetlands will likely be most vulnerable to climate change.
Wet Prairie Communities	Michigan's wet prairie communities are already imperiled ecosystems that will likely be highly vulnerable to climate change due to their sensitivity to changes in hydrology and the current high levels of fragmentation, shoreline development, and invasive species competition.
Fen Communities	Fen communities are likely highly vulnerable to climate change. As peatland ecosystems with organic soils, these communities are especially sensitive to changes in soil moisture and increased evapotranspiration. If soil moisture decreases and if evapotranspiration is greater than precipitation, then peat soils will decompose and peatland ecosystems will be detrimentally impacted. In addition, the capacity of fens to disperse is limited because they are restricted to specific hydrologic and geologic settings.
Bog Communities	Bog communities are likely highly vulnerable to climate change. As peatland ecosystems with organic soils, these communities are especially sensitive to changes in soil moisture and increased evapotranspiration. If soil moisture decreases and if evapotranspiration is greater than precipitation, then peat soils will decompose and peatland ecosystems will be detrimentally impacted.
Shrub Wetland Communities	Shrub wetland communities are likely to benefit from climate change. Shrub wetlands are common communities across their ranges that have a high capacity to invade open wetlands. Climate change will likely favor shrub wetlands over open wetlands as temperatures increase and growing seasons lengthen.
Forested Wetland Communities	Forested wetlands/forested coastal wetlands are likely moderately to highly vulnerable to climate change. Forested wetlands are especially sensitive to changes in soil moisture and hydrology. In addition, many forested wetlands are currently stressed by high deer herbivory levels and invasive species.

PALUSTRINE/TERRESTRIAL	
Wooded Dune and Swale Complex	The vulnerability of wooded dune and swale complex will vary depending on the region of the state. Complexes in the thumb and northern Lower Peninsula may be more vulnerable due to higher levels of fragmentation, shoreline development, and invasive species competition compared to the complexes in the Upper Peninsula. The vulnerability of the system as a whole will likely depend on whether the Great Lakes water levels lower or rise. If Great Lakes water levels decline, wooded dune and swale complexes could potentially increase in area over long periods of time (i.e., hundreds of years). Wetlands within wooded dune and swale complexes will likely be negatively impacted (especially peatlands) while some upland systems may benefit (i.e., dry-mesic northern forest).
TERRESTRIAL COMMUNITIES	
Prairie Communities	Michigan's prairie communities are imperiled ecosystems that may benefit from climate change.
Savanna Communities	Michigan's savanna communities are imperiled ecosystems that may slightly benefit from climate change.
Forest Communities	The impact of climate change on Michigan's forested communities will range from being highly vulnerable to likely increasing. In general, northern and mesic systems (e.g., boreal forest, mesic northern forest) will be more vulnerable than southern and dry to dry-mesic forested communities (e.g., dry southern forest, dry-mesic southern forest).
PRIMARY COMMUNITIES	
Coastal Sand Communities	Michigan's primary communities may benefit from climate change. Primary communities are already adapted to high temperatures and extreme conditions, and many of them occur along the Great Lakes shoreline and will likely be buffered against climate change.
Bedrock Grassland and Glade	Michigan's bedrock glade communities may benefit from climate change. Bedrock glade communities are already adapted to high temperatures and extreme conditions and often occur near the Great Lakes and will likely be buffered against climate change.
Cobble Shore Communities	Michigan's cobble shore communities may benefit from climate change. Cobble shore communities are already adapted to high temperatures and extreme conditions and occur along the Great Lakes shoreline and will likely be buffered against climate change.
Bedrock Lakeshore Communities	Michigan's bedrock lakeshore communities may benefit from climate change. Bedrock lakeshore communities are already adapted to high temperatures and extreme conditions occurring along the shoreline, and will likely be buffered against climate change.
Lakeshore Cliff Communities	Michigan's lakeshore cliff communities may benefit or be negatively impacted by climate change. Lakeshore cliff communities are already adapted to extreme conditions and occur along the Great Lakes shoreline and therefore will likely be buffered against climate change. However, many species of lakeshore cliff communities are sensitive to increasing temperature and decreasing moisture, and certain lakeshore cliff types may be more susceptible to climate change (i.e., limestone lakeshore cliff and sandstone lakeshore cliff).

Inland Cliff Communities	Michigan's inland cliff communities may benefit or be negatively impacted by climate change. Inland cliff communities are already adapted to extreme conditions and often occur near the Great Lakes and therefore will likely be buffered against climate change. However, many species of inland cliff communities are sensitive to increasing temperature and decreasing moisture, and certain inland cliff types may be more susceptible to climate change (i.e., limestone cliff and sandstone cliff).
Subterranean/Sink Communities	Michigan's subterranean/sink communities may be negatively impacted by climate change. Sinkholes will likely be negatively impacted while caves will likely be buffered from climate change.

2. Longer Growing Season

Most natural communities are likely to benefit from a longer growing season. However, diversity in mixed hardwood-conifer systems may be detrimentally impacted. The present climate regime provides a competitive advantage to the conifers that retain their leaves throughout the year. While the broad-leaved deciduous trees are dormant, pine, hemlock, fir, spruce, cedar, juniper, and yew are able to continue to photosynthesize when temperatures are above freezing. If the period of dormancy for broad-leaved deciduous trees is shortened, the competitive advantage to the conifers will be reduced. Over time, a longer growing season may result in reductions in the frequency of conifers for some natural communities, especially those occurring near the floristic tension zone in mid Lower Michigan. Communities that may be detrimentally impacted include dry-mesic northern forest, mesic northern forest, boreal forest, hardwood-conifer swamp, rich tamarack swamp, rich conifer swamp, and poor conifer swamp. Many of the conifer species are very long-lived, and white pine reaches heights well above the hardwood canopy (i.e., it forms a super canopy above the hardwoods). Thus, a reduction in the abundance of conifers due to a longer growing season is likely to be a relatively slow process. Confidence scores for this variable ranged from low to high but were overall low (1.3).

3. Phenological Changes

Because most of the dominant plants (i.e., trees, grasses, and sedges) in the natural communities are wind pollinated, this variable was consistently assessed as neutral (i.e., 0). Confidence scores for this variable were consistently low (1.0). A much more thorough review of the plant and animals pollinators and dispersers for each natural community would need to be conducted to increase the confidence score.

4. Latitude Range Expansion or Contraction

Many natural communities are restricted in their movement because the soils or bedrock they require are geographically limited. This is especially true for the bedrock natural communities. Natural communities such as alvar, northern bald, bedrock glades, bedrock shorelines, and bedrock cliffs, are all severely restricted in their movement. In addition, large water bodies such as the Great Lakes block their northward and southward movement, especially in the Upper Peninsula. Lastly, agricultural fields and development further limit opportunities for range expansion, especially in southern Lower Michigan. Confidence for this variable was scored as low or high for this variable but was low overall (1.4).

5. Intrinsic Ability to Disperse

This variable was difficult to apply consistently. The primary difficulty encountered was that many of the communities that have a very high intrinsic or natural ability to disperse, such as grasslands, are now extremely fragmented and rare. This is especially evident in southern Lower Michigan, where agricultural fields and development severely restrict natural dispersal opportunities. Confidence scores for this variable ranged from low to high and were overall low to medium (1.6).

6. Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

An increase in the frequency or intensity of extreme events (e.g., fire, drought, windstorms, and floods) is likely to lead to a decrease in the acreage of both upland and wetland forests and a subsequent increase in savanna and open lands (both uplands and wetlands). An increase in the frequency of downbursts, will lead to higher rates of windthrow, especially in forested wetlands where trees are shallowly rooted. The loss of canopy cover will favor shrubs and herbaceous species that are most competitive in conditions of mid and high levels of light. Similarly, an increase in the frequency of fire will result in reductions in forest canopy cover and provide a competitive advantage to open land species. Increases in the frequency of droughts and floods have the potential to negatively impact forest canopy cover and hasten the conversion to savanna and open natural communities. However, increases in the frequency of fire have the potential to benefit fire-adapted forest communities (e.g., dry northern or southern forest). Confidence scores for this variable ranged from low to high and were overall medium (1.9).

7. Great Lakes Lower Water Levels

Lower water levels in the Great Lakes would lead to a direct expansion lakeward of the open natural communities that currently occupy the shoreline. This was widely observed when Great Lakes water levels dropped during the late 1990s and early to mid 2000s. Communities such as sand and gravel beach and open dunes are likely to expand lakeward where the newly exposed shoreline is comprised of sand. Current Great Lakes marshes are likely to expand or move lakeward as well. Bedrock shorelines will expand where retreating water levels expose fresh bedrock. Similarly, cobble shores will expand or arise where bedrock cobble is freshly exposed. The vertical face of lakeshore bedrock cliffs will increase as water levels drop and expose more of the cliff face. New lakeshore bedrock cliffs may also be exposed with retreating water levels. Alvar and bedrock glades will eventually come to dominate the landward portions of the bedrock lakeshore communities, and over a longer time period, forests will move lakeward. Confidence scores for this variable ranged from low to high and were overall low to medium (1.6).

Several climate models suggest the potential for higher Great Lakes water levels, but overall fluctuations are predicted to be within their normal range of variation (Lofgren et al. 2002, Lofgren et al. 2011). Long-term increases in Great Lakes water levels beyond their normal range of variation will initially cause reductions in the acreage of many of the coastal natural communities, but this change is likely to be temporary as wave, wind, ice, and storm disturbances facilitate the creation of open, primary communities along the lakeshore.

8. Reduction in Regional Groundwater and Surface Water Levels

Reductions in regional groundwater and surface water levels are likely to lead to a significant decrease in acreages of both open and forested wetlands. In many locations, the loss of wetlands will result in a subsequent expansion of adjacent upland natural communities. However, this conversion often may not be predictable. The soils of many wetlands are composed of organic soils (e.g., peat, muck). Reductions in ground and surface water levels will lead to an oxidation of the peat/organic soil, which will hasten its decomposition and significantly reduce its overall volume. The result would be a lowering of the land surface in these former wetlands. For example, where there was once ten feet of peat overlaying mineral soil, there may be only a foot or less of organic material mixed with mineral soils due to compression, decomposition, and mixing by animals and plants. These soils are likely to have high organic content and thus high water holding capacity. Thus, the plant communities that develop on former peat soils will likely be comprised of a mix of wetland and upland plants. Some of the natural communities that could occupy former peatlands might include mesic prairie, mesic sand prairie, wet-mesic prairie, mesic southern forest, and mesic northern forest. Lastly, as these peatlands dry, they will be especially prone to catching fire, which would lead to the direct loss of organic material.

In addition to changes in wetlands, a reduction in regional ground and surface water levels is likely to result in significant declines in species diversity for both inland and lakeshore cliffs. Many cliffs have areas of groundwater seepage along their faces where mosses, lichens, liverworts, and ferns are abundant. In many cases, the cessation of groundwater seepage from the face of a cliff will lead to the loss of these species. Confidence scores for this variable ranged from low to high and were overall medium (1.8).

9. Wetter Winters and Springs and Drier Summers and Falls

This variable was not easy to accurately assess. The growth of most woody plants is concentrated during the spring and early summer. Consequently, wetter winters and springs followed by drier summers and falls may not significantly impact most woody species, and those that are already well-adapted to drier conditions, such as many oaks and pines, may benefit. However, drier summers and falls increases the chances of wildfires, which overtime could lead to significant reductions in forest canopy cover and an increase in the frequency of stand replacement events for boreal forest, dry northern forest, and dry-mesic northern forest. The scenario of wetter winters and springs followed by drier summers and falls will likely favor species well adapted to drier conditions. Therefore, natural communities such as dry and dry-mesic prairies, oak barrens, oak opening, oak-pine barrens, pine barrens, alvar, bedrock shorelines, and bedrock glades may expand their acreages. Confidence scores for this variable ranged from low to medium but were overall low (1.1).

10. Overall Drier Climate (greater evaporation and evapotranspiration and drier soils)

The average annual precipitation in Michigan is approximately 30 inches, which favors the establishment and growth of trees. A drier climate is likely to result in a decrease in the overall acreage of all wetland communities (i.e., marshes, prairies, fens, bogs, shrublands, and forests). Mesic and boreal forests are also likely to be adversely impacted by an overall drier climate. Drought stress reduces survival of trees, especially seedlings/saplings, and makes trees more sensitive to pest outbreaks and pathogens. Communities that are well adapted to drier conditions and which may expand in acreage include upland prairies, savannas, bedrock glades, open dunes, and oak and pine forests. Confidence scores for this variable ranged from low to high and were overall low to medium (1.6).

11. Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
This attribute was especially difficult to score for several reasons. First, because of the large number of potential invasives plants, animals, and pathogens, we lacked the range of expertise needed to fully assess the potential threats posed by the potential expansion of these species resulting from climate change. Secondly, the potential for future, new introductions and their potential impacts is unknown. Thirdly, in many instances, an invasion may result in detrimental impacts for one community but may indirectly benefit a different, adjacent community. For example, a tree pathogen may severely reduce canopy cover, which may result in an expansion of an adjacent open community. There are numerous examples of this interaction in both wetlands and uplands but the interactions can be complex and hard to predict. For example, a tree pathogen in a dry-mesic northern forest or boreal forest on thin soils over bedrock may result in widespread tree mortality and a severe reduction of canopy cover. Consequently, the community would be especially vulnerable to a catastrophic fire event. In this example, the tree pathogen could cause a decrease in the acreage of dry-mesic northern forest or boreal forest and a subsequent increase in the acreage an adjacent bedrock glade. Confidence scores for this variable ranged from low to high but were overall low (1.1).

12. Average Vulnerability
In general, our assessment indicates that most wetland communities will be negatively impacted by a change in climate that includes warmer and drier conditions. In particular, fens, bogs, and forested wetlands are predicted to be most impacted, with the greatest changes expected in the conifer-dominated wetlands. A number of coastal wetlands also are likely vulnerable to climate change including lakeplain systems, open coastal wetlands, forested wetlands, and wooded dune and swale complexes. In addition to these wetlands, several upland forests are likely to be negatively impacted, especially boreal forest and mesic northern forest. Reduction in groundwater and surface water levels, overall drier climate, and increased levels of invasive plants, pests, pathogens, grazers, and browsers were the variables that contributed most frequently to the vulnerability of these natural communities. Conversely, many other upland community types have the potential to expand in acreage, and thus, potentially benefit. Upland community types that have the potential to benefit from a warmer and drier climate include prairies, savannas, open dunes, sand and gravel beach, Great Lakes cobble shores, bedrock glades, and bedrock shorelines.

13. Average Confidence
In general, our confidence in assessing the various variables was scored low (1.4 on a scale of 1 to 3). The highest confidence scores, on average, were assigned for the variables of Increased Frequency or Intensity of Extreme Events (1.9) and Reduction in Regional Groundwater and Surface Water Levels (1.8). The lowest confidence scores were assigned to Phenological Change (1.0), Increased Air and Surface Temperatures (1.1), Wetter Winters and Springs and Drier Summers and Falls (1.1), and Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers (1.1). The overall low confidence scores is an indication that there are far more unknowns than knowns when it comes to understanding the potential impacts of climate change.

Spatial Analysis to Identify Vulnerable Areas Due to Climate Change and Other Stressors

For the spatial analysis, we used projections from Climate Wizard (Girvetz et al. 2009) to estimate the amount of climate change Michigan may experience in the future in terms of mean annual temperature, annual precipitation, and moisture availability. Mean annual temperature is predicted to increase by 5.1 to 5.5^{o}F (2.8 to 3.1^{o}C) across most of the state by mid-century (2050s), based on projections from an ensemble of 16 global circulation models (GCMs) and a medium emissions scenario (A1B) (Figure 1, Girvetz et al. 2009). A small area along Lake Huron in the northeast Lower Peninsula may experience a smaller increase in mean annual temperature, while the area around the Keweenaw Peninsula and Isle Royale in the Upper Peninsula may experience a larger increase in mean annual temperature by mid-century (Figure 1, Girvetz et al. 2009). Mean annual precipitation is predicted to change or increase by 5 to 8% across the state and coastal zone by the 2050s, with some parts of the state potentially experiencing greater increases in annual precipitation than others (Figure 1, Girvetz et al. 2009). It is important to note, though, that climate change projections for precipitation tend to vary widely and are generally more uncertain than temperature projections (Winkler et al. 2012).

Annual moisture availability is predicted to decrease across the state by mid-century, based on predicted annual change in Hamon AET:PET Moisture Metric for 2040-2069 (Girvetz et al. 2009) (Figure 1). Southern Michigan is predicted to experience the greatest percent change or decrease in annual moisture in the state (Figure 1). The northern Lower Peninsula, the southern half of the eastern Upper Peninsula along Lakes Michigan and Huron, the Keweenaw Peninsula, and some small areas along Lake Superior are predicted to experience intermediate decreases in annual moisture in the state (Figure 1). Most of the Upper Peninsula is predicted to experience the least amount of change or decrease in annual moisture in the state (Figure 1). Changes in seasonal moisture also are predicted but were not examined or included in this analysis.

Eleven different data layers representing or indicating two climate change associated impacts or stressors and nine non-climate related stressors were compiled and/or developed for the spatial analysis. For each data layer or stressor, watersheds that were in the highest stress category were mapped in red. Watersheds that were considered to be in the moderate stress categories for that stressor were shown in orange or yellow. Watersheds that were considered to be in the lowest stress categories were shown in light or dark green.

Most of the watersheds in the coastal zone along Lake Erie and Saginaw Bay were in the highest or second highest stress categories for percent natural land cover, percent agricultural land cover, and percent natural riparian land cover (Figures 2, 3 and 4). A number of watersheds in the coastal zone along Lake Michigan in the Lower Peninsula also were in the higher stress categories for percent natural land cover (Figure 2). The percent natural land cover and percent agricultural land cover data indicate that half or a little over half of the land cover in these watersheds is not natural, and has been developed for residential, commercial, industrial, and/or agricultural use (Figures 2 and 3). The percent natural riparian cover data indicate that over half of the land within 200 ft (60 m) of streams within these watersheds is not natural and has been developed (Figure 4). Most of the watersheds along Lake Huron, northern Lake Michigan, and Lake Superior were in the moderate or low stress categories for percent natural land cover, percent agricultural land cover, and percent natural riparian cover (Figures 2, 3 and 4).

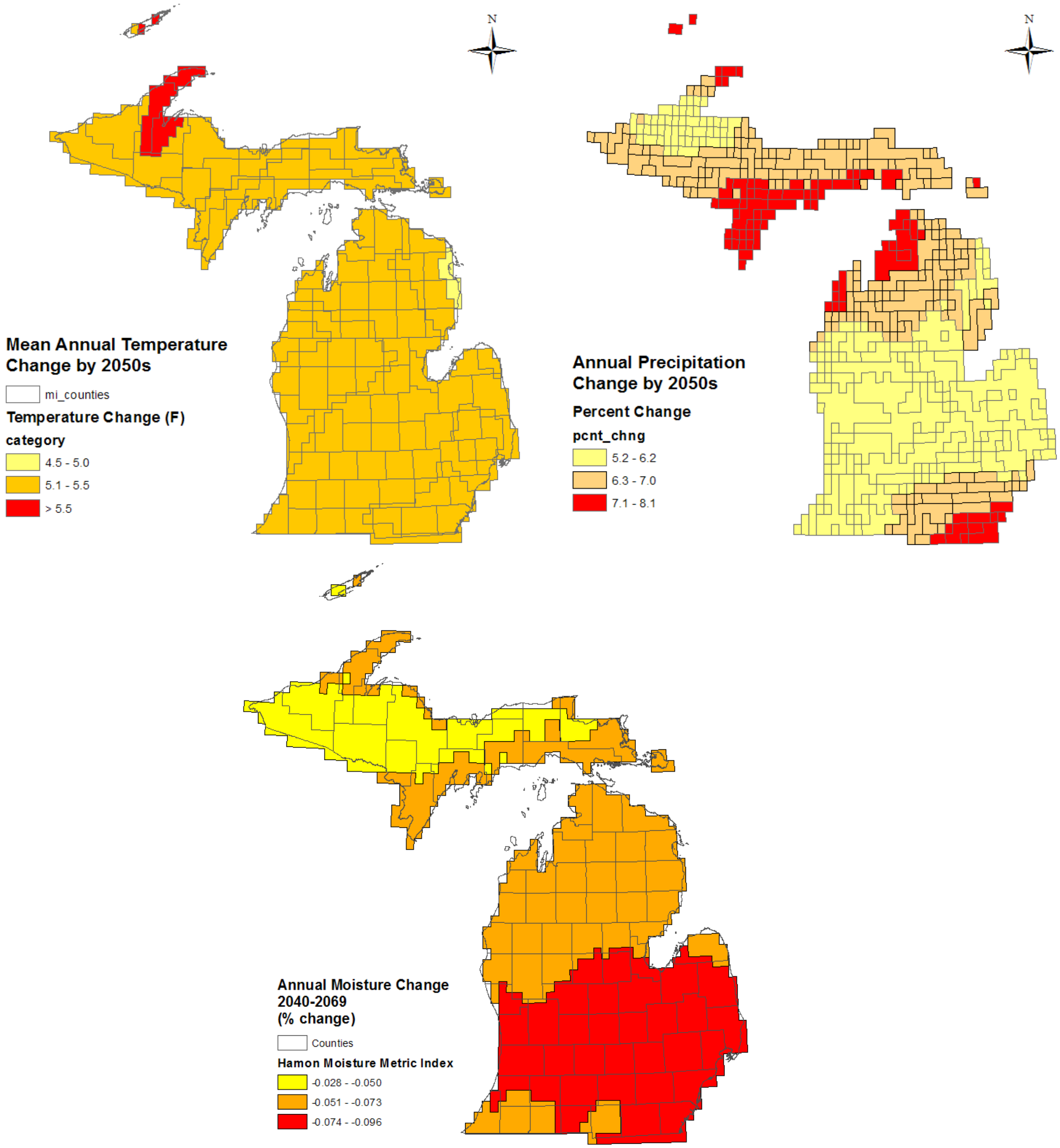

Figure 1. Climate change projections for Michigan in terms of (1) change in mean or average annual temperature by 2050s (top left), (2) percent change in annual precipitation by 2050s (top right) and (3) percent change in annual moisture by 2040-2069 (bottom center). Climate change projections were generated by The Nature Conservancy's ClimateWizard (www.climatewizard.org) (Girvetz et al. 2009). Projections were based on a median ensemble of 16 GCMs and medium emissions scenario (A1B).

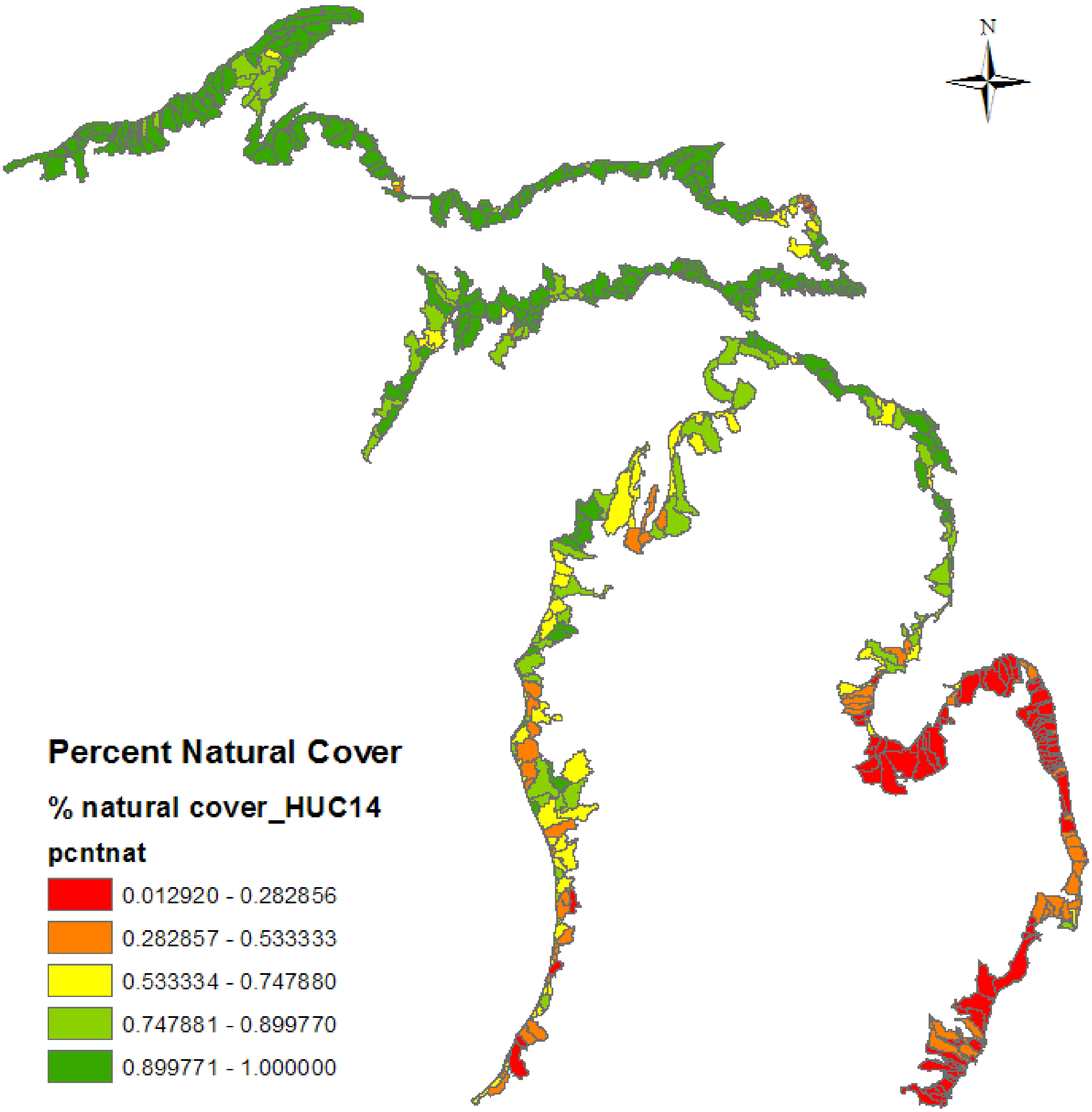

Figure 2. Map showing categories of percent natural land cover in HUC14 watersheds in coastal zone in Michigan. Land cover data from NOAA Coastal Change Analysis Program (CCAP) (NOAA 2006). Lower percentages of natural land cover indicate higher stress (i.e., red areas indicate higher stress, green areas indicate lower stress).

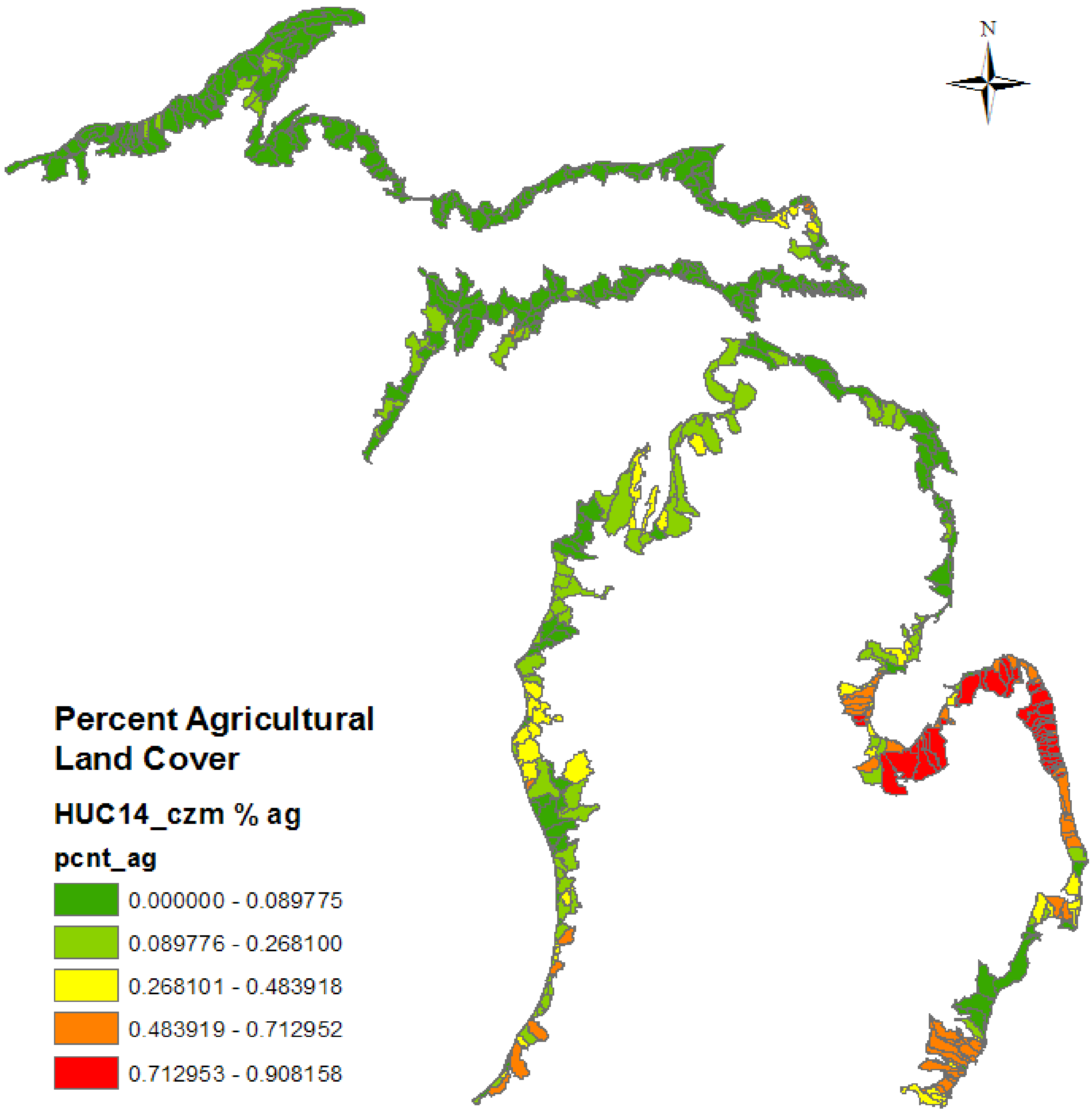

Figure 3. Map showing categories of percent agricultural land cover in HUC14 watersheds in coastal zone in Michigan. Land cover data from NOAA Coastal Change Analysis Program (CCAP) (NOAA 2006). Higher percentages of agricultural land cover indicate higher stress (i.e., red areas indicate higher stress, green areas indicate lower stress).

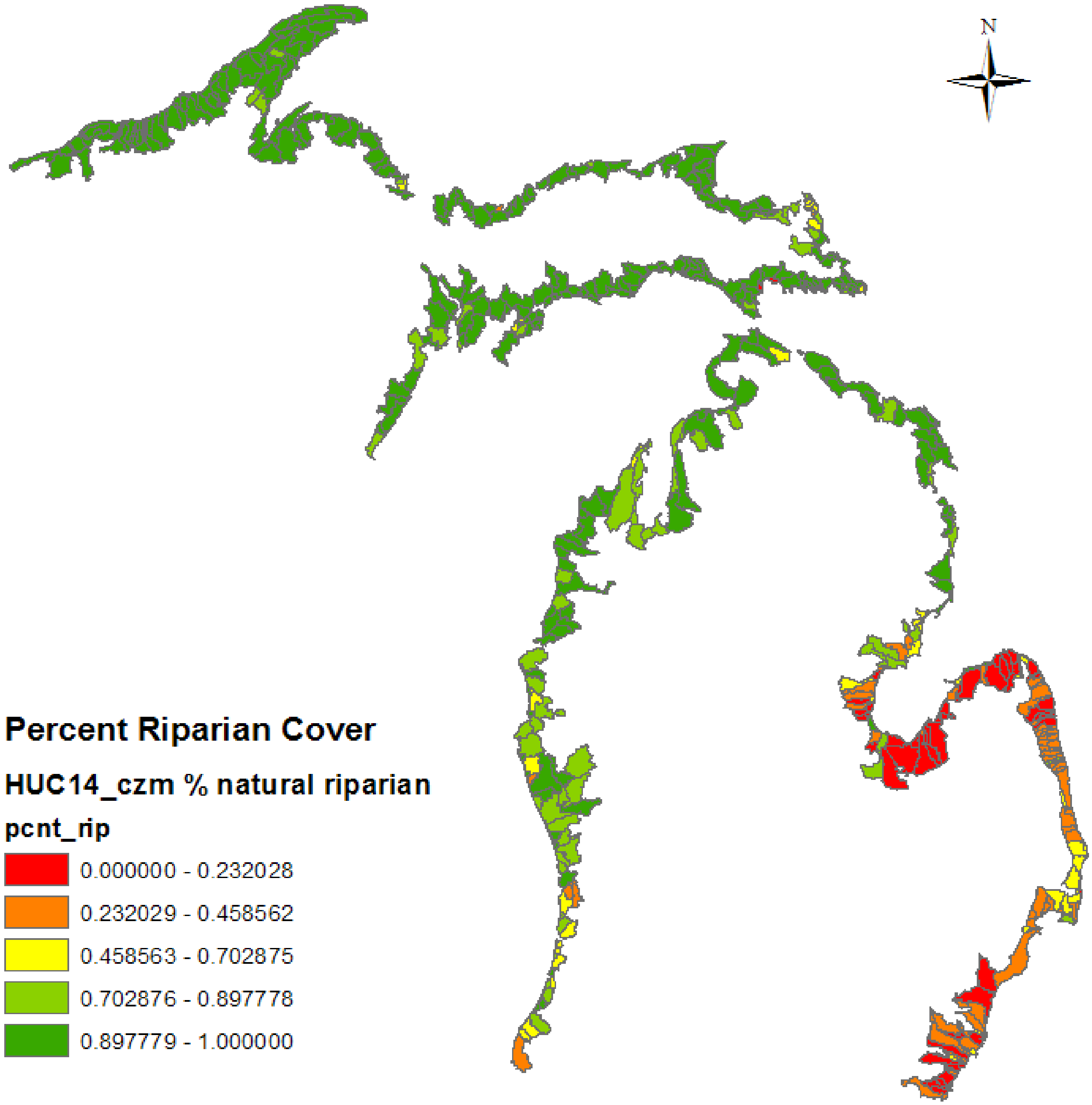

Figure 4. Map showing categories of percent natural riparian cover (natural land cover within 200 ft/60 m of a stream) in HUC14 watersheds in coastal zone in Michigan. Land cover data from NOAA Coastal Change Analysis Program (CCAP) (NOAA 2006). Lower percentages of natural riparian cover indicate higher stress (i.e., red areas indicate higher stress, green areas indicate lower stress).

Results of the spatial analysis were used to indicate geographic areas or watersheds along the coastal zone that may be more vulnerable to climate change impacts and other stressors on the landscape. Percent natural land cover, percent agricultural land cover, and percent natural riparian cover were used to indicate areas that may be more vulnerable to several climate change and non-climate-related stressors. Watersheds in the higher stress categories for percent natural land cover are likely experiencing higher levels of landscape fragmentation, and may be more vulnerable to non-point source pollution, and decreased water levels and increased flooding due to climate change than watersheds in the moderate or low stress categories for this stressor. Similarly, watersheds in the higher stress categories for percent natural riparian land cover may be more vulnerable to increased flooding and non-point source pollution than watersheds in the low or moderate stress categories for this stressor. Percent agricultural land cover was used to indicate an additional stressor on water availability due to agricultural use. Watersheds in the higher stress categories for percent agricultural land cover may be experiencing or may be more vulnerable to higher levels of water withdrawal for agricultural use than watersheds in the low to moderate stress categories for this stressor.

Fewer watersheds were in the highest or second highest stress categories for percent impervious surface (Figure 5), road density (Figure 6), and stream-road intersections (Figure 7) than the numbers of watersheds that were in the highest stress categories for percent natural land cover, percent agricultural land cover, and percent natural riparian cover. Only about 10% of the watersheds in the coastal zone were in the highest or second highest stress categories for percent impervious surface. These were located along Lake Erie, Saginaw Bay, and southern Lake Michigan near more developed or urbanized areas, and a few watersheds were located in the Upper Peninsula (Figure 5). Basically, the same watersheds were in the highest or second highest stress categories for road density (Figure 6). Only nine watersheds were in the highest and second highest stress categories for stream-road intersections, and were located along Lake Erie and scattered along the shoreline in the Upper Peninsula (Figure 7).

Watersheds in the higher stress categories for percent impervious surface may be more vulnerable to decreased water levels in rivers, streams, lakes, and wetlands and increased flooding due to climate change than watersheds in the moderate or low stress categories for this stressor. These watersheds also may be experiencing higher levels of non-point source pollution than watersheds in the moderate or low stress categories (Figure 5). Watersheds in the higher categories for road density may be characterized by a greater degree of landscape fragmentation, and may contain more barriers to dispersal/movement for terrestrial species than watersheds in the low to moderate categories for this stressor (Figure 6). Watersheds in the higher stress categories for stream-road intersections may contain more barriers to dispersal/movement for aquatic animal species than watersheds in the low to moderate categories (Figure 7).

Non-agricultural groundwater withdrawals were included in the spatial analysis because they represent an existing stressor on the groundwater supply. There were only a small number of watersheds in the coastal zone in the highest or second highest category for this stressor (Figure 8). This data layer was used with the percent agricultural land cover layer to indicate relative levels of groundwater withdrawal or stress on water availability across watersheds. Watersheds with higher densities of groundwater withdrawal sites and higher percentage of agricultural land cover may be more vulnerable to climate change impacts on groundwater resources.

Point source pollution also represents an existing additional stressor on aquatic and wetland habitats or systems. Data on the number or density of point source pollution sites within watersheds were compiled to indicate relative levels of point source pollution across watersheds (Figure 9). Watersheds with higher densities of point source pollution sites and/or in higher stress categories for indicators of non-point source pollution (i.e., percent natural cover, percent impervious surface, and percent natural riparian cover) may be experiencing higher levels of pollution. These areas also may be more vulnerable to potential impacts of climate change because they are already stressed.

The density of dams (i.e., # dams per stream mile) and locations of *Phragmites* and boat access sites also were included in the spatial analysis. The density of dams was used to indicate relative amounts of barriers to dispersal or movement for aquatic animal species across watersheds. Only one watershed along the coastal zone was in the highest stress category for density of dams. The *Phragmites* locations were based on available data and areas where surveys and/or mapping for *Phragmites* have occurred (Figure 10). As a result, *Phragmites* may occur in areas that have not been surveyed or mapped. Boat access sites occur throughout the state and coastal zone (Figure 11). Boat access sites indicate areas where zebra mussels and potentially other aquatic invasive species occur or likely occur. Dams, *Phragmites*, and boat access sites also generally indicate areas that have been disturbed to some degree.

The cumulative analysis combined data from eight of the non-climate stressors or data layers (see Table 4 for list of stressors) to identify high, moderate and low stress areas based on multiple non-climate stressors. The analysis identified a number of watersheds in the coastal zone that were in the highest stress categories for multiple non-climate stressors (Table 5 and Figure 12). The cumulative or combined non-climate stressor scores (i.e., number of stressors for which a watershed was in the highest stress category) ranged from 0 to 5 (out of a maximum score of 8). No watershed was in the highest stress category for all eight stressors. Watersheds that had a combined stressor score of 3, 4, or 5 and were in the highest stress category for 3-5 different stressors were considered high stress areas. Watersheds that had a combined stressor score of 1 or 2 and were in the highest stress category for 1 or 2 stressors were considered moderate stress areas. Watersheds that had a combined stressor score of 0 and were not in the highest stress category for any of the 8 stressors in the analysis were considered low stress areas.

Table 5. Summary of results of cumulative stressor analysis.

Combined Non-Climate Stressor Score (# of stressors in highest category	**Number of Watersheds (N=582)**	**Stress Category (High, Moderate, Low Stress Area)**
0	257	Low Stress Area
1	198	Moderate Stress Area
2	98	Moderate Stress Area
3	20	High Stress Area
4	8	High Stress Area
5	1	High Stress Area

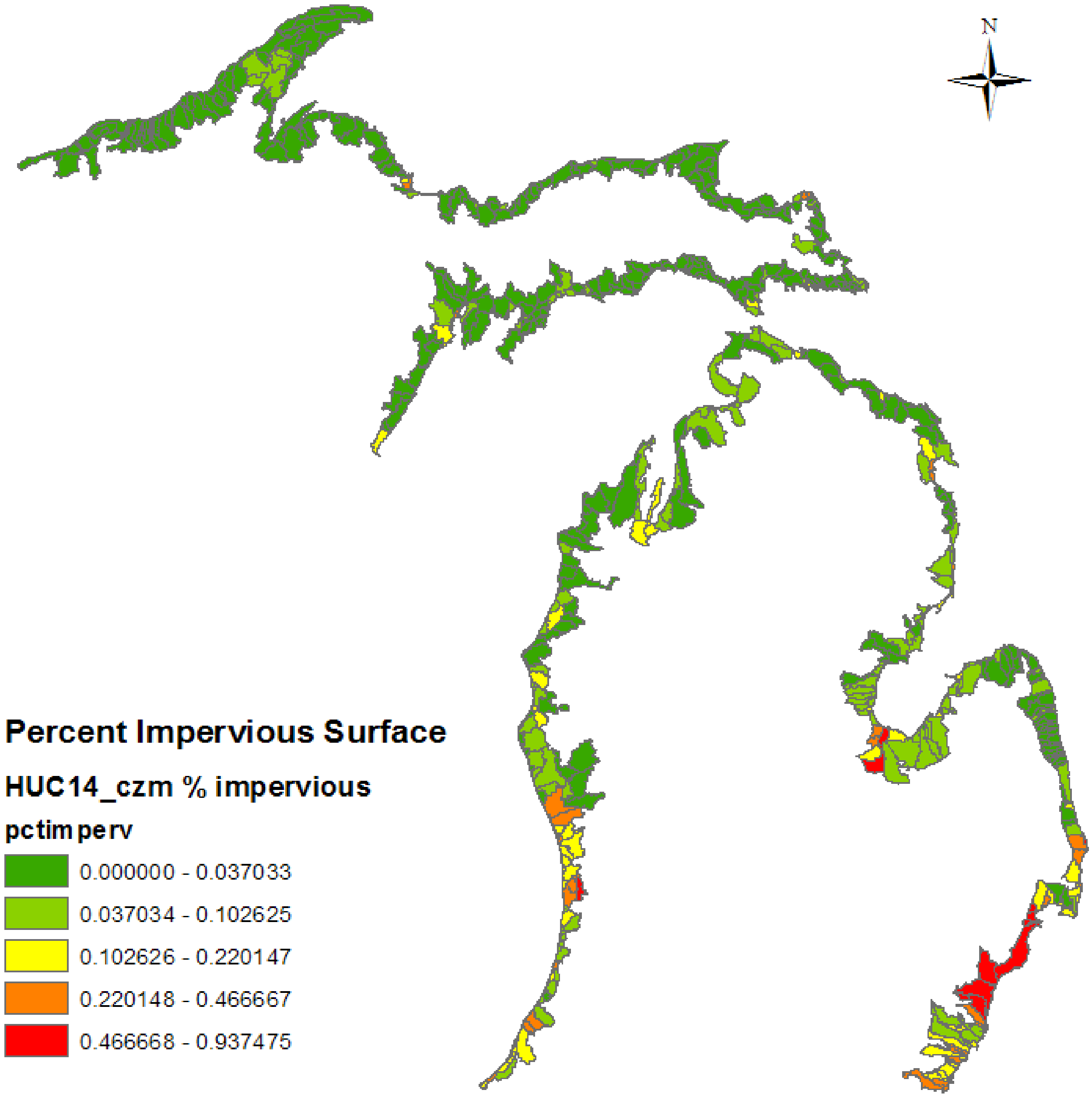

Figure 5. Map showing categories of percent impervious surface in HUC14 watersheds in coastal zone in Michigan. Land cover data used to calculate percent impervious surface were from NOAA Coastal Change Analysis Program (CCAP) (NOAA 2006). Higher percentages of impervious surface indicate higher stress (i.e., red areas indicate higher stress, green areas indicate lower stress).

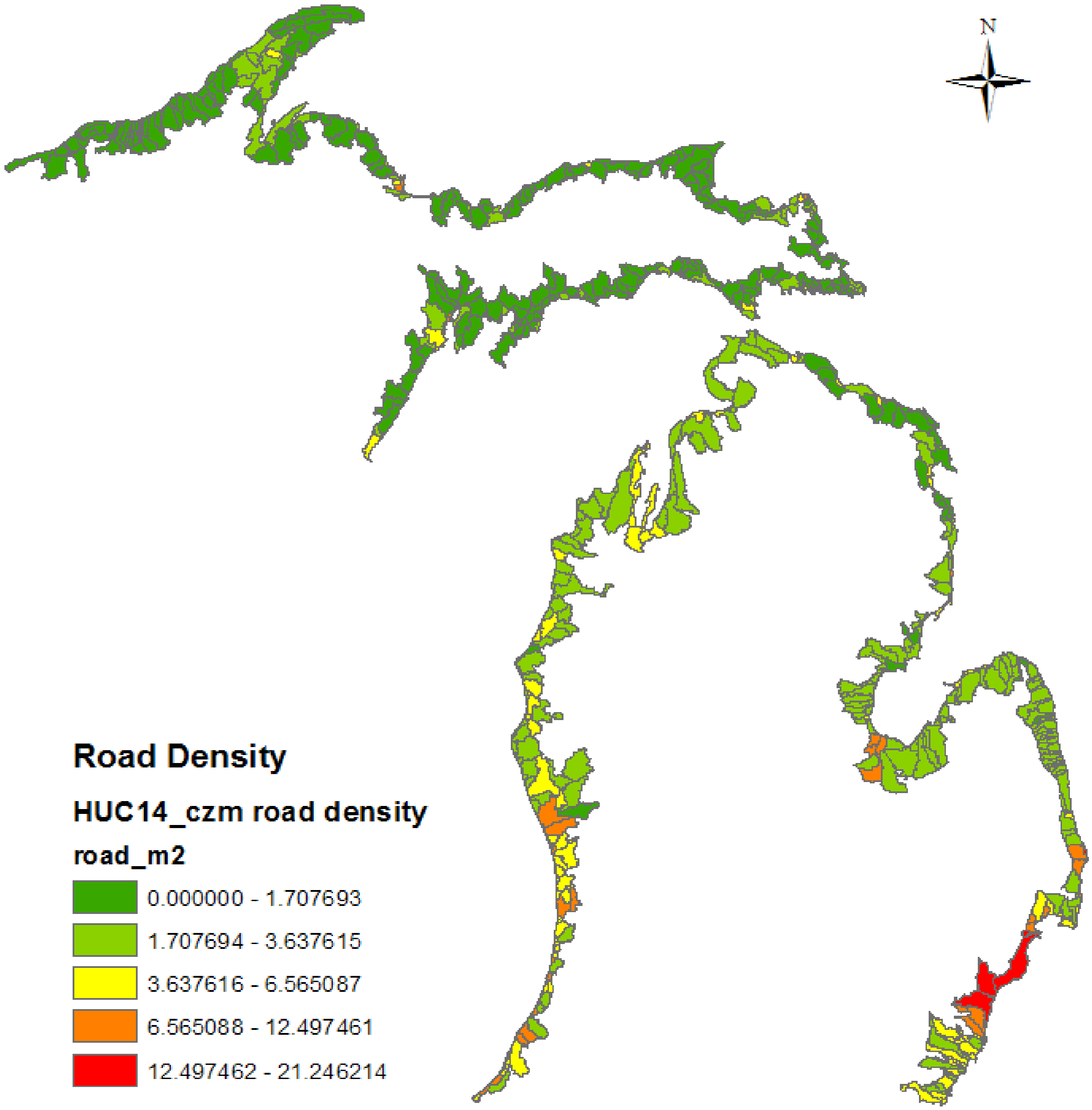

Figure 6. Map showing categories of road density in HUC14 watersheds in coastal zone in Michigan. Data used to calculate road density from the Michigan Framework dataset. Higher road densities indicate higher stress (i.e., red areas indicate higher stress, green areas indicate lower stress).

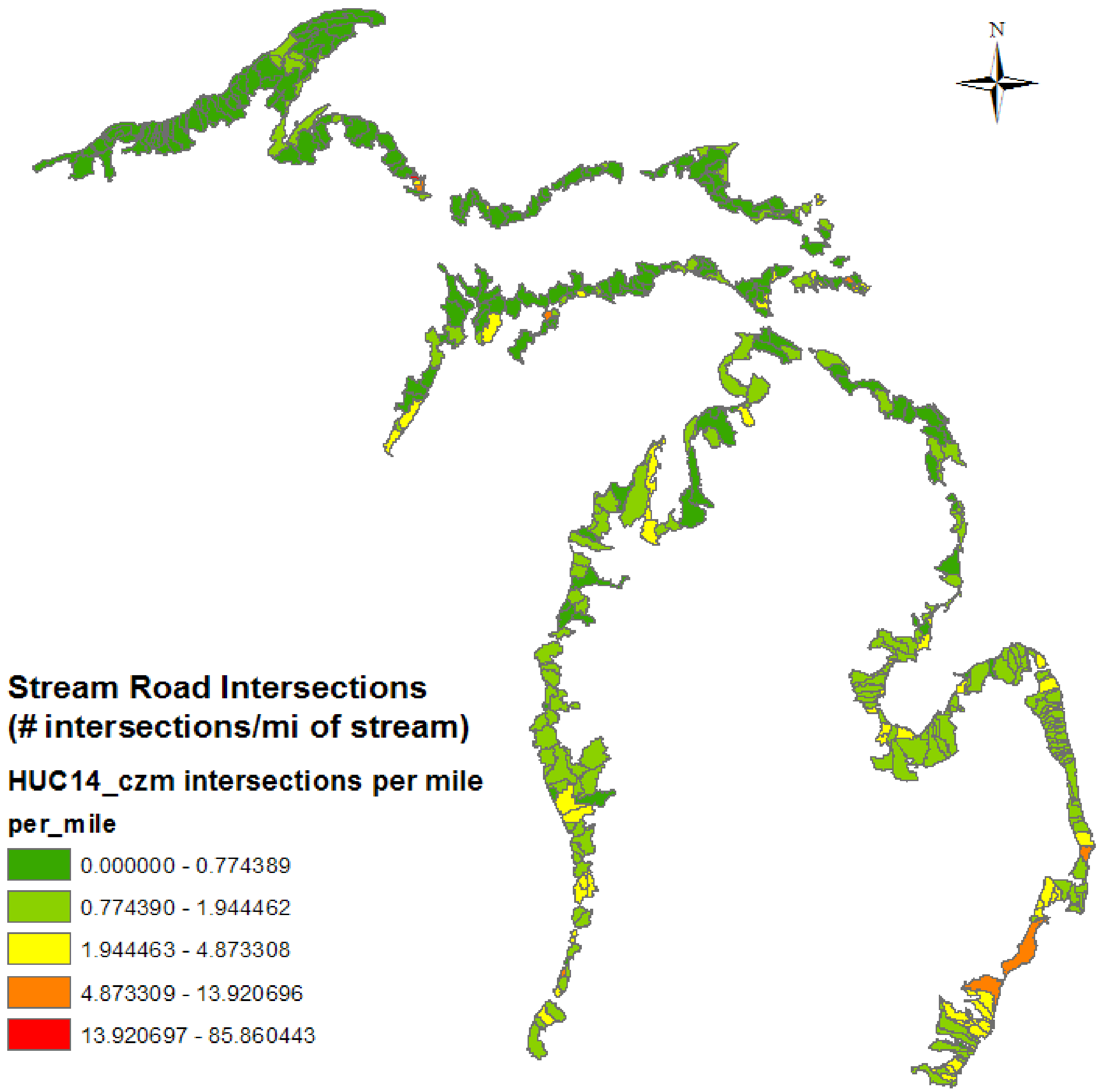

Figure 7. Map showing categories of stream road intersections per stream mile in HUC14 watersheds in coastal zone in Michigan. Data used to calculate stream road intersections were from the Michigan Framework dataset. Higher numbers of stream-road intersections indicate higher stress (i.e., red areas indicate higher stress, green areas indicate lower stress).

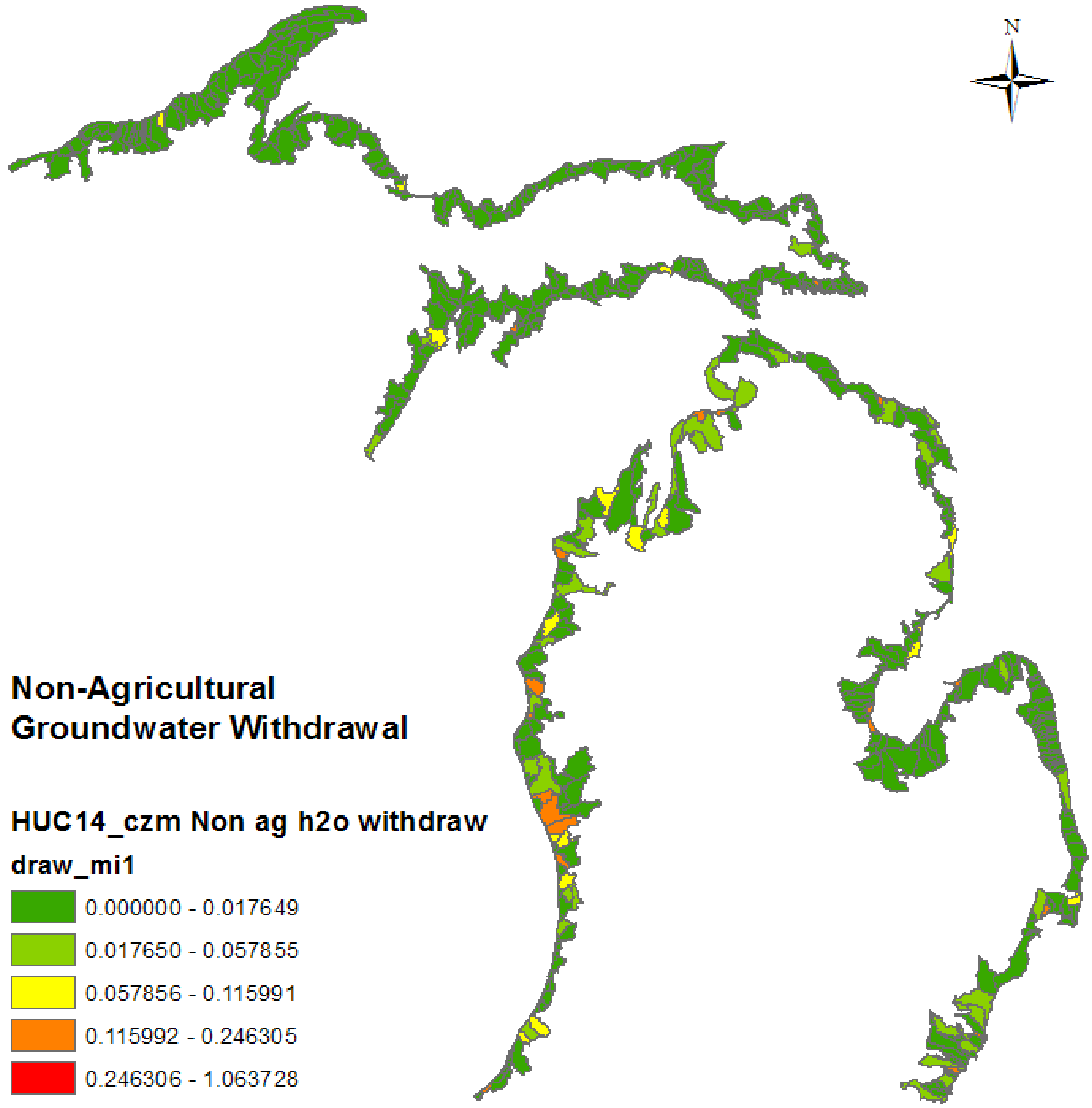

Figure 8. Map showing categories of the number of non-agricultural groundwater withdrawals per square mile in HUC14 watersheds in coastal zone in Michigan. Point data on groundwater withdrawals from the Michigan Department of Information Technology Center for Geographic Information library. Higher numbers of withdrawals per square mile indicate higher stress (i.e., red areas indicate higher stress, green areas indicate lower stress).

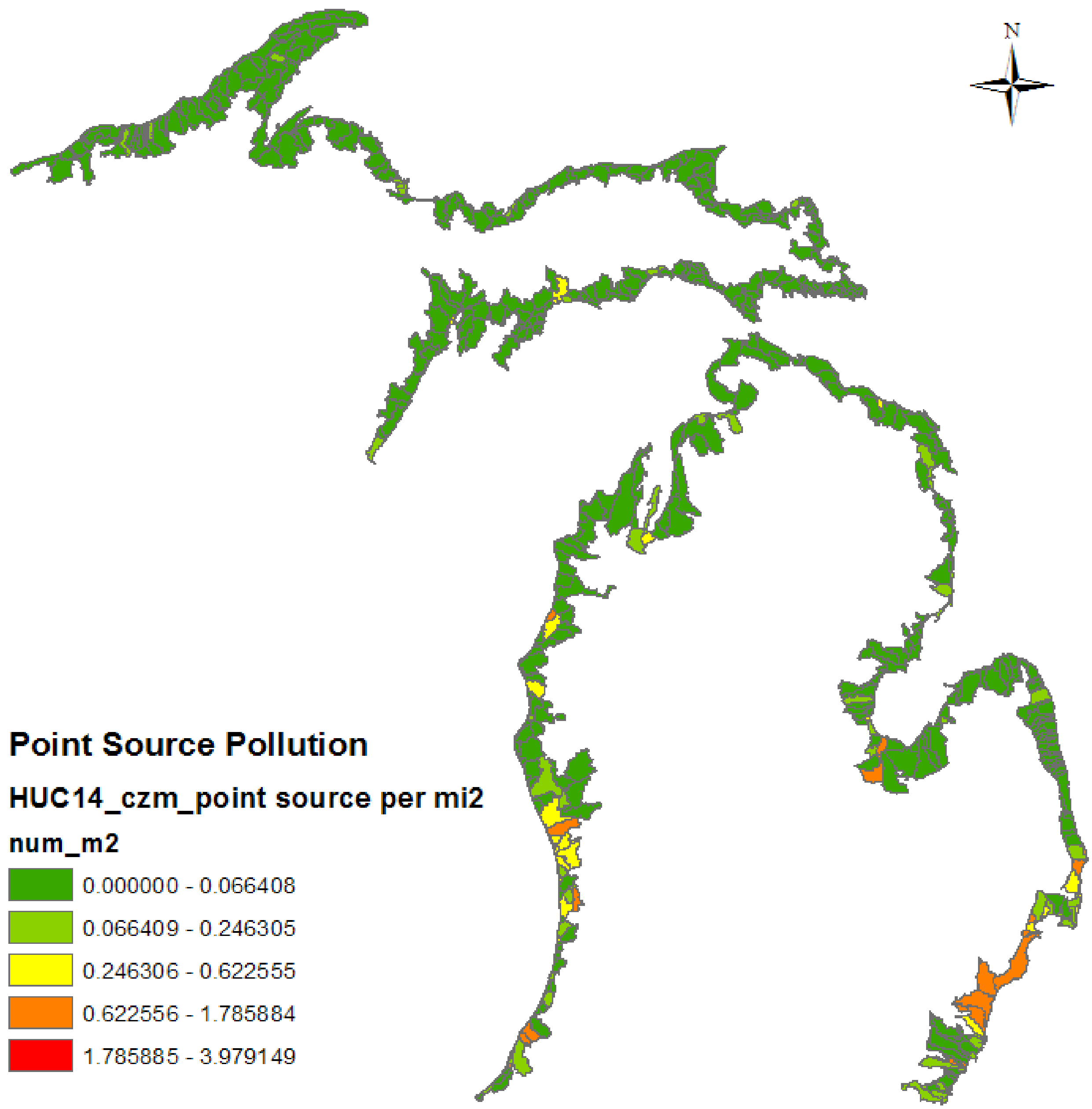

Figure 9. Map showing categories of the number of point source pollution discharge sites per square mile in HUC14 watersheds in coastal zone in Michigan. Point discharge (NPDES) data obtained from the U. S. Environmental Protection Agency (2009). Higher numbers of point source discharge sites per square mile indicate higher stress (i.e., red areas indicate higher stress, green areas indicate lower stress).

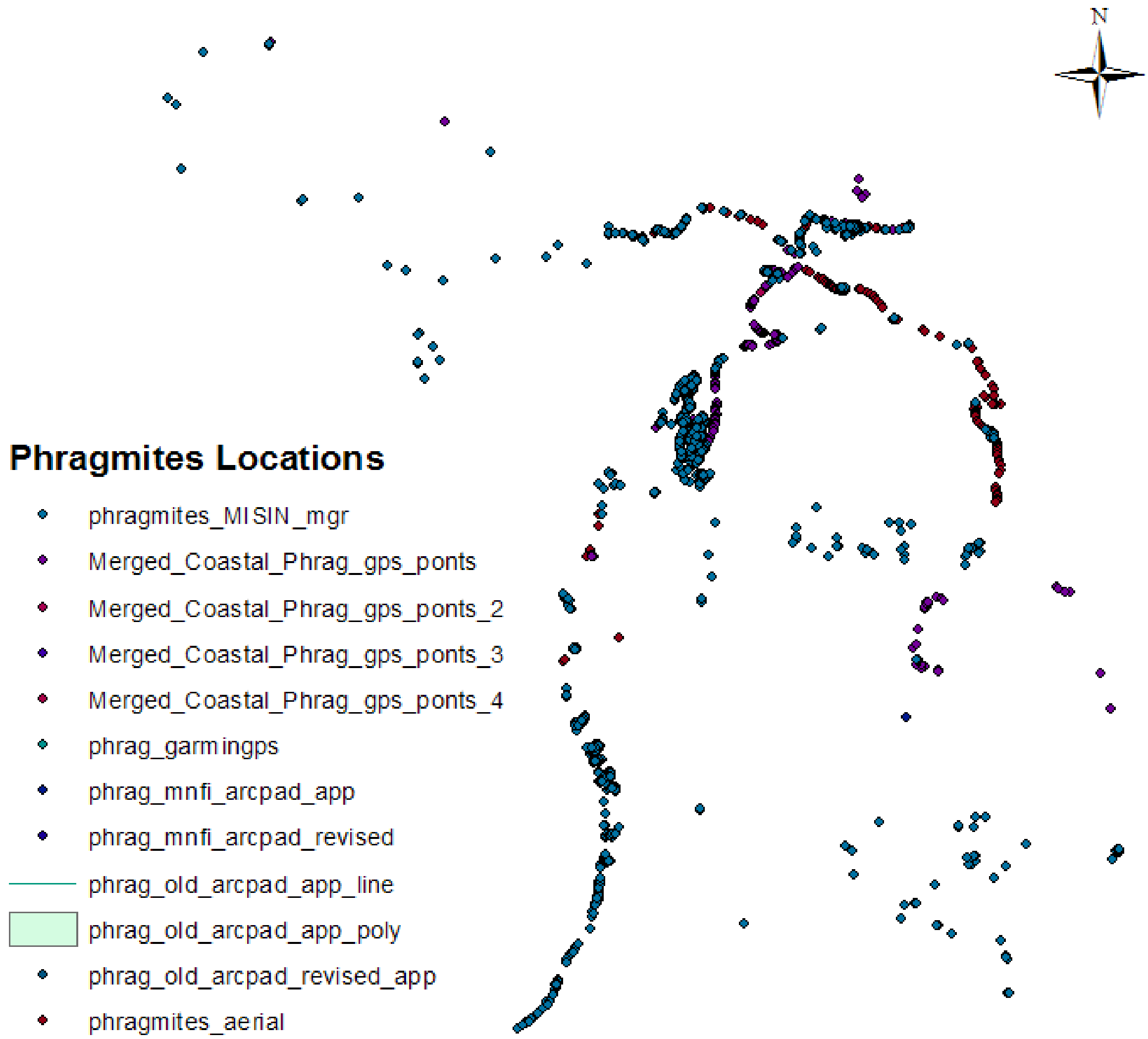

Figure 10. Map showing locations of the invasive common reed (*Phragmites australis*) along the coastal zone in Michigan. Data was obtained from the Midwest Invasive Species Information Network (MISIN) (http://www.misin.msu.edu/) and from MNFI surveys.

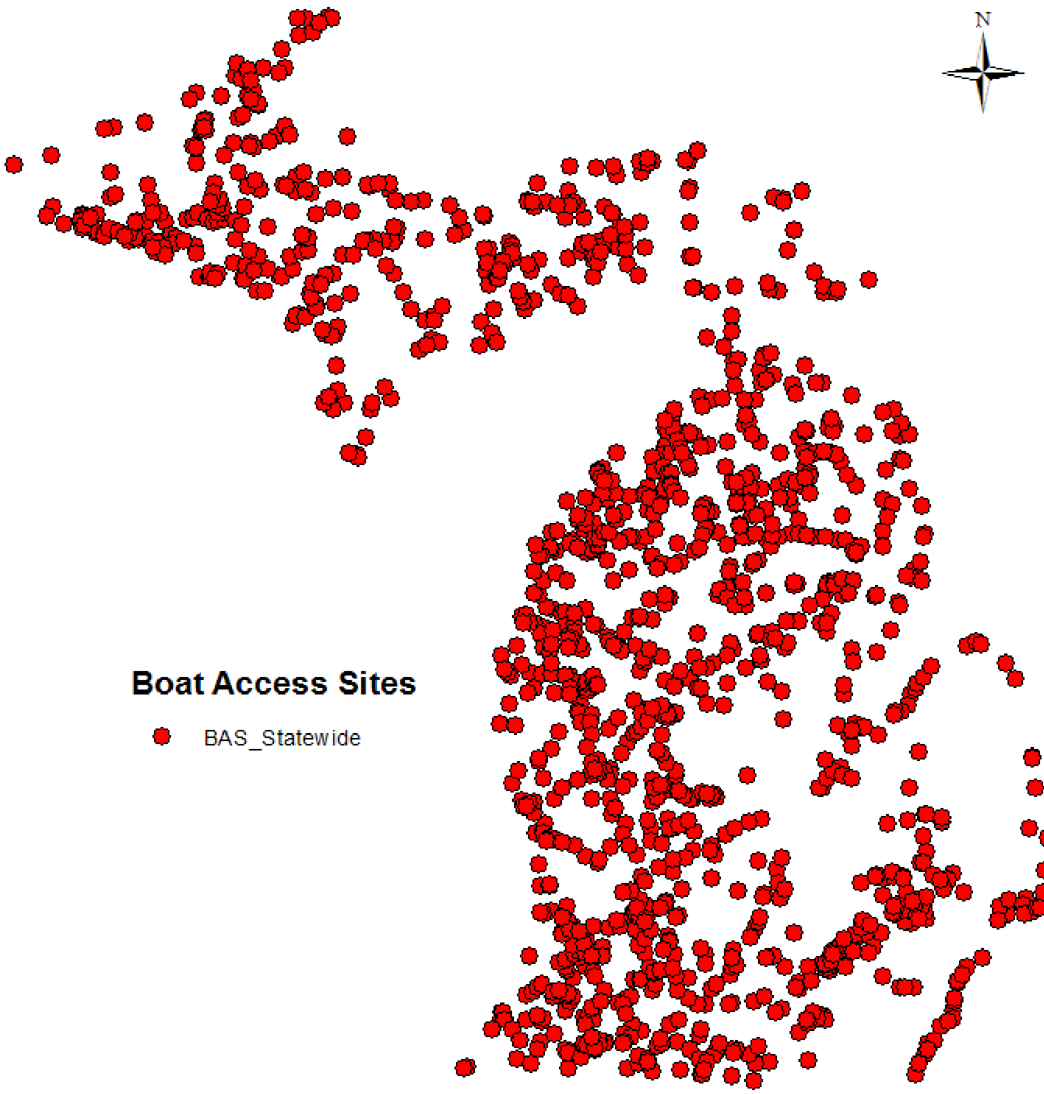

Figure 11. Map showing locations of boat access sites in Michigan. Data from Michigan Department of Natural Resources BAS_Statewide dataset.

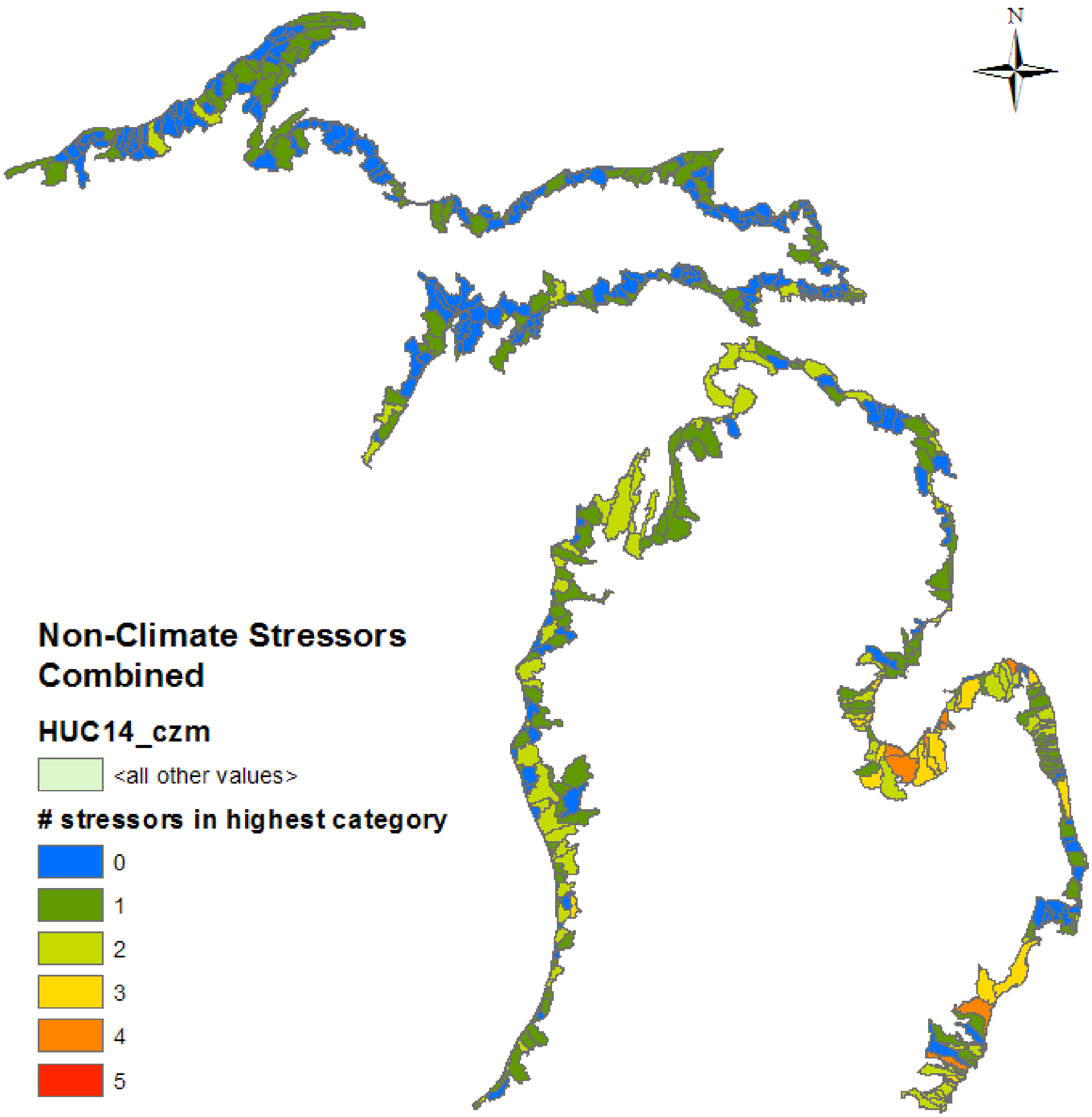

Figure 12. Map showing HUC14 watersheds in Michigan's coastal zone considered high, moderate, and low stress areas based on a cumulative analysis of eight non-climate stressors. For this analysis, watersheds with combined stressor scores of 3, 4, or 5 were considered high (or higher) stress areas (red, orange, and yellow areas). Watersheds with combined stressor scores of 1 or 2 were considered moderate stress areas (light green and dark green areas), and those with a score of 0 were considered low stress areas (blue areas).

To identify geographic areas along Michigan's coastal zone where natural communities sensitive to climate change may be particularly vulnerable due to climate change and other stressors on the landscape, we overlaid known occurrences of these natural communities onto the climate change projection maps and the maps of high, moderate, and low stress areas based on the cumulative stressor analysis and individual stressors. We conducted the analysis on five natural community groups that included communities that occur in the coastal zone and were identified as likely vulnerable to climate change based on our assessment. We identified geographic areas or watersheds in which each natural community group may be more vulnerable due to climate change and other stressors on the landscape by overlaying known occurrences of natural communities in each group onto available climate change maps and stressor maps that were compiled and used for this project. We also identified areas in which each natural community may be less vulnerable or more resilient to climate change based on this analysis. The results of the spatial analysis for the five natural community groups and specific natural communities within these groups are provided below.

<u>Lakeplain Systems</u>

This natural community group included lakeplain wet prairie, lakeplain wet-mesic prairie, lakeplain oak openings, and wet-mesic flatwoods. The current distribution of lakeplain systems in the coastal zone is limited to watersheds in three main areas along Lake Erie, the St. Clair Delta, and Saginaw Bay, and one watershed along Lake Michigan in the southwest corner of the state. Based on climate projections that were available and used for this project, lakeplain systems, or lakeplain prairies and savannas, may be exposed to similar changes in mean or average annual temperature and annual moisture but different levels of change in annual precipitation across its distribution in Michigan's coastal zone (Figure 13). Lakeplain systems may experience intermediate increases in annual average temperature but greater decreases in annual moisture compared to other parts of the state (Figure 13). They may experience greater increases in annual precipitation along Lake Erie than in other parts of its distribution (Figure 13). However, climate change projections for precipitation tend to be more uncertain than temperature projections (Winkler at al. 2012). It is unclear how lakeplain systems will be impacted by increased temperature and precipitation, but a drier climate or drier conditions will likely negatively impact these natural communities.

Lakeplain systems occur in watersheds that appear to be highly impacted by non-climate stressors throughout its current distribution in the state. Forty-percent of the watersheds (i.e., 8 of 20 watersheds) in which lakeplain prairies and savannas have been documented had combined stressor scores of 3 or 4, which were considered high stress areas for this analysis (Figure 14). All of these watersheds were in the highest stress category for percent natural cover (Figure 15) and *Phragmites* (i.e., *Phragmites* was present in the watershed), except for one watershed in which *Phragmites* had not been recorded or mapped (although it may occur in this watershed as well). Of the remaining 12 watersheds in which this natural community group occurs, eleven of them had combined stressor scores of 1 or 2, which were considered moderate stress areas, and one watershed had a combined stressor score of 0, which was considered a low stress area (Figure 14). However, some of these watersheds were in the highest or second highest stress categories for individual stressors that can impact lakeplain systems including *Phragmites* and percent natural land cover, road density, and percent impervious surface (Figure 15), which can lead to landscape fragmentation, increased flooding and runoff, and decreased water levels.

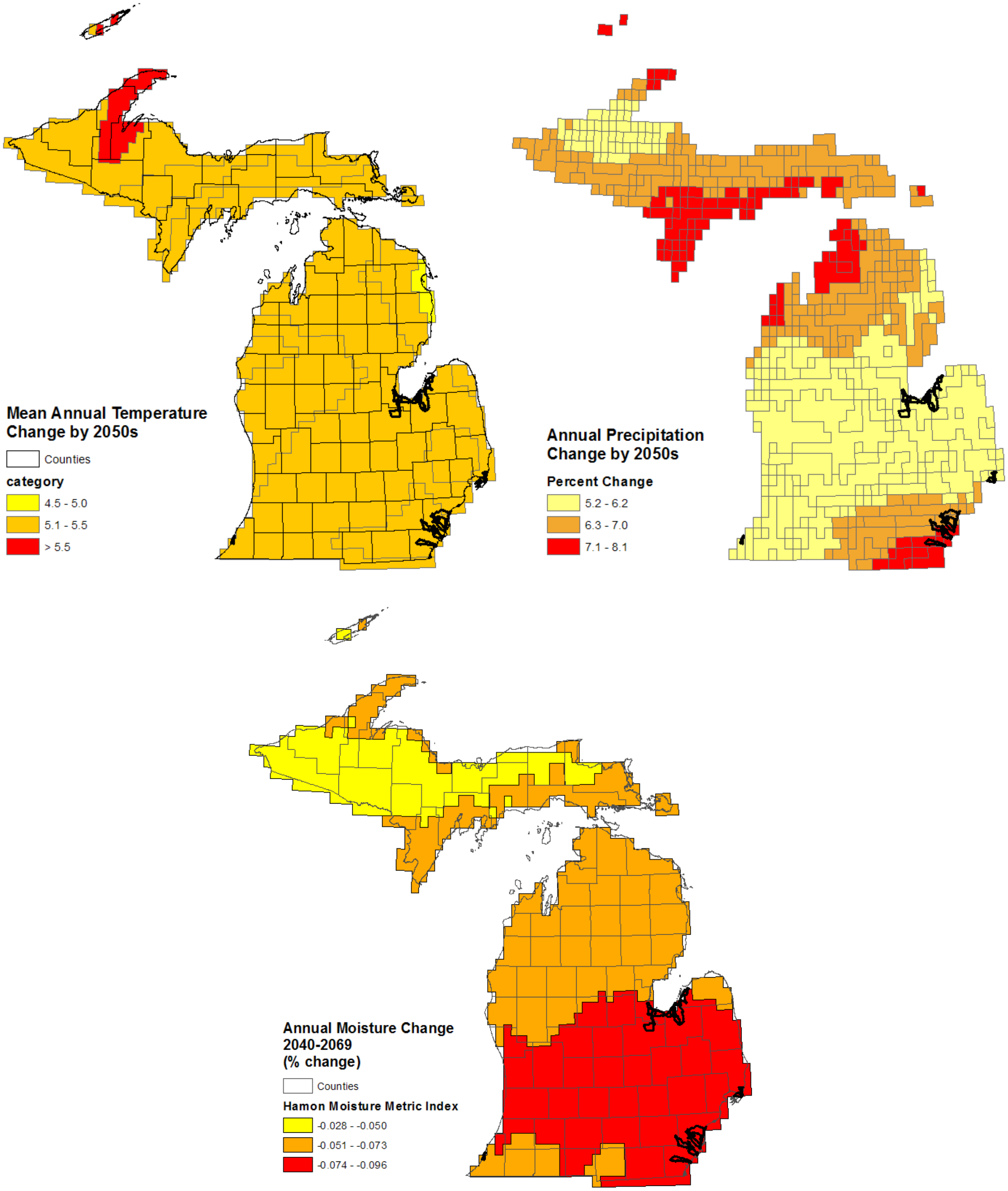

Figure 13. Maps indicating lakeplain systems' potential exposure to climate change in the coastal zone based on climate change projections for Michigan (based on data from Climate Wizard) and the HUC14 watersheds in the coastal zone in which lakeplain systems have been documented (outlined in black, based on MNFI 2012).

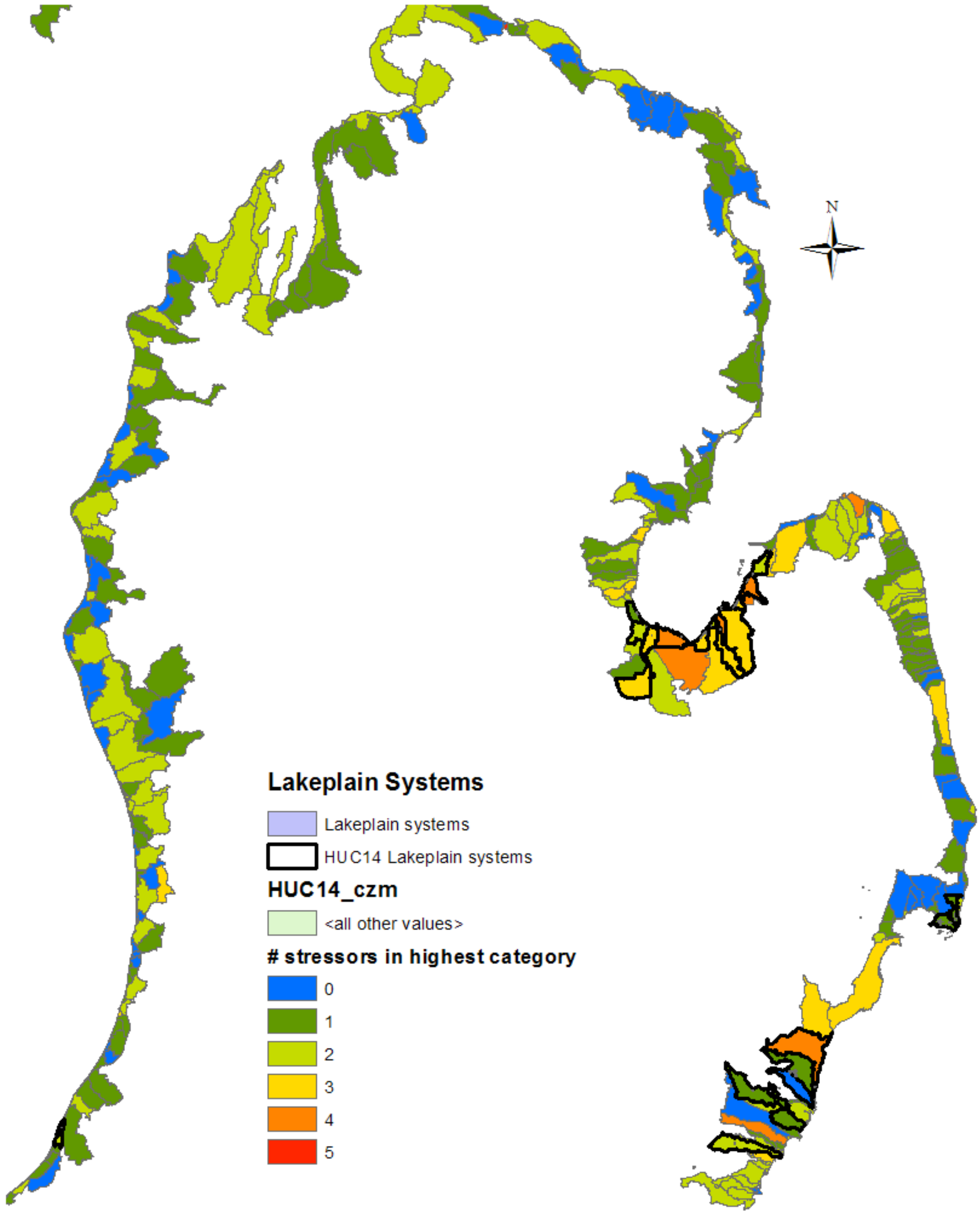

Figure 14. Map of the HUC14 watersheds in Michigan's coastal zone in which lakeplain systems have been documented (outlined in black, based on MNFI 2012) and their combined stressor scores indicating high stress (red, orange, and yellow), moderate stress (light and dark green), and low stress areas (blue), based on a cumulative analysis of a subset of non-climate stressors.

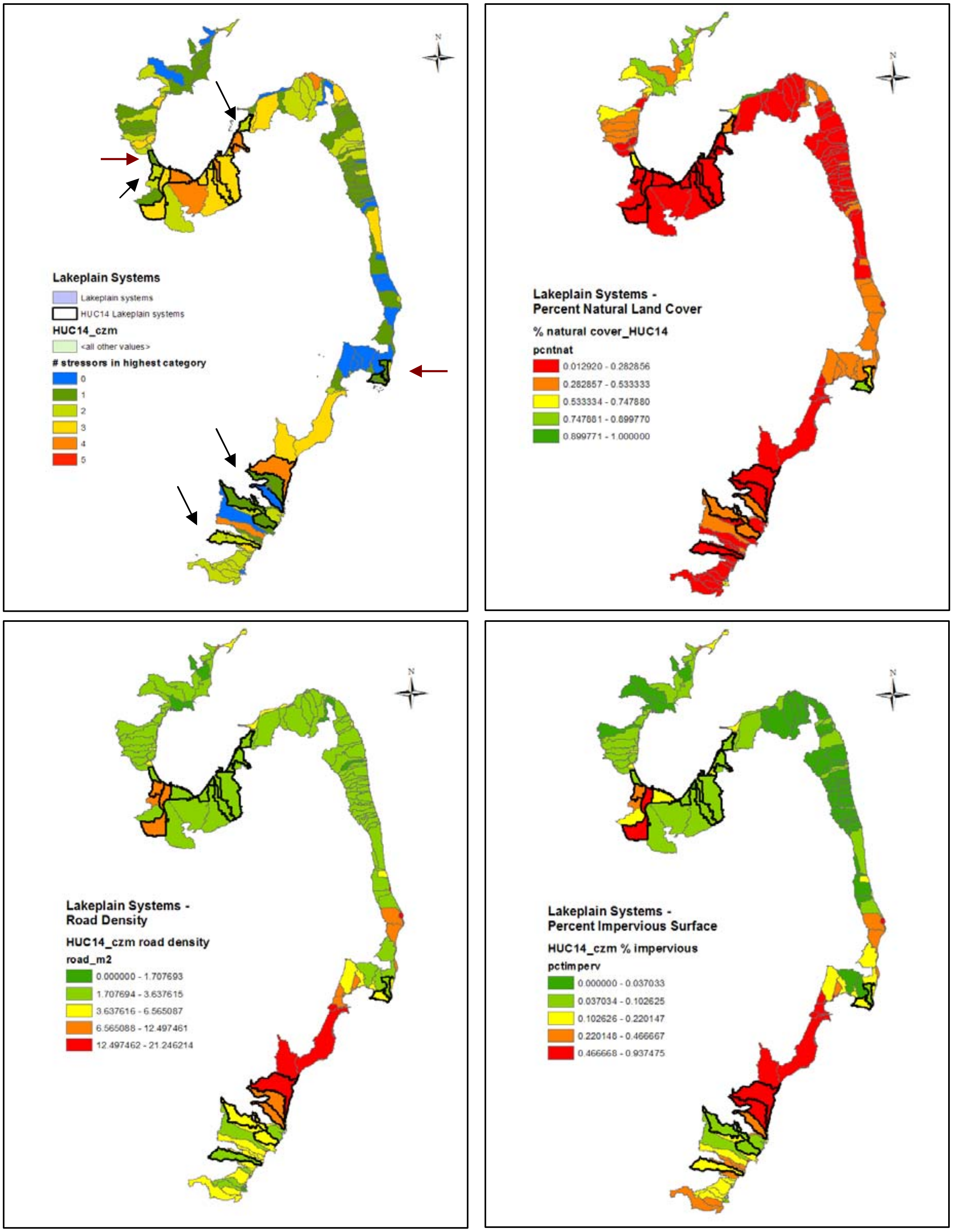

Figure 15. Maps indicating the HUC14 watersheds in Michigan's coastal zone in which lakeplain systems have been documented (outlined in black) and results for all stressors combined and specific individual stressors (red – highest stress, orange/yellow – moderate stress, light/dark green – lowest stress). Black arrows indicate additional vulnerable watersheds for lakeplain systems (i.e., moderate combined stress areas in higher stress categories for individual stressors). Brown arrows indicate less vulnerable watersheds.

Based on the spatial analysis of climate change projections and other non-climate stressors on the landscape, lakeplain systems appear to be vulnerable due to climate change and other stressors throughout its distribution in the coastal zone. They may be particularly vulnerable in the watersheds that were considered high stress areas based on the cumulative analysis and stressor scores (i.e., red, orange and yellow-colored watersheds) (Figure 14). They also may be more vulnerable in the watersheds that were considered moderate stress areas (i.e., light and dark green-colored areas) and were also in the highest or second highest stress categories for percent natural cover and other stressors (Figure 15). Lakeplain systems may be less vulnerable in the watersheds that were considered low or moderate stress areas, based on the combined stressor scores, and were in the lower stress categories for percent natural cover and other stressors (Figure 15). These include several watersheds along Saginaw Bay and the St. Clair River Delta, and one watershed along Lake Michigan. Lakeplain systems along Lake Michigan in the southwest corner of the state also may be less vulnerable because this area may experience less of a decrease in annual moisture than along Lake Erie and Saginaw Bay (Figure 13).

Forested Wetlands

The forested wetlands group included rich conifer swamp, northern hardwood swamp, southern hardwood swamp, and floodplain forest. Forested wetlands as a group may be exposed to similar changes in average annual temperature and annual moisture availability across most of their distribution in the coastal zone, except for a few watersheds along the Lake Huron shoreline and the Keweenaw Peninsula for temperature, and along the Lake Superior shoreline for moisture (Figure 16). But forested wetlands may experience different changes in annual precipitation across their distribution in the coastal zone. Forested wetlands may experience low to moderate changes in annual precipitation across most of its distribution in the coastal zone, except for some areas along the Lake Michigan shoreline in the northwest Lower Peninsula and eastern Upper Peninsula and the tip of the Keweenaw Peninsula which may experience greater increases in annual precipitation (Figure 16). It is important to note, though, that precipitation projections tend to vary widely in general (Winkler at al. 2012). It is unclear how forested wetlands will be impacted by increased temperature and/or precipitation, but a drier climate or drier conditions will likely negatively impact these natural communities.

Almost all the watersheds in which forested wetlands have been documented in the coastal zone were considered low to moderate stress areas based on the cumulative stressor analysis (Figure 17). The watersheds that were considered high or moderate stress areas were primarily due to the scoring for the presence of *Phragmites* and/or boat access sites. However, these stressors do not significantly impact forested wetlands. Most of the watersheds in which occurrences of forested wetlands have been documented in the coastal zone also were primarily in the lowest stress categories for individual non-climate stressors (Figure 18). Some watersheds along Lake Michigan and Saginaw Bay were in moderate stress categories for several individual stressors including percent natural cover, road density, percent impervious surface, and/or non-agricultural groundwater withdrawal (Figure 18). Forested wetlands may be more vulnerable to climate change in these watersheds. Forested wetlands also may be more vulnerable in southern Michigan as this part of the state is predicted to experience a greater decrease in annual moisture compared to other parts of the state (Figure 16). Conversely, forested wetlands may be less vulnerable to climate change in the watersheds that were considered low or moderate stress areas and were in the lowest stress categories for individual stressors (Figures 17 and 18).

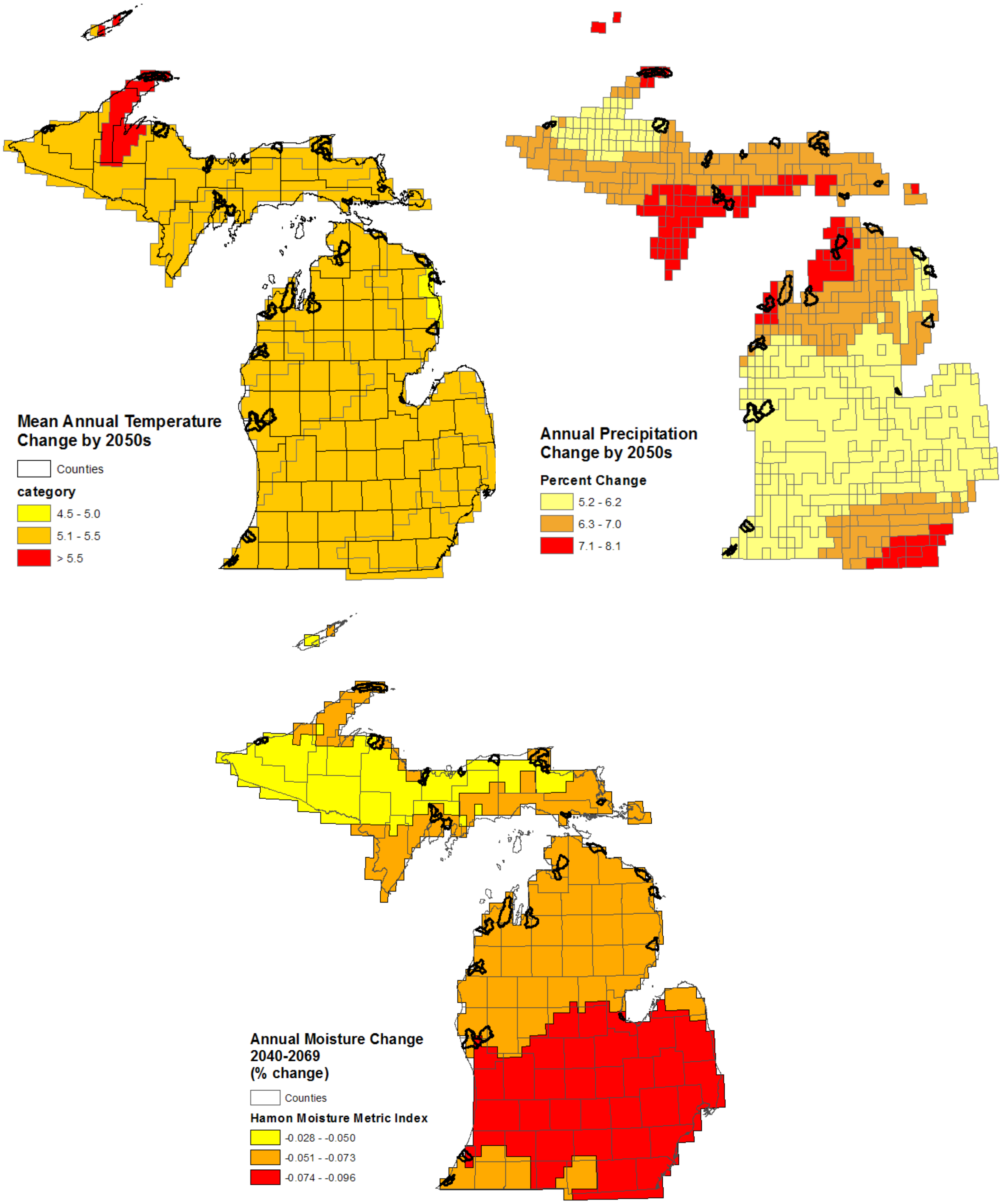

Figure 16. Maps indicating forested wetlands' potential exposure to climate change in the coastal zone based on climate change projections for Michigan (data from Climate Wizard) and the HUC14 watersheds in the coastal zone in which forested wetlands have been documented (outlined in black, based on MNFI 2012).

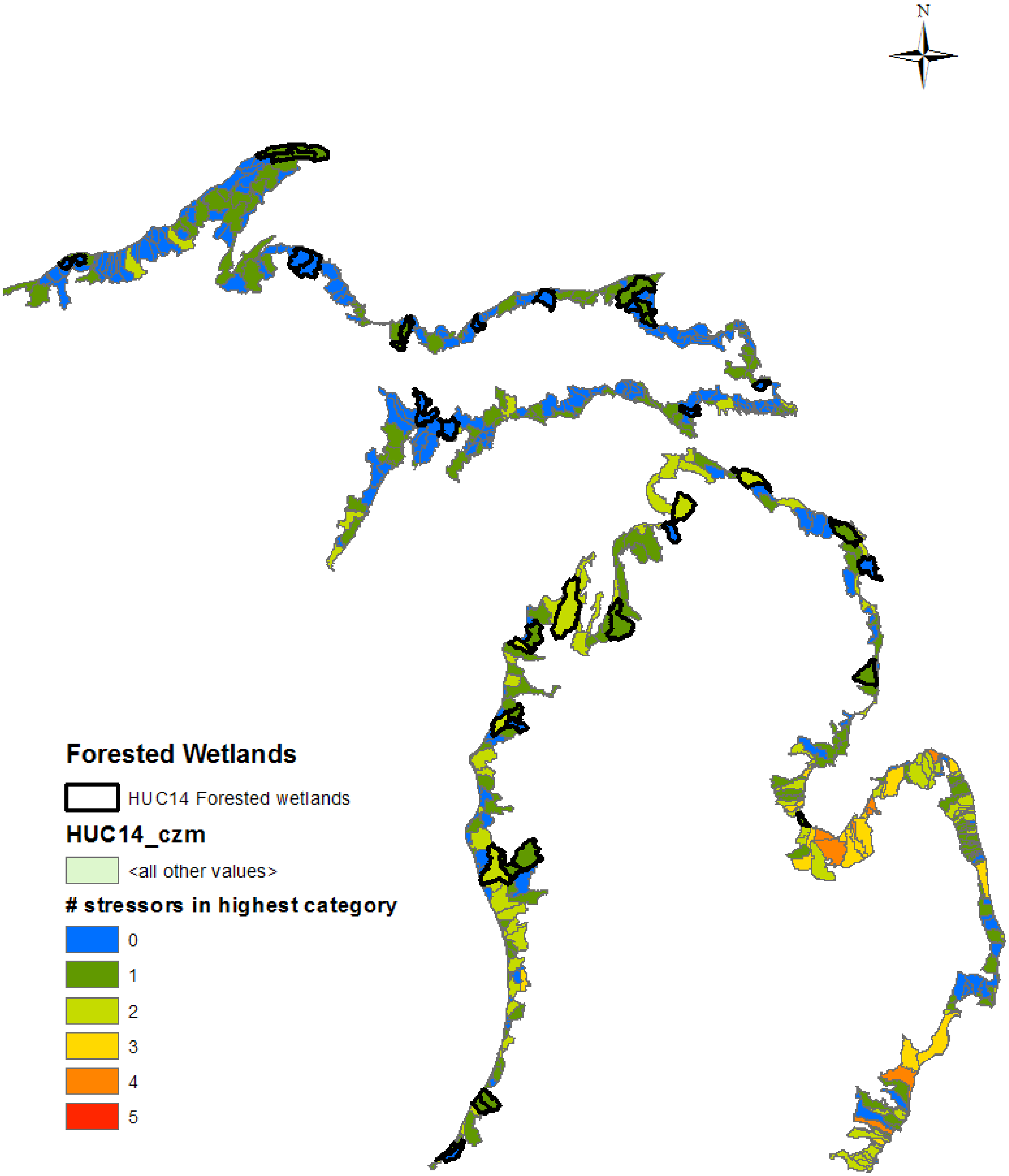

Figure 17. Map indicating the HUC14 watersheds in Michigan's coastal zone in which occurrences of forested wetland communities have been documented (outlined in black, based on MNFI 2012), and the combined stressor scores for these watersheds indicating high stress (red, orange, and yellow), moderate stress (light and dark green), and low stress (blue) areas, based on a cumulative analysis of a subset of non-climate stressors.

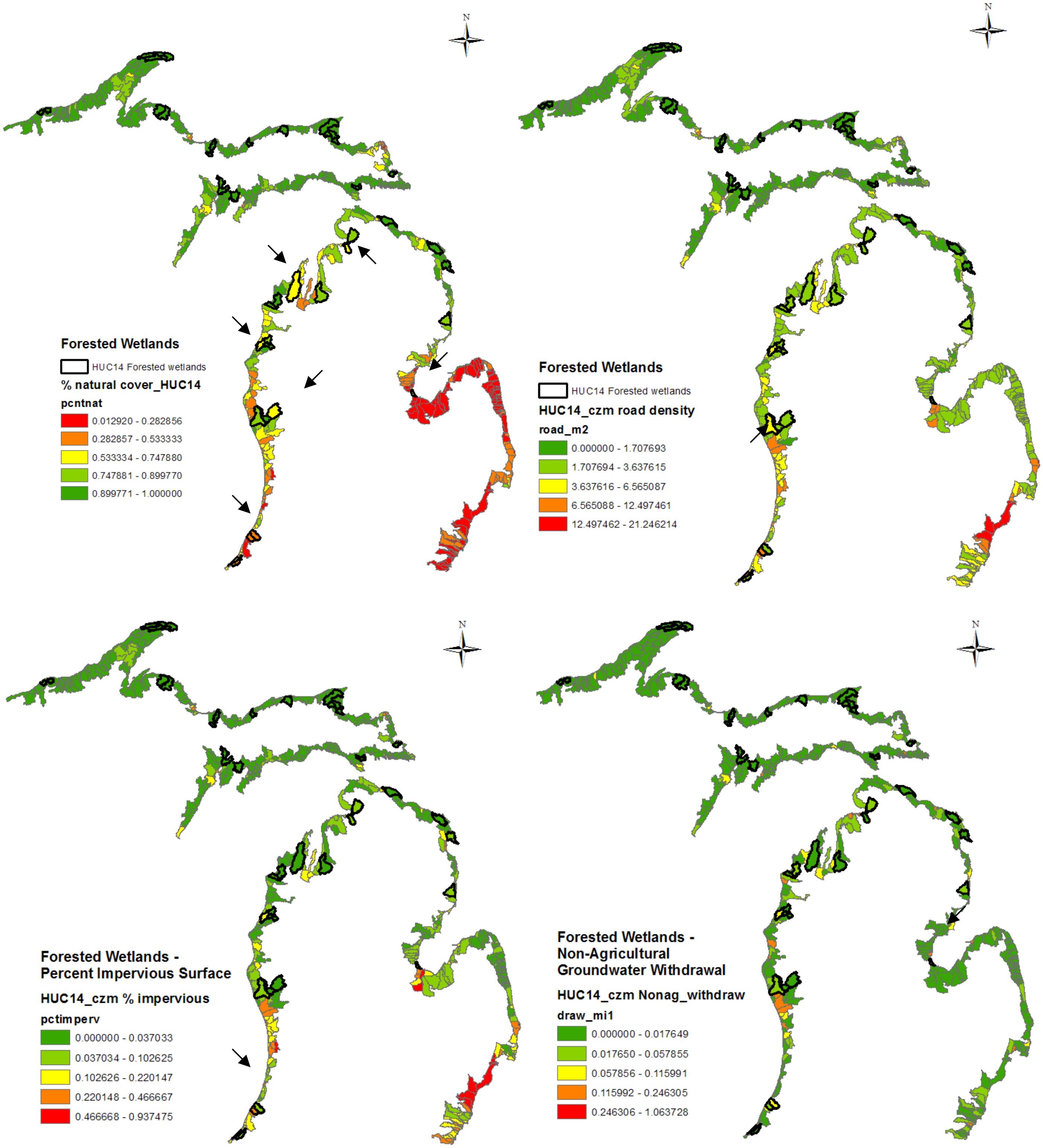

Figure 18. Maps indicating HUC14 watersheds in Michigan's coastal zone in which occurrences of forested wetlands have been documented (outlined in black) and results for specific individual stressors (red – highest stress, orange/yellow – moderate stress, light/dark green – lowest stress). Black arrows indicate additional watersheds in which forested wetlands may be more vulnerable to climate change due to other stressors (i.e., moderate stress areas based on combined stressor scores in the moderate stress categories (orange and yellow categories) for individual stressors).

Open Coastal Wetlands

The open coastal wetlands natural community group included coastal plain marsh, interdunal wetland, coastal fen, and Great Lakes marsh. Open coastal wetlands may experience similar changes in average annual temperature, but may experience different changes in annual precipitation and annual moisture across its distribution (Figure 19). Open coastal wetlands may experience a similar increase in average annual temperature across its distribution except along the Lake Huron shoreline in the northeast Lower Peninsula where they may experience a slightly lower increase and in the Keweenaw Peninsula where they may experience more of an increase (Figure 19). This natural community group may be exposed to greater increases in annual precipitation in the southeast and northwest portions of the Lower Peninsula, along the Lake Michigan shoreline in the Upper Peninsula, and potentially the tip of the Keweenaw Peninsula (Figure 19). Open coastal wetlands along the Lake Erie and southern Lake Michigan shorelines may experience greater decreases in moisture availability than other parts of their distribution (Figure 19). It is unclear how open coastal wetlands will be impacted by increased temperature and/or precipitation, but a drier climate will likely negatively impact these natural communities.

Different types of natural communities within this group may experience different levels or amounts of climate change. For example, coastal fens occur along the northern Lake Michigan and northern Lake Huron shorelines, while coastal plain marshes occur primarily along the southern Lake Michigan shoreline (Kost and Penskar 2000, Cohen et al. 2010). As a result, coastal plain marshes may experience greater decreases in moisture availability and smaller percent increases in annual precipitation than coastal fens based on their distributions and climate change projections for the state. Great Lakes marshes are distributed throughout the entire coastal zone (Albert 2001), and interdunal wetlands occur throughout the coastal zone except along southern Lake Erie (Albert 2007). These natural community types may experience varying levels of climate change throughout their distribution.

Most of the watersheds in which occurrences of open coastal wetlands have been documented (102 of 110 watersheds (93%)) were considered to be low or moderate stress areas based on the cumulative analysis (combined stressor scores of 0, 1, or 2) (Figure 20). Only eight watersheds were considered high stress areas (combined stressor scores of 3 or 4). Most of the watersheds in which open coastal wetlands occur (71/110 watersheds (65%)) were in the highest stress category for presence of *Phragmites* and/or boat access sites. A number of the watersheds in which open coastal wetlands occur were in the highest or second highest stress categories for percent natural land cover, percent natural riparian cover, and other stressors such as road density, percent impervious surface, non-agricultural groundwater withdrawal, and point source pollution to a lesser degree (Figures 21). Open coastal wetlands may be particularly vulnerable due to climate change in the watersheds that were considered high stress areas based on the cumulative analysis (Figure 20). These natural communities also may be more vulnerable in the watersheds that were considered moderate or low stress areas based on the cumulative analysis and were in the highest or second highest stress categories for individual stressors, particularly percent natural land cover, road density, and/or percent impervious surface (Figure 21). As a result, open coastal wetlands may be particularly vulnerable along Lake Erie, Saginaw Bay, and scattered locations along Lake Michigan. Conversely, open coastal wetlands may be less vulnerable in the watersheds that were in low or moderate stress areas along the northern Lake Michigan, Lake Huron, and Lake Superior shorelines (Figures 20 and 21).

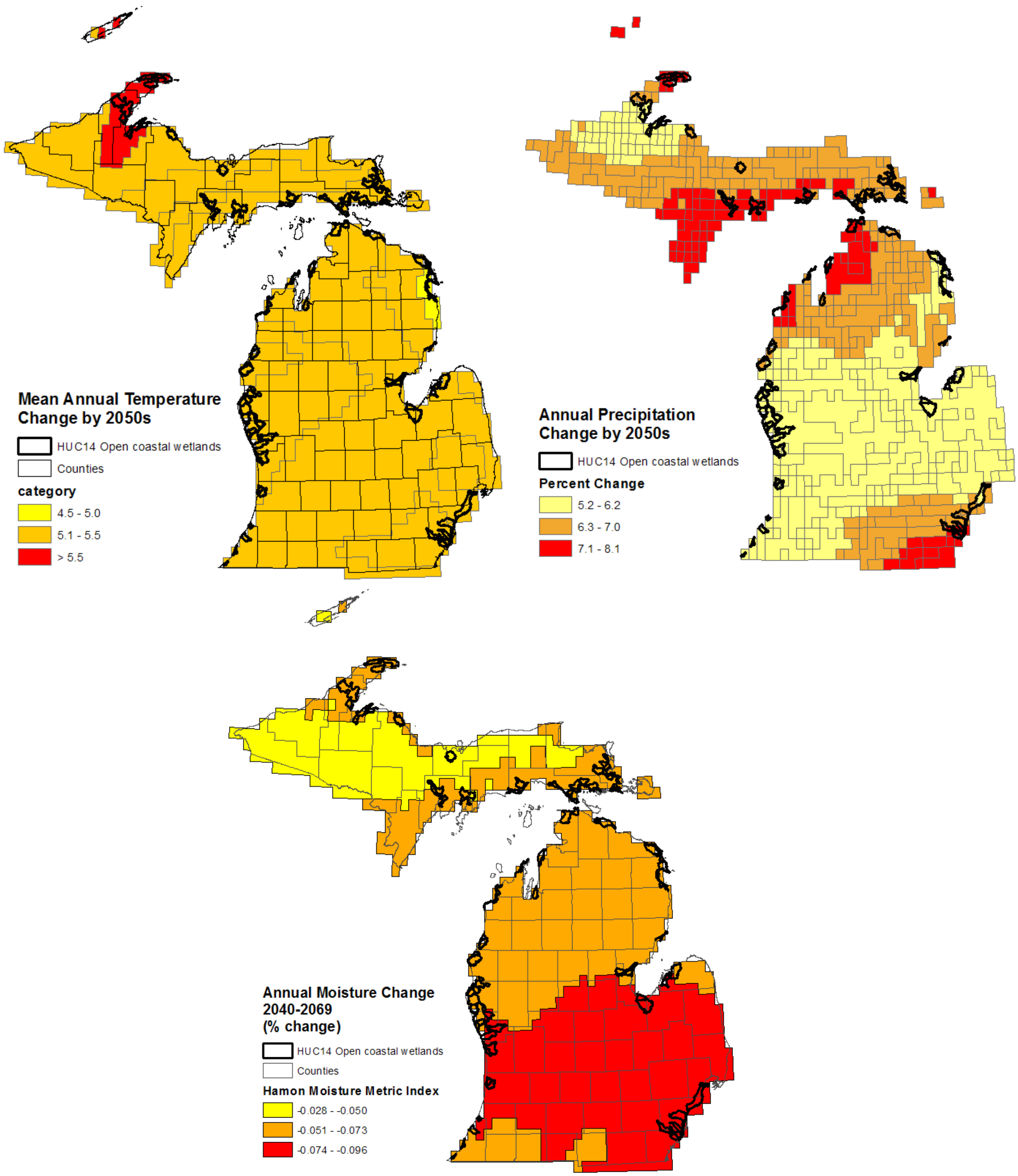

Figure 19. Maps of climate change projections for Michigan (based on data from Climate Wizard) and the HUC14 watersheds in the coastal zone in which open coastal wetlands have been documented (outlined in black, based on MNFI 2012), indicating potential exposure to climate change in Michigan.

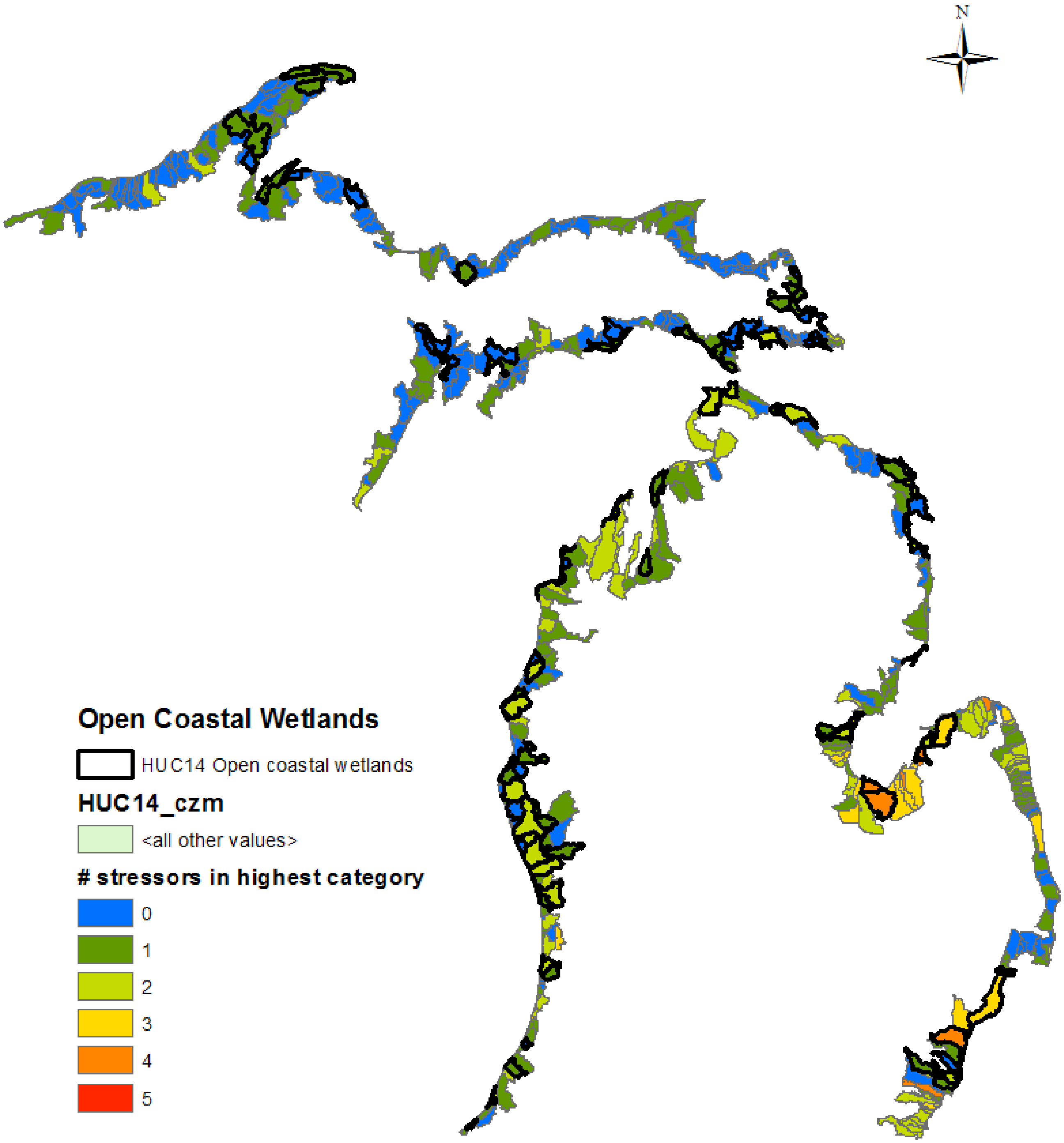

Figure 20. Map indicating HUC14 watersheds in Michigan's coastal zone in which occurrences of open coastal wetland communities have been documented (outlined in black, based on MNFI 2012), and their combined stressor scores indicating high stress (red, orange, and yellow), moderate stress (light and dark green), and low stress (blue) areas, based on a cumulative analysis of a subset of non-climate stressors.

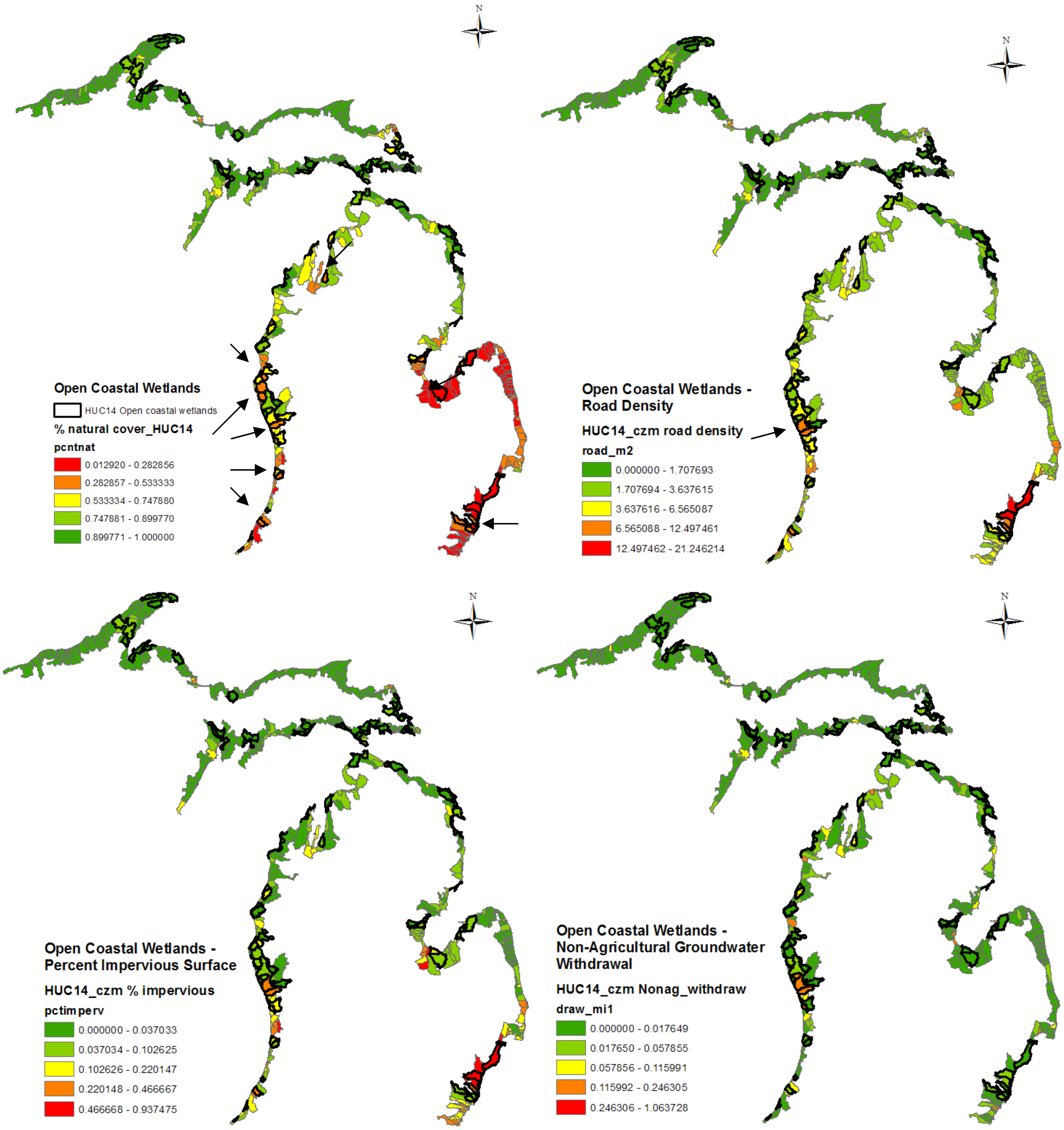

Figure 21. Maps indicating HUC14 watersheds in Michigan's coastal zone in which occurrences of open coastal wetlands have been documented (outlined in black) and results for specific individual stressors (red – highest stress, orange/yellow – moderate stress, light/dark green – lowest stress). Black arrows indicate additional watersheds in which open wetlands may be particularly vulnerable to climate change due to other stressors (i.e., moderate stress areas for stressors combined and second highest or moderate stress categories for individual stressors).

Upland Forest

The upland forest natural community group included boreal forest, mesic northern forest, and mesic southern forest. These natural communities may experience the same increase in average annual temperature across most of its distribution in the coastal zone, except in the Keweenaw Peninsula where they may experience more of a temperature increase (Figure 22). Upland forest communities in the coastal zone also may experience similar changes in annual moisture across its distribution, except along a section of the southern Lake Michigan shoreline which may experience a greater decrease in annual moisture availability, and some areas along Lake Superior which may experience less of a decrease (Figure 22). Changes in annual precipitation may vary across the distribution of this natural community group (Figure 22), although precipitation projections generally vary widely and are more uncertain than temperature projections (Winkler et al. 2012). It is unclear how this natural community group will be impacted by increased precipitation, but a drier climate will likely negatively impact the natural communities in this group.

All the watersheds in which these upland forest natural communities occur were considered low to moderate stress areas based on the cumulative stressor analysis (i.e., combined stressor scores of 0, 1, or 2) (Figure 23). However, the watersheds that had combined stressor scores of 1 or 2 were in the highest stress categories for presence of *Phragmites* and/or boat access sites, which don't really impact the natural communities in this group. Most of the watersheds in the coastal zone in which this natural community group occurs also were in the lowest stress categories for most of the individual stressors. A small number of watersheds were in the moderate stress categories (orange and yellow categories) for several stressors that do impact natural communities in this group, including percent natural land cover and road density (Figure 24). Upland forest communities may be more vulnerable due to climate change and other stressors in these watersheds, which were located primarily along the southern Lake Michigan shoreline (Figure 24). Occurrences along this shoreline also may be more vulnerable to climate change as the southern part of the state is predicted to experience greater decreases in moisture availability than the northern Lower Peninsula and the Upper Peninsula (Figure 22). Upland forest communities in watersheds along the Lake Superior and northern Lake Michigan shorelines may be less vulnerable to climate change due to other stressors and projected climate changes, although occurrences in the Keweenaw Peninsula may experience greater increases in temperature and potentially precipitation (Figure 22).

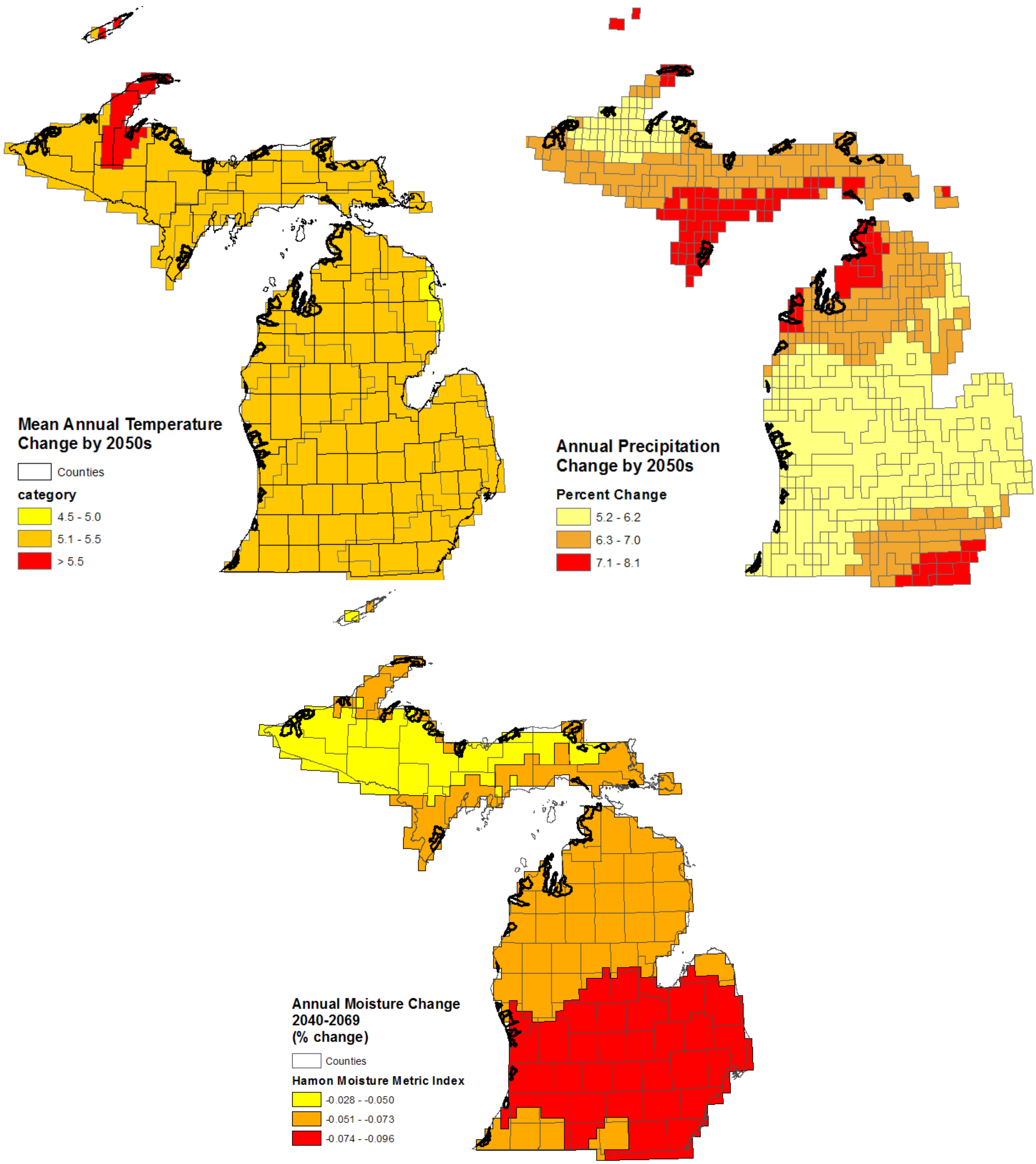

Figure 22. Maps of climate change projections for Michigan (based on data from Climate Wizard) and the HUC14 watersheds in the coastal zone in which occurrences of upland forest natural communities have been documented (outlined in black, based on MNFI 2012), indicating this natural community group's potential exposure to climate change in Michigan.

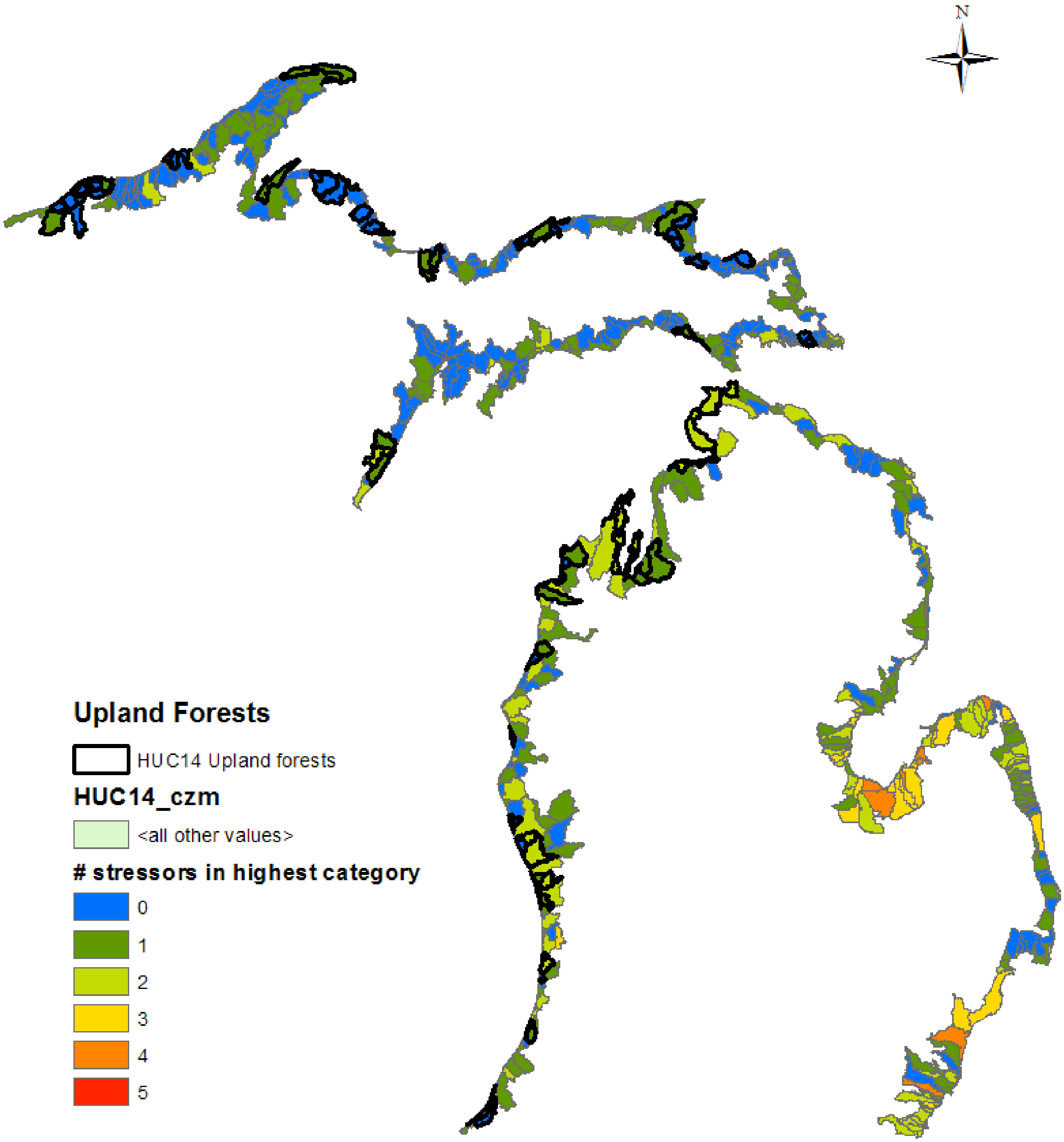

Figure 23. Map indicating HUC14 watersheds in Michigan's coastal zone in which occurrences of the upland forest natural community group have been documented (outlined in black, based on MNFI 2012), and their combined stressor scores which indicate high stress (red, orange, and yellow), moderate stress (light and dark green), and low stress (blue) areas, based on a cumulative analysis of a subset of non-climate stressors.

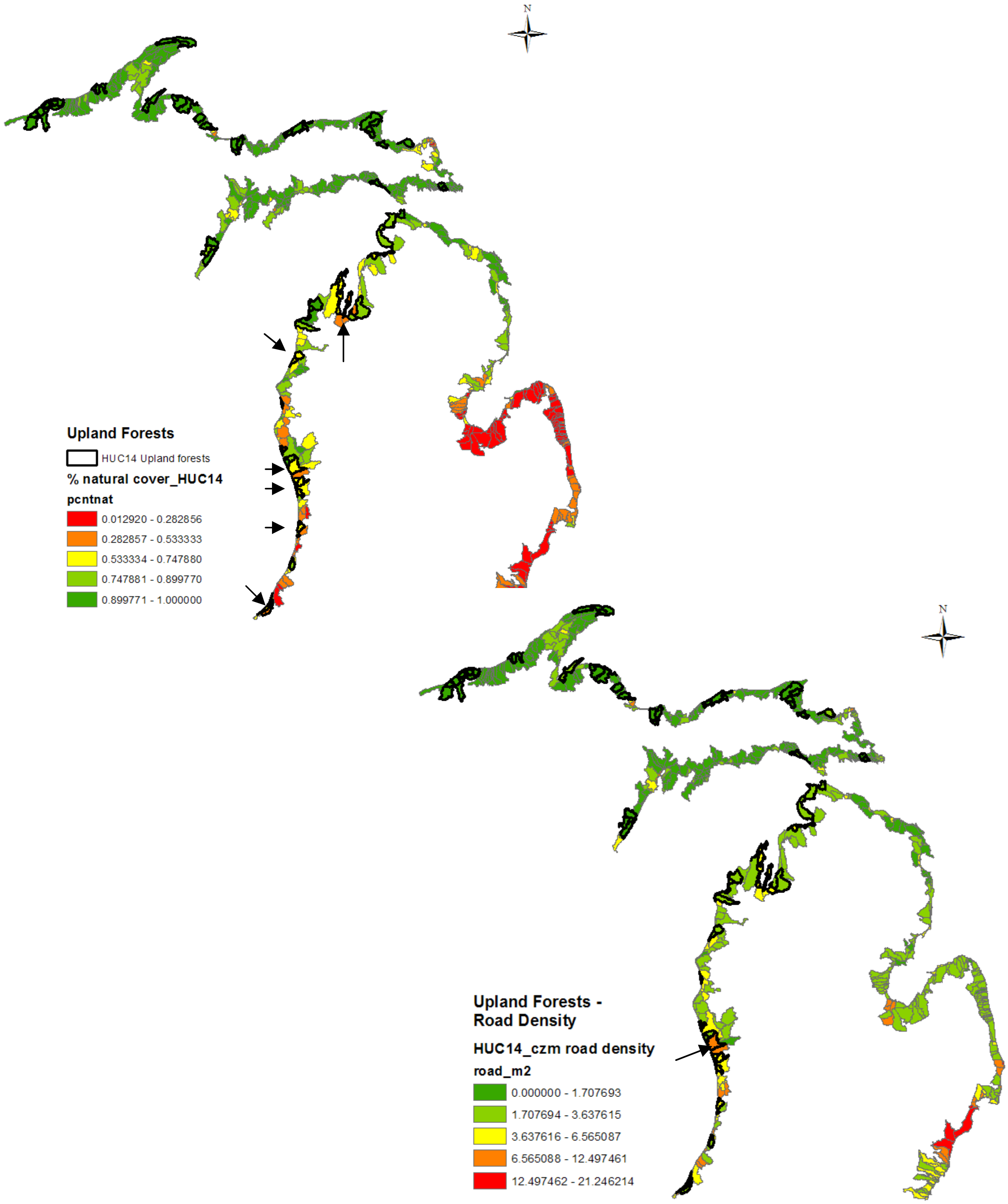

Figure 24. Maps indicating HUC14 watersheds in Michigan's coastal zone in which upland forest occurrences have been documented (outlined in black) and results for specific individual stressors (red – highest stress, orange/yellow – moderate stress, light/dark green – lowest stress). Black arrows indicate additional watersheds in which upland forest communities may be more vulnerable to climate change due to other stressors (i.e., moderate stress areas for stressors combined and moderate stress categories for individual stressors).

Wooded Dune and Swale Complex

Wooded dune and swale complexes are comprised of natural communities that fit into the coastal wetland, forested wetland, and upland forest groups. Wooded dune and swale complexes may experience similar changes in average annual temperature, annual precipitation, and moisture availability across its distribution in the coastal zone except for potentially a few specific areas. Some of the wooded dune and swale complexes along Lake Huron in the northeast Lower Peninsula may experience less of an increase in average annual temperature, while complexes in the Keweenaw Peninsula may experience more of an increase (Figure 25). These natural communities may experience a greater change or increase in annual precipitation along the northern Lake Michigan shoreline in the northwest Lower Peninsula and eastern Upper Peninsula (Figure 25). It is important to note though that climate change projections for precipitation tend to vary widely and are generally more uncertain than temperature projections (Winkler et al. 2012). Wooded dune and swale complexes along the Lake Superior shoreline in the eastern Upper Peninsula may experience less of a decrease in moisture availability (Figure 25). It is unclear how wooded dune and swale complexes will be impacted by increased temperature and precipitation, but a drier climate may negatively impact these natural communities.

In terms of other stressors on the landscape, almost all the watersheds in which wooded dune and swale complexes occur were considered low to moderate stress areas (i.e., combined scores of 0, 1 or 2) based on the cumulative stressor analysis (Figure 26). Most of the watersheds that were considered moderate stress areas were in the highest stress categories for *Phragmites* and/or boat access sites (i.e., *Phragmites* and/or boat access sites were present). Some of the watersheds also were in the highest stress categories for other stressors such as percent natural land cover, percent natural riparian cover, road density, and/or dams. Some additional watersheds that were considered low or moderate stress areas based on the cumulative analysis were in the moderate stress categories for several individual stressors such as percent natural cover, percent impervious surface, and road density (Figure 27). Wooded dune and swale complexes may be particularly vulnerable due to climate change and other stressors on the landscape in the watersheds that were considered high or moderate stress areas based on the cumulative analysis and were in the high or moderate stress categories for individual stressors such as percent natural cover, percent impervious surface, and road density (Figures 26 and 27). Conversely, wooded dune and swale complexes may be less vulnerable to climate change in the watersheds that were considered low stress areas based on the cumulative analysis, which were located primarily along the Lake Michigan shoreline in the eastern Upper Peninsula and the Lake Superior shoreline. Wooded dune and swale complexes along the Lake Superior shoreline in the central and western Upper Peninsula except in the Keweenaw Peninsula may be particularly less vulnerable or more resilient to climate change since these areas are predicted to experience less of a decrease in annual moisture compared to other parts of the state, and the Keweenaw Peninsula and northern Lake Michigan may be exposed to greater increases in average annual temperature or annual precipitation (Figure 25).

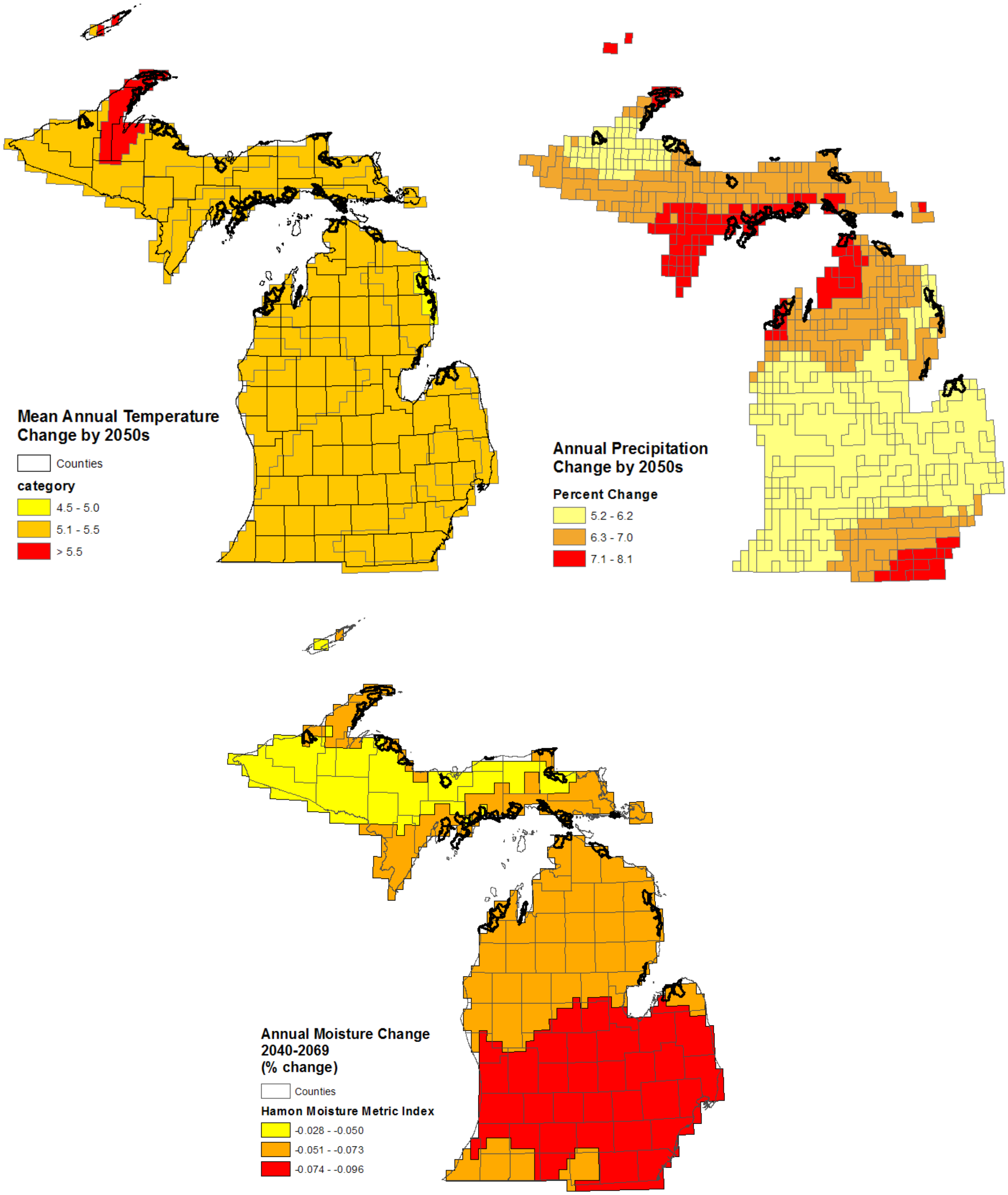

Figure 25. Maps of climate change projections for Michigan (based on data from Climate Wizard) and the HUC14 watersheds in the coastal zone in which occurrences of wooded dune and swale have been documented (outlined in black, based on MNFI 2012), indicating this natural community group's potential exposure to climate change in Michigan.

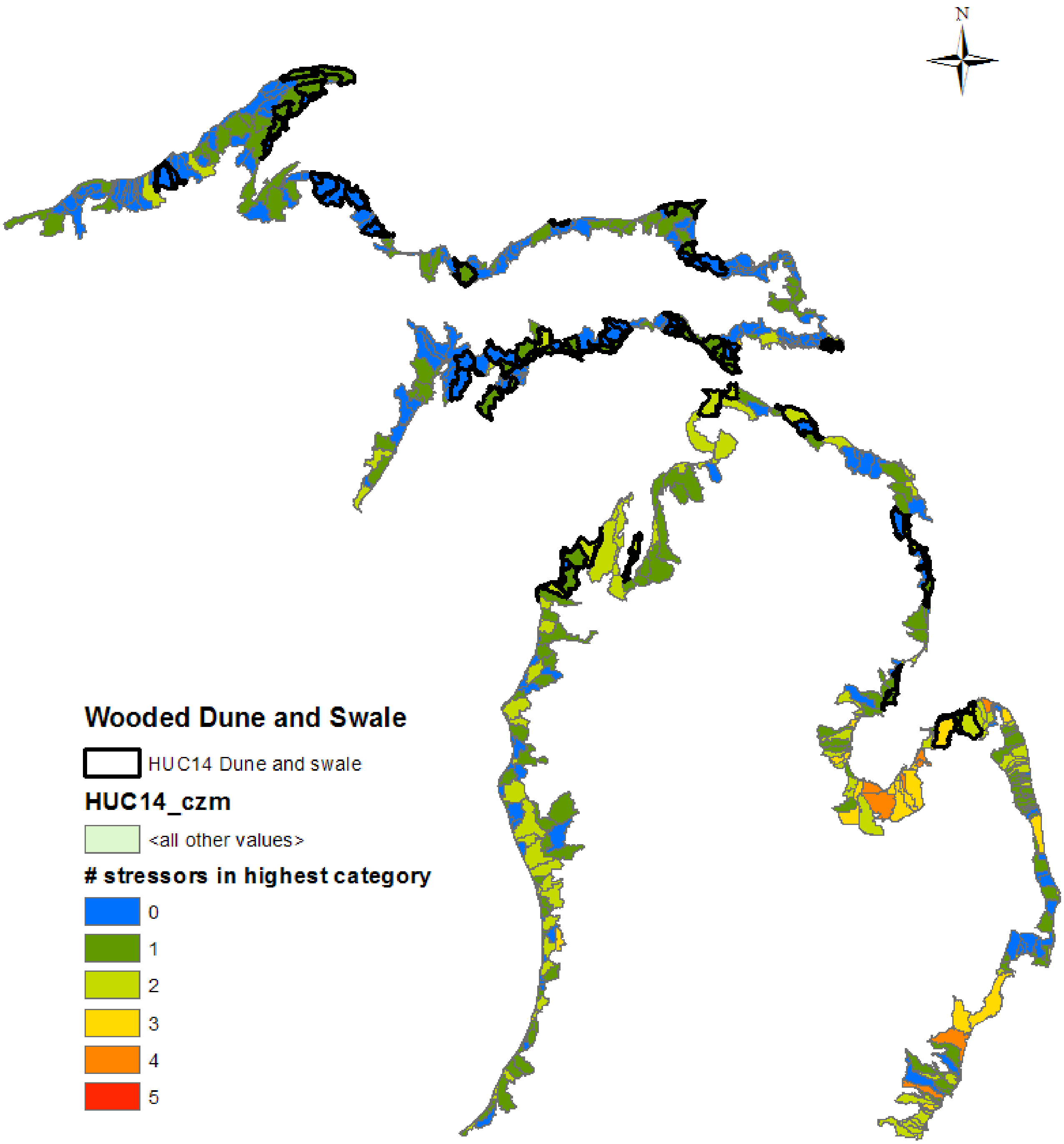

Figure 26. Map indicating HUC14 watersheds in Michigan's coastal zone in which occurrences of wooded dune and swale complexes have been documented (outlined in black, based on MNFI 2012), and their combined stressor scores indicating high stress (red, orange, and yellow), moderate stress (light and dark green), and low stress (blue) areas, based on a cumulative analysis of a subset of non-climate stressors.

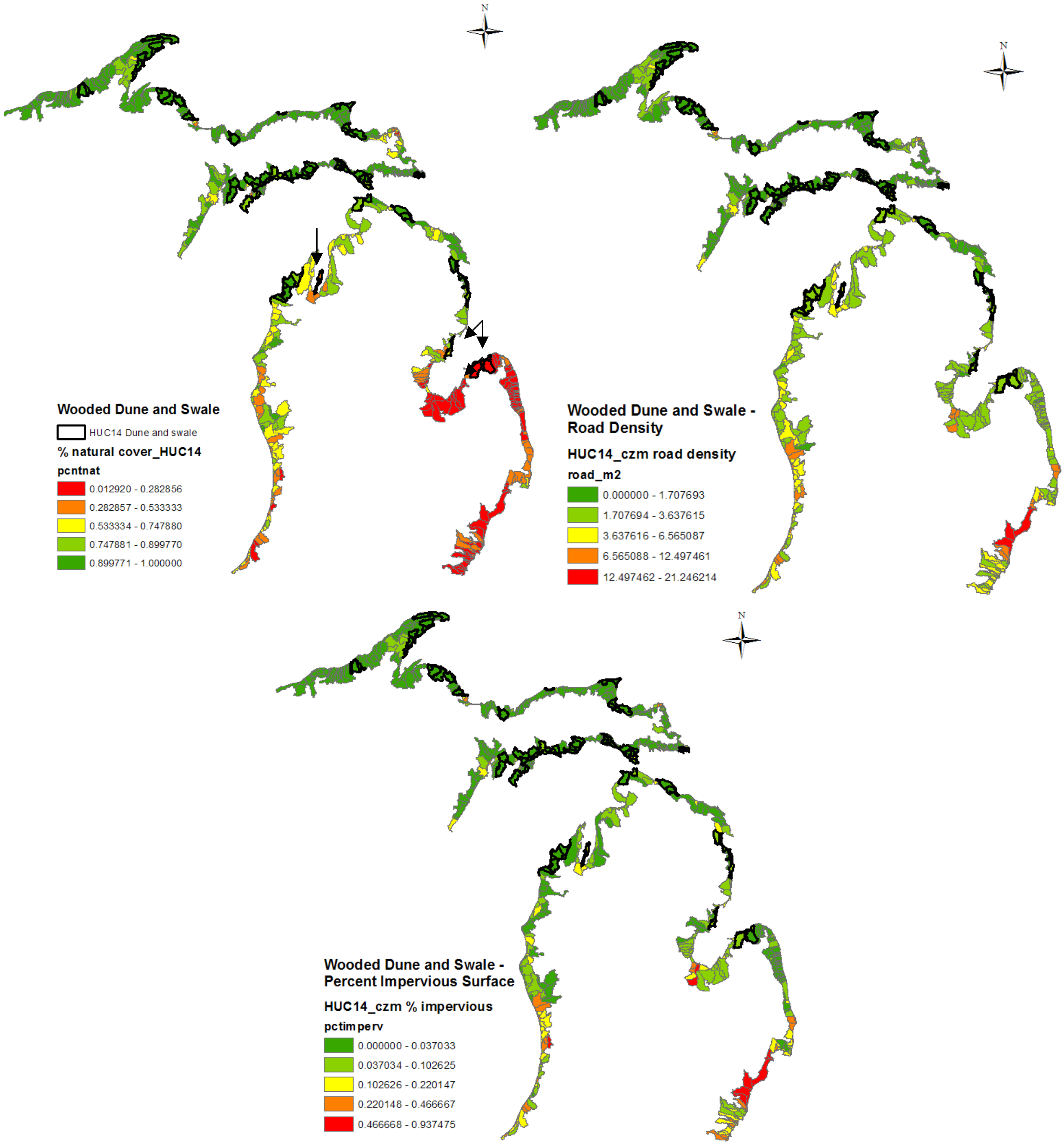

Figure 27. Maps indicating HUC14 watersheds in Michigan's coastal zone in which occurrences of wooded dune and swale complexes have been documented (outlined in black) and results for individual stressors (red - highest stress category, orange/yellow – moderate stress categories, and light/dark green – lowest stress categories). Black arrows indicate watersheds that were considered moderate stress areas based on combined stressor scores and were in the moderate stress categories for certain individual stressors.

Identification of Potential Climate Change Adaptation Strategies and Areas

Potential climate change adaptation strategies were identified for natural communities in Michigan in general, for each natural community group that occurs in Michigan (Appendices 7-23), and for specific natural communities that occur in the coastal zone and are likely vulnerable to climate change based on our vulnerability assessment (Appendices 24-38). The goal of these strategies is to reduce the vulnerability of natural communities to actual or expected climate change effects by helping them cope with, adjust to, or recover from changing conditions without significant loss or disruption of ecosystem function or structure. These strategies, and adaptation strategies in general, focus on three main aspects: 1) building resistance to climate-related stressors to tolerate, withstand, or prevent effects of climate change; 2) enhancing resilience to cope with or recover from climate change and associated impacts; and 3) facilitating ecological transitions or transformations that fit with changing environmental conditions (Glick et al. 2011, Comer et al. 2012). Many of the potential adaptation strategies are already being utilized to address other conservation or management objectives. Many of these strategies also provide other benefits in addition to helping natural communities adapt to climate change.

<u>Potential climate change adaptation strategies for natural communities in Michigan in general</u>

- Identify and protect examples of the full range of existing or current natural communities in the state to maintain representation.
    - Protecting or maintaining a diversity of natural communities will help ensure that as many combinations of physical environments and biological communities as possible are represented and protected. This will increase the chances that somewhere in the system, there will be areas that provide the biotic and abiotic conditions or resources that natural communities might need to cope with or recover from climate change effects (West et al. 2009).
    - Conduct surveys to identify and map occurrences of all existing or current natural communities and assess status or condition and viability of occurrences. Identify major plant and animal species that comprise these natural communities. These efforts will provide baseline information to facilitate other adaptation efforts. (Yale Mapping Framework 2012)

- To enhance the resilience of natural communities and their component species, conserve and protect numerous occurrences of high-quality examples of natural communities in different ecological regions of the state.

- Reduce current stressors, especially stressors that will likely be exacerbated by climate change (e.g., invasive species, deer herbivory, hydrologic alterations, disease).

- Improve management and restoration of protected or managed areas to support resilience.
    - Examples include riparian forest plantings to shade streams and offset localized warming; prescribed fire to reduce fuel loads and potential for catastrophic wildfires; adjusting restoration projects to include species that may be more resilient to anticipated changes; and identifying new ways to deal with invasive species under a changing climate (Mawdsley et al. 2009, West et al. 2009).

- Protect, maintain, and/or restore large, intact, natural landscapes and ecological processes/functions (e.g., maintaining or restoring hydrology/natural hydrologic regime).
    - Focus especially on large, intact landscapes that contain diversity of natural communities.

- Identify and protect geophysical settings, or structural and functional attributes, needed to support diversity of species and natural communities.
    - This could include identifying physical landscape units or land facets, which are recurring landscape units with uniform topographic and soil attributes, and protecting areas with a diversity of physical landscape units or land facets and maintaining connectivity among these units across the landscape (Hunter et al. 1988, Beier and Brost 2010). This also could include identifying areas of high topographic complexity (Yale Mapping Framework 2012).

- Identify and manage areas that will provide future climate space for species and natural communities.
    - Develop and use models to forecast species and natural community vulnerability to climate change, and map future climate envelopes and areas that can support species and natural communities under changing climate conditions (Yale Mapping Framework 2012).

- Design new natural areas and restoration sites to maximize resilience.
    - Examples of this strategy could include protection or restoration of open coastal wetland communities that occur in or adjacent to gently sloped or gradual shorelines where these communities may be able to expand or move lakeward or landward as Great Lakes levels recede or rise compared to communities that occur in or adjacent to steep or abrupt shorelines; or establishment of protected area networks along latitudinal or elevational gradients may be a viable adaptation strategy for certain species or natural communities, providing spatial flexibility for distributions to shift along these gradients as climatic conditions change (Mawdsley et al. 2009).

- Identify and protect climate refugia.
    - Climate refugia are habitats and regions within the landscape that are expected to retain more stable climates, and are naturally buffered from extreme variations in climate and other environmental conditions (e.g., extreme temperatures or fluctuations in water availability) (National Climate Change Adaptation Research Facility (NCCARF) 2012). Climate refugia provide areas where natural communities and other elements of biodiversity can persist, and potentially expand, disperse, or shift their range from under changing climate conditions.
    - Climate refugia can include areas within the current geographic range of a species or natural community (internal refugia), or areas outside the current range that are expected to become suitable for a species or natural community under future climate conditions (external refugia) (NCCARF 2012).
    - Climate refugia can be identified and protected at multiple levels or spatial scales. These include macrorefugia which are large-scale areas that maintain stable

climates or temperatures, and are protected from rapid or extreme changes in climate, such as mountains, valleys, or forests; and microrefugia which are smaller areas that are protected from extreme temperature or climate fluctuations, such as valley floors, boulder fields, or tree hollows (NCCARF 2012). Climate refugia also can be identified at the species, population, or plant community level; ecosystem level; and landscape level (Yale Mapping Framework 2012). Identifying climate refugia at the species, population, or plant community level includes identifying areas that will likely remain suitable for species, populations, or plant communities into the future, or areas where these elements may be able to move to as climates change (Yale Mapping Framework 2012). Identifying climate refugia at the ecosystem level includes identifying ecosystems that provide environmental conditions that are expected to undergo limited change under climate warming, which could include habitats that may be naturally more resilient to climate change (e.g., spring-fed streams, groundwater-fen wetlands) (Yale Mapping Framework 2012). Identifying climate refugia at the landscape level could include identifying large-scale areas projected to maintain stable climates, areas that provided refugia for species during the last glacial period, and/or areas containing high physiographic or topographic complexity (Yale Mapping Framework 2012). Studies have shown that areas with a high degree of variability in landscape topography and geology/soils generally provide variable climatic conditions (especially temperature and moisture), and can support a diversity of species that have different thermal and moisture requirements for survival (Yale Mapping Framework 2012).

- Identify and protect or maintain natural communities, landforms, and landscape complexes that function as climate refugia.
    - Examples of natural communities that can function as climate refugia include communities that occur as complexes: floodplain forest, wooded dune and swale complex, and Great Lakes marsh. These natural community types often contain numerous zones with diverse natural communities.
    - In addition, natural communities that occur as matrix or large patch communities can also function as climate refugia. For example, mesic northern forest can occur as matrix systems with high levels of topographic diversity and numerous inclusions of wetlands and bedrock outcroppings. Those natural communities and landscapes that have gradients in elevation, soil moisture, and water table can provide species the opportunity to shift as climate changes.
    - Natural communities and landscape settings that experience moderated climates may also function as climate refugia. For example, coastal ecosystems and large wetland systems (i.e., swamp complexes and riparian ecosystems) may experience less severe climate change due to local climate moderation.
    - Groundwater-influenced ecosystems (e.g., fens and conifer swamps) will likely be buffered from climate change, and may therefore function as climate refugia.
    - Rich conifer swamps provide unique microclimates and can function as climate refugia.

- Maintain and restore ecological connectivity.
  - Identify, map, and maintain or restore corridors, stepping stones, and refugia for species to move or migrate in response to a changing climate; or connectivity between current and potential future locations for species or systems, land facets, ecological land units, climate refugia, or areas of high ecological integrity to facilitate movement of species and natural communities (Yale Mapping Framework 2012). This could include maintaining or restoring floodplain corridors, wetland ecosystems, and matrix communities or habitat.
  - Because invasive species will likely benefit from climate change (due to longer growing season and milder winters), efforts to maintain or restore connectivity should address potential impacts from invasive species.

- Identify and manage transitions/transition zones.
  - This could include assisted migrations to facilitate range shifts or expansions, or management activities that promote certain species or natural communities that might benefit under a changing climate (e.g., planting species that are more resilient to climate change in a particular area as part of restoration efforts).

- Identify short and long-term management objectives incorporating potential impacts and uncertainty due to climate change. Incorporate climate change impacts into existing management plans, programs, and activities. Manage proactively and anticipate change.
  - Managers may actively manage some species or natural communities that are vulnerable to climate change in the short term, but may decide to reduce or shift management in the long-term. For example, aspen and red pine are projected to decrease in Michigan due to climate change (Prasad et al. 2007). These species are currently important for wildlife and forest management in the state, but management focus on these species may need to be re-evaluated in the future.

- Evaluate and enhance monitoring efforts to assess and monitor impacts of climate change, and inform and guide adaptation and adaptive management efforts.

- Establish rolling easements to allow for long-term fluctuations for certain natural communities (e.g., coastal ecosystems) across space and time.

- Incorporate biodiversity needs into broader societal adaptation efforts (Mawdsley et al. 2009). For example, protecting and/or restoring forests and wetlands for climate change adaptation can enhance ecological services and reduce potential impacts of extreme storm events on human and natural communities.

- Review and modify existing laws, regulations and policies that relate to biodiversity management and conservation to address climate change impacts

- Provide information to land managers, policy makers, and the public regarding potential impacts of climate change on natural communities and biodiversity in general and potential adaptation strategies, and work with these groups to develop and implement climate change adaptation strategies and opportunities for collaboration.

Potential adaptation strategies and areas for vulnerable natural communities in the coastal zone

Potential strategies and areas for adaptation efforts were identified for the natural community groups in Michigan's coastal zone that are likely vulnerable to climate change. These recommendations are based on the results of the vulnerability assessment, the spatial analysis of stressors and natural community occurrences, and expert knowledge of the natural communities and the threats facing them. These potential strategies and areas should be viewed as initial recommendations which can be further developed and refined, particularly as new and/or improved information regarding potential climate change impacts, other stressors, and natural communities becomes available. These potential adaptation strategies focus mainly on actions related to land and water conservation, management, and restoration. Additional adaptation strategies, particularly related to planning, policy, and/or outreach, should be considered as well.

The following potential adaptation strategies and areas were specifically identified for the natural community groups that occur in the coastal zone and are likely vulnerable to climate change:

- Reduce stressors to current occurrences of natural communities that are vulnerable to climate change in the coastal zone, including controlling invasive species, restoring hydrology, reducing deer densities/deer browse pressure, and/or implementing prescribed fire.
    - Occurrences of natural communities that are likely vulnerable to climate change have been documented in a number of watersheds throughout the coastal zone (Figure 28). Although this strategy could probably be applied to many occurrences within these watersheds, natural communities that are located in watersheds that appear to be experiencing higher levels of stress from non-climate stressors may be more vulnerable due to climate change and these other stressors. As a result, natural community occurrences in watersheds that are considered high or moderate stress areas, based on the cumulative analysis and/or individual stressors, may be priority areas in which this adaptation strategy could be applied (Figures 28 and 29). This adaptation strategy may be particularly relevant for natural communities in coastal watersheds in the southern Lower Peninsula, of which many were in the higher stress categories for multiple stressors, particularly in certain areas (e.g., along Lake Erie and Saginaw Bay) (Figures 2-9, 28 and 29). Reducing stressors to occurrences in watersheds that were considered high stress areas may be a higher priority in the short term, but focusing on occurrences in watersheds that were lower or moderate stress areas may more effective for facilitating or increasing resilience in the long term. Examples of watersheds that were considered more moderately stressed areas based on the cumulative analysis and individual stressors include watersheds along Lake Huron in the northeast Lower Peninsula, and watersheds along Lake Michigan in Ottawa, Muskegon, and Oceana counties, and in Manistee, Benzie, Leelanau, and Grand Traverse counties (Figures 2-9, 28 and 29). However, even within regions that were considered higher stress areas, there were particular watersheds that were considered moderate or low stress areas (e.g., several watersheds in the St. Clair River Delta and along Lake Erie and Saginaw Bay, Figures 28 and 29) that could be potential priority areas for applying this strategy. This would help increase resilience of natural communities in these areas.

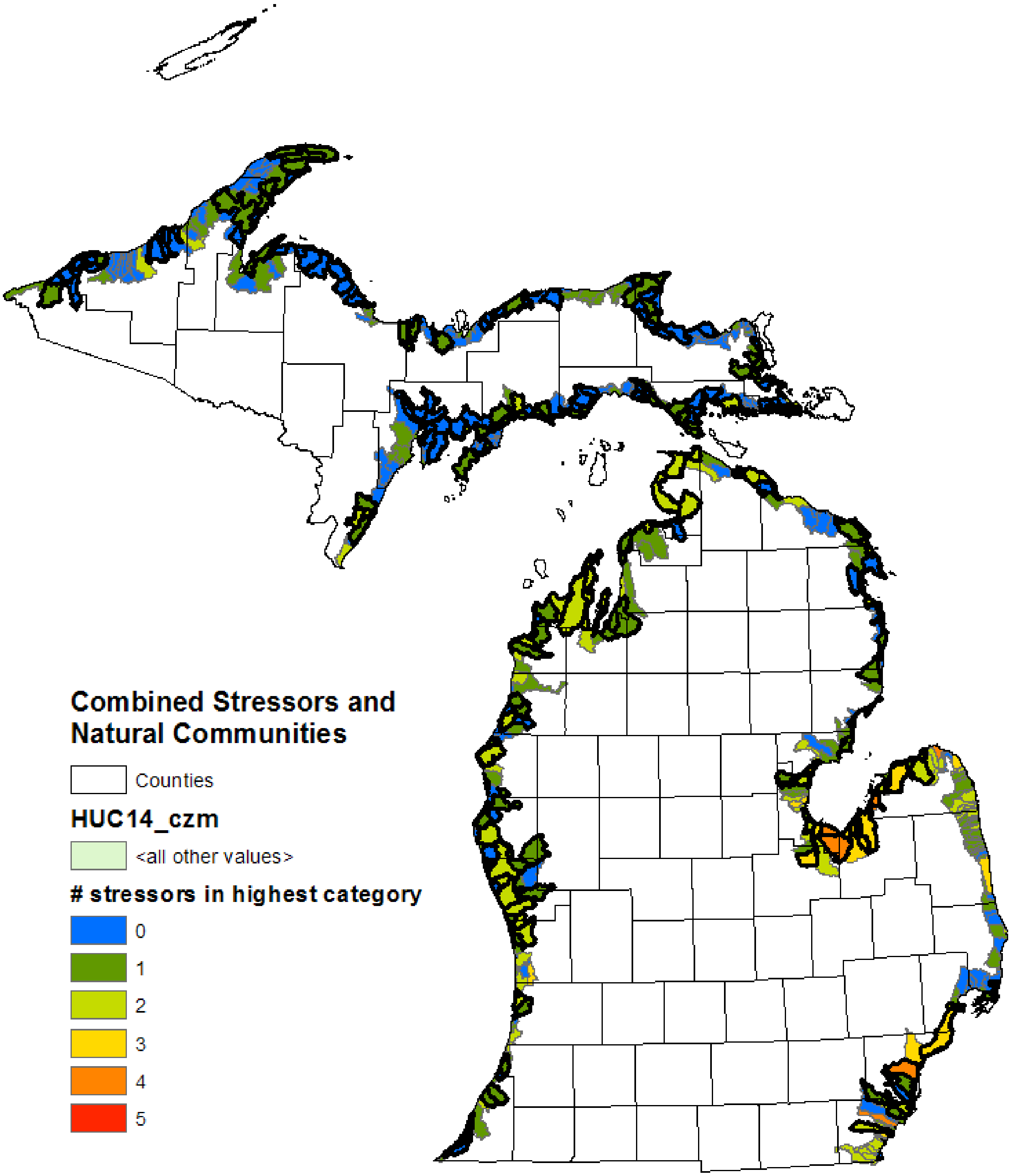

Figure 28. Map indicating all the HUC14 watersheds in the coastal zone that contain at least one occurrence of natural communities likely vulnerable to climate change (outlined in black, based on MNFI 2012), and their combined stressor scores used to indicate high stress (red, orange, and yellow), moderate stress (light and dark green), and low stress (blue) areas, based on a cumulative analysis of a subset of non-climate stressors.

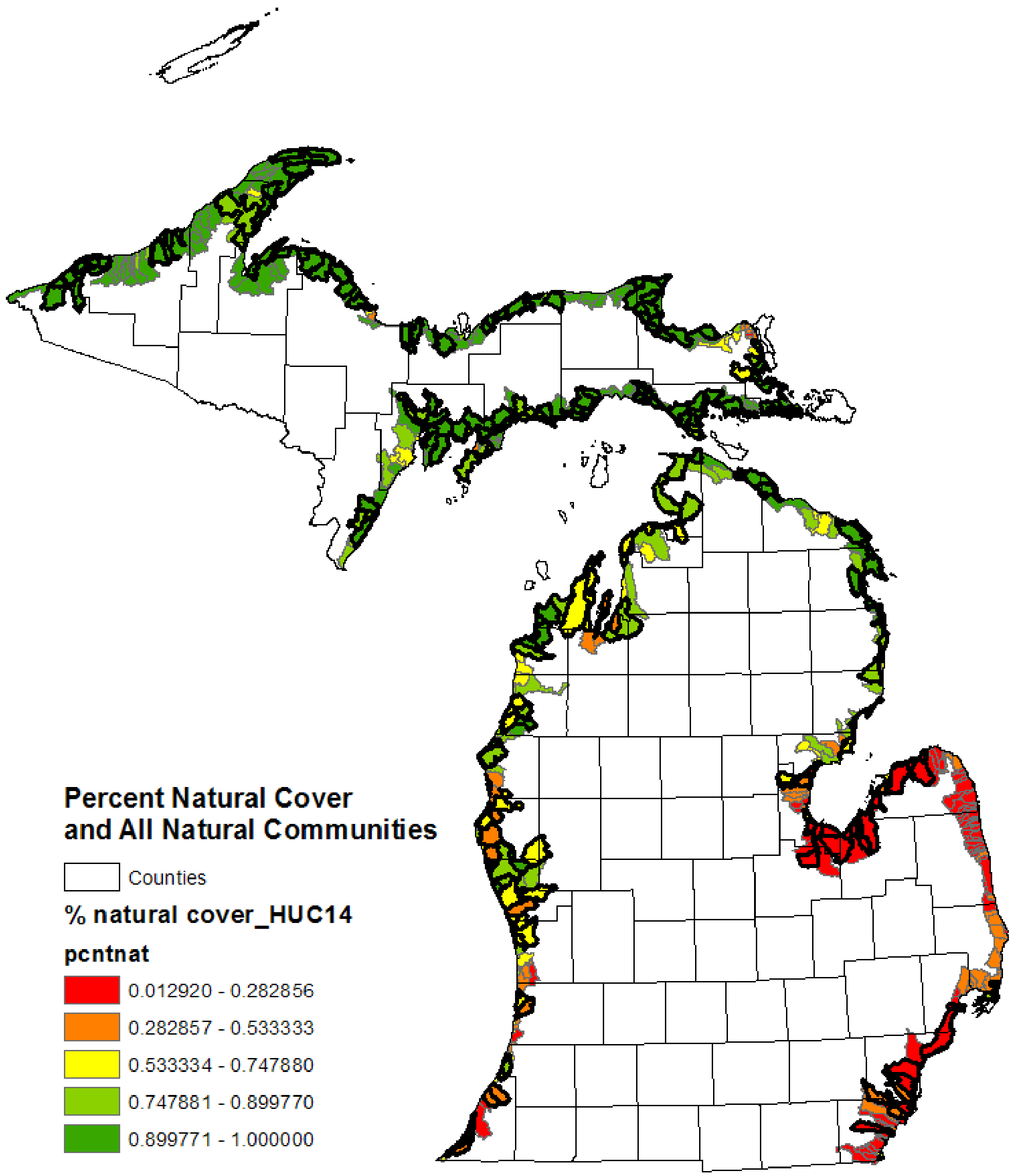

Figure 29. Map indicating all the HUC14 watersheds in the coastal zone that contain at least one occurrence of natural communities likely vulnerable to climate change (outlined in black, MNFI 2012), and their combined stressor scores used to indicate high stress (red, orange, and yellow), moderate stress (light and dark green), and low stress (blue) areas, based on a cumulative analysis of a subset of non-climate stressors.

- To enhance resilience of the natural communities that are likely vulnerable to climate change, and their component species, conserve, protect, and restore numerous examples of different types of natural communities within each group, particularly high quality examples, in different ecological regions of the state.
    - High quality occurrences (i.e., those ranked as having excellent or good viability or probability of persistence) of the natural communities in the coastal zone that are likely vulnerable to climate change are located in many watersheds throughout the coastal zone (Figure 30). High quality occurrences in watersheds that were considered lower stress areas may be less vulnerable or more resilient to climate change than occurrences in higher stress areas. To enhance resilience, high quality occurrences of natural communities that occur in watersheds that were considered lower stress areas (e.g., combined stressor scores of 0 and 1) may be priority areas for this strategy (Figure 30). Watersheds with multiple high quality occurrences of natural communities also may represent priority areas for this strategy (e.g., in the St. Clair River Delta and along the Lake Superior shoreline in Marquette County) (Figure 30).

- Focus restoration and conservation efforts on natural communities that occur as complexes (e.g., Great Lakes marsh, wooded dune and swale) or occur as part of larger functioning wetlands or landscapes. Protect, maintain, and/or restore large, intact, natural landscapes and ecological processes/functions.
    - An example of a large, intact, natural landscape complex comprised of multiple communities that would be a potential area for applying this strategy is an area along the Lake Superior shoreline in Marquette County (Figure 31). Watersheds that were considered lower stress areas, particularly based on stressors that contribute to landscape fragmentation, may be priority places to examine for applying this strategy.

- Identify and protect climate refugia. Focus restoration and conservation efforts on natural community groups, specific natural communities, landforms, and/or landscape complexes that can provide or function as climate refugia (e.g., rich conifer swamps, floodplain forest, groundwater-influenced ecosystems such as fens and conifer swamps, mesic northern forest, wooded dune and swale complexes).
    - High quality occurrences of forested wetland natural communities, upland forest communities, and wooded dune and swale complexes, particularly in low stress or less stressed areas, may be more resilient and effective at providing climate refugia. Watersheds that contain high quality occurrences or large landscape complexes of these natural communities may be priority areas for this strategy (Figures 31, 33, 36, 37 and 38).

- Because most of the natural communities in the coastal zone likely vulnerable to climate change are wetland communities, adaptation strategies related to restoring natural hydrological regimes/functions, reducing stressors that alter hydrology and impact water availability and quality, and protecting water resources (e.g., groundwater) are particularly relevant and important.
    - Watersheds that were in the moderate/high stress categories for natural land cover, impervious surface, riparian cover, and groundwater withdrawal may be potential areas for restoration and stressor reduction efforts (Figures 2, 4, 5 and 8).

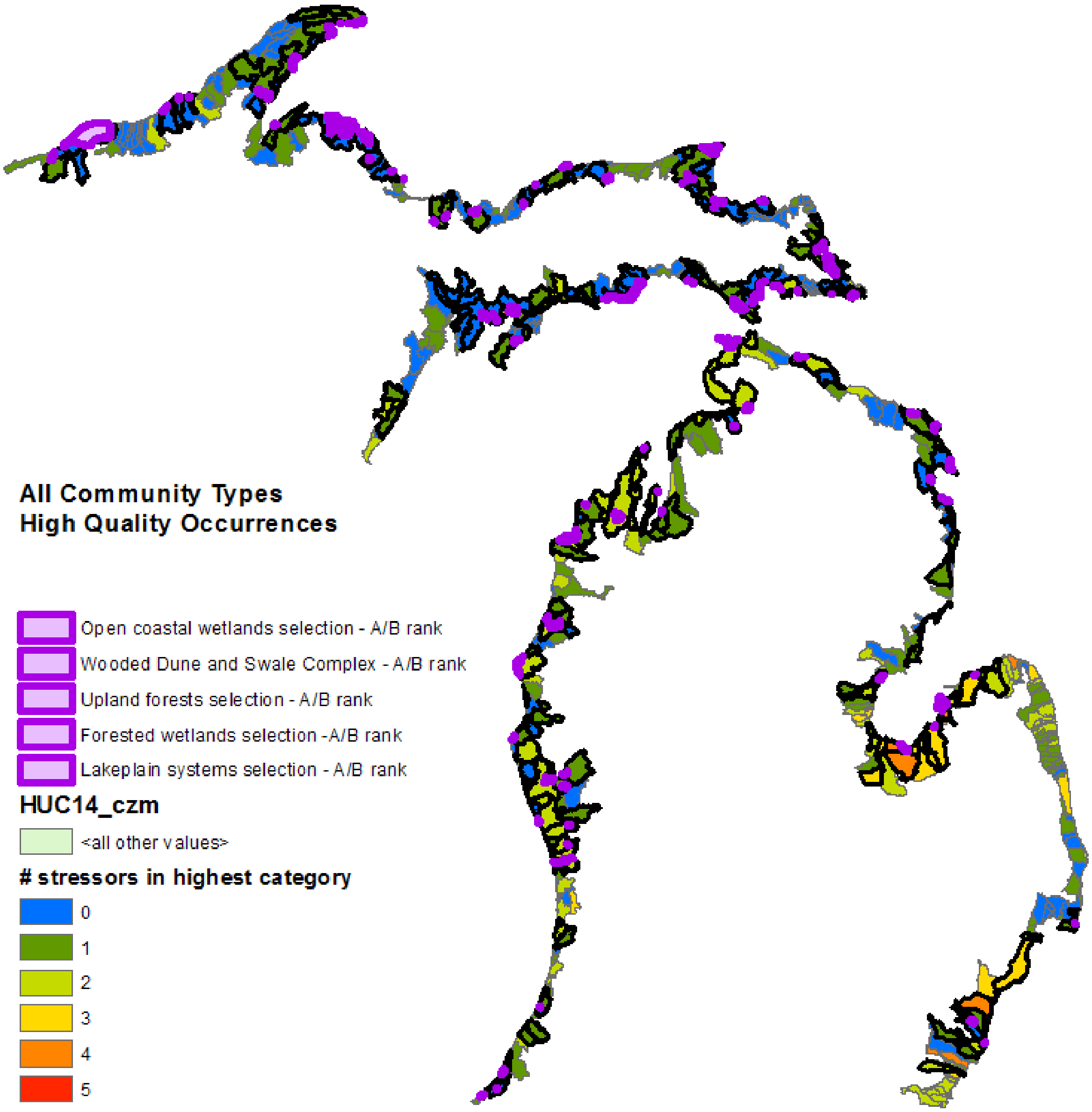

Figure 30. Map showing all the HUC14 watersheds in the coastal zone which contain occurrences of natural communities that are likely vulnerable to climate change (areas outlined in black), including high quality occurrences of all vulnerable natural communities (purple polygons), and their combined stressor scores used to indicate high stress (red, orange, and yellow), moderate stress (light and dark green), and low stress (blue) areas, based on a cumulative analysis of a subset of non-climate stressors.

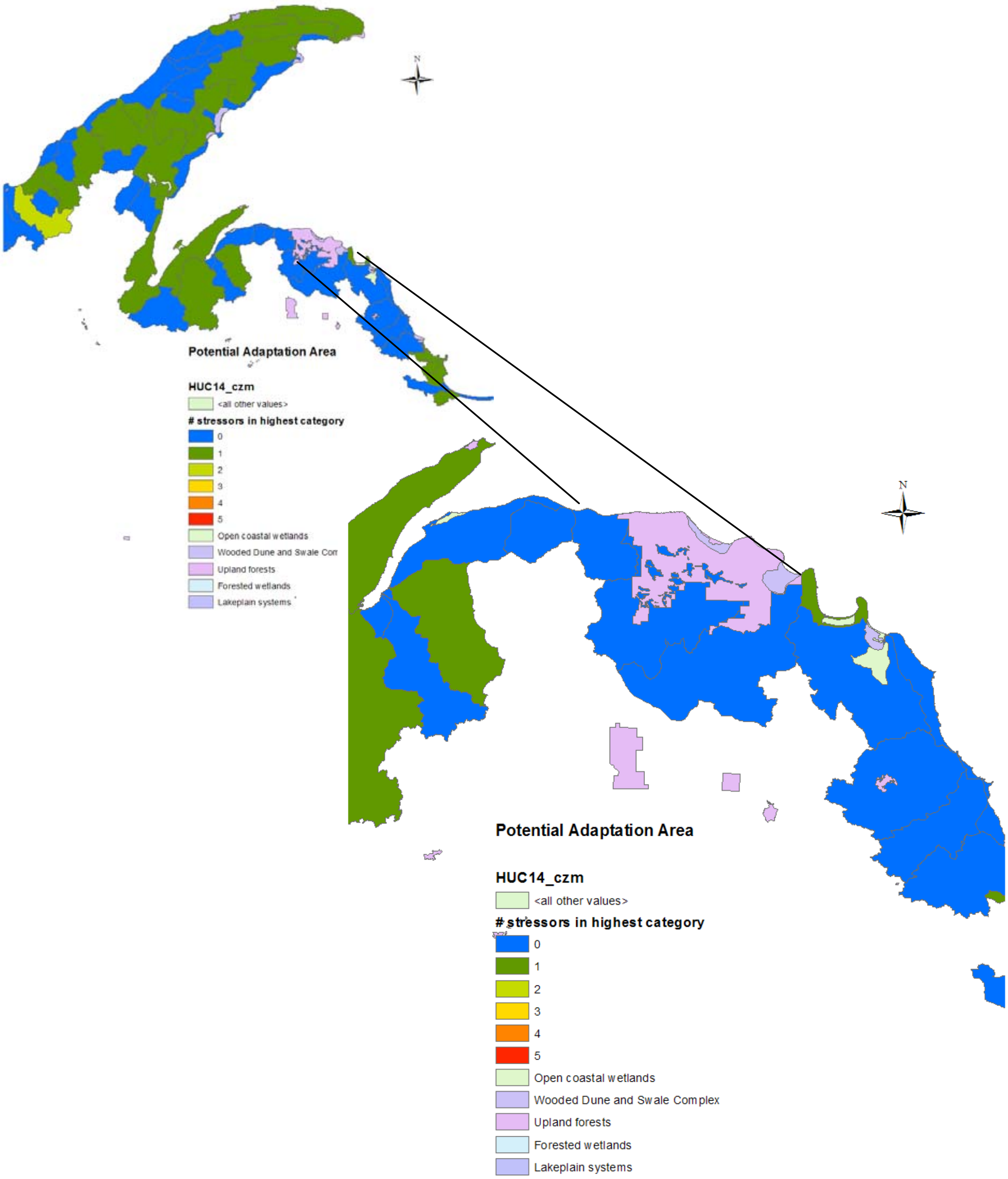

Figure 31. Map showing area along the Lake Superior shoreline east of the Keweenaw Peninsula with two large landscape complexes comprised of occurrences of upland forest natural communities, forested wetlands, open coastal wetlands, and/or wooded dune and swale complexes.

- Establish rolling easements to allow for long-term fluctuations of coastal ecosystems across space and time.

- Identify long-term management objectives for these natural communities and occurrences.
  - Natural communities that are vulnerable to climate change in the coastal zone may decline, shift their distributions, and/or change their composition, structure, and/or functions in the future. Long-term management objectives should be developed for these natural communities taking into account potential impacts of climate change and uncertainty around those impacts. Long-term management objectives may differ substantially from short-term objectives (e.g., managing for natural communities that have certain biophysical characteristics or provide similar functions rather than certain species presence or composition). Having a clear understanding of short-term and long-term management objectives will help identify the adaptation strategies that may be most appropriate and effective to apply, and when and where they should be applied or not be applied (e.g., where adaptation may no longer be possible, cost-effective, or aligned with management objectives) under changing conditions.

- Monitor the status and distribution of these natural communities, and their response to impacts from climate change and adaptation efforts. Adjust adaptation efforts according to natural communities' response and management objectives.

Potential adaptation strategies and areas are provided below for each of the five natural community groups that occur in the coastal zone and are vulnerable to climate change.

<u>Lakeplain Systems</u>
Michigan's lakeplain prairies and savannas (i.e., lakeplain wet prairies and wet-mesic prairies, lakeplain oak opening, and wet-mesic flatwoods) are already critically imperiled ecosystems that will likely be highly vulnerable to climate change due to their sensitivity to changes in hydrology and the current high levels of fragmentation, shoreline development, fire suppression, hydrologic alteration, and invasive species competition. The climate envelope for lakeplain prairies and savannas will likely shift northward following climate change. However, corresponding latitude range expansion of lakeplain prairies and savannas is unlikely due to the existing fragmentation within their current range and limited extent of their current distribution. Wet-mesic flatwoods, also are limited by its restricted hydrologic and physiographic setting.

Potential Adaptation Strategies
- Reduce stressors to current lakeplain prairies and savannas by controlling invasive species, restoring hydrology, and implementing prescribed fire.
- Restore numerous lakeplain prairies and savannas across their range to increase the resilience of the type, especially along the northern edge of distribution so could potentially move in response to changing climate where opportunities allow. Increase connectivity between occurrences of lakeplain systems and with other natural communities where possible.
- Identify long-term management objectives for lakeplain prairies and savannas.
- Monitor the status and distribution of these natural communities, and response to climate change and adaptation efforts. Adjust adaptation efforts as needed.

Potential Areas for Adaptation in the Coastal Zone
Lakeplain prairies and savannas in Michigan are already extremely limited in their distribution, and threatened by a number of stressors across its distribution. To enhance resilience of these natural communities, adaptation efforts should occur throughout their distribution. Occurrences of these natural communities, particularly high quality occurrences, located in watersheds that may be experiencing low or moderate stress due to non-climate stressors could be priority areas for adaptation efforts, especially efforts to reduce stressors. Examples of low to moderate stress watersheds that could be priority areas for adaptation efforts for lakeplain systems include several watersheds in the St. Clair River Delta and along Saginaw Bay and Lake Erie, and one watershed along Lake Michigan (Figures 14, 15 and 32). Occurrences in higher stress watersheds may be potential areas for restoration efforts. Managing for lakeplain prairies and savannas along the current northern limit of their distribution in the Saginaw Bay area could help this natural community potentially expand its range northward in the future, if possible.

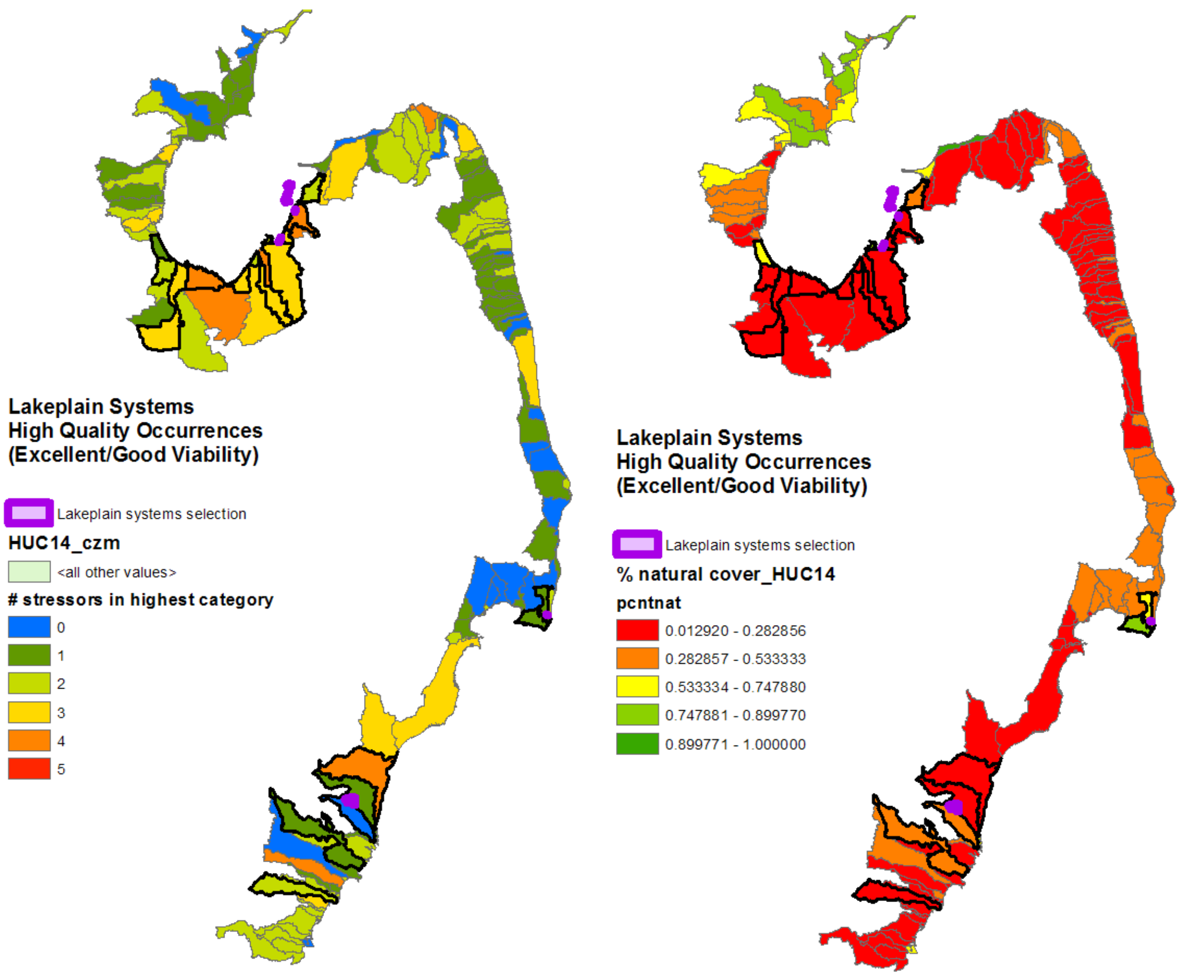

Figure 32. Map showing HUC14 watersheds along the Lake Erie coastal zone in Michigan that contain occurrences of lakeplain systems (areas outlined in black), including high quality occurrences (purple dots/polygons), and the combined stressor scores (red – highest stress, blue – lowest stress) based on a cumulative analysis of a subset of non-climate stressors and percent natural land cover.

Forested Wetlands

Forested wetlands (i.e., rich conifer swamp, northern hardwood swamp, southern hardwood swamp, and floodplain forest) are likely moderately to highly vulnerable to climate change. Forested wetlands are especially sensitive to changes in soil moisture and hydrology. In addition, many forested wetlands are currently stressed by high deer herbivory levels and invasive species.

Potential Adaptation Strategies

- Reduce stressors to current forested wetland communities by controlling invasive species and reducing deer densities. Reduce stressors that impact water\moisture availability.
- Focus restoration and conservation on forested wetland systems that can function as climate refugia (i.e., floodplain forest and rich conifer swamp).
    - Natural communities and landscape settings that experience moderated climates may also function as climate refugia. For example, coastal ecosystems and large wetland systems (i.e., swamp complexes and riparian ecosystems) may experience less severe climate change due to local climate moderation.
    - Groundwater influenced ecosystems (fens and conifer swamps) will likely be buffered from climate change and may therefore function as climate refugia.
    - Look for opportunities to restore, expand, and connect forested wetland systems (e.g., along river corridors). Address potential for invasive species to spread.
- To enhance the resilience of forested wetland communities and their component species, target numerous examples of high-quality examples in different ecological regions of the state for conservation and restoration.
- Identify long-term management objectives for forested wetland communities.
- Monitor the status and distribution of these natural communities, and response to climate change and adaptation efforts. Adjust adaptation efforts as needed.

Potential Areas for Adaptation in the Coastal Zone

Potential areas for adaptation efforts for forested wetlands in the coastal zone include areas that can provide or function as climate refugia, high quality examples of these natural communities in different ecological regions of the state, and occurrences of these natural communities that are impacted by stressors that may be exacerbated by climate change. Forested wetland systems, such as floodplain forests and rich conifer swamp forests, can provide or function as climate refugia, particularly along the coastal zone where climate change may be moderated by the Great Lakes. Occurrences of floodplain forest and rich conifer swamp in the coastal zone could be targeted for conservation and restoration efforts to provide climate refugia. Almost all the occurrences of forested wetlands that have been documented in watersheds along the coastal zone are floodplain forest and rich conifer swamp. High quality examples of forested wetlands in the coastal zone, particularly in watersheds that were considered low or moderate stress areas, may be potential priority areas for conservation and restoration efforts (Figure 33). High quality examples in the coastal zone in different ecological regions of the state should be targeted. Some watersheds along Lake Michigan and Saginaw Bay were in moderate stress categories for several individual stressors including percent natural cover, road density, percent impervious surface, and/or non-agricultural groundwater withdrawal (Figure 18). Forested wetlands in these watersheds may be more vulnerable, and may be potential areas for restoration and efforts to reduce existing stressors. Closer examination of forested wetland occurrences within these watersheds can identify where specific efforts to reduce existing stressors are needed.

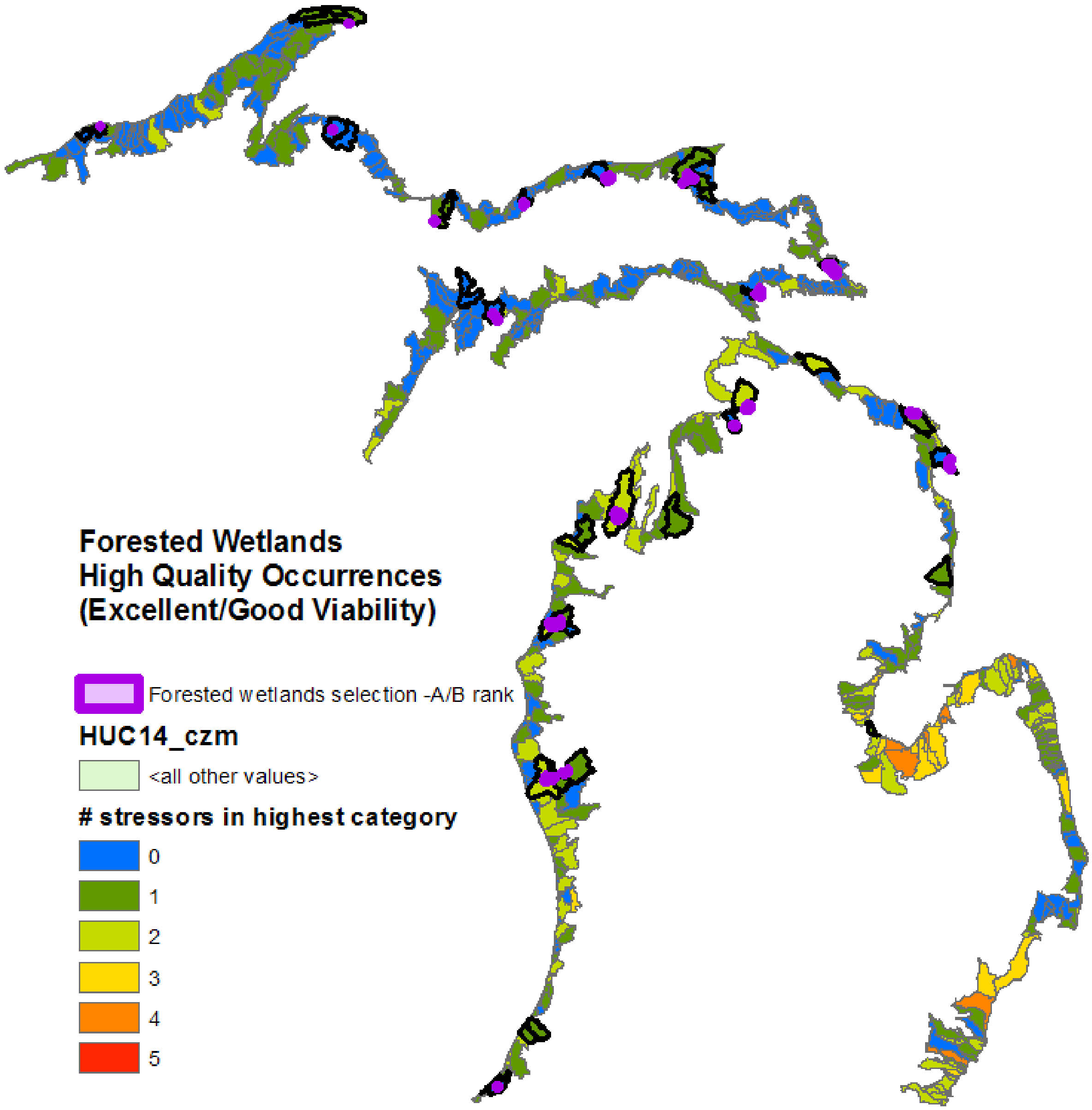

Figure 33. Map of HUC14 watersheds in the coastal zone in which occurrences of forested wetland natural communities have been documented (areas outlined in black), including high quality occurrences of forested wetland communities within these watersheds (purple dots/ polygons), and the combined stressor scores/categories for the watersheds (red/orange/yellow – high stress, light/dark green – moderate stress, and blue – low stress) based on a cumulative analysis of a subset of non-climate stressors.

Open Coastal Wetlands

Open coastal wetlands (i.e., coastal plain marsh, interdunal wetland, coastal fen, and Great Lakes marsh) will likely be moderately to highly vulnerable to climate change. The degree of vulnerability of open coastal wetlands will vary depending on the region of the state. Open coastal wetlands in the southern Lower Peninsula will likely be most vulnerable due to current high levels of fragmentation, shoreline development, and invasive species competition. In other words, where these systems are currently stressed, open wetlands will likely be most vulnerable to climate change. Invasive plant competition will likely be exacerbated by climate change, especially in the southern Lower Peninsula. Coastal wetlands are restricted to the Great Lakes shoreline. These systems will likely not be able to expand or contract their range latitudinally due to climate change. These systems are adapted to changing water levels and have a high capacity for dispersal. However, the ability of open coastal wetlands to disperse is limited in the southern part of the state where fragmentation and shoreline development are prevalent.

Potential Adaptation Strategies

- Reduce stressors to current open coastal wetlands by controlling invasive species. Reduce stressors that impact the hydrology in these systems.
- Establish rolling easements to allow for long-term fluctuations of coastal ecosystems across space and time.
- Focus restoration and conservation efforts on open wetlands that occur as complexes (i.e., Great Lakes marsh) or occur as part of larger functioning wetlands or landscapes.
- To enhance the resilience of wetland ecosystems and their component species, target numerous examples of high-quality wetlands in different ecological regions of the state for conservation and restoration.
- Identify long-term management objectives for open coastal wetland communities.
- Monitor the status and distribution of these natural communities, and response to climate change and adaptation efforts. Adjust adaptation efforts as needed.

Potential Areas for Adaptation in the Coastal Zone

Potential areas for adaptation of open coastal wetlands include high quality occurrences of these natural communities, occurrences that are part of large, intact complexes, and areas that provide opportunities for open coastal wetlands to expand, contract, and/or shift along the coastal zone in response to changing Great Lakes water levels. High quality occurrences of open coastal wetlands , particularly in lower stress areas, may be less vulnerable or more resilient to climate change, and may be priority areas for adaptation efforts (Figures 21 and 34). High quality open coastal wetlands in different ecological regions of the state should be targeted for conservation and restoration efforts, particularly since some types of open coastal wetlands only occur in certain parts of the state. High quality occurrences of open coastal wetlands in watersheds that were moderate or high stress areas may be considered priority areas for restoration efforts or efforts to reduce stressors such as invasive species (Figure 34). Closer examination of open coastal wetland occurrences within these watersheds can identify where specific efforts to reduce existing stressors are needed. Shorelines that have more gradual or gently-sloped bathymetry and topography provide more likely areas where open coastal wetlands can fluctuate and expand or shift lakeward or landward in response to changes in Great Lakes water levels (Figure 35). Analysis of the bathymetry and potential barriers along the shoreline can help identify these potential areas. These areas should be monitored, and protected or managed.

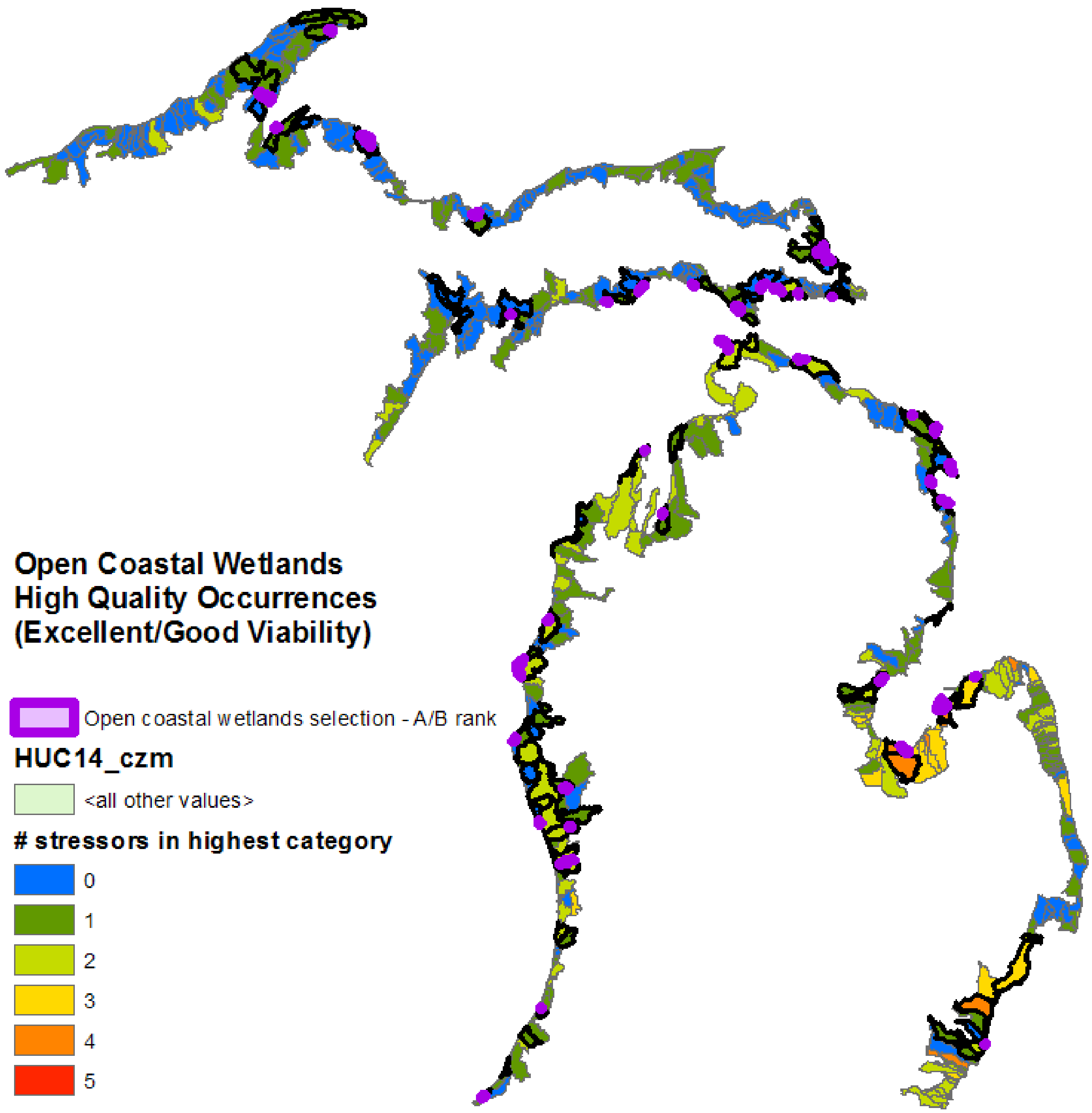

Figure 34. Map of HUC14 watersheds in the coastal zone in which occurrences of open coastal wetland natural communities have been documented (areas outlined in black), including locations of high quality occurrences of open coastal wetland within these watersheds (purple dots/polygons), and the combined stressor scores/categories for the watersheds (red/orange/yellow – high stress, light/dark green – moderate stress, and blue – low stress) based on a cumulative analysis of a subset of non-climate stressors.

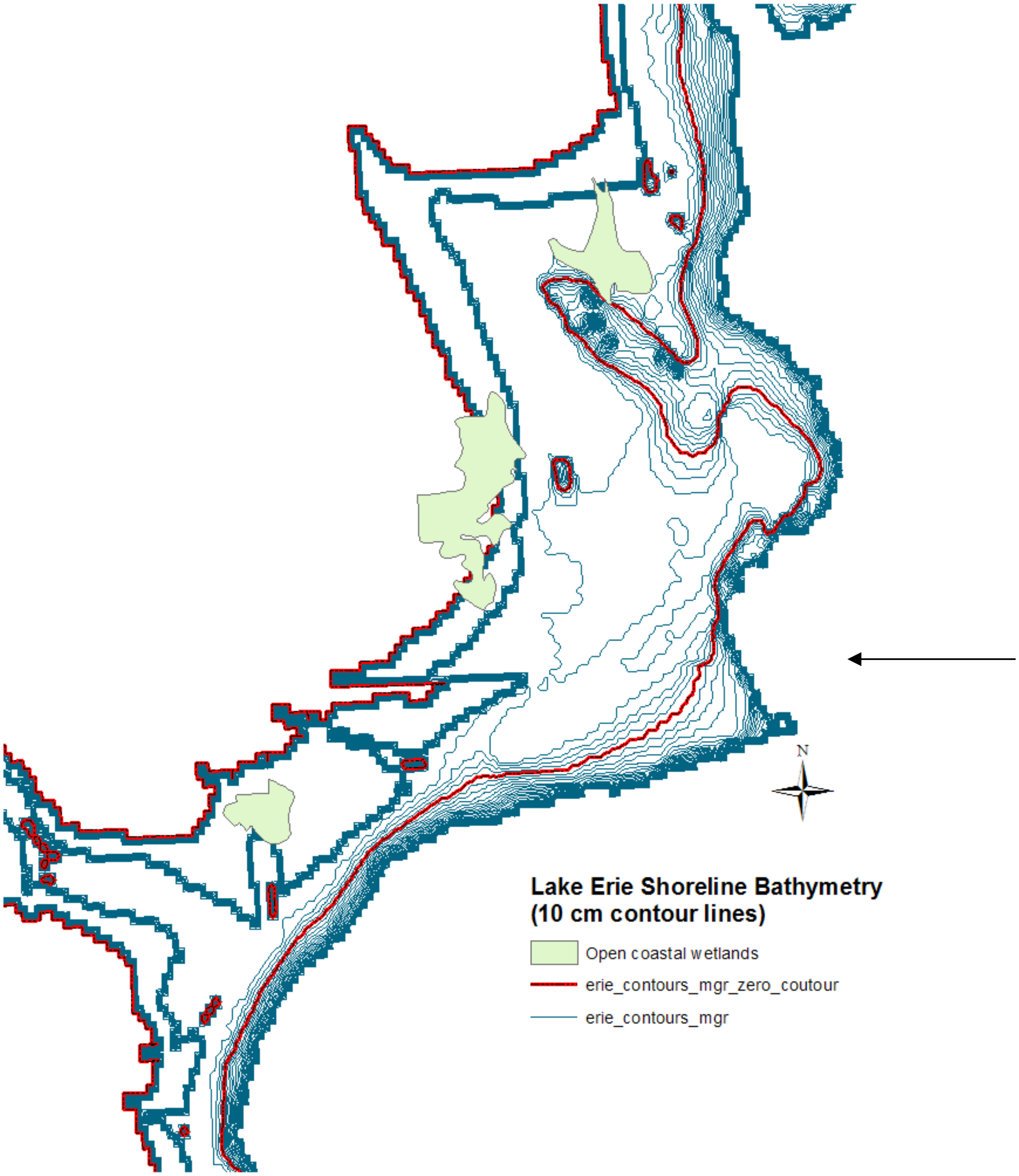

Figure 35. Map showing example of one area along the Lake Erie shoreline in Michigan (indicated by black arrow) where an open coastal wetland may be able to fluctuate and expand or shift lakeward (or landward) in response to potential changes in Great Lakes water levels due to climate change based on shoreline bathymetry data. The red line represents the zero contour line, and the blue lines indicate successive 10-cm changes in elevation from the zero contour line. Areas with contour lines that are closer together indicate a steeper gradient. Areas with contour lines that are spaced further apart indicate a more gradual gradient.

Upland Forests

The impact of climate change on Michigan's coastal forested communities (i.e., boreal forest, mesic northern forest, and mesic southern forest) will range from being highly vulnerable to slightly vulnerable. Boreal forest is likely highly vulnerable to climate change. Predicted climate change will likely be detrimental to the suite of conifer species that dominates this system (i.e., white spruce, paper birch, balsam fir, northern white cedar, and trembling aspen). In addition, boreal forest is currently stressed in the southern portion of its range by high deer herbivory levels. In Michigan, this community occurs at the southern extent of its range. With climate change, the current range of boreal forest will likely contract northward. The capacity of boreal forest to disperse is limited though because the community is restricted to a specific physiographic setting along Great Lakes shoreline. The dispersal ability of boreal forest is also limited by the failure of cedar to regenerate in landscapes where deer densities are high.

Mesic northern forest and mesic southern forest are likely vulnerable and slightly vulnerable to climate change, respectively. Both these communities have widespread distributions in Michigan but are currently stressed by invasive species and deer herbivory. Predicted climate change will likely exacerbate the current threats to this system, and will likely be detrimental to the canopy cohort in mesic northern forests. In forested landscapes, these communities have a high ability to disperse. However, in the southern part of the state, the dispersal ability of both communities is limited due to high levels of fragmentation.

Potential Adaptation Strategies

- Reduce stressors to current forested communities by controlling invasive species and reducing deer browse pressure.
- Conserve and restore numerous forested communities across their range to increase the resilience of the different types. Restore or increase connectivity where possible.
- Natural communities that occur as matrix or large patch communities can also function as climate refugia. For example, mesic northern forest can occur as matrix systems with high levels of topographic diversity and numerous inclusions of wetlands and bedrock outcroppings. Natural communities and landscapes that have gradients in elevation, soil moisture, and water table can provide species the opportunity to shift as climate changes.
- Identify long-term management objectives for upland forest communities, especially boreal forest communities which will likely shift or contract northward and/or change significantly in species composition due to climate change.
- Monitor the status and distribution of these natural communities, and response to climate change and adaptation efforts. Adjust adaptation efforts as needed.

Potential Areas for Adaptation in the Coastal Zone

Potential areas for adaptation efforts for upland forest communities in the coastal zone include matrix or large patch communities that can provide or function as climate refugia, high quality examples of upland forest communities in different ecological regions of the state, and occurrences of these natural communities that are impacted by stressors that may be exacerbated by climate change. Occurrences of boreal forest, mesic northern forest, and mesic southern forest, including high quality examples of these communities, have been documented in a moderate number of watersheds along the coastal zone throughout the state (Figure 36). These watersheds, particularly the ones with high quality occurrences, are potential areas for adaptation efforts for this natural community group. Matrix communities such as mesic northern forests may provide or function as climate refugia, especially large patch occurrences of this natural community. These areas could be targeted for adaptation efforts to potentially provide climate refugia (Figure 37). To enhance resilience of upland forest communities across their range, adaptation efforts also may need to focus on occurrences in areas that may experience high or moderate levels of stress due to climate change and/or non-climate stressors (based on the cumulative analysis and/or individual stressors). These areas are located primarily along Lake Michigan in the southern part of the state (Figures 23 and 24). Occurrences in these watersheds may be priority areas for efforts to reduce existing stressors. Closer examination of these occurrences can identify where specific efforts to reduce existing stressors are needed.

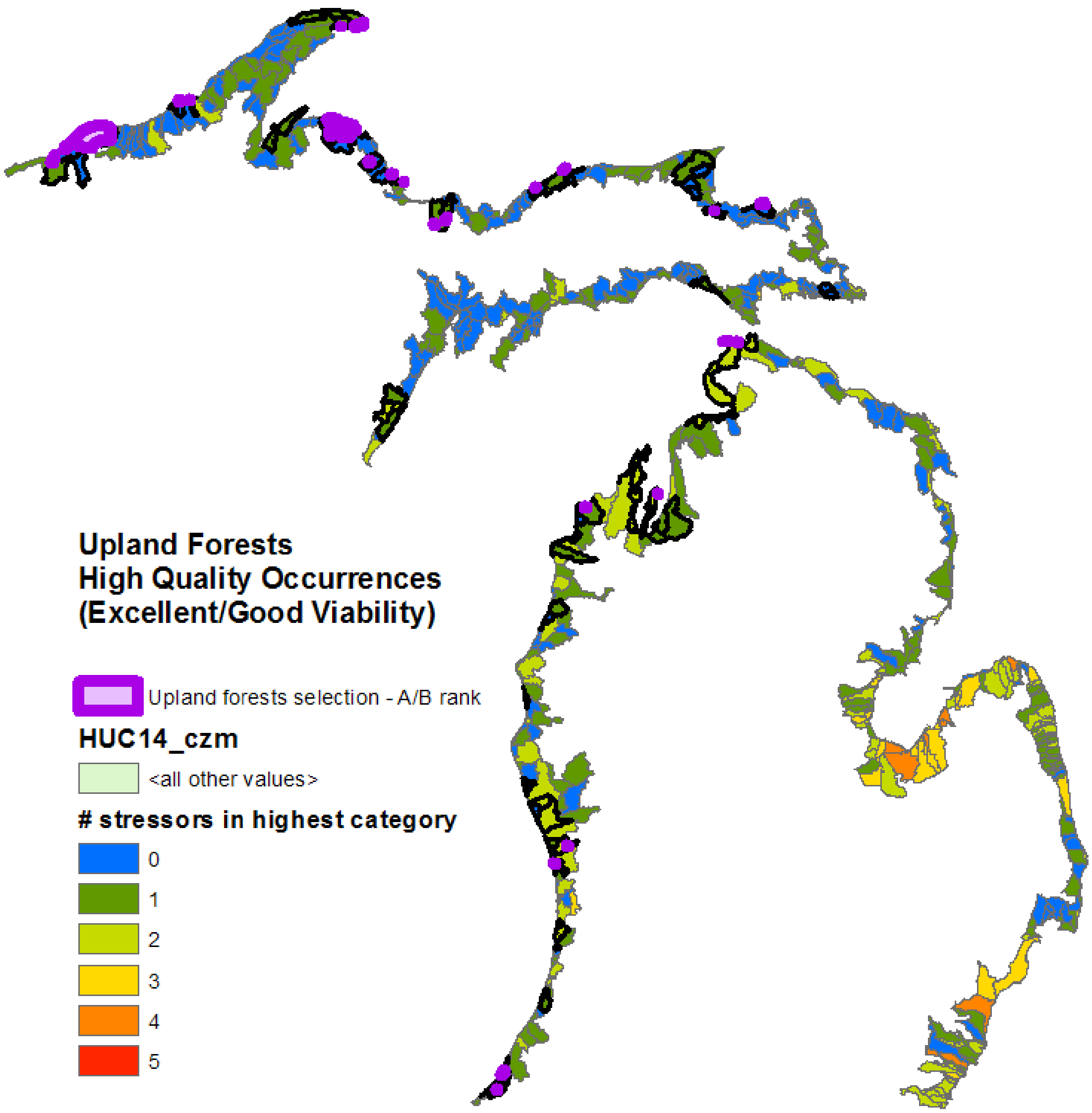

Figure 36. Map of HUC14 watersheds in the coastal zone in which occurrences of upland forest natural communities have been documented (areas outlined in black), including high quality occurrences of upland forest communities (purple dots/polygons), and the combined stressor scores/categories for the watersheds (ranging from red/orange/yellow – high stress to blue – low stress) based on a cumulative analysis of a subset of non-climate stressors.

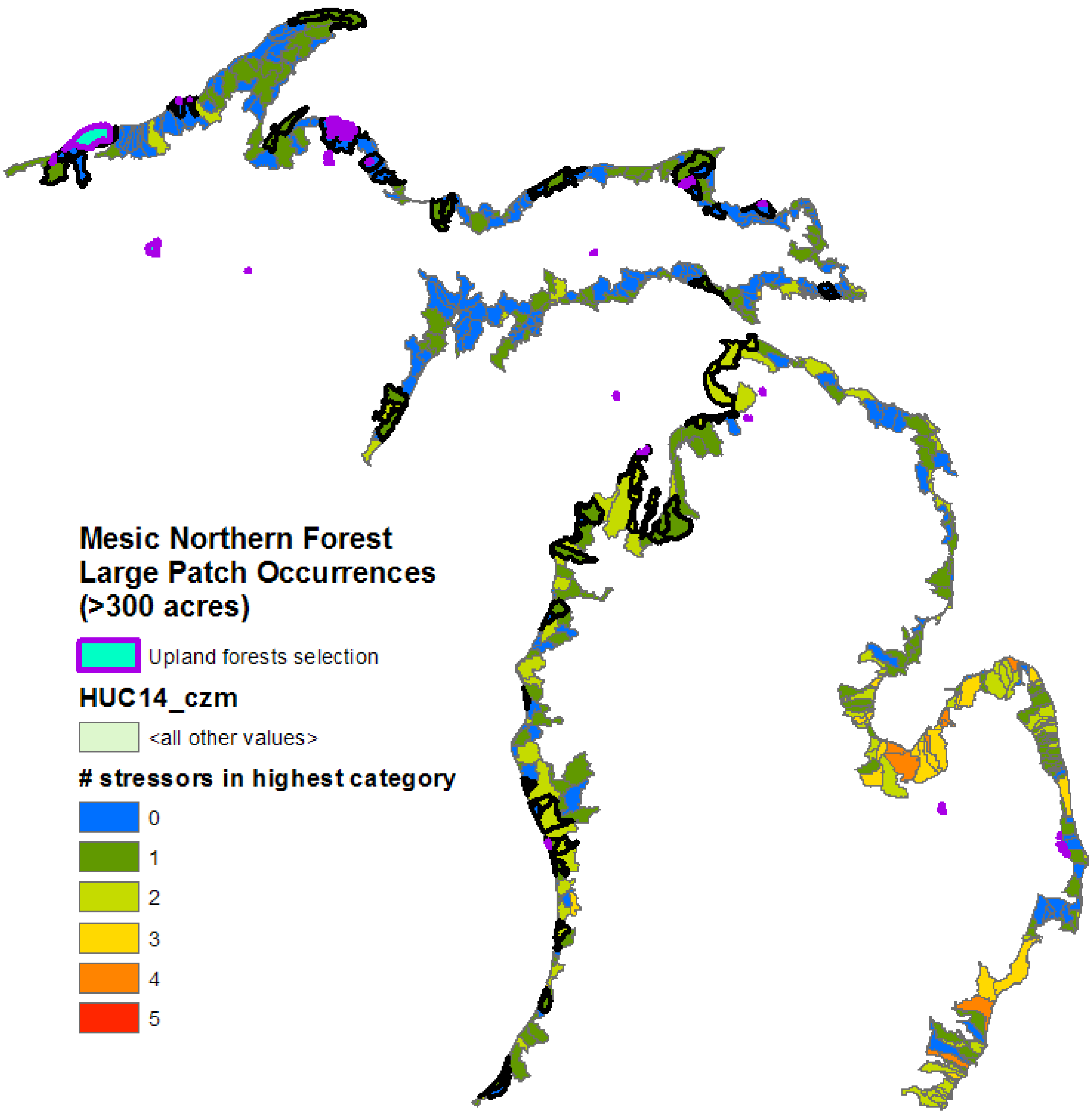

Figure 37. Map of large patch occurrences (>300 acres in area) of mesic northern forests (purple polygons) in Michigan's coastal zone, which may provide or function as climate refugia.

Wooded Dune and Swale Complex

The vulnerability of wooded dune and swale complexes will vary depending on the region of the state. Complexes in the Lower Peninsula may be more vulnerable to climate change due to higher levels of fragmentation, shoreline development, and invasive species competition impacting these complexes compared to those in the Upper Peninsula. In other words, where these systems are currently stressed, wooded dune and swale complexes will likely be vulnerable to climate change. The vulnerability of the system as a whole will likely depend on whether the Great Lakes water levels lower or rise. If Great Lakes water levels decline, wooded dune and swale complexes could potentially increase in area over long periods of time (i.e., hundreds of years). Vulnerability to climate change is also very hard to assess for wooded dune and swale complexes because this system is composed of so many different natural communities that will respond differently to climate change. Wetlands within wooded dune and swale complexes will likely be negatively impacted (especially peatlands) while some upland systems may benefit (i.e., dry-mesic northern forest). The diverse array of communities that occur within wooded dune and swale complexes will likely increase the overall adaptive capacity of this system. In addition, these are dynamic systems that are responsive to changes in the Great Lakes water levels. Because of the proximity of these systems to the Great Lakes, severity of climate change may be less compared to inland systems.

Potential Adaptation Strategies

- Reduce stressors to current wooded dune and swale complexes by controlling invasive species and reducing deer densities.
- Establish rolling easements to allow for long-term fluctuations of coastal ecosystems across space and time.
- Because of the proximity of these ecosystems to the Great Lakes and the high degree of beta diversity found within wooded dune and swale complexes, treatment of these complexes as climate refugia makes sense.
- Identify long-term management objectives for wooded dune and swale complexes.
- Monitor the status and distribution of these natural communities, and response to climate change and adaptation efforts. Adjust adaptation efforts as needed.

Potential Areas for Adaptation in the Coastal Zone

Wooded dune and swale complexes in watersheds that were in high or moderate stress categories for combined and/or individual stressors may be priority areas for efforts to reduce stressors to existing occurrences (Figures 26 and 27). *Phragmites* has been documented in most of the watersheds in the Lower Peninsula in which wooded dune and swale complexes occur, and in a subset of the watersheds along the Lake Michigan and Lake Huron shorelines in the eastern Upper Peninsula. Wooded dune and swale complexes in these watersheds may be priority areas for invasive species control, and presence of invasive species should be monitored at all occurrences of this natural community. High quality occurrences of wooded dune and swale complexes could be targeted for conservation and/or restoration efforts to provide potential climate refugia and to enhance resistance and resilience within this natural community type (Figure 38).

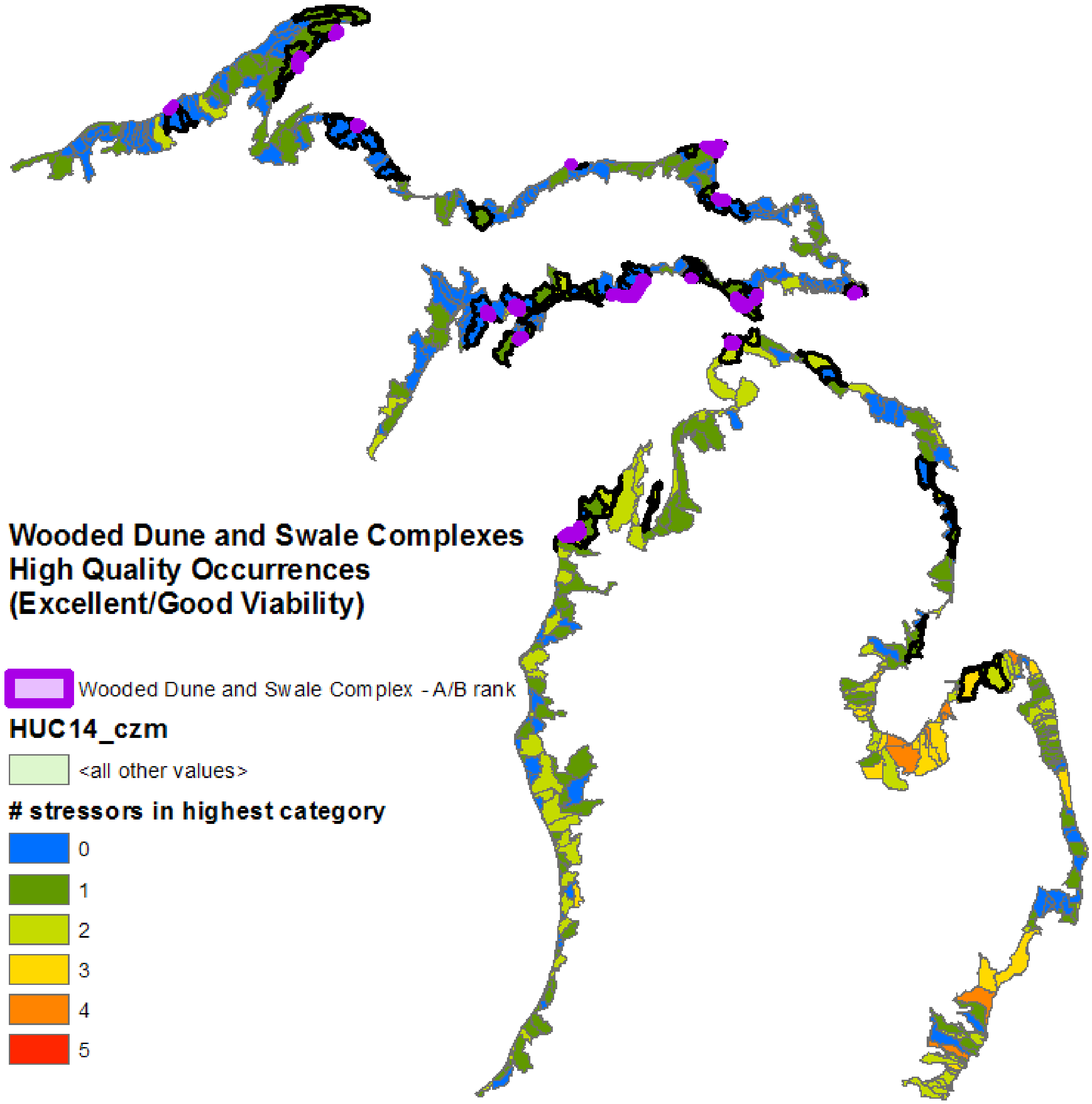

Figure 38. Map of HUC14 watersheds in the coastal zone in which occurrences of wooded dune and swale complexes have been documented (areas outlined in black), including locations of high quality occurrences of wooded dune and swale complexes (purple dots/polygons), and the combined stressor scores/categories for the watersheds (red/orange/yellow – high stress, light/dark green – moderate stress, and blue – low stress) based on a cumulative analysis of a subset of non-climate stressors.

Share results broadly

Project results, including some of the results from the natural community vulnerability assessment, have been shared with several different audiences. Information about the climate change vulnerability assessment and associated results have been presented at various meetings and conferences including the 2011 Michigan Wetlands Association Annual Conference and 2012 Workshop on Climate Change Adaptation in the Northwoods: Information, Tools and Collaboration. The audience at the Michigan Wetlands Association Annual Conference included federal, state, and local wetland managers, researchers, and policymakers. Participants in the Northwoods Climate Change Adaptation Workshop included researchers and managers from federal, state, and local agencies, conservation organizations, and academic institutions who are interested or engaged in climate change adaptation efforts in forests in Michigan, Wisconsin, and Minnesota. Results also will be presented at the 2013 Stewardship Network's Annual Conference, National Adaptation Forum in 2013, and other meetings/conferences in the future.

Initial project results also have been shared with various partners and stakeholders including managers, planners, and/or researchers from the MDEQ Coastal Management Program and Wetlands Program, MDNR Wildlife Division and Forest Management Division, The Nature Conservancy, U.S. Forest Service, Michigan State University, and Wayne State University. Final results including copies of the reports will be shared with these and additional partners and stakeholders including other programs or divisions within the MDEQ and MDNR, NatureServe and other programs in the Natural Heritage Network, the Michigan Climate Coalition (MCC), local and regional conservation organizations (e.g., Trust for Public Land and the Huron River Watershed Council have asked for copies of the assessment results or project report), U.S. Forest Service, U.S. Fish and Wildlife Service (including the Upper Midwest and Great Lakes Landscape Conservation Cooperative), Northwoods Climate Change Response Framework, and other agencies, organizations, and institutions that are currently involved or have potential to be involved in climate change adaptation efforts at local, state, regional, and national levels. We will be sharing project results and working with other Michigan State University Extension (MSUE) staff to provide project results and assistance to agencies and organizations involved in adaptation efforts at the local level. For example, several individuals in Michigan's Sea Grant Program and similar programs in the surrounding states have been specifically tasked with helping local communities identify and develop climate change adaptation efforts. We have already spoken with two of these individuals, and will be sharing project results and reports with them. We also are presenting some project information and results to natural resource educators within MSUE during their monthly conference call/webinar in December 2012. Opportunities exist to share project results through other webinars.

In addition to sharing project results with various partners and stakeholders through presentations, meetings, webinars, reports, and direct communications, we will be sharing information about and results from the vulnerability assessment through various websites. These include websites for the MNFI, MDNR, MDEQ, MCC, and/or NatureServe; Notre Dame's Climate Change Collaboratory; DataBasin; and/or Climate Adaptation Knowledge Exchange (CAKE). We will work with the MDEQ, MDNR, and other partners to identify other appropriate and useful outlets for sharing information and results from this project.

Discussion

Climate Change Vulnerability Assessment

This analysis indicates that natural communities comprised of light-demanding, drought-tolerant species are likely to expand in acreage. This may include upland prairies, savannas, bedrock glades, bedrock shorelines, open dunes, and sand and gravel beaches. At least initially, Great Lakes marshes and cobble shores are also likely to expand in acreage, as water levels in the Great Lakes recede. Conversely, communities comprised of species that require constant moisture (i.e., wetlands) or constant moisture and shade (i.e., forested wetlands) are likely to decline in acreage. In particular, bogs, fens, and forested wetlands, especially those in which conifers are a significant component, are likely to decline. Over time, mesic and wetland conifers are likely to be outcompeted by broad-leaved deciduous species, especially in the Lower Peninsula. Reductions in mesic and wetland conifers will significantly reduce structural diversity in boreal forest, mesic northern forest, poor conifer swamp, rich conifer swamp, hardwood-conifer swamp, and rich tamarack swamp. Reductions in the abundance of mesic and wetland confers will result in significant reductions in overall landscape diversity.

The natural communities of Michigan represent species assemblages that share relatively similar environment requirements (e.g., temperature, moisture, light, soils, etc.). Changes in environmental conditions will result in changes in species composition. Some of the responses by species to environmental changes are well understood but many others are not. The overall low confidence scores in our assessment is an indication of the uncertainly regarding potential impacts of climate change on natural communities. Although this report seems to suggest that whole communities may be able to migrate, in many cases, new species assemblages will arise to reflect the new environmental conditions. Thus, novel combinations of species may arise that do not reflect our present understanding of Michigan natural community species composition. In many cases, these changes will appear slowly. For example, many of the dominant tree species can live several hundred years, and once well established, have relatively broad tolerances for changes in temperature and moisture. The most easily observable changes in the natural communities of Michigan are likely to be found along the shorelines of the Great Lakes. Changes in Great Lakes water levels can result in rapid changes in the acreages of coastal natural communities. If Great Lakes water levels drop, as some models predict, efforts to prevent the widespread colonization of invasive plants on the newly exposed sediments will be a critical step in facilitating the establishment of high-quality coastal natural communities, especially Great Lakes marsh.

The results of our vulnerability assessment of natural communities to climate change in Michigan, particularly in the coastal zone, should be viewed as initial or preliminary for several reasons. The first reason is that the approach that we developed and used for this assessment was a good start but should be further refined. The expert panel that we convened to provide review of and feedback on our natural community vulnerability assessment identified a number of concerns with the approach we used. One concern was that we combined sensitivity and exposure to climate change impacts when we assessed and scored the variables for different natural communities. Sensitivity and exposure to climate change are two different things, and should be assessed separately. Another concern was that some of the variables were correlated and not independent (e.g., wetter winters and springs and drier summers and fall and overall drier climate, although they are little different in that the previous variable addressed changes in timing or seasonality of precipitation while the latter addressed changes in drought and overall precipitation; latitude range expansion and contraction and intrinsic ability to disperse). Some variables contained multiple factors which were assessed together but perhaps should have been assessed separately (e.g., wetter winters and springs and drier summers and falls). Assessing a community's ability to expand or contract its range latitudinally and intrinsic ability to disperse included evaluating the likelihood of dispersal or range expansion or contraction given current anthropogenic stressors or constraints. Intrinsic ability and actual feasibility to move or expand due to anthropogenic constraints on the landscape could have been assessed separately.

Our assessment also focused on potential impacts of climate change on certain aspects of natural communities but not others. For example, we assessed the vulnerability of some natural communities to climate change based on potential impacts to the dominant overstory tree species in those communities, but did not specifically consider or address impacts to other components of the vegetation assemblage (other than invasive species). This is because MNFI's natural community classification is generally defined by dominant or overstory species. However, while overstory species might not be impacted by or be able to move or respond to climate change in a short period of time, understory and/or ground layer species can move and respond more quickly to climate change. As a result, climate change will likely impact the quality or composition of some natural communities before impacting their distribution or extent. Also, some natural communities may be more dependent on species composition or interspecific interactions, while other communities may be more dependent on the physical environment. The variables that we scored for the assessment did not specifically address a natural community's dependence on species composition, interspecific interactions, or a certain physical environment, although we did consider this when we assessed a natural community's vulnerability to climate change. For the phonological change variable, we considered a natural community's vulnerability to changes in timing of flowering and pollinators, but did not examine vulnerability to phenological change in terms of increased weather variability.

The expert panel provided the following suggestions for refining the vulnerability assessment:

- Separate sensitivity from exposure to climate change; include exposure explicitly in assessment.
- Simplify and reduce the number of variables.
- Make variables/factors more independent.
- Make variables/factors as specific or compartmentalized as possible.
- Identify and focus on most important variables/factors that affect/structure natural communities – e.g., summer drought stress, soil type.
- Focus more on ecological relationships.
- Focus on mechanisms, and make variables/factors as mechanistic as possible so that factors that contribute to vulnerability can be clearly identified.
- Add current threats and non-climate stressors to vulnerability assessment.
- Consider spatial response/variability in addition to temporal response.
- Integrate global and state ranks for natural communities into assessment.
- With really uncertain factors, look at different scenarios (e.g., Great Lakes water levels).
- Work with other states and NatureServe.

Vulnerability assessments of habitats, natural communities, landscapes, or ecosystems are still fairly new, and available tools or approaches for conducting such assessments are limited. The approach and criteria that we developed and used for this assessment could serve as a model or tool that could be further developed and utilized for other vulnerability assessment efforts. Other methods or approaches for assessing the vulnerability of natural communities to climate change were recommended by the panel of experts. These include the following:

- Focusing on a small number of functional or structural attributes that significantly impact or determine the vulnerability of natural communities to climate change, and assessing vulnerability based on these attributes – e.g., sensitivity to extreme temperatures, moisture availability, substrate availability, invasive species, and climate variability.
- Assessing vulnerability to climate change in terms of impacts to the extent and quality of natural communities by first assessing the sensitivity of natural communities to climate change and specific factors by scoring degree of sensitivity to identify which communities might be most sensitive, and then assessing the direction of sensitivity, exposure, adaptive capacity, and reasons why natural community is vulnerable.
- Instead of focusing on natural communities that are based on vegetation assemblages which can change over time due to climate change and other factors, focus on identifying and assessing landscape units that are based on more enduring factors – e.g., physiography, climate, geology, soils, and topography. Other researchers have used a similar approach in terms of using some combination of topographic and soil variables to define landscape units or "land facets" for use as surrogates in conservation planning (see Beier and Brost 2010 for summary of researchers who have utilized this approach). Land facets are defined as recurring areas of relatively uniform topographic and soil attributes (Beier and Brost 2010). Beier and Brost (2010) report that researchers have found that species presence and distributions are largely a function of climate, topography, geology, time, disturbance regime, and other species present (Amundson and Jenny 1997), and that land facets can be used to represent and conserve most biodiversity in an area.

NatureServe also recently developed and piloted a Habitat Climate Change Vulnerability Index (HCCVI) to assess the vulnerability of ecosystems and habitats (Comer et al. 2012). This tool is similar to NatureServe's Climate Change Vulnerability Index (CCVI) for assessing the vulnerability of species to climate change. The HCCVI assesses climate change sensitivity and ecological resilience for a natural community within its distribution in a given ecoregion by combining numerical index scores and qualitative expert categorizations to produce an overall vulnerability index score that combines scores for both sensitivity and resilience (Comer et al. 2012). A natural community's sensitivity to climate change is assessed based on direct effects from exposure to climate change (e.g., climate stress index, climate envelope shift index), and resilience is assessed based on indirect effects (e.g., landscape condition, invasive species effects) and adaptive capacity of the natural community (e.g., plant/animal diversity, vulnerability of keystone species) (see Comer et al. 2012 for more information). Our natural community vulnerability assessment approach considered some factors that were similar to some of the HCCVI measures (e.g., landscape condition, invasive species, vulnerability of dominant overstory species), but we assessed them in a more qualitative and general manner. The NatureServe HCCVI is a more sophisticated and quantitative approach to assessing the vulnerability of natural communities, which potentially could be used in the future to further assess natural communities in Michigan.

Spatial Analysis and Adaptation Strategies

The spatial analysis that we conducted could be enhanced by incorporating some additional data which were not available for this project. These include spatially-explicit models or projections of areas that that may be more prone or vulnerable to increased disturbance such as increased flooding or fire, and hydrological changes such as decreased water levels and increased temperatures in rivers, streams, lakes, and wetlands; changes in groundwater levels and/or recharge; increased flooding; and changes in Great Lakes water levels and potential impacts given shoreline bathymetry. Incorporating additional data on current non-climate stressors such as the occurrence or prevalence of invasive species in addition to *Phragmites* would enhance the spatial analysis of stressors. Finer resolution, downscaled climate data, particularly those that specifically address or take into account lake effect, would enhance our ability to identify areas that may experience greater changes or impacts from climate change. Information on ecological thresholds for climate change impacts and non-climate stressors would enhance our ability to identify areas that may be higher stress for natural communities. For example, researchers have found that stream and wetland health can become impacted when impervious surface coverage in a watershed exceeds 10%, and stream health can become degraded when impervious surface coverage exceeds 30% (Schueler 1994, Hicks 1995, Arnold and Gibbons 1996). We used this information to identify the percent impervious surface categories below 10% as low stress, the 10-22% category as moderate stress, and the categories above 22% as high stress. Incorporating these data in the spatial analysis would refine our analysis help us better identify areas where species and natural communities may be more vulnerable or more resilient which can help inform and guide adaptation efforts.

Summary and Next Steps

This project represents a significant step toward assessing potential impacts of climate change on natural features in Michigan, particularly in the coastal zone, and developing and implementing appropriate and effective adaptation strategies for natural features that are vulnerable to climate change. This effort represents the first attempt to systematically assess the vulnerability of the range of natural communities in Michigan to climate change, particularly those that occur in the coastal zone. We compiled, synthesized, and applied information regarding potential impacts from climate change and existing non-climate stressors to identify how specific natural communities in Michigan may be impacted by or respond to climate change. This project also included initial efforts to utilize results from the vulnerability assessment to identify potential strategies and areas for adaptation efforts for natural communities that are likely vulnerable to climate change to help these communities and component species adapt to climate change. Prior to this project, the vulnerability of broad categories of habitats or natural communities in the state had been generally assessed or proposed (e.g., wetlands will likely be impacted by climate change). Adaptation strategies also had been proposed for certain species or biodiversity in general but not for specific natural communities or areas in the state.

This effort also provides an example of an adaptation planning framework or approach that can be utilized in Michigan, which includes identifying conservation targets (e.g., natural communities), assessing vulnerability of conservation targets, identifying where conservation targets may be particularly vulnerable or resilient, and identifying potential strategies and areas where adaptation efforts may be implemented. Others have developed overall frameworks for adaptation planning (Glick et al. 2011). Our effort provides an example of how this framework can be specifically applied to natural features or natural communities in Michigan, and an initial approach for doing this. This general framework and approach can be applied to assist in adaptation planning and implementation for species, other elements of biodiversity, and human systems or communities that are vulnerable to climate change in Michigan. Working with experts, this framework and specific components and approaches should be further developed and refined (e.g., additional stressors or data that should be included in the spatial analysis or vulnerability assessment, different approach for analyzing data, and/or different approach for using the results to identify or prioritize adaptation strategies or areas).

We recommend the following additional next steps for further developing and refining climate change vulnerability assessment and adaptation efforts for natural communities in Michigan:

- Conduct additional or follow-up vulnerability assessment of natural communities in Michigan when better data become available. For example, finer resolution, downscaled climate data for Michigan that takes into account lake effect will be available soon. Spatial data layers mapping multiple stressors in the Great Lakes also will be available soon as part of the Great Lakes Environmental Assessment and Mapping Project. A spatially explicit model is currently being developed to identify potential impacts of climate change on stream temperatures.
- Conduct additional analysis to identify more specific or detailed strategies and potential areas for adaptation efforts at a finer spatial scale for natural communities that are likely vulnerable to climate change.
- Work with experts to further develop and refine the framework and approach for assessing vulnerability of natural communities and identifying adaptation strategies and areas.
- Investigate and conduct analysis to identify land facets in Michigan, and potential network of land facets that could help facilitate adaptation of vulnerable natural features in the state.
- Investigate and conduct analysis to identify climate refugia in Michigan.
- Combine climate change analyses or incorporate results and potential adaptation strategies and areas with existing or current conservation needs and priorities/efforts for natural communities, especially those vulnerable to climate change (e.g., existing efforts to protect or manage high quality occurrences of natural communities).
- Share project results more widely.

In summary, climate change has the potential to significantly impact natural communities in Michigan, benefitting some communities and component species while adversely impacting other communities and species. Natural communities may expand, contract, or shift their distributions or ranges in the state in response to climate change. Natural communities also may change in composition, structure, and/or function. Some communities, or components within them, may respond quickly to climate change, while other communities and/or components may take hundreds of years to respond. Because different species or other aspects of natural communities will likely respond in different ways and at various rates, new or novel natural communities may appear in the state. Natural communities also may be more vulnerable to climate change in some parts of the state than others due to climate change and other stressors on the landscape. Climate change impacts and response of natural communities and species to these impacts can be highly variable and uncertain. Vulnerability assessments can help managers identify and justify changes in conservation/management priorities and strategies, and anticipate success or failure of conservation strategies (e.g., conservation easements define what is protected now but species may change in the future with climate impacts). Managers will need to clearly identify long-term management objectives, and address thresholds and uncertainty (e.g., whether the objective is to conserve particular species assemblages, land facets, and/or ecological functions or processes, at what cost, and at what point should management priorities/ objectives change). Monitoring the status, condition and distribution of natural communities will be even more important because of potential for new or increased impacts from climate change, and uncertainty around those impacts and natural communities' responses to impacts and adaptation efforts. Finally, Michigan's coastal zone may experience dramatic impacts from climate change, but also has the potential to moderate some potential impacts (e.g., due to lake effect). Some natural communities in the coastal zone also may provide or function as climate refugia. Given that such a high diversity of species and natural communities occur in Michigan's coastal zone, climate change adaptation efforts in the coastal zone are particularly important.

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APPENDICES

Appendix 1. Key to codes and definitions for global and state ranks.

<u>NatureServe Conservation Status Ranks</u>

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.

Appendix 2. Agenda and list of participants for meeting with experts in 2012 to obtain feedback on the approach and criteria we developed and used to assess the vulnerability of natural communities to climate change.

Agenda
Natural Community Climate Change Vulnerability Assessment
Friday, April 27, 2012
Stevens T. Mason Building, 530 W. Allegan St., Lansing
4th Floor Central Conference Room
10:00 am – 2:00 pm

1. Introductions (5 mins)

2. Overview of MNFI climate change vulnerability assessment project (5 mins)

3. Developing an approach for assessing natural communities to climate change
    - Assessing climate change vulnerability in general (15 mins)
    - Our project's approach (20 mins)
    - Discussion about vulnerability assessment approach and criteria (1 hr 15 mins)

4. Working Lunch – Catered lunch (1 hr)
    - Continue discussion about approach and criteria (30 mins)

5. Discussion and review of vulnerability assessment scores/rankings for select natural communities or groups of natural communities (1 hr)

6. Wrap-up

Materials provided:

1) MNFI Natural Community Climate Change Vulnerability Assessment Report (2011) - Draft report (please do not distribute)
2) NWF Scanning the Conservation Horizon Executive Summary (2011) – Provides overview of climate change vulnerability assessment in general
3) UCS Michigan Climate Change Impacts (2003) – Provides background on potential climate change impacts in the Great Lakes region and specifically Michigan

Appendix 2. Agenda and list of participants for meeting with experts in 2012 to obtain feedback on the approach and criteria we developed and used to assess the vulnerability of natural communities to climate change – Continued.

<u>Expert Meeting Participants:</u>
Amy Clark-Eagle, Michigan Department of Natural Resources, Forest Management Division
Joshua Cohen, Michigan Natural Features Inventory
Michael Donovan, Michigan Department of Natural Resources, Wildlife Division
Dr. Kimberly Hall, The Nature Conservancy
Anne Hokanson, Michigan Department of Environmental Quality
Chris Hoving, Michigan Department of Natural Resources, Wildlife Division
Dr. Dan Kashian, Wayne State University
Michael Kost, Michigan Natural Features Inventory
Yu Man Lee, Michigan Natural Features Inventory
Mark McKay, Michigan Department of Natural Resources, Wildlife Division
Glenn Palmgren, Michigan Department of Natural Resources, Parks and Recreation Division
Doug Pearsall, The Nature Conservancy
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Appendix 3. Summary of stressors and associated data layers compiled and/or developed for the spatial analysis, and data sources and description.

Stressor/Data Layer	Data Source(s) and Description
Change in average annual air temperature	Projections for change in average annual air temperature in Michigan for the year 2050 were downloaded from The Nature Conservancy's Climate Wizard (www.climatewizard.org) (Girvetz et al. 2009). Projections were based on a median of an ensemble of 16 global circulation models (GCMs) using a medium emissions scenario (A1B).
Change in average annual precipitation	Projections for change in average annual precipitation 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. Projections were based on a median of an ensemble of 16 global circulation models (GCMs) using a medium emissions scenario (A1B).
Change in moisture availability	Projections for changes in moisture by 2050 using the Hamon Moisture Metric were downloaded from NatureServe. Projections were based on an ensemble of 16 global circulation models (GCMs) using a medium emissions scenario (A1B).
Lake Erie bathymetry	Lake Erie bathymetry data were obtained from the National Oceanographic and Atmospheric Administration National Geophysical Data Center (http://www.ngdc.noaa.gov/mgg/greatlakes/erie.html). Cells with a value from -1 meter to +1 meter were extracted and used to generate 10 centimeter contour lines using the ESRI Spatial Analyst Contour tool.
CCAP land cover	The source of land cover data is the NOAA Coastal Change Analysis Program (CCAP) (NOAA, 2006). This is a thematic land cover raster dataset with a pixel resolution of 30 meters.
Percent natural cover	The CCAP values 8 – 22 were reclassified to a value of one representing natural land cover types and the CCAP values of 2 – 7 were reclassified to a value of zero representing non-natural cover types. Reclassification was done using the ArcGIS 10 Spatial Analyst Reclassify tool. The amount of each cover type within a given HUC was summarized utilizing the ArcGIS Spatial Analyst Tabulate Areas tool. The percent of natural land cover in each HUC was calculated as the amount of natural cover types divided by the total of both natural and non-natural cover types. The ArcGIS Fisher-Jenks natural breaks algorithm (Slocum 1999, de Smith 2009) was used to group the resulting percentage into five categories. The HUC14s in the category with the lowest percentage of natural land cover types were selected as the highest stressed HUCs for the percentage of natural land cover.

Percent agricultural cover	The CCAP values 6 and 7 were reclassified to a value of one representing agricultural land and the CCAP values of 2 through 5 and 8 through 22 were reclassified to a value of zero representing non-agricultural land. Reclassification was done using the ArcGIS 10 Spatial Analyst Reclassify tool. The amount of each cover type within a given HUC was summarized utilizing the ArcGIS Spatial Analyst Tabulate Areas tool. The percent of agricultural land cover in each HUC was calculated as the amount of agricultural land divided by the total of both agricultural and non-agricultural land. The ArcGIS Fisher-Jenks natural breaks algorithm (Slocum 1999, de Smith 2009) was used to group the resulting percentage into five categories. HUC14s in the category with the highest percentage of agricultural land cover were selected as the highest stressed HUCs for agricultural land.
Percent natural riparian cover	Natural and non-natural cover types within a 60 meter buffer of streams were extracted from the statewide CCAP dataset using the Extract by Mask tool. The amount of each cover type within a given HUC was summarized utilizing the ArcGIS Spatial Analyst Tabulate Areas tool. The percent of natural riparian land cover in each HUC was calculated as the amount of natural cover types divided by the total of both natural and non-natural cover types. The ArcGIS Fisher-Jenks natural breaks algorithm (Slocum 1999, de Smith 2009) was used to group the resulting percentage into five categories. The HUC14s in the category with the lowest percentage of natural land cover types in riparian areas were selected as the highest stressed HUCs for the percentage of riparian natural land cover.
Percent impervious surface	The CCAP values 2 – 4 were reclassified to a value of one representing impervious cover types and the CCAP values of 5 - 22 were reclassified to a value of zero representing pervious cover types. Reclassification was done using the ArcGIS 10 Spatial Analyst Reclassify tool. The amount of pervious and impervious cover types within a given HUC was summarized utilizing the ArcGIS Spatial Analyst Tabulate Areas tool. The percent of impervious land cover in each HUC was calculated as the amount of impervious types divided by the total of both pervious and impervious cover types. The ArcGIS Fisher-Jenks natural breaks algorithm (Slocum 1999, de Smith 2009) was used to group the resulting percentage into 5 categories. HUC14s in the category with the highest percentage of impervious cover types were selected as the highest stressed HUCs for impervious surface.
Streams	Utilized the baseflow_7_1 stream dataset available from the Michigan Department of Information technology Center for Geographic Information. (http://michigan.gov/cgi.)
Roads	Utilized the Michigan Framework dataset (allroads_miv11a) version 11A available from the Michigan Department of Information technology Center for Geographic Information. (http://michigan.gov/cgi).
Road density	The length of roads with in each HUC14 was calculated by using the ESRI Intersect tool to combine the HUC with the roads, then selecting the HUC lines and deleted them. As a result of this process the resultant road lines were attributed with the HUC variables. The road length was then summarized using the SHED_ID field. The density of roads was determined by dividing the length of roads in each HUC by the HUC area. The ArcGIS Fisher-Jenks natural breaks algorithm (Slocum 1999, de Smith 2009) was used to group the HUC14s into five categories based on road density. HUC14s in the highest road density category were selected as the highest stressed HUCs for road density.

Stream-road intersections	Using Geospatial Modeling Environment tools (http://www.spatialecology.com/gme/), created a point at each location that a stream (baseflow_7_1) dataset and a road (allroads_miv11a) intersected. The resulting points were then summarized for each HUC14. To normalize for length of streams in each HUC an index was created by dividing the number of points in each HUC by the length of stream mile sin the HUC. The ArcGIS Fisher-Jenks natural breaks algorithm (Slocum 1999, de Smith 2009) was used to group the road-stream intersection index into five categories and the HUCs in the highest number of crossings per stream mile category selected as the most impaired for road-stream intersections.
Invasive species - *Phragmites* locations	Phragmites location data was obtained from the Midwest Invasive Species Information Network (MISIN) (http://www.misin.msu.edu/) and from MNFI surveys.
Boat access sites	The source of boat access sites is the Michigan Department of Natural Resources BAS_Statewide dataset. Those HUC14s that intersected a BAS point were selected for the boat access stressor.
Dams	The source of dams is the MIWIMN_ NABD_FINAL_FILTER dataset obtained from the Michigan State University Department of Fisheries and Wildlife. The National Anthropogenic Barrier Dataset (NABD) (http://ecosystems.usgs.gov/fishhabitat/) accounts for medium and large dams (ranging in size from > 2 m to > 30 m) in the United States, but does not account for dams < 2 m high. The number of dams within each HUC14 was combined with the length of streams in each HUC to create an index of the number of dams per linear mile of streams. The index of dams per linear mile was then classified into five categories using the Fisher-Jenks natural breaks algorithm, The highest density category was then selected. The ArcGIS Fisher-Jenks natural breaks algorithm (Slocum 1999, de Smith 2009) was used to group the HUC14s into five categories based on the number of dams per linear stream miles. The HUC14s with the highest number of dams per stream mile were selected as the highest stressed HUCs for dams.
Non-agricultural groundwater withdrawal	Point groundwater withdraws obtained form the Michigan Department of Information Technology Center for Geographic Information library (www.michigan.gov\cgi). The number of withdraw sites in each HUC14 was summarized. To normalize for HUC area the count divided by the HUC area to produce an index of the number of sites per square mile. The ArcGIS Fisher-Jenks natural breaks algorithm (Slocum 1999, de Smith 2009) was used to group the index into five categories and the HUCs in the highest number of withdrawal sites per square mile category selected as the most impaired for non-agricultural groundwater withdrawal.
Pollution - Point source pollution	Point discharge (NPDES) data obtained from the US EPA (www.epa.gov/enviro/geo_data.html) dated 2009. The number of discharge sites in each HUC14 was summarized. To normalize for HUC area the count divided by the HUC area to produce an index of the number of sites per square mile. The ArcGIS Fisher-Jenks natural breaks algorithm (Slocum 1999, de Smith 2009) was used to group the index into five categories and the HUCs in the highest number of points per square mile category selected as the most impaired for point discharges.

Appendix 4. Land cover types or classes in the NOAA Coastal Change Analysis Program (CCAP) land cover data (NOAA 2006).

VALUE	CLASS_NAME
2	Developed, High Intensity
3	Developed, Medium Intensity
4	Developed, Low Intensity
5	Developed, Open Space
6	Cultivated Crops
7	Pasture/Hay
8	Grassland/Herbaceous
9	Deciduous Forest
10	Evergreen Forest
11	Mixed Forest
12	Scrub/Shrub
13	Palustrine Forested Wetland
14	Palustrine Scrub/Shrub Wetland
15	Palustrine Emergent Wetland
19	Unconsolidated Shore
20	Bare Land
21	Open Water
22	Palustrine Aquatic Bed

Appendix 5. Natural community vulnerability and confidence scores for 76 natural communities in Michigan and 11 climate change variables. Two sets of scores (from two MNFI ecologists) are provided for each natural community.

NATURAL COMMUNITY GROUPS	Increased Air and Surface Temperature		Longer Growing Season		Phenological Change	
Natural Communities	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**
MARSH COMMUNITIES						
Submergent Marsh	-1	1	1	1	0	1
Submergent Marsh	-1	1	1	1	0	1
Emergent Marsh	0	1	1	1	0	1
Emergent Marsh	1	1	3	1	0	1
Great Lakes Marsh	0	1	1	1	0	1
Great Lakes Marsh	1	1	3	1	0	1
Northern Wet Meadow	0	1	1	1	0	1
Northern Wet Meadow	1	1	3	1	0	1
Southern Wet Meadow	0	1	1	1	0	1
Southern Wet Meadow	1	1	3	1	0	1
Inland Salt Marsh	0	1	1	1	0	1
Inland Salt Marsh	1	1	3	1	0	1
Intermittent Wetland	0	1	1	1	0	1
Intermittent Wetland	1	1	3	1	0	1
Coastal Plain Marsh	0	1	1	1	0	1
Coastal Plain Marsh	1	1	3	1	0	1
Interdunal Wetland	0	1	**0**	**1**	0	1
Interdunal Wetland	-1	1	**0**	**1**	0	1
WET PRAIRIE COMMUNITIES						
Wet Prairie	0	1	**-1**	**1**	0	1
Wet Prairie	1	1	**1**	**1**	0	1
Wet-mesic Prairie	0	1	**-1**	**1**	0	1
Wet-mesic Prairie	1	1	**1**	**1**	0	1
Wet-mesic Sand Prairie	0	1	**-1**	**1**	0	1
Wet-mesic Sand Prairie	1	1	**1**	**1**	0	1
Lakeplain Wet Prairie	0	1	**-1**	**1**	0	1
Lakeplain Wet Prairie	1	1	**1**	**1**	0	1
Lakeplain Wet-mesic Prairie	0	1	**-1**	**1**	0	1
Lakeplain Wet-mesic Prairie	1	1	**1**	**1**	0	1
FEN COMMUNITIES						
Prairie Fen	-1	1	**-1**	**1**	0	1
Prairie Fen	-1	1	**1**	**1**	0	1
Northern Fen	-1	1	**-1**	**1**	0	1
Northern Fen	-1	1	**1**	**1**	0	1
Coastal Fen	-1	1	**-1**	**1**	0	1
Coastal Fen	-1	1	**1**	**1**	0	1
Patterned Fen	-1	1	**-1**	**1**	0	1
Patterned Fen	-1	1	**1**	**1**	0	1
Poor Fen	-1	1	**-1**	**1**	0	1
Poor Fen	-1	1	**1**	**1**	0	1
BOG COMMUNITIES						
Bog	-1	1	-1	1	0	1
Bog	-1	1	-1	1	0	1
Muskeg	-1	1	-1	1	0	1
Muskeg	-1	1	-1	1	0	1

Appendix 5. Natural community vulnerability and confidence scores for 76 natural communities in Michigan and 11 climate change variables. Two sets of scores (from two MNFI ecologists) are provided for each natural community.

NATURAL COMMUNITY GROUPS	Increased Air and Surface Temperature		Longer Growing Season		Phenological Change	
Natural Communities	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**
SHRUB WETLAND COMMUNITIES						
Northern Shrub Thicket	0	1	3	2	0	1
Northern Shrub Thicket	1	1	5	3	0	1
Southern Shrub-carr	0	1	3	2	0	1
Southern Shrub-carr	1	1	5	3	0	1
Inundated Shrub Swamp	0	1	3	2	0	1
Inundated Shrub Swamp	1	1	5	3	0	1
FORESTED WETLAND COMMUNITIES						
Poor Conifer Swamp	-1	1	-1	1	0	1
Poor Conifer Swamp	-1	1	-1	1	0	1
Rich Conifer Swamp	-1	1	-1	1	0	1
Rich Conifer Swamp	-1	1	-1	1	0	1
Rich Tamarack Swamp	-1	1	-1	1	0	1
Rich Tamarack Swamp	-1	1	-1	1	0	1
Hardwood-Conifer Swamp	-1	1	-1	1	0	1
Hardwood-Conifer Swamp	-1	1	-1	1	0	1
Northern Hardwood Swamp	-1	1	**-1**	**1**	0	1
Northern Hardwood Swamp	1	1	**1**	**2**	0	1
Southern Hardwood Swamp	1	1	1	1	0	1
Southern Hardwood Swamp	1	1	1	2	0	1
Floodplain Forest	1	1	1	1	-1	1
Floodplain Forest	1	1	3	2	0	1
Wet-mesic Flatwoods	1	1	1	1	0	1
Wet-mesic Flatwoods	1	1	1	2	0	1
PALUSTRINE/TERRESTRIAL COMMUNITIES						
Wooded Dune and Swale Complex	0	1	0	1	0	1
Wooded Dune and Swale Complex	0	1	0	1	0	1
TERRESTRIAL COMMUNITIES						
PRAIRIE COMMUNITIES						
Dry Sand Prairie	1	1	1	1	0	1
Dry Sand Prairie	0	1	1	2	0	1
Dry-mesic Prairie	1	1	1	1	0	1
Dry-mesic Prairie	1	1	1	2	0	1
Mesic Sand Prairie	1	1	1	1	0	1
Mesic Sand Prairie	1	1	1	2	0	1
Mesic Prairie	1	1	0	1	0	1
Mesic Prairie	1	1	1	2	0	1
Hillside Prairie	1	1	1	1	0	1
Hillside Prairie	1	1	1	2	0	1
SAVANNA COMMUNITIES						
Pine Barrens	1	1	1	1	0	1
Pine Barrens	1	2	1	2	0	1
Oak-Pine Barrens	1	1	1	1	0	1
Oak-Pine Barrens	1	2	1	2	0	1

Appendix 5. Natural community vulnerability and confidence scores for 76 natural communities in Michigan and 11 climate change variables. Two sets of scores (from two MNFI ecologists) are provided for each natural community.

NATURAL COMMUNITY GROUPS	Increased Air and Surface Temperature		Longer Growing Season		Phenological Change	
Natural Communities	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**
Oak Barrens	1	1	1	1	0	1
Oak Barrens	1	2	1	2	0	1
Oak Openings	1	1	1	1	0	1
Oak Openings	1	2	1	2	0	1
Lakeplain Oak Openings	1	1	**-1**	**1**	0	1
Lakeplain Oak Openings	1	1	**1**	**2**	0	1
Bur Oak Plains	0	3	0	3	0	3
Bur Oak Plains						
FOREST COMMUNITIES						
Dry Northern Forest	1	1	-1	1	0	1
Dry Northern Forest	1	1	-1	1	0	1
Dry-mesic Northern Forest	1	1	-1	1	0	1
Dry-mesic Northern Forest	1	1	-1	1	0	1
Mesic Northern Forest	-1	1	-1	1	0	1
Mesic Northern Forest	-1	1	-1	1	0	1
Dry Southern Forest	1	1	1	1	0	1
Dry Southern Forest	1	1	1	1	0	1
Dry-mesic Southern Forest	1	1	1	1	0	1
Dry-mesic Southern Forest	1	1	1	1	0	1
Mesic Southern Forest	-1	1	**1**	**1**	0	1
Mesic Southern Forest	-1	1	**3**	**2**	0	1
Boreal Forest	-3	1	-3	1	0	1
Boreal Forest	-1	1	-1	1	0	1
PRIMARY COMMUNITIES						
COASTAL SAND COMMUNITIES						
Sand and Gravel Beach	1	1	0	1	0	1
Sand and Gravel Beach	0	1	0	1	0	1
Open Dunes	1	1	0	1	0	1
Open Dunes	1	1	1	1	0	1
Great Lakes Barrens	1	1	0	1	0	1
Great Lakes Barrens	1	1	1	1	0	1
Alvar	1	1	0	1	0	1
Alvar	1	1	1	1	0	1
BEDROCK GLADE COMMUNITIES						
Limestone Bedrock Glade	1	1	0	1	0	1
Limestone Bedrock Glade	1	1	-1	1	0	1
Granite Bedrock Glade	1	1	0	1	0	1
Granite Bedrock Glade	1	1	-1	1	0	1
Volcanic Bedrock Glade	1	1	0	1	0	1
Volcanic Bedrock Glade	1	1	-1	1	0	1
Northern Bald	1	1	0	1	0	1
Northern Bald	1	1	-1	1	0	1
COBBLE SHORE COMMUNITIES						
Limestone Cobble Shore	1	1	-1	1	0	1
Limestone Cobble Shore	1	1	1	1	0	1

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NATURAL COMMUNITY GROUPS	Increased Air and Surface Temperature		Longer Growing Season		Phenological Change	
Natural Communities	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**
Sandstone Cobble Shore	1	1	-1	1	0	1
Sandstone Cobble Shore	1	1	1	1	0	1
Volcanic Cobble Shore	1	1	-1	1	0	1
Volcanic Cobble Shore	1	1	1	1	0	1
BEDROCK LAKESHORE COMMUNITIES						
Limestone Bedrock Lakeshore	1	1	-1	1	0	1
Limestone Bedrock Lakeshore	1	1	1	1	0	1
Sandstone Bedrock Lakeshore	1	1	-1	1	0	1
Sandstone Bedrock Lakeshore	1	1	1	1	0	1
Granite Bedrock Lakeshore	1	1	**-1**	**1**	0	1
Granite Bedrock Lakeshore	1	1	**1**	**1**	0	1
Volcanic Bedrock Lakeshore	1	1	-1	1	0	1
Volcanic Bedrock Lakeshore	1	1	1	1	0	1
LAKESHORE CLIFF COMMUNITIES						
Limestone Lakeshore Cliff	-1	1	-1	1	0	1
Limestone Lakeshore Cliff	0	1	1	1	0	1
Sandstone Lakeshore Cliff	-1	1	-1	1	0	1
Sandstone Lakeshore Cliff	0	1	1	1	0	1
Granite Lakeshore Cliff	0	1	0	1	0	1
Granite Lakeshore Cliff	1	1	1	1	0	1
Volcanic Lakeshore Cliff	0	1	0	1	0	1
Volcanic Lakeshore Cliff	1	1	1	1	0	1
INLAND CLIFF COMMUNITIES						
Limestone Cliff	-1	1	-1	1	0	1
Limestone Cliff	0	1	1	1	0	1
Sandstone Cliff	-1	1	-1	1	0	1
Sandstone Cliff	0	1	1	1	0	1
Granite Cliff	-1	1	-1	1	0	1
Granite Cliff	0	1	1	1	0	1
Volcanic Cliff	0	1	0	1	0	1
Volcanic Cliff	1	1	1	1	0	1
SUBTERRANEAN/SINK COMMUNITIES						
Cave	0	3	0	3	0	3
Cave	0	3	0	3	0	3
Sinkhole	-1	1	0	1	0	3
Sinkhole	0	1	1	1	0	1
JGC						
MAK						

Appendix 5. Natural community vulnerability and confidence scores for 76 natural communities in Michigan and 11 climate change variables. Two sets of scores (from two MNFI ecologists) are provided for each natural community.

NATURAL COMMUNITY GROUPS	Latitude Range Expansion or Contraction		Ability to Disperse		Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)	
Natural Communities	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**
MARSH COMMUNITIES						
Submergent Marsh	0	1	**3**	**2**	0	1
Submergent Marsh	0	1	**5**	**3**	0	1
Emergent Marsh	0	1	3	2	1	1
Emergent Marsh	0	1	**5**	**3**	0	1
Great Lakes Marsh	0	1	**3**	**2**	0	1
Great Lakes Marsh	0	1	**5**	**3**	0	1
Northern Wet Meadow	**-1**	**1**	1	1	1	1
Northern Wet Meadow	**-5**	**3**	3	1	3	2
Southern Wet Meadow	**1**	**1**	1	1	1	1
Southern Wet Meadow	**5**	**3**	3	1	3	2
Inland Salt Marsh	0	1	-5	3	**0**	**1**
Inland Salt Marsh	0	1	-5	3	**1**	**2**
Intermittent Wetland	0	1	**-1**	**1**	1	1
Intermittent Wetland	0	1	**1**	**2**	3	3
Coastal Plain Marsh	**1**	**1**	-3	2	1	1
Coastal Plain Marsh	**3**	**1**	-3	1	1	2
Interdunal Wetland	0	1	**1**	**1**	0	1
Interdunal Wetland	0	1	**-1**	**1**	0	1
WET PRAIRIE COMMUNITIES						
Wet Prairie	1	1	**-3**	**3**	3	1
Wet Prairie	1	1	**-1**	**1**	3	2
Wet-mesic Prairie	1	1	**-3**	**3**	3	1
Wet-mesic Prairie	1	1	**-1**	**1**	3	2
Wet-mesic Sand Prairie	1	1	**-3**	**3**	3	1
Wet-mesic Sand Prairie	1	1	**-1**	**1**	3	2
Lakeplain Wet Prairie	1	1	**-3**	**3**	3	1
Lakeplain Wet Prairie	1	1	**-1**	**1**	3	1
Lakeplain Wet-mesic Prairie	1	1	**-3**	**3**	3	1
Lakeplain Wet-mesic Prairie	1	1	**-1**	**1**	3	1
FEN COMMUNITIES						
Prairie Fen	1	1	-3	2	3	1
Prairie Fen	1	1	-3	1	3	1
Northern Fen	-1	1	-3	2	3	1
Northern Fen	-1	1	-3	1	3	1
Coastal Fen	-1	1	**1**	**1**	3	1
Coastal Fen	-1	1	**1**	**1**	3	1
Patterned Fen	-1	1	-3	2	3	1
Patterned Fen	-1	1	-3	1	3	1
Poor Fen	-1	1	-3	2	3	1
Poor Fen	-1	1	-3	1	3	1
BOG COMMUNITIES						
Bog	-1	1	-3	2	0	1
Bog	-1	1	-3	1	1	1
Muskeg	-1	1	-3	2	0	1
Muskeg	-1	1	-3	1	1	1

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NATURAL COMMUNITY GROUPS	Latitude Range Expansion or Contraction		Ability to Disperse		Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)	
Natural Communities	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**
SHRUB WETLAND COMMUNITIES						
Northern Shrub Thicket	-1	1	3	2	1	1
Northern Shrub Thicket	-1	1	5	3	3	2
Southern Shrub-carr	3	1	3	2	1	1
Southern Shrub-carr	1	1	5	3	3	2
Inundated Shrub Swamp	1	1	1	2	1	1
Inundated Shrub Swamp	1	1	3	1	3	2
FORESTED WETLAND COMMUNITIES						
Poor Conifer Swamp	-3	1	-1	1	-3	2
Poor Conifer Swamp	-1	1	-1	1	-3	2
Rich Conifer Swamp	-3	1	-1	1	-3	2
Rich Conifer Swamp	-1	1	-1	1	-3	2
Rich Tamarack Swamp	-1	1	-1	1	-3	2
Rich Tamarack Swamp	-1	1	1	1	-5	2
Hardwood-Conifer Swamp	-1	1	-1	1	-3	2
Hardwood-Conifer Swamp	-1	1	-1	1	-3	2
Northern Hardwood Swamp	-3	1	-1	1	-3	2
Northern Hardwood Swamp	-1	1	1	1	-3	2
Southern Hardwood Swamp	1	1	1	1	-3	2
Southern Hardwood Swamp	1	1	1	1	-3	2
Floodplain Forest	1	1	1	1	-3	2
Floodplain Forest	1	1	1	1	-3	2
Wet-mesic Flatwoods	1	1	**-3**	**3**	-5	2
Wet-mesic Flatwoods	0	1	**-1**	**1**	-3	2
PALUSTRINE/TERRESTRIAL COMMUNITIES						
Wooded Dune and Swale Complex	-1	1	1	1	-1	1
Wooded Dune and Swale Complex	0	1	1	1	-1	1
TERRESTRIAL COMMUNITIES						
PRAIRIE COMMUNITIES						
Dry Sand Prairie	1	1	1	1	3	2
Dry Sand Prairie	1	1	1	1	5	3
Dry-mesic Prairie	1	1	**-3**	**3**	3	2
Dry-mesic Prairie	1	1	**-3**	**1**	5	3
Mesic Sand Prairie	1	1	**-3**	**3**	3	2
Mesic Sand Prairie	1	1	**-3**	**1**	5	3
Mesic Prairie	1	1	**-3**	**3**	3	2
Mesic Prairie	1	1	**-3**	**1**	5	3
Hillside Prairie	1	1	-1	1	3	2
Hillside Prairie	1	1	-3	1	5	3
SAVANNA COMMUNITIES						
Pine Barrens	-1	1	1	1	3	2
Pine Barrens	0	1	1	1	5	3
Oak-Pine Barrens	-1	1	1	1	3	2
Oak-Pine Barrens	0	1	1	1	5	3

Appendix 5. Natural community vulnerability and confidence scores for 76 natural communities in Michigan and 11 climate change variables. Two sets of scores (from two MNFI ecologists) are provided for each natural community.

NATURAL COMMUNITY GROUPS	Latitude Range Expansion or Contraction		Ability to Disperse		Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)	
Natural Communities	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**
Oak Barrens	1	1	**-1**	**1**	3	2
Oak Barrens	1	1	**1**	**1**	5	3
Oak Openings	1	1	**-3**	**1**	3	2
Oak Openings	1	1	**-1**	**1**	5	3
Lakeplain Oak Openings	1	1	**-3**	**3**	3	3
Lakeplain Oak Openings	1	1	**-1**	**1**	3	1
Bur Oak Plains	0	3	0	3	0	3
Bur Oak Plains						
FOREST COMMUNITIES						
Dry Northern Forest	-1	1	3	1	3	2
Dry Northern Forest	0	1	1	1	1	1
Dry-mesic Northern Forest	-1	1	3	1	3	2
Dry-mesic Northern Forest	0	1	1	1	1	1
Mesic Northern Forest	-3	1	1	1	-3	1
Mesic Northern Forest	-1	1	3	2	-5	3
Dry Southern Forest	1	1	3	1	3	2
Dry Southern Forest	1	1	1	1	1	1
Dry-mesic Southern Forest	1	1	3	1	3	2
Dry-mesic Southern Forest	1	1	1	1	1	1
Mesic Southern Forest	1	1	**1**	**1**	-3	2
Mesic Southern Forest	3	3	**3**	**3**	-5	3
Boreal Forest	-5	2	**0**	**1**	-5	2
Boreal Forest	-5	3	**-1**	**2**	-3	2
PRIMARY COMMUNITIES						
COASTAL SAND COMMUNITIES						
Sand and Gravel Beach	0	1	5	3	3	1
Sand and Gravel Beach	0	1	5	3	5	3
Open Dunes	0	1	3	3	3	1
Open Dunes	0	1	5	3	5	1
Great Lakes Barrens	0	1	1	1	3	1
Great Lakes Barrens	1	1	1	1	0	1
Alvar	-1	1	-1	1	3	1
Alvar	-1	3	-1	1	3	2
BEDROCK GLADE COMMUNITIES						
Limestone Bedrock Glade	-1	1	**1**	**1**	5	2
Limestone Bedrock Glade	0	1	**3**	**1**	5	1
Granite Bedrock Glade	-1	1	1	1	5	2
Granite Bedrock Glade	0	1	1	1	5	1
Volcanic Bedrock Glade	-1	1	**1**	**1**	5	2
Volcanic Bedrock Glade	0	1	**3**	**3**	5	3
Northern Bald	-1	1	**0**	**1**	5	3
Northern Bald	0	1	**1**	**1**	5	2
COBBLE SHORE COMMUNITIES						
Limestone Cobble Shore	0	1	3	3	5	2
Limestone Cobble Shore	0	3	5	1	5	3

Appendix 5. Natural community vulnerability and confidence scores for 76 natural communities in Michigan and 11 climate change variables. Two sets of scores (from two MNFI ecologists) are provided for each natural community.

NATURAL COMMUNITY GROUPS	Latitude Range Expansion or Contraction		Ability to Disperse		Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)	
Natural Communities	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**
Sandstone Cobble Shore	0	1	3	3	3	2
Sandstone Cobble Shore	0	1	5	3	5	3
Volcanic Cobble Shore	0	1	3	3	5	2
Volcanic Cobble Shore	0	1	5	3	5	3
BEDROCK LAKESHORE COMMUNITIES						
Limestone Bedrock Lakeshore	0	1	3	3	5	2
Limestone Bedrock Lakeshore	0	3	5	1	5	3
Sandstone Bedrock Lakeshore	0	1	3	3	3	2
Sandstone Bedrock Lakeshore	0	1	5	3	5	3
Granite Bedrock Lakeshore	0	1	1	3	5	2
Granite Bedrock Lakeshore	0	1	1	1	3	1
Volcanic Bedrock Lakeshore	0	1	3	3	5	2
Volcanic Bedrock Lakeshore	0	1	5	3	5	3
LAKESHORE CLIFF COMMUNITIES						
Limestone Lakeshore Cliff	0	1	1	3	-1	1
Limestone Lakeshore Cliff	0	3	1	1	0	2
Sandstone Lakeshore Cliff	0	1	1	3	-1	1
Sandstone Lakeshore Cliff	0	3	1	1	0	2
Granite Lakeshore Cliff	0	1	1	3	0	1
Granite Lakeshore Cliff	0	3	1	1	0	2
Volcanic Lakeshore Cliff	0	1	1	3	0	1
Volcanic Lakeshore Cliff	0	3	1	1	0	2
INLAND CLIFF COMMUNITIES						
Limestone Cliff	0	1	0	1	-1	1
Limestone Cliff	0	3	0	3	0	2
Sandstone Cliff	0	1	0	1	-1	1
Sandstone Cliff	0	3	0	3	0	2
Granite Cliff	0	1	0	3	0	1
Granite Cliff	0	3	0	3	0	2
Volcanic Cliff	0	1	0	1	0	1
Volcanic Cliff	0	3	0	3	0	2
SUBTERRANEAN/SINK COMMUNITIES						
Cave	0	3	0	3	0	1
Cave	0	3	0	3	0	3
Sinkhole	0	3	0	3	0	1
Sinkhole	0	1	0	1	0	1
JGC						
MAK						

Appendix 5. Natural community vulnerability and confidence scores for 76 natural communities in Michigan and 11 climate change variables. Two sets of scores (from two MNFI ecologists) are provided for each natural community.

NATURAL COMMUNITY GROUPS	Great Lakes Lower Water Levels		Reduction in Regional Groundwater and Surface Water Levels		Wetter Winters and Springs and Drier Summers and Falls	
Natural Communities	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**
MARSH COMMUNITIES						
Submergent Marsh	0	3	-1	1	-1	1
Submergent Marsh	0	1	-3	1	0	1
Emergent Marsh	0	3	-1	1	-1	1
Emergent Marsh	0	1	-3	1	0	1
Great Lakes Marsh	5	3	-1	1	-1	1
Great Lakes Marsh	3	3	0	1	0	1
Northern Wet Meadow	0	3	-1	2	-1	1
Northern Wet Meadow	0	1	-3	1	-1	1
Southern Wet Meadow	0	3	-1	2	-1	1
Southern Wet Meadow	0	1	-3	1	-1	1
Inland Salt Marsh	0	3	-5	3	-1	1
Inland Salt Marsh	0	1	-5	3	-1	1
Intermittent Wetland	0	3	-1	2	-1	1
Intermittent Wetland	0	1	-1	1	1	1
Coastal Plain Marsh	0	3	-3	2	-1	1
Coastal Plain Marsh	0	1	-5	3	1	1
Interdunal Wetland	**3**	**3**	**-3**	**2**	-1	1
Interdunal Wetland	**1**	**1**	**-5**	**3**	0	1
WET PRAIRIE COMMUNITIES						
Wet Prairie	0	3	-5	2	-1	1
Wet Prairie	0	1	-3	2	0	1
Wet-mesic Prairie	0	3	-5	2	-1	1
Wet-mesic Prairie	0	1	-3	2	0	1
Wet-mesic Sand Prairie	0	3	-5	2	-1	1
Wet-mesic Sand Prairie	0	1	-3	2	0	1
Lakeplain Wet Prairie	1	1	-5	2	-1	1
Lakeplain Wet Prairie	1	1	-5	1	1	1
Lakeplain Wet-mesic Prairie	1	1	-5	2	-1	1
Lakeplain Wet-mesic Prairie	1	1	-5	1	1	1
FEN COMMUNITIES						
Prairie Fen	0	3	-5	3	-1	1
Prairie Fen	0	1	-5	3	0	1
Northern Fen	**1**	**1**	-5	3	-1	1
Northern Fen	**-1**	**1**	-5	3	0	1
Coastal Fen	3	3	-5	3	-1	1
Coastal Fen	3	1	-5	3	0	1
Patterned Fen	0	3	-5	3	-1	1
Patterned Fen	0	1	-5	3	0	1
Poor Fen	0	3	-5	3	-1	1
Poor Fen	0	1	-5	3	0	1
BOG COMMUNITIES						
Bog	0	3	-3	1	-1	1
Bog	0	1	-5	3	-3	1
Muskeg	0	3	-3	1	-1	1
Muskeg	0	1	-5	3	-3	1

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NATURAL COMMUNITY GROUPS	Great Lakes Lower Water Levels		Reduction in Regional Groundwater and Surface Water Levels		Wetter Winters and Springs and Drier Summers and Falls	
Natural Communities	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**
SHRUB WETLAND COMMUNITIES						
Northern Shrub Thicket	0	3	-1	1	-1	1
Northern Shrub Thicket	0	1	-3	1	1	1
Southern Shrub-carr	0	3	-1	1	-1	1
Southern Shrub-carr	0	1	-3	1	1	1
Inundated Shrub Swamp	0	3	-1	1	-1	1
Inundated Shrub Swamp	0	1	-3	1	1	1
FORESTED WETLAND COMMUNITIES						
Poor Conifer Swamp	0	3	-1	1	-1	1
Poor Conifer Swamp	0	1	-3	2	-1	1
Rich Conifer Swamp	0	3	-5	3	-1	1
Rich Conifer Swamp	-1	1	-5	3	-1	1
Rich Tamarack Swamp	0	3	-5	3	-1	1
Rich Tamarack Swamp	0	1	-5	3	-1	1
Hardwood-Conifer Swamp	0	3	-5	3	-1	1
Hardwood-Conifer Swamp	-1	1	-5	3	-1	1
Northern Hardwood Swamp	0	3	-3	2	-1	1
Northern Hardwood Swamp	0	1	-5	3	1	1
Southern Hardwood Swamp	0	3	-3	2	-1	1
Southern Hardwood Swamp	0	1	-5	3	1	1
Floodplain Forest	1	3	-3	2	-1	1
Floodplain Forest	0	1	-3	2	0	1
Wet-mesic Flatwoods	0	3	-3	2	-1	1
Wet-mesic Flatwoods	0	1	-3	3	0	1
PALUSTRINE/TERRESTRIAL COMMUNITIES						
Wooded Dune and Swale Complex	1	1	-1	1	0	1
Wooded Dune and Swale Complex	0	1	-1	1	0	1
TERRESTRIAL COMMUNITIES						
PRAIRIE COMMUNITIES						
Dry Sand Prairie	0	3	0	1	1	1
Dry Sand Prairie	0	3	0	1	1	2
Dry-mesic Prairie	0	3	**0**	**1**	1	1
Dry-mesic Prairie	0	3	**0**	**1**	1	2
Mesic Sand Prairie	0	3	**0**	**1**	1	1
Mesic Sand Prairie	0	3	**-1**	**1**	1	2
Mesic Prairie	0	3	**0**	**1**	1	1
Mesic Prairie	0	3	**-1**	**1**	1	2
Hillside Prairie	0	3	0	1	1	1
Hillside Prairie	0	3	0	1	1	2
SAVANNA COMMUNITIES						
Pine Barrens	0	3	0	1	1	1
Pine Barrens	0	3	0	1	1	1
Oak-Pine Barrens	0	3	0	1	1	1
Oak-Pine Barrens	0	3	0	1	1	1

Appendix 5. Natural community vulnerability and confidence scores for 76 natural communities in Michigan and 11 climate change variables. Two sets of scores (from two MNFI ecologists) are provided for each natural community.

NATURAL COMMUNITY GROUPS	Great Lakes Lower Water Levels		Reduction in Regional Groundwater and Surface Water Levels		Wetter Winters and Springs and Drier Summers and Falls	
Natural Communities	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**
Oak Barrens	0	3	0	1	1	1
Oak Barrens	0	3	0	1	1	1
Oak Openings	0	3	0	1	1	1
Oak Openings	0	3	0	1	1	1
Lakeplain Oak Openings	1	1	-1	1	1	1
Lakeplain Oak Openings	0	1	0	1	3	1
Bur Oak Plains	0	3	0	3	0	3
Bur Oak Plains						
FOREST COMMUNITIES						
Dry Northern Forest	0	3	0	1	1	1
Dry Northern Forest	0	2	0	2	-1	1
Dry-mesic Northern Forest	0	3	0	1	1	1
Dry-mesic Northern Forest	0	1	-1	2	-1	1
Mesic Northern Forest	0	3	0	1	-3	2
Mesic Northern Forest	0	1	-1	2	-1	2
Dry Southern Forest	0	3	0	1	1	1
Dry Southern Forest	0	2	-1	2	-1	1
Dry-mesic Southern Forest	0	3	0	1	1	1
Dry-mesic Southern Forest	0	1	-1	2	-1	1
Mesic Southern Forest	0	3	0	1	-1	1
Mesic Southern Forest	0	1	-1	2	-1	2
Boreal Forest	1	1	0	1	-3	2
Boreal Forest	0	1	0	1	-1	1
PRIMARY COMMUNITIES						
COASTAL SAND COMMUNITIES						
Sand and Gravel Beach	5	3	**0**	**1**	0	1
Sand and Gravel Beach	5	3	**1**	**1**	0	1
Open Dunes	5	3	0	1	1	1
Open Dunes	5	3	0	1	0	1
Great Lakes Barrens	1	1	0	1	1	1
Great Lakes Barrens	1	1	0	1	1	1
Alvar	1	1	0	1	1	1
Alvar	3	2	1	1	1	1
BEDROCK GLADE COMMUNITIES						
Limestone Bedrock Glade	**1**	**1**	0	1	1	1
Limestone Bedrock Glade	**5**	**1**	0	1	3	1
Granite Bedrock Glade	**1**	**1**	0	1	1	1
Granite Bedrock Glade	**5**	**1**	0	1	3	1
Volcanic Bedrock Glade	**1**	**1**	0	1	1	1
Volcanic Bedrock Glade	**5**	**1**	0	1	3	1
Northern Bald	0	3	0	1	1	1
Northern Bald	0	3	0	3	1	1
COBBLE SHORE COMMUNITIES						
Limestone Cobble Shore	5	3	0	1	0	1
Limestone Cobble Shore	5	3	0	1	1	1

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NATURAL COMMUNITY GROUPS	Great Lakes Lower Water Levels		Reduction in Regional Groundwater and Surface Water Levels		Wetter Winters and Springs and Drier Summers and Falls	
Natural Communities	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**
Sandstone Cobble Shore	5	3	0	1	-1	1
Sandstone Cobble Shore	5	3	0	1	0	1
Volcanic Cobble Shore	5	3	0	1	0	1
Volcanic Cobble Shore	5	3	**-1**	1	0	1
BEDROCK LAKESHORE COMMUNITIES						
Limestone Bedrock Lakeshore	5	3	0	1	0	1
Limestone Bedrock Lakeshore	5	3	0	1	1	1
Sandstone Bedrock Lakeshore	5	3	0	1	-1	1
Sandstone Bedrock Lakeshore	5	3	0	1	0	1
Granite Bedrock Lakeshore	5	3	0	1	0	1
Granite Bedrock Lakeshore	3	1	0	3	0	1
Volcanic Bedrock Lakeshore	5	3	0	1	0	1
Volcanic Bedrock Lakeshore	5	3	**-1**	1	0	1
LAKESHORE CLIFF COMMUNITIES						
Limestone Lakeshore Cliff	1	1	-1	1	-1	1
Limestone Lakeshore Cliff	1	1	-1	2	0	1
Sandstone Lakeshore Cliff	1	1	-1	1	-1	1
Sandstone Lakeshore Cliff	1	1	-1	2	0	1
Granite Lakeshore Cliff	1	1	0	1	0	1
Granite Lakeshore Cliff	1	1	-1	2	0	1
Volcanic Lakeshore Cliff	1	1	0	1	0	1
Volcanic Lakeshore Cliff	1	1	-1	2	0	1
INLAND CLIFF COMMUNITIES						
Limestone Cliff	0	1	-1	1	-1	1
Limestone Cliff	0	2	-1	2	0	1
Sandstone Cliff	0	1	-1	1	-1	1
Sandstone Cliff	0	2	-1	2	0	1
Granite Cliff	0	2	0	1	0	1
Granite Cliff	0	2	-1	2	0	1
Volcanic Cliff	0	1	0	1	0	1
Volcanic Cliff	0	2	-1	2	0	1
SUBTERRANEAN/SINK COMMUNITIES						
Cave	0	3	0	1	0	2
Cave	0	1	0	1	0	1
Sinkhole	1	1	-1	1	0	1
Sinkhole	0	1	0	1	0	1
JGC						
MAK						

Appendix 5. Natural community vulnerability and confidence scores for 76 natural communities in Michigan and 11 climate change variables. Two sets of scores (from two MNFI ecologists) are provided for each natural community.

NATURAL COMMUNITY GROUPS	Overall Drier Climate (>evaporation and evapotranspiration and drier soils)		Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers		Average	
Natural Communities	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**
MARSH COMMUNITIES					**-0.4**	**1.4**
Submergent Marsh	-3	1	-3	3	-0.5	1.5
Submergent Marsh	-3	1	-3	1	-0.4	1.2
Emergent Marsh	-3	1	-3	3	-0.3	1.5
Emergent Marsh	-3	1	-5	1	-0.2	1.2
Great Lakes Marsh	-3	1	-3	3	0.1	1.5
Great Lakes Marsh	-1	1	-5	1	0.5	1.4
Northern Wet Meadow	-3	1	-3	3	-0.5	1.5
Northern Wet Meadow	-3	3	-1	1	-0.3	1.5
Southern Wet Meadow	-3	1	**-5**	**3**	**-0.5**	1.5
Southern Wet Meadow	-3	3	**-3**	**1**	**0.5**	1.5
Inland Salt Marsh	-3	1	**-5**	**3**	-1.6	1.7
Inland Salt Marsh	-5	3	**-3**	**1**	-1.3	1.6
Intermittent Wetland	-3	1	-3	2	**-0.6**	1.4
Intermittent Wetland	-1	1	-3	1	**0.4**	1.3
Coastal Plain Marsh	-3	1	-3	2	-0.9	1.5
Coastal Plain Marsh	-5	3	-3	1	-0.6	1.5
Interdunal Wetland	-3	1	-3	3	-0.5	1.5
Interdunal Wetland	-3	1	-3	1	-1.1	1.2
WET PRAIRIE COMMUNITIES					-0.6	1.3
Wet Prairie	-1	1	-3	3	**-0.9**	**1.6**
Wet Prairie	-1	1	-3	1	**-0.2**	**1.2**
Wet-mesic Prairie	-1	1	-3	3	**-0.9**	**1.6**
Wet-mesic Prairie	-1	1	-3	1	**-0.2**	**1.2**
Wet-mesic Sand Prairie	-1	1	-3	3	**-0.9**	**1.6**
Wet-mesic Sand Prairie	-1	1	-3	1	**-0.2**	**1.2**
Lakeplain Wet Prairie	-1	1	-5	3	**-1.0**	**1.5**
Lakeplain Wet Prairie	1	1	-5	1	**-0.2**	**1.0**
Lakeplain Wet-mesic Prairie	-1	1	-5	3	**-1.0**	**1.5**
Lakeplain Wet-mesic Prairie	1	1	-5	1	**-0.2**	**1.0**
FEN COMMUNITIES					-1.1	1.5
Prairie Fen	-5	3	**-5**	**3**	-1.5	1.8
Prairie Fen	-5	3	**-3**	**1**	-1.1	1.4
Northern Fen	-5	3	-1	1	-1.3	1.5
Northern Fen	-5	3	-1	1	-1.2	1.4
Coastal Fen	**-5**	**3**	-3	1	-0.9	1.5
Coastal Fen	**-1**	**1**	-1	1	-0.1	1.2
Patterned Fen	-5	3	-1	1	-1.4	1.6
Patterned Fen	-5	3	-1	1	-1.1	1.4
Poor Fen	-5	3	-1	1	-1.4	1.6
Poor Fen	-5	3	-1	1	-1.1	1.4
BOG COMMUNITIES					-1.6	1.4
Bog	-5	3	-1	1	-1.5	1.5
Bog	-5	3	-1	1	-1.7	1.4
Muskeg	-5	3	-1	1	-1.5	1.5
Muskeg	-5	3	-1	1	-1.7	1.4

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NATURAL COMMUNITY GROUPS	Overall Drier Climate (>evaporation and evapotranspiration and drier soils)		Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers		Average	
Natural Communities	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**
SHRUB WETLAND COMMUNITIES					0.4	1.4
Northern Shrub Thicket	-1	1	-1	1	0.2	1.4
Northern Shrub Thicket	-3	2	-1	1	0.6	1.5
Southern Shrub-carr	-1	1	-3	1	0.4	1.4
Southern Shrub-carr	-3	2	-3	1	0.6	1.5
Inundated Shrub Swamp	-1	1	-1	1	0.2	1.4
Inundated Shrub Swamp	-3	2	-1	1	0.6	1.4
FORESTED WETLAND COMMUNITIES					-1.5	1.5
Poor Conifer Swamp	-3	2	-5	2	-1.7	1.5
Poor Conifer Swamp	-5	2	-5	2	-1.9	1.4
Rich Conifer Swamp	-3	2	-5	3	-2.1	1.7
Rich Conifer Swamp	-5	2	-3	2	-2.0	1.5
Rich Tamarack Swamp	-3	2	-5	3	-1.9	1.7
Rich Tamarack Swamp	-5	2	-5	2	-2.1	1.5
Hardwood-Conifer Swamp	-3	2	-5	3	-1.9	1.7
Hardwood-Conifer Swamp	-5	2	-5	2	-2.2	1.5
Northern Hardwood Swamp	-3	2	-5	3	-1.9	1.6
Northern Hardwood Swamp	-3	2	-3	1	-1.0	1.5
Southern Hardwood Swamp	-3	2	-3	2	-0.8	1.5
Southern Hardwood Swamp	-3	2	-3	1	-0.8	1.5
Floodplain Forest	-3	2	-5	2	-1.0	1.5
Floodplain Forest	-3	2	-3	1	-0.5	1.4
Wet-mesic Flatwoods	-3	2	-5	3	-1.5	1.8
Wet-mesic Flatwoods	-3	2	-3	1	-1.0	1.5
PALUSTRINE/TERRESTRIAL COMMUNITIES					-0.4	1.0
Wooded Dune and Swale Complex	-1	1	-3	1	-0.5	1.0
Wooded Dune and Swale Complex	0	1	-3	1	-0.4	1.0
TERRESTRIAL COMMUNITIES						
PRAIRIE COMMUNITIES					0.3	1.5
Dry Sand Prairie	3	2	-3	1	0.7	1.4
Dry Sand Prairie	3	1	-3	1	0.8	1.5
Dry-mesic Prairie	1	1	**-5**	**2**	0.0	1.5
Dry-mesic Prairie	1	1	**-3**	**1**	0.4	1.5
Mesic Sand Prairie	1	1	**-5**	**2**	0.0	1.5
Mesic Sand Prairie	1	1	**-3**	**1**	0.3	1.5
Mesic Prairie	1	1	**-5**	**2**	**-0.1**	**1.5**
Mesic Prairie	1	1	**-3**	**1**	**0.3**	**1.5**
Hillside Prairie	3	2	-3	1	0.5	1.4
Hillside Prairie	1	1	-3	1	0.4	1.5
SAVANNA COMMUNITIES					0.5	1.7
Pine Barrens	3	3	-3	2	0.5	1.5
Pine Barrens	3	2	-3	1	0.8	1.6
Oak-Pine Barrens	3	3	**-5**	**3**	0.4	1.6
Oak-Pine Barrens	3	2	**-3**	**1**	0.8	1.6

Appendix 5. Natural community vulnerability and confidence scores for 76 natural communities in Michigan and 11 climate change variables. Two sets of scores (from two MNFI ecologists) are provided for each natural community.

NATURAL COMMUNITY GROUPS	Overall Drier Climate (>evaporation and evapotranspiration and drier soils)		Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers		Average	
Natural Communities	Vulnerability	Confidence	Vulnerability	Confidence	Vulnerability	Confidence
Oak Barrens	3	3	**-5**	**3**	0.4	1.6
Oak Barrens	3	2	**-3**	**1**	0.9	1.6
Oak Openings	3	3	**-5**	**3**	0.2	1.6
Oak Openings	3	2	**-3**	**1**	0.7	1.6
Lakeplain Oak Openings	3	1	**-5**	**3**	0.0	1.5
Lakeplain Oak Openings	3	1	**-3**	**1**	0.7	1.1
Bur Oak Plains	0	3	0	3	0.0	3.0
Bur Oak Plains					0.0	
FOREST COMMUNITIES					-0.4	1.5
Dry Northern Forest	3	3	**-3**	**2**	0.5	1.5
Dry Northern Forest	1	2	**-3**	**1**	-0.1	1.3
Dry-mesic Northern Forest	3	3	**-5**	**2**	0.4	1.5
Dry-mesic Northern Forest	1	2	**-3**	**1**	-0.2	1.2
Mesic Northern Forest	-3	2	-5	3	-1.6	1.5
Mesic Northern Forest	-3	2	-5	3	-1.4	1.7
Dry Southern Forest	3	3	-5	2	0.7	1.5
Dry Southern Forest	1	2	-3	1	0.1	1.3
Dry-mesic Southern Forest	3	3	-5	2	0.7	1.5
Dry-mesic Southern Forest	1	2	-3	1	0.1	1.2
Mesic Southern Forest	-1	3	-5	2	-0.7	1.5
Mesic Southern Forest	-3	2	-5	3	-0.6	2.1
Boreal Forest	-3	2	-5	3	-2.4	1.5
Boreal Forest	-1	1	-5	1	-1.6	1.4
PRIMARY COMMUNITIES					0.7	1.4
COASTAL SAND COMMUNITIES					0.9	1.3
Sand and Gravel Beach	1	1	-1	1	1.3	1.4
Sand and Gravel Beach	0	1	-1	1	1.4	1.5
Open Dunes	3	2	-3	2	1.2	1.5
Open Dunes	5	2	-1	1	1.9	1.5
Great Lakes Barrens	1	2	-3	2	0.5	1.2
Great Lakes Barrens	1	1	-3	1	0.4	1.0
Alvar	3	1	-3	2	0.4	1.1
Alvar	1	1	-3	1	0.5	1.4
BEDROCK GLADE COMMUNITIES					1.1	1.3
Limestone Bedrock Glade	3	1	-3	2	0.7	1.2
Limestone Bedrock Glade	3	2	-3	1	1.5	1.1
Granite Bedrock Glade	3	1	-1	2	0.9	1.2
Granite Bedrock Glade	3	1	-1	1	1.5	1.0
Volcanic Bedrock Glade	3	1	-1	2	0.9	1.2
Volcanic Bedrock Glade	3	1	-1	1	1.6	1.4
Northern Bald	3	1	-1	2	0.7	1.5
Northern Bald	5	2	-1	1	1.0	1.5
COBBLE SHORE COMMUNITIES					1.2	1.5
Limestone Cobble Shore	1	1	-3	1	1.0	1.5
Limestone Cobble Shore	0	1	-3	1	1.4	1.5

Appendix 5. Natural community vulnerability and confidence scores for 76 natural communities in Michigan and 11 climate change variables. Two sets of scores (from two MNFI ecologists) are provided for each natural community.

NATURAL COMMUNITY GROUPS	Overall Drier Climate (>evaporation and evapotranspiration and drier soils)		Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers		Average	
Natural Communities	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**	**Vulnerability**	**Confidence**
Sandstone Cobble Shore	1	1	-1	1	0.9	1.5
Sandstone Cobble Shore	0	1	-1	1	1.5	1.5
Volcanic Cobble Shore	1	1	-1	1	1.2	1.5
Volcanic Cobble Shore	1	1	-1	1	1.5	1.5
BEDROCK LAKESHORE COMMUNITIES					1.2	1.5
Limestone Bedrock Lakeshore	1	1	-3	1	1.0	1.5
Limestone Bedrock Lakeshore	0	1	-3	1	1.4	1.5
Sandstone Bedrock Lakeshore	1	1	-1	1	0.9	1.5
Sandstone Bedrock Lakeshore	0	1	-1	1	1.5	1.5
Granite Bedrock Lakeshore	1	1	**-1**	**1**	1.0	1.5
Granite Bedrock Lakeshore	1	1	**1**	**1**	1.0	1.2
Volcanic Bedrock Lakeshore	1	1	-1	1	1.2	1.5
Volcanic Bedrock Lakeshore	1	1	-1	1	1.5	1.5
LAKESHORE CLIFF COMMUNITIES					-0.1	1.3
Limestone Lakeshore Cliff	-1	1	-1	1	**-0.5**	**1.2**
Limestone Lakeshore Cliff	-1	1	-1	1	**0.0**	**1.4**
Sandstone Lakeshore Cliff	-1	1	-1	1	**-0.5**	**1.2**
Sandstone Lakeshore Cliff	-1	1	-1	1	**0.0**	**1.4**
Granite Lakeshore Cliff	0	1	-1	1	0.1	1.2
Granite Lakeshore Cliff	-1	1	-1	1	0.1	1.4
Volcanic Lakeshore Cliff	0	1	-1	1	0.1	1.2
Volcanic Lakeshore Cliff	-1	1	-1	1	0.1	1.4
INLAND CLIFF COMMUNITIES					-0.3	1.4
Limestone Cliff	-1	1	-1	1	-0.6	1.0
Limestone Cliff	-1	1	-1	1	-0.2	1.6
Sandstone Cliff	-1	1	-1	1	-0.6	1.0
Sandstone Cliff	-1	1	-1	1	-0.2	1.6
Granite Cliff	-1	1	-1	1	-0.4	1.3
Granite Cliff	-1	1	-1	1	-0.2	1.6
Volcanic Cliff	0	1	-1	1	-0.1	1.0
Volcanic Cliff	-1	1	-1	1	-0.1	1.6
SUBTERRANEAN/SINK COMMUNITIES					-0.1	1.7
Cave	0	1	0	1	0.0	2.2
Cave	0	1	0	1	0.0	2.1
Sinkhole	-1	1	-1	1	-0.3	1.5
Sinkhole	0	1	-1	1	0.0	1.0
JGC						
MAK						

Appendix 6. Average Vulnerability Scores and Average Confidence Scores for Natural Community Groups in Michigan.

Natural Community Groups	Average Vulnerability	Average Confidence
PALUSTRINE COMMUNITIES	-0.7	1.4
MARSH COMMUNITIES	-0.4	1.4
WET PRAIRIE COMMUNITIES	-0.6	1.3
FEN COMMUNITIES	-1.1	1.5
BOG COMMUNITIES	-1.6	1.4
SHRUB WETLAND COMMUNITIES	0.4	1.4
FORESTED WETLAND COMMUNITIES	-1.5	1.5
PALUSTRINE/TERRESTRIAL COMMUNITIES	-0.4	1.0
TERRESTRIAL COMMUNITIES	0.1	1.6
PRAIRIE COMMUNITIES	0.3	1.5
SAVANNA COMMUNITIES	0.5	1.7
FOREST COMMUNITIES	-0.4	1.5
PRIMARY COMMUNITIES	0.7	1.4
COASTAL SAND COMMUNITIES	0.9	1.3
BEDROCK GLADE COMMUNITIES	1.1	1.3
COBBLE SHORE COMMUNITIES	1.2	1.5
BEDROCK LAKESHORE COMMUNITIES	1.2	1.5
LAKESHORE CLIFF COMMUNITIES	-0.1	1.3
INLAND CLIFF COMMUNITIES	-0.3	1.4
SUBTERRANEAN/SINK COMMUNITIES	-0.1	1.7

Appendix 7. Summary of Climate Change Vulnerability Assessment for Marsh Communities/Open Wetlands.

MARSH COMMUNITIES/OPEN WETLANDS

Open wetlands will likely be moderately to highly vulnerable to climate change. The degree of vulnerability of open wetlands will vary depending on the region of the state with open wetlands in the southern Lower Peninsula being most vulnerable due to high levels of fragmentation and invasive species competition. In other words, where these systems are currently stressed, open wetlands will likely be most vulnerable to climate change. Increasing air and surface temperature and a longer growing season may benefit these wetlands systems by increasing plant productivity, however, these changes will likely also impart a competitive advantage to invasive species and can lead to woody encroachment of open wetlands. In open wetlands that have standing water, increasing temperature can lead to increased water temperature which can result in eutrophication. Those open wetlands that are northerly in distribution will likely contract due to climate change, while those wetlands that are distributed in the southern part of the state will potentially expand in range. Many open wetlands have limited dispersal ability because they are restricted by a specific hydrologic setting (i.e., inland salt marsh, intermittent wetland, coastal plain marsh, and interdunal wetland). Those open wetlands that are less restrictive in terms of their physiographic setting will likely have a high ability to disperse (i.e., submergent marsh, emergent marsh, northern wet meadow, and southern wet meadow). However, the ability of open wetlands to disperse is limited in the southern part of the state where fragmentation is prevalent. It is unclear how open wetlands will be impacted by increased frequency or intensity of extreme events. Many open wetlands will likely benefit from increased fire, flooding, and wind events while increased droughts will likely negatively impact open wetlands. Flash flooding events could increase detrimental impacts from sedimentation and pollution. Lower Great Lakes levels would likely result in the increase of Great Lakes marsh and interdunal wetland, especially in the northern portion of their range. However, where invasive species are prevalent, lower water levels could result in increased levels of invasive species in coastal wetlands. Inland open wetlands will most likely not be impacted by lower Great Lakes water levels. The reduction in regional groundwater and surface water levels will likely be very detrimental to open wetlands. Drier open wetlands might be more susceptible to invasive species and woody encroachment. It is unclear how open wetlands will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetland systems. As noted above, drier open wetlands might be more susceptible to invasive species and woody encroachment. It remains unclear whether the increase in winter precipitation will be in snow or rain. Also, if ice cover decreases in the winter, coastal wetlands will be impacted as winter wave activity will change. A drier climate will likely negatively impact open wetlands. A key factor for many of Michigan's open wetlands is the relationship of precipitation and evapotranspiration. Organic soils develop where precipitation is greater than evapotranspiration. If climate change results in the decrease in precipitation and the increase in evapotranspiration that could lead to the decomposition of wetland organic soils, which would dramatically alter these wetlands and likely lead to the encroachment from woody species and invasives. Open wetlands in southern Michigan are currently stressed by invasive species. Invasive plant competition will likely be exacerbated by climate change, especially in the southern Lower Peninsula.

Appendix 7. Summary of Climate Change Vulnerability Assessment for Marsh Communities/Open Wetlands (Continued).

Increased Air and Surface Temperature
Increasing air and surface temperature and a longer growing season may benefit these wetlands systems by increasing plant productivity, however, these changes will likely also impart a competitive advantage to invasive species and can lead to woody encroachment of open wetlands. In open wetlands that have standing water, increasing temperature can lead to increased water temperature which can result in eutrophication.

Longer Growing Season
Open wetlands could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season could also be detrimental for open wetlands if it allows for the increase in the prevalence of woody encroachment (especially invasives) within this open wetland system.

Phenological Change
It is not clear how potential climate driven changes in phenology will impact open wetlands.

Latitude Range Expansion or Contraction
Those open wetlands that are northerly in distribution will likely contract due to climate change, while those wetlands that are distributed in the southern part of the state will potentially expand in range.

Ability to Disperse
Many open wetlands have limited dispersal ability because they are restricted by a specific hydrologic setting (i.e., inland salt marsh, intermittent wetland, coastal plain marsh, and interdunal wetland). Those open wetlands that are less restrictive in terms of their physiographic setting will likely have a high ability to disperse (i.e., submergent marsh, emergent marsh, northern wet meadow, and southern wet meadow). However, the ability of open wetlands to disperse is limited in the southern part of the state where fragmentation is prevalent.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)
It is unclear how open wetlands will be impacted by increased frequency or intensity of extreme events. Many open wetlands will likely benefit from increased fire, flooding, and wind events while increased droughts will likely negatively impact open wetlands. Flash flooding events could increase detrimental impacts from sedimentation and pollution.

Great Lakes Lower Water Levels
Lower Great Lakes levels would likely result in the increase of Great Lakes marsh and interdunal wetland, especially in the northern portion of their range. However, where invasive species are prevalent, lower water levels could result in increased levels of invasive species in coastal wetlands. Inland open wetlands will most likely not be impacted by lower Great Lakes water levels

Appendix 7. Summary of Climate Change Vulnerability Assessment for Marsh Communities/Open Wetlands (Continued).

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels will likely be very detrimental to open wetlands. Drier open wetlands might be more susceptible to invasive species and woody encroachment.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how open wetlands will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetland systems. As noted above, drier open wetlands might be more susceptible to invasive species and woody encroachment. It remains unclear whether the increase in winter precipitation will be in snow or rain. Also, if ice cover decreases in the winter, coastal wetlands will be impacted as winter wave activity will change.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact open wetlands. A key factor for many of Michigan's open wetlands is the relationship of precipitation and evapotranspiration. Organic soils develop where precipitation is greater than evapotranspiration. If climate change results in the decrease in precipitation and the increase in evapotranspiration that could lead to the decomposition of wetland organic soils, which would dramatically alter these wetlands and likely lead to the encroachment from woody species and invasives.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Open wetlands in southern Michigan are currently stressed by invasive species. Invasive plant competition will likely be exacerbated by climate change, especially in the southern Lower Peninsula.

Adaptation Strategies
Reduce stressors to current Great Lakes marsh by controlling invasive species.

Establish rolling easements to allow for long-term fluctuations of coastal ecosystems across space and time.

Focus restoration and conservation efforts on open wetlands that occur as complexes (i.e., Great Lakes marsh) or occur as part of larger functioning wetlands or landscapes.

To enhance the resilience of wetland ecosystems and their component species, target numerous examples of high-quality wetlands in different ecological regions of the state for conservation and restoration.

Appendix 8. Summary of Climate Change Vulnerability Assessment for Wet Prairie Communities.

WET PRAIRIE COMMUNITIES

Michigan's wet prairie communities are already imperiled ecosystems that will likely be highly vulnerable to climate change due to their sensitivity to changes in hydrology and the current high levels of fragmentation, shoreline development, and invasive species competition.

Increased Air and Surface Temperature

Wet prairies could potentially benefit from increased air and surface temperature with increased plant productivity. However, increased air and surface temperature could also be detrimental for wet prairies by increasing the prevalence of woody encroachment (especially invasives) within these open wetland systems.

Longer Growing Season

Wet prairies could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season could also be detrimental for wet prairies if it allows for the increase in the prevalence of woody encroachment (especially invasives) within these open wetland systems. This might occur since a longer growing season could mean that water levels would be drawn down for longer periods of time during the growing season.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

The climate envelope for wet prairies will likely shift northward following climate change. However, corresponding latitude range expansion of wet prairie systems is unlikely due to the current fragmentation of their current range.

Ability to Disperse

The ability of this system to disperse is limited by fragmentation and the limited extent of the current distribution of wet prairies.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Increased fire and flooding would likely benefit wet prairies but increased drought events may negatively impact wet prairies.

Great Lakes Lower Water Levels

Lower Great Lakes levels could potentially benefit lakeplain wet-mesic prairie and lakeplain wet prairie. However, where invasive species are prevalent, lower water levels could result in increased levels of invasive species in coastal wetlands. Benefits to these wet prairie types from lower Great Lakes water levels are unlikely to be realized due to the fragmentation and degradation of the lakeplain landscapes where lakeplain prairies occur.

Appendix 8. Summary of Climate Change Vulnerability Assessment for Wet Prairie Communities (Continued).

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels could potentially be detrimental to wet prairies. Drier wet prairies might be more susceptible to invasive species and woody encroachment.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how wet prairies will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetland systems. As noted above, drier wet prairies might be more susceptible to invasive species and woody encroachment. It remains unclear whether the increase in winter precipitation will be in snow or rain and how the timing of precipitation will change.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact wet prairies with increased encroachment from woody species and invasives.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Wet prairies are currently stressed by invasive plants. Invasive plant competition will likely be exacerbated by climate change.

Adaptation strategies
Reduce stressors to current wet prairies by controlling invasive species and implementing prescribed fire.

Restore numerous wet prairies across their range to increase the resilience of the

Appendix 9. Summary of Climate Change Vulnerability Assessment for Fen Communities.

FEN COMMUNITIES

Fen communities are likely highly vulnerable to climate change. As peatland ecosystems with organic soils, these communities are especially sensitive to changes in soil moisture and increased evapotranspiration. If soil moisture decreases and if evapotranspiration is greater than precipitation, then peat soils will decompose and peatland ecosystems will be detrimentally impacted. In addition, the capacity of fens to disperse is limited because they are restricted to specific hydrologic and geologic settings.

Increased Air and Surface Temperature

Fens could potentially benefit from increased air and surface temperature with increased plant productivity. However, increased air and surface temperature could also be detrimental for fens by increasing the prevalence of woody encroachment within these open wetland systems.

Longer Growing Season

Fens could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season could also be detrimental for fens if it allows for the increase in the prevalence of woody encroachment within these open wetland systems.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

Fens are restricted to specific hydrologic and geologic settings. With climate change, the current restricted range could contract to where precipitation is greater than evapotranspiration.

Ability to Disperse

The capacity of fens to disperse is limited because the community is restricted to a specific hydrologic and geologic setting. In the southern part of the state, the ability of fens to disperse is also limited by fragmentation.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

It is unclear if fens would be negatively impacted or benefited by increased frequency or intensity of extreme events. Fens could potentially benefit from increased fire, flooding and wind events but could also be negatively impacted by extreme droughts. Flash flooding events could increase detrimental impacts from sedimentation and pollution.

Great Lakes Lower Water Levels

Lower Great Lakes levels would likely result in the increase of coastal fen. However, if invasive species become prevalent, lower water levels could result in increased levels of invasive species in coastal fens.

Appendix 9. Summary of Climate Change Vulnerability Assessment for Fen Communities (Continued).

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels could potentially be extremely detrimental to fens. Drier fens might be more susceptible to invasive species and woody encroachment.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how fens will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetlands systems. As noted above, drier fens might be more susceptible to invasive species and woody encroachment. It remains unclear whether the increase in winter precipitation will be in snow or rain. Also, if ice cover decreases in the winter, coastal fen will be negatively impacted as winter wave activity will increase.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact fens with increased encroachment from woody species and invasives. A key factor for Michigan's fens is the relationship of precipitation and evapotranspiration. Organic soils develop where precipitation is greater than evapotranspiration. If climate change results in the decrease in precipitation and the increase in evapotranspiration that could lead to the decomposition of wetland organic soils, which would dramatically alter these wetlands and likely lead to the encroachment from woody species and invasives.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Invasive plant competition will likely be exacerbated by climate change. Fens in southern Michigan are currently stressed by invasive species encroachment.

Adaptation strategies
Reduce stressors to current fens by controlling invasive species, restoring hydrology, and implementing prescribed fire.

Establish rolling easements to allow for long-term fluctuations of coastal ecosystems across space and time.

Restore numerous fens across their range to increase the resilience of the type.

As groundwater influenced ecosystems, fens may be buffered against climate change and therefore may function as wetland climate refugia.

Appendix 10. Summary of Climate Change Vulnerability Assessment for Bog Communities.

BOG COMMUNITIES

Bog communities are likely highly vulnerable to climate change. As peatland ecosystems with organic soils, these communities are especially sensitive to changes in soil moisture and increased evapotranspiration. If soil moisture decreases and if evapotranspiration is greater than precipitation, then peat soils will decompose and peatland ecosystems will be detrimentally impacted.

Increased Air and Surface Temperature

Increased air and surface temperature will likely be detrimental for acidic peatlands. Sphagnum mosses are very sensitive to temperature and would likely decline with increasing temperatures. In addition, increased temperature may lead to woody encroachment.

Longer Growing Season

A longer growing season could be detrimental for bogs and muskegs if it allows for the increase in the prevalence of woody encroachment.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

The current range of bogs and muskegs will likely contract to where precipitation is greater than evapotranspiration.

Ability to Disperse

The capacity of bogs and muskegs to disperse is limited because the community is restricted to a specific physiographic setting. In the southern part of the state, the ability of peatlands to disperse is also limited by fragmentation.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

It is unclear if bogs and muskegs would be negatively impacted or benefited by increased frequency or intensity of extreme events. Impact will likely depend on landscape setting. On balance, bogs and muskegs will likely benefit from increased fire, wind events, and flooding but negatively impacted by extreme droughts.

Great Lakes Lower Water Levels

Changes in Great Lakes water levels will not likely impact bog communities.

Reduction in Regional Groundwater and Surface Water Levels

The reduction in regional groundwater and surface water levels could potentially be detrimental to bogs and muskegs. Drier bog communities might be more susceptible to invasive species and woody encroachment.

Appendix 10. Summary of Climate Change Vulnerability Assessment for Bog Communities (Continued).

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how bog communities will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetlands systems. As noted above, drier bogs and muskegs might be more susceptible to invasive species and woody encroachment. It remains unclear whether the increase in winter precipitation will be in snow or rain.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact bogs and muskegs with increased encroachment from woody species and invasives. A key factor for Michigan's fens is the relationship of precipitation and evapotranspiration. Organic soils develop where precipitation is greater than evapotransipiration. If climate change results in the decrease in precipitation and the increase in evapotranspiration that could lead to the decomposition of wetland organic soils, which would dramatically alter these wetlands and likely lead to the encroachment from woody species and invasives.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Invasive plant competition will likely be exacerbated by climate change.

Adaptation strategies
Reduce stressors to current bogs and muskegs by controlling invasive species, restoring hydrology, and implementing prescribed fire.

Conserve numerous bogs and muskegs across their range to increase the resilience of the type.

Appendix 11. Summary of Climate Change Vulnerability Assessment for Shrub Wetland Communities.

SHRUB WETLAND COMMUNITIES

Shrub wetland communities are likely to benefit from climate change. Shrub wetlands are common communities across their ranges that have a high capacity to invade open wetlands. Climate change will likely favor shrub wetlands over open wetlands as temperatures increase and growing seasons lengthen.

Increased Air and Surface Temperature

Shrub wetlands will likely be positively impacted by increased air and surface temperature with plant productivity increasing. Conditions suitable for shrub encroachment in open wetlands will increase.

Longer Growing Season

A longer growing season will likely be beneficial to shrub wetlands with increased shrub encroachment in open wetlands..

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

With climate change, the current range of southern shrub-carr and inundated shrub swamp will likely expand while northern shrub thicket will likely contract.

Ability to Disperse

These shrub wetlands have a widespread distribution in Michigan and a high capacity to disperse across a variety of landscapes.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Shrub wetland will likely be positively impacted by increased frequency or intensity of extreme events. Two of the shrub wetlands (northern shrub thicket and southern shrub-carr) are successional communities that will likely benefit from increased fire, drought, flooding and wind events.

Great Lakes Lower Water Levels

Changes in Great Lakes water levels will not likely impact shrub wetlands.

Reduction in Regional Groundwater and Surface Water Levels

It is unclear how shrub wetlands will be impacted by reduction in regional groundwater and surface water levels. In certain landscape settings, the reduction in regional groundwater and surface water levels may benefit shrub wetlands (i.e., where open wetlands convert to shrub wetlands following a lowering of the water table).

Appendix 11. Summary of Climate Change Vulnerability Assessment for Shrub Wetland Communities (Continued).

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how shrub wetland communities will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetlands systems. It remains unclear whether the increase in winter precipitation will be in snow or rain.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact shrub wetlands.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Invasive plant competition will likely be exacerbated by climate change, especially in the southern Lower Peninsula. Invasive plant competition will likely be exacerbated by climate change. Southern shrub-carr is currently stressed by invasive plants.

Adaptation strategies
Reduce stressors to current shrub wetland communities by controlling invasive species.

Appendix 12. Summary of Climate Change Vulnerability Assessment for Forested Wetland/Forested Coastal Wetland Communities.

FORESTED WETLAND/FORESTED COASTAL WETLAND COMMUNITIES

Forested wetlands/forested coastal wetlands are likely moderately to highly vulnerable to climate change. Forested wetlands/coastal wetlands are especially sensitive to changes in soil moisture and hydrology. In addition, many forested wetlands/coastal wetlands are currently stressed by high deer herbivory levels and invasive species. The information for forested wetlands below is the same for forested coastal wetlands.

Increased Air and Surface Temperature

Conifer-dominated forested wetlands will likely be negatively impacted by increased air and surface temperature with plant productivity of hardwood competition increasing. Hardwood-dominated forested wetlands may benefit from increased air and surface temperatures.

Longer Growing Season

A longer growing season will likely be detrimental to conifer-dominate forested wetlands with hardwood competition being imparted a competitive advantage over the current conifer canopy dominants. In addition, longer growing seasons can allow for increased tree pests. Hardwood-dominated forested wetlands may benefit from a longer growing season.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact forested wetlands. For floodplain forests, the potential change in the timing of over-the-bank flooding could have negative ramifications for plants that depend on seasonal flooding for seed set and establishment.

Latitude Range Expansion or Contraction

With climate change, the current range of northern and conifer-dominated forested wetlands (poor conifer swamp, rich conifer swamp, rich tamarack swamp, hardwood-conifer swamp, and northern hardwood swamp) could contract. Southern and hardwood-dominated forested wetlands (southern hardwood swamp and floodplain forest) may expand with climate change. A suitable climatic envelope for wet-mesic flatwoods could expand to the north following climate change, however, this system is restricted in range to a specific hydrologic and physiographic context.

Ability to Disperse

The capacity of forested wetlands to disperse is limited because these ecosystems are restricted to specific hydrologic and geologic setting. The ability of forested wetlands in the southern part of the state is limited by fragmentation.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Forested wetlands will likely be negatively impacted by increased frequency or intensity of extreme events. Forested wetlands will likely be negatively impacted by fire, drought, flooding, and wind events.

Appendix 12. Summary of Climate Change Vulnerability Assessment for Forested Wetland/Forested Coastal Wetland Communities (Continued).

Great Lakes Lower Water Levels
Changes in Great Lakes water levels will not likely impact most forested wetland systems.

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels would be very detrimental to forested wetland communities.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how forested wetland communities will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetlands systems. It remains unclear whether the increase in winter precipitation will be in snow or rain. If snow cover decreases, then winter deer browse pressures will likely increase and rich conifer swamp and hardwood-conifer swamp will be very negatively impacted.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact forested wetland communities. A key factor for many of Michigan's forested wetlands is the relationship of precipitation and evapotranspiration. Organic soils develop where precipitation is greater than evapotransipiration. If climate change results in the decrease in precipitation and the increase in evapotranspiration that could lead to the decomposition of wetland organic soils, which would dramatically alter these wetlands.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Invasive plant competition will likely be exacerbated by climate change. Rich conifer swamp and hardwood-conifer swamp are currently stressed across their ranges by high deer herbivory levels, which have locally limited the regeneration capacity of these systems. Higher levels of deer and winter deer browse pressure will be very detrimental to these already stressed systems. Increased pests would be very detrimental to forested wetlands. A climate change induced increase in emerald ash borer would be devastating to ash, which is an important canopy species in hardwood-dominated forested wetland communities.

Adaptation strategies
Reduce stressors to current forested wetland communities by controlling invasive species and reducing deer densities.

Rich conifer swamps provide unique microclimates and can function as climate refugia.

Focus restoration and conservation on those forested systems that function as climate refugia (i.e., floodplain forest and rich conifer swamp).

Appendix 12. Summary of Climate Change Vulnerability Assessment for Forested Wetland/Forested Coastal Wetland Communities (Continued).

Those natural communities and landscape settings that experience moderated climates may also function as climate refugia. For example, coastal ecosystems and large wetlands systems (i.e., swamp complexes and riparian ecosystems) may experience less severe climate change due to local climate moderation.

To enhance the resilience of forested wetland communities and their component species, target numerous examples of high-quality examples in different ecological regions of the state for conservation and restoration.

Groundwater influenced ecosystems (fens and conifer swamps) will likely be buffered from climate change and may therefore function as climate refugia.

Appendix 13. Summary of Climate Change Vulnerability Assessment for Palustrine/Terrestrial Communities/Wooded Dune and Swale Complex.

PALUSTRINE/TERRESTRIAL COMMUNITIES
WOODED DUNE AND SWALE COMPLEX

The vulnerability of wooded dune and swale complex will vary depending on the region of the state with complexes in the thumb and northern Lower Peninsula being more vulnerable due to higher levels of fragmentation, shoreline development, and invasive species competition compared to the complexes in the Upper Peninsula. In other words, where these systems are currently stressed, wooded dune and swale complexes will likely be vulnerable to climate change. The vulnerability of the system as a whole will likely depend on whether the Great Lakes water levels lower or rise. If Great Lakes water levels decline, wooded dune and swale complexes could potentially increase in area over long periods of time (i.e., hundreds of years). Vulnerability to climate change is very hard to assess for wooded dune and swale complexes because this system is composed of so many different natural communities that will respond differently to climate change. Wetlands within wooded dune and swale complexes will likely be negatively impacted (especially peatlands) while some upland systems may benefit (i.e., dry-mesic northern forest). The diverse array of communities that occur within wooded dune and swale complexes will likely increase the overall adaptive capacity of this system. In addition, these are dynamic systems that are responsive to changes in the Great Lakes water levels. Because of the proximity of these systems to the Great Lakes, severity of climate change may be less compared to inland systems.

Increased Air and Surface Temperature

It is not clear how wooded dune and swale complexes will be impacted by increased air and surface temperature. Wooded dune and swale complexes could potentially benefit from increased air and surface temperature with increased plant productivity. However, increased air and surface temperature could also be detrimental for wooded dune and swale complexes by increasing the prevalence of invasive plants and pests. Also increased temperatures would likely result in increased water temperatures, which can lead to eutrophication.

Longer Growing Season

Wooded dune and swale complex could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season could also be detrimental for wooded dune and swale complex if it allows for the increase in the prevalence of woody encroachment (especially invasives) within this open wetland system.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

Wooded dune and swale complex is restricted to the Great Lakes. This system may experience latitude range contraction due to climate change as the climate in the Upper Peninsula and the northern Lower Peninsula become less favorable for the more northerly species that compose this system.

Appendix 13. Summary of Climate Change Vulnerability Assessment for Palustrine/Terrestrial Communities/Wooded Dune and Swale Complex (Continued).

Ability to Disperse
Wooded dune and swale complex is a dynamic ecosystem with a high capacity to move over time. This ecosystem has historically tracked the natural fluctuations of the Great Lakes water levels. However, the ability of this system to disperse is limited where shoreline development and fragmentation are prevalent. In addition, the ability of wooded dune and swale complex to disperse is restricted by its specific physiographic context associated with Great Lakes features and processes.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)
It is unclear if wooded dune and swale complex would be negatively impacted or benefited by increased frequency or intensity of extreme events. Overall, wooded dune and swale complex will likely be negatively impacted by increased fire, drought, flooding and wind events. However, component natural communities within a given wooded dune and swale complex may benefit from increased disturbance.

Great Lakes Lower Water Levels
Lower Great Lakes levels would likely result in the increase of wooded dune and swale complex, especially in the northern portion of its range over a long time period. This ecosystem has historically tracked the natural fluctuations of the Great Lakes water levels. However, where invasive species are prevalent, lower water levels could result in increased levels of invasive species in coastal wetlands.

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels could potentially be detrimental to wooded dune and swale complex. Changes in hydrology of the open wetlands could result in woody species encroachment (including invasives) and shifts in species composition.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how wooded dune and swale complex will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetlands systems. It remains unclear whether the increase in winter precipitation will be in snow or rain. Also, if ice cover decreases in the winter, wooded dune and swale complex will be impacted as winter wave activity will change. If snow cover decreases, then winter deer browse pressures will likely increase and this system will be very negatively impacted.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate may negatively impact wooded dune and swale complex.

Appendix 13. Summary of Climate Change Vulnerability Assessment for Palustrine/Terrestrial Communities/Wooded Dune and Swale Complex (Continued).

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Wooded dune and swale complex is currently stressed by invasive plants in the southern portion of its range. Impacts from invasives will likely be exacerbated by climate change and may expand throughout the range of wooded dune and swale complex. Wooded dune and swale complex is currently stressed by high deer herbivory levels, which has locally limited the regeneration capacity of this system. This is especially prevalent in complexes along northern Lake Michigan where deer winter at high densities. Higher levels of deer and winter deer browse pressure will be very detrimental to this system.

Adaptation strategies
Reduce stressors to current wooded dune and swale complexes by controlling invasive species and reducing deer densities.

Establish rolling easements to allow for long-term fluctuations of coastal ecosystems across space and time.

Because of the proximity of these ecosystems to the Great Lakes and the high degree of beta diversity found within wooded dune and swale complexes, treatment of these complexes as climate refugia makes sense.

Appendix 14. Summary of Climate Change Vulnerability Assessment for Prairie Communities.

PRAIRIE COMMUNITIES

Michigan's prairie communities are imperiled ecosystems that may benefit from climate change.

Increased Air and Surface Temperature

Prairies could potentially benefit from increased air and surface temperature with increased plant productivity.

Longer Growing Season

Prairies could potentially benefit from a longer growing season with increased plant productivity.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

The climate envelope for prairies will likely shift northward following climate change. However, corresponding latitude range expansion of prairie systems is unlikely due to the current fragmentation of their current range.

Ability to Disperse

The ability of this system to disperse is limited by fragmentation and the limited extent of the current distribution of prairies.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Increased fire and drought would likely benefit prairies but increased flooding may negatively impact prairies.

Great Lakes Lower Water Levels

Changes in Great Lakes water levels will not likely impact prairie communities.

Reduction in Regional Groundwater and Surface Water Levels

The reduction in regional groundwater and surface water levels will not likely impact prairie systems. In certain landscape settings, the reduction in regional groundwater and surface water levels could potentially be beneficial to prairies.

Wetter Winters and Springs and Drier Summers and Falls

It is unclear how prairies will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely benefit prairie systems. It remains unclear whether the increase in winter precipitation will be in snow or rain and how the timing of precipitation will change.

Appendix 14. Summary of Climate Change Vulnerability Assessment for Prairie Communities (Continued).

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely benefit prairies.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Prairies are currently stressed by invasive plants. Invasive plant competition will likely be exacerbated by climate change.

Adaptation strategies
Reduce stressors to current prairies by controlling invasive species and implementing prescribed fire.

Restore numerous prairies across their range to increase the resilience of the type.

Appendix 15. Summary of Climate Change Vulnerability Assessment for Savanna Communities.

SAVANNA COMMUNITIES

Michigan's savanna communities are imperiled ecosystems that may slightly benefit from climate change.

Increased Air and Surface Temperature

Savanna could potentially benefit from increased air and surface temperature with increased plant productivity.

Longer Growing Season

Savannas could potentially benefit from a longer growing season with increased plant productivity.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

The climate envelope for most savannas will likely shift northward following climate change. However, corresponding latitude range expansion of savanna systems is unlikely due to the current fragmentation of their current range. The range of northern barrens systems (i.e., pine barrens and oak-pine barrens) will likely contract with climate change.

Ability to Disperse

The ability of savannas to disperse is limited by fragmentation and the limited extent of the current distribution of savannas.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Increased fire, windthrow, and drought would likely benefit savannas but increased flooding may negatively impact prairies.

Great Lakes Lower Water Levels

Changes in Great Lakes water levels will not likely impact savanna communities. Lower Great Lakes levels could potentially benefit lakeplain oak openings. However, where invasive species are prevalent, lower water levels could result in increased levels of invasive species in coastal wetlands. Benefits to this natural community type from lower Great Lakes water levels are unlikely to be realized due to the fragmentation and degradation of the lakeplain landscapes where this system occurs.

Reduction in Regional Groundwater and Surface Water Levels

The reduction in regional groundwater and surface water levels will not likely impact savanna systems.

Appendix 15. Summary of Climate Change Vulnerability Assessment for Savanna Communities (Continued).

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how savannas will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely benefit savanna systems. It remains unclear whether the increase in winter precipitation will be in snow or rain and how the timing of precipitation will change.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely benefit savanna communities.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Savanna communities are currently stressed by invasive plants. Invasive plant competition will likely be exacerbated by climate change.

Adaptation strategies
Reduce stressors to current savanna communities by controlling invasive species and implementing prescribed fire.

Restore numerous savanna communities across their range to increase the resilience of the type.

Appendix 16. Summary of Climate Change Vulnerability Assessment for Forest Communities.

FORESTED COMMUNITIES

The impact of climate change on Michigan's forested communities will range from being highly vulnerable to likely increasing. In general, northern and mesic systems (e.g., boreal forest, mesic northern forest) will be more vulnerable than southern and dry to dry-mesic forested communities (e.g., dry southern forest, dry-mesic southern forest).

Increased Air and Surface Temperature

Impacts of increased air and surface temperature will depend on forest type. Dry southern forest, dry northern forest, dry-mesic northern forest, and dry-mesic southern forest will likely benefit from increased air and surface temperature with increased plant productivity. Boreal forest, mesic northern forest, and mesic southern forest will likely be negatively impacted by increased air and surface temperature with plant productivity of hardwood competition increasing at the expense of the conifer and/or mesic canopy.

Longer Growing Season

Impacts of a longer growing season will depend on forest type. Southern forest systems will likely benefit from increased air and surface temperature with increased plant productivity. Northern forest systems will likely be negatively impacted by increased air and surface temperature with plant productivity of hardwood competition increasing at the expense of the conifer and/or mesic canopy. In addition, longer growing seasons can allow for increased tree pests, especially for conifers.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

The climate envelope for southern forest systems will likely shift northward following climate change. The range of northern forested systems will likely contract with climate change.

Ability to Disperse

Forested communities have widespread distributions. In forested landscapes, forested communities have a high ability to disperse. In the southern portion of the state, the dispersal ability of forest communities is limited due to fragmentation.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Increased fire, windthrow, and drought would likely be detrimental to mesic and boreal forested communities, while the dry and dry-mesic forested systems may benefit.

Great Lakes Lower Water Levels

Changes in Great Lakes water levels will not likely impact forested communities.

Appendix 16. Summary of Climate Change Vulnerability Assessment for Forest Communities (Continued).

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels could potentially be detrimental to forested communities. Important attributes of forested communities that are linked to ground water and surface water (i.e., vernal pools and seeps) would be negatively impacted.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how forested systems will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely benefit drier forested systems while being detrimental to mesic systems. It remains unclear whether the increase in winter precipitation will be in snow or rain and how the timing of precipitation will change. If snow cover decreases, then winter deer browse pressures will likely increase and some forested systems will be very negatively impacted (i.e., boreal forest and mesic northern forest). In addition, decreased snow cover and therefore insular could lead to increased root damage due to soil freezing (more frequent freezing of the root zone) (i.e., mesic northern forest and mesic southern forest).

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely benefit drier forested systems and be detrimental to mesic forested systems.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Invasive plant competition will likely be exacerbated by climate change. Many forested systems are currently stressed by high deer herbivory levels, which have locally limited the regeneration capacity of these forests. Higher levels of deer and winter deer browse pressure will be very detrimental to many forested system. In addition, many forested communities are also currently stressed by invasive pests (i.e., beech bark disease, emerald ash borer). Increased pests would be detrimental to many forested communities.

Adaptation strategies
Reduce stressors to current forested communities by controlling invasive species and reducing deer browse pressure.

Conserve and restore numerous forested communities across their range to increase the resilience of the different types.

Natural communities that occur as matrix or large patch communities can also function as climate refugia. For example, mesic northern forest can occur as matrix systems with high levels of topographic diversity and numerous inclusions of wetlands and bedrock outcroppings. Those natural communities and landscapes that have gradients in elevation, soil moisture, and water table can provide species the opportunity to shift as climate changes.

Appendix 17. Summary of Climate Change Vulnerability Assessment for Primary Communities/Coastal Sand Communities.

PRIMARY COMMUNITIES

Michigan's primary communities may benefit from climate change. Primary communities are already adapted to high temperatures and extreme conditions and many of them occur along the Great Lakes shoreline and will likely be buffered against climate change.

Increased Air and Surface Temperature

Primary communities could potentially benefit from increased air and surface temperature with increased plant productivity.

Longer Growing Season

Primary communities could potentially benefit from a longer growing season with increased plant productivity. In some primary communities (i.e., alvar, Great Lakes barrens, open dunes) a longer growing season may be detrimental if it allows for tree and shrub encroachment.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact primary communities.

Latitude Range Expansion or Contraction

Many primary communities are restricted to the Great Lakes shoreline. These systems will not likely experience latitude range expansion or contraction due to climate change. Those primary communities that have a northerly distribution and have a significant conifer component (i.e., alvar and great lakes barrens may contract).

Ability to Disperse

Many primary communities are restricted to the Great Lakes shoreline but are adapted to track changes of the shoreline and therefore likely have a high ability to disperse. Alvar is restricted to a specific physiographic setting and likely has a limited capacity for dispersal.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Increased frequency or intensity of extreme events will likely benefit primary communities.

Great Lakes Lower Water Levels

Lower Great Lakes levels would likely result in the increase of primary communities, especially in northern Michigan. However, where invasive species are prevalent, lower water levels could result in increased levels of invasive species in primary communities.

Reduction in Regional Groundwater and Surface Water Levels

The reduction in regional groundwater and surface water levels will not likely impact primary communities.

Appendix 17. Summary of Climate Change Vulnerability Assessment for Primary Communities/Coastal Sand Communities (Continued).

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how primary communities will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely benefit primary communities. It remains unclear whether the increase in winter precipitation will be in snow or rain and how the timing of precipitation will change. Also, if ice cover decreases in the winter, coastal primary communities will be impacted as winter wave activity will change.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely benefit primary communities.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Primary communities are currently stressed by invasive plants. Invasive plant competition will likely be exacerbated by climate change.

Adaptation strategies
Reduce stressors to current primary communities by controlling invasive species.

Restore numerous primary communities across their range to increase the resilience of the type.

Appendix 18. Summary of Climate Change Vulnerability Assessment for Bedrock Grassland and Glade Communities.

BEDROCK GLADE COMMUNITIES

Michigan's bedrock glade communities may benefit from climate change. Bedrock glade communities are already adapted to high temperatures and extreme conditions and often occur near the Great Lakes and will likely be buffered against climate change.

Increased Air and Surface Temperature

Bedrock glade communities could potentially benefit from increased air and surface temperature with increased plant productivity.

Longer Growing Season

Bedrock glade communities could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season may be detrimental if it allows for tree and shrub encroachment and canopy closure.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact bedrock glade communities.

Latitude Range Expansion or Contraction

Bedrock glade communities are restricted to specific physiographic settings. These systems will likely slightly contract or sustain their current range.

Ability to Disperse

Bedrock glade communities are restricted to specific physiographic settings tied to bedrock types and therefore have a limited ability to disperse.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Increased frequency or intensity of extreme events will likely benefit bedrock glade communities.

Great Lakes Lower Water Levels

Lower Great Lakes levels would likely result in the increase of bedrock glade communities. However, where invasive species are prevalent, lower water levels could result in increased levels of invasive species in bedrock glade communities.

Reduction in Regional Groundwater and Surface Water Levels

The reduction in regional groundwater and surface water levels will not likely impact bedrock glade communities.

Appendix 18. Summary of Climate Change Vulnerability Assessment for Bedrock Grassland and Glade Communities (Continued).

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how bedrock glade communities will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely benefit bedrock glade communities. It remains unclear whether the increase in winter precipitation will be in snow or rain and how the timing of precipitation will change.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely benefit bedrock glade communities.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Bedrock glade communities are currently stressed by invasive plants and deer herbivory. Invasive plant competition and deer herbivory will likely be exacerbated by climate change.

Adaptation strategies
Reduce stressors to current bedrock glade communities by controlling invasive species and reducing deer herbivory.

Conserve and restore numerous bedrock glade communities across their range to increase the resilience of the type.

Appendix 19. Summary of Climate Change Vulnerability Assessment for Cobble Shore Communities.

COBBLE SHORE COMMUNITIES

Michigan's cobble shore communities may benefit from climate change. Cobble shore communities are already adapted to high temperatures and extreme conditions and occur along the Great Lakes shoreline and will likely be buffered against climate change.

Increased Air and Surface Temperature

Cobble shore communities could potentially benefit from increased air and surface temperature with increased plant productivity.

Longer Growing Season

Cobble shore communities could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season may be detrimental if it allows for tree and shrub encroachment.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact cobble shore communities.

Latitude Range Expansion or Contraction

Cobble shore communities are restricted to specific physiographic settings along the Great Lakes shoreline. These systems will not likely experience latitude range expansion or contraction due to climate change.

Ability to Disperse

Cobble shore communities are restricted to specific physiographic settings along the Great Lakes shoreline but are adapted to track changes of the shoreline and therefore likely have a high ability to disperse.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Increased frequency or intensity of extreme events will likely benefit cobble shore communities.

Great Lakes Lower Water Levels

Lower Great Lakes levels would likely result in the increase of cobble shore communities. However, where invasive species are prevalent, lower water levels could result in increased levels of invasive species in cobble shore communities.

Reduction in Regional Groundwater and Surface Water Levels

The reduction in regional groundwater and surface water levels will not likely impact cobble shore communities.

Appendix 19. Summary of Climate Change Vulnerability Assessment for Cobble Shore Communities (Continued).

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how cobble shore communities will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely benefit cobble shore communities. It remains unclear whether the increase in winter precipitation will be in snow or rain and how the timing of precipitation will change. Also, if ice cover decreases in the winter, cobble shore communities will be impacted as winter wave activity will change.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely benefit cobble shore communities.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Cobble shore communities are currently stressed by invasive plants. Invasive plant competition will likely be exacerbated by climate change.

Adaptation strategies
Reduce stressors to current cobble shore communities by controlling invasive species.

Restore numerous cobble shore communities across their range to increase the resilience of the type.

Appendix 20. Summary of Climate Change Vulnerability Assessment for Bedrock Lakeshore Communities.

BEDROCK LAKESHORE COMMUNITIES

Michigan's bedrock lakeshore communities may benefit from climate change. Bedrock lakeshore communities are already adapted to high temperatures and extreme conditions and occur along the Great Lakes shoreline and will likely be buffered against climate change.

Increased Air and Surface Temperature

Bedrock lakeshore communities could potentially benefit from increased air and surface temperature with increased plant productivity.

Longer Growing Season

Bedrock lakeshore communities could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season may be detrimental if it allows for tree and shrub encroachment.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact bedrock lakeshore communities.

Latitude Range Expansion or Contraction

Bedrock lakeshore communities are restricted to specific physiographic settings along the Great Lakes shoreline. These systems will not likely experience latitude range expansion or contraction due to climate change.

Ability to Disperse

Bedrock lakeshore communities are restricted to specific physiographic settings along the Great Lakes shoreline but are adapted to track changes of the shoreline and therefore likely have a high ability to disperse.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Increased frequency or intensity of extreme events will likely benefit bedrock lakeshore communities.

Great Lakes Lower Water Levels

Lower Great Lakes levels would likely result in the increase of bedrock lakeshore communities. However, where invasive species are prevalent, lower water levels could result in increased levels of invasive species in bedrock lakeshore communities.

Reduction in Regional Groundwater and Surface Water Levels

The reduction in regional groundwater and surface water levels will not likely impact bedrock lakeshore communities.

Appendix 20. Summary of Climate Change Vulnerability Assessment for Bedrock Lakeshore Communities (Continued).

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how bedrock lakeshore communities will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely benefit bedrock lakeshore communities. It remains unclear whether the increase in winter precipitation will be in snow or rain and how the timing of precipitation will change. Also, if ice cover decreases in the winter, bedrock lakeshore communities will be impacted as winter wave activity will change.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely benefit bedrock lakeshore communities.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Bedrock lakeshore communities are currently stressed by invasive plants. Invasive plant competition will likely be exacerbated by climate change.

Adaptation strategies
Reduce stressors to current bedrock lakeshore communities by controlling invasive species.

Restore numerous bedrock lakeshore communities across their range to increase the resilience of the type.

Appendix 21. Summary of Climate Change Vulnerability Assessment for Lakeshore Cliff Communities.

LAKESHORE CLIFF COMMUNITIES

Michigan's lakeshore cliff communities may benefit or be negatively impacted by climate change. Lakeshore cliff communities are already adapted to extreme conditions and occur along the Great Lakes shoreline and therefore will likely be buffered against climate change. However, many species of lakeshore cliff communities are sensitive to increasing temperature and decreasing moisture, and certain lakeshore cliff types may be more susceptible to climate change (i.e., limestone lakeshore cliff and sandstone lakeshore cliff).

Increased Air and Surface Temperature

Lakeshore cliff communities could potentially benefit from increased air and surface temperature with increased plant productivity. However, many species of lakeshore cliff communities are sensitive to increasing temperature and decreasing moisture, and certain lakeshore cliff types may be negatively impacted by climate change (i.e., limestone lakeshore cliff and sandstone lakeshore cliff).

Longer Growing Season

Lakeshore cliff communities could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season may be detrimental if it allows for increased exposure to desiccation.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact lakeshore cliff communities.

Latitude Range Expansion or Contraction

Lakeshore cliff communities are restricted to specific physiographic settings along the Great Lakes shoreline. These systems will not likely experience latitude range expansion or contraction due to climate change.

Ability to Disperse

Lakeshore cliff communities are restricted to specific physiographic settings along the Great Lakes shoreline and have a very low ability to disperse over long periods of time.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Increased frequency or intensity of extreme events will not likely impact lakeshore cliff communities. However, less resistant bedrock types (i.e., sandstone lakeshore cliff and limestone lakeshore cliff) may be more susceptible to weathering with increased frequency or intensity of extreme events.

Appendix 21. Summary of Climate Change Vulnerability Assessment for Lakeshore Cliff Communities (Continued.

Great Lakes Lower Water Levels
Over very long periods of time, lower Great Lakes levels could result in the increase of lakeshore cliff communities. However, where invasive species are prevalent, lower water levels could result in increased levels of invasive species in lakeshore cliff communities.

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water could potentially negatively impact lakeshore cliff communities since groundwater seepages through and over cliffs contribute to the structural and floristic diversity of cliff systems.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how lakeshore cliff communities will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls could be detrimental to some lakeshore cliff communities. It remains unclear whether the increase in winter precipitation will be in snow or rain and how the timing of precipitation will change. Also, if ice cover decreases in the winter, lakeshore cliff communities will be impacted as winter wave activity will change. Increased winter waves could lead to increased erosion of less resistant bedrock types (sandstone lakeshore cliff and limestone lakeshore cliff). In addition, more freezing and thawing along cliff faces during the winter could lead to increased sloughing of limestone and sandstone from the cliff faces.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely be detrimental to lakeshore cliff communities.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers Invasive plant competition will likely be exacerbated by climate change.

Adaptation strategies
Reduce stressors to current lakeshore cliff communities by controlling invasive species.

Restore numerous lakeshore cliff communities across their range to increase the resilience of the type.

Appendix 22. Summary of Climate Change Vulnerability Assessment for Inland Cliff Communities.

INLAND CLIFF COMMUNITIES

Michigan's inland cliff communities may benefit or be negatively impacted by climate change. Inland cliff communities are already adapted to extreme conditions and often occur near the Great Lakes and therefore will likely be buffered against climate change. However, many species of inland cliff communities are sensitive to increasing temperature and decreasing moisture, and certain inland cliff types may be more susceptible to climate change (i.e., limestone cliff and sandstone cliff).

Increased Air and Surface Temperature

Inland cliff communities could potentially benefit from increased air and surface temperature with increased plant productivity. However, many species of inland cliff communities are sensitive to increasing temperature and decreasing moisture, and certain inland cliff types may be negatively impacted by climate change (i.e., limestone cliff, granite cliff, and sandstone cliff).

Longer Growing Season

Inland cliff communities could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season may be detrimental if it allows for increased exposure to desiccation.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact inland cliff communities.

Latitude Range Expansion or Contraction

Inland cliff communities are restricted to specific physiographic settings. These systems will not likely experience latitude range expansion or contraction due to climate change.

Ability to Disperse

Inland cliff communities are restricted to specific physiographic settings and have a very low ability to disperse over long periods of time.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Increased frequency or intensity of extreme events will not likely impact inland cliff communities. However, less resistant bedrock types (i.e., sandstone cliff and limestone cliff) may be more susceptible to weathering with increased frequency or intensity of extreme events.

Great Lakes Lower Water Levels

Changes in Great Lakes water levels will not likely impact inland cliff communities.

Appendix 22. Summary of Climate Change Vulnerability Assessment for Inland Cliff Communities (Continued).

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water could potentially negatively impact inland cliff communities since groundwater seepages through and over cliffs contribute to the structural and floristic diversity of cliff systems.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how inland cliff communities will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls could be detrimental to some inland cliff communities. It remains unclear whether the increase in winter precipitation will be in snow or rain and how the timing of precipitation will change. More freezing and thawing along cliff faces during the winter could lead to increased sloughing of limestone and sandstone from the cliff faces.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely be detrimental to inland cliff communities.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers Invasive plant competition will likely be exacerbated by climate change.

Adaptation strategies
Reduce stressors to current inland cliff communities by controlling invasive species.

Restore numerous inland cliff communities across their range to increase the resilience of the type.

Appendix 23. Summary of Climate Change Vulnerability Assessment for Subterranean/Sink Communities.

SUBTERRANEAN/SINK COMMUNITIES

Michigan's subterranean/sink communities may be negatively impacted by climate change. Sinkholes will likely be negatively impacted while caves will likely be buffered from climate change.

Increased Air and Surface Temperature

Sinkholes will likely be negatively impacted by increasing air and surface temperature. Many species of sinkholes are sensitive to increasing temperature and decreasing moisture and increasing water temperatures can lead to eutrophication of sinkhole waters..

Longer Growing Season

A longer growing season will not likely have an impact on sinkholes and caves.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact sinkholes and caves communities.

Latitude Range Expansion or Contraction

Sinkholes and caves are restricted to specific physiographic settings. These systems will not likely experience latitude range expansion or contraction due to climate change.

Ability to Disperse

Sinkholes and caves are restricted to specific physiographic settings.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Increased frequency or intensity of extreme events will not likely impact sinkholes and caves.

Great Lakes Lower Water Levels

Changes in Great Lakes water levels will not likely impact sinkholes and caves. However, over very long periods of times, sinkholes in near shore areas of the Great Lakes could be exposed with dropping Great Lakes water levels.

Reduction in Regional Groundwater and Surface Water Levels

The reduction in regional groundwater and surface water could potentially negatively impact sinkholes.

Wetter Winters and Springs and Drier Summers and Falls

It is unclear how sinkholes and caves will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls could be detrimental to some sinkholes. It remains unclear whether the increase in winter precipitation will be in snow or rain and how the timing of precipitation will change.

Appendix 23. Summary of Climate Change Vulnerability Assessment for Subterranean/Sink Communities (Continued).

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely be detrimental to sinkholes.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
In sinkholes, invasive plant competition may be exacerbated by climate change.

Adaptation strategies
Reduce stressors to current sinkhole and cave communities by controlling invasive species.

Conserve and restore numerous sinkhole and cave communities across their range to increase the resilience of the type.

Appendix 24. Summary of Climate Change Vulnerability Assessment for Boreal Forest.

BOREAL FOREST

Boreal forest is likely highly vulnerable to climate change. In Michigan, this community occurs at the southern extent of its range. Predicted climate change will likely be detrimental to the suite of conifer species that dominates this system (i.e., white spruce, paper birch, balsam fir, northern white cedar, and trembling aspen). In addition, boreal forest is currently stressed in the southern portion of its range by high deer herbivory levels.

Increased Air and Surface Temperature

Boreal forest will likely be negatively impacted by increased air and surface temperature with plant productivity of hardwood competition increasing at the expense of the conifer canopy. It is unclear how increasing temperatures will impact coastal fog, which is a critical source of moisture for these systems.

Longer Growing Season

A longer growing season will likely be detrimental to boreal forest with hardwood competition being gaining a competitive advantage over the current conifer canopy dominants. In addition, longer growing seasons can allow for increased tree pests, especially for conifers.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

With climate change, the current range of boreal forest will likely contract northward. In Michigan, this community occurs at the southern extent of its range.

Ability to Disperse

Boreal forest has a widespread distribution in Michigan along northern coastal areas. The capacity of boreal forest to disperse is limited because the community is restricted to a specific physiographic setting along Great Lakes shoreline. The dispersal ability of boreal forest is also limited by the failure of cedar to regenerate in landscapes where deer densities are high.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Boreal forest will likely be negatively impacted by increased frequency or intensity of extreme events. Boreal forest will likely be negatively impacted by fire, drought, flooding and wind events.

Great Lakes Lower Water Levels

Changes in Great Lakes water levels will not likely impact this system. Over long periods of time, lower Great Lakes water levels may increase the total area of boreal forest with boreal forest expanding lakeward.

Appendix 24. Summary of Climate Change Vulnerability Assessment for Boreal Forest (Continued).

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels will not likely impact boreal forest.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how boreal forest will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on boreal forest. It remains unclear whether the increase in winter precipitation will be in snow or rain. If snow cover decreases, then winter deer browse pressures will likely increase and this system will be very negatively impacted. In addition, it is unclear how the timing and amount of coastal fog will be impacted by climate change. Coastal fog is a critical source of moisture for these systems.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact boreal forest.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Invasive plant competition will likely be exacerbated by climate change. As noted above, boreal forest is currently stressed in southern portions of its range by high deer herbivory levels, which has locally limited the regeneration capacity of this system. Higher levels of deer and winter deer browse pressure will be very detrimental to this system. Increased pests that impact conifer species would be detrimental to boreal forest.

Adaptation strategies
Reduce stressors to current boreal forest by controlling invasive species and reducing deer densities.

Appendix 25. Summary of Climate Change Vulnerability Assessment for Coastal Fen.

COASTAL FEN

Coastal fen is likely moderately vulnerable to climate change. As a peatland ecosystem with organic soils, this community is especially sensitive to changes in soil moisture and increased evapotranspiration. If soil moisture decreases and if evapotranspiration is greater than precipitation, then peat soils will decompose and peatland ecosystems will be detrimentally impacted. In addition, the capacity of coastal fen to disperse is limited because the community is restricted to a specific hydrologic and geologic setting.

Increased Air and Surface Temperature

Coastal fen could potentially benefit from increased air and surface temperature with increased plant productivity. However, increased air and surface temperature could also be detrimental for coastal fen by increasing the prevalence of woody encroachment within this open wetland system.

Longer Growing Season

Coastal fen could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season could also be detrimental for coastal fen if it allows for the increase in the prevalence of woody encroachment within this open wetland system.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

Coastal fen is restricted to a specific hydrologic and geologic setting associated with the Great Lakes. With climate change, the current restricted range could contract to where precipitation is greater than evapotranspiration.

Ability to Disperse

Coastal fen has historically tracked the natural fluctuations of the Great Lakes water levels. However, the capacity of coastal fen to disperse is limited because the community is restricted to a specific hydrologic and geologic setting.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

It is unclear if coastal fen would be negatively impacted or benefited by increased frequency or intensity of extreme events. Coastal fen could potentially benefit from increased fire, flooding and wind events but could also be negatively impacted by extreme droughts. Flash flooding events could increase detrimental impacts from sedimentation and pollution.

Appendix 25. Summary of Climate Change Vulnerability Assessment for Coastal Fen (Continued).

Great Lakes Lower Water Levels
Lower Great Lakes levels would likely result in the increase of coastal fen. However, if invasive species become prevalent, lower water levels could result in increased levels of invasive species in coastal wetlands.

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels could potentially be detrimental to coastal fen. Drier fens might be more susceptible to invasive species and woody encroachment.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how coastal fens will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetlands systems. As noted above, drier fens might be more susceptible to invasive species and woody encroachment. It remains unclear whether the increase in winter precipitation will be in snow or rain. Also, if ice cover decreases in the winter, coastal fen will be negatively impacted as winter wave activity will increase.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact coastal fen with increased encroachment from woody species and invasives.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Invasive plant competition will likely be exacerbated by climate change.

Adaptation strategies
Reduce stressors to current coastal fens by controlling invasive species.

Establish rolling easements to allow for long-term fluctuations of coastal ecosystems across space and time.

Appendix 26. Summary of Climate Change Vulnerability Assessment for Coastal Plain Marsh.

COASTAL PLAIN MARSH

Coastal plain marsh is an already imperiled wetland community that will likely be highly vulnerable to climate change due to the sensitivity of this ecosystem to hydrology.

Increased Air and Surface Temperature

Coastal plain marsh could potentially benefit from increased air and surface temperature with increased plant productivity. However, increased air and surface temperature could also be detrimental for coastal plain marsh by increasing the prevalence of woody encroachment (especially invasives) within this open wetland system. Also increased temperatures would likely result in increased water temperatures, which can lead to eutrophication.

Longer Growing Season

Coastal plain marsh could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season could also be detrimental for coastal plain marsh if it allows for the increase in the prevalence of woody encroachment (especially invasives) within this open wetland system. This might occur since a longer growing season could mean that water levels would be drawn down for longer periods of time during the growing season.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

Coastal plain marsh could expand to the north following climate change.

Ability to Disperse

Coastal plain marsh are restricted to a very specific hydrologic setting and therefore this natural community has a very limited ability to disperse across a landscape. Within a wetland basin, coastal plain marsh does have the ability to disperse.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Increased fire and flooding would likely benefit this system but increased drought events may negatively impact coastal plain marsh. Flash flooding events could increase detrimental impacts from sedimentation and pollution.

Great Lakes Lower Water Levels

Changes in Great Lakes water levels will not likely impact this system.

Appendix 26. Summary of Climate Change Vulnerability Assessment for Coastal Plain Marsh (Continued).

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels could potentially be detrimental to coastal plain marsh. Drier marshes might be more susceptible to invasive species and woody encroachment.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how coastal plain marsh will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetlands systems. As noted above, drier marshes might be more susceptible to invasive species and woody encroachment. It remains unclear whether the increase in winter precipitation will be in snow or rain and how the timing of precipitation will change.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact coastal plain marsh with increased encroachment from woody species and invasives.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Coastal plain marsh is currently stressed by invasive plants. Invasive plant competition will likely be exacerbated by climate change.

Adaptation strategies
Reduce stressors to current coastal plain marshes by controlling invasive species, reducing off-road vehicle impacts, and implementing prescribed fire.

Appendix 27. Summary of Climate Change Vulnerability Assessment for Floodplain Forest.

FLOODPLAIN FOREST
Floodplain forest is likely vulnerable to climate change. This community is sensitive to changes in soil moisture and hydrology. In addition, floodplain forest is currently stressed by invasive species, a threat that will likely be exacerbated by climate change. Because floodplain forests occur within riparian channels, these systems will likely be slightly buffered against climate change.

Increased Air and Surface Temperature
It is not clear how floodplain forest will be impacted by increased air and surface temperature. Floodplain forest could potentially benefit from increased air and surface temperature with increased plant productivity. However, increased air and surface temperature could also be detrimental for floodplain forest by increasing the prevalence of invasive plants and pests.

Longer Growing Season
Floodplain forest could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season could also be detrimental for floodplain forest if it allows for the increase in invasive plants and invasive pests.

Phenological Change
It is not clear how potential climate driven changes in phenology will impact this community. The potential change in the timing of over-the-bank flooding could have negative ramifications for plants that depend on seasonal flooding for seed set and establishment.

Latitude Range Expansion or Contraction
With climate change, the current range of floodplain forest could expand.

Ability to Disperse
Although floodplain forest has a widespread distribution in Michigan, the capacity of floodplain forest to disperse is restricted to river channels with active floodplains.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)
It is not clear how floodplain forests will be impacted by increased frequency or intensity of extreme events. Floodplain forest will likely be negatively impacted by fire, drought, and wind events. Increased flooding may be detrimental or beneficial. Increased flash flooding could increase sedimentation and pollution.

Great Lakes Lower Water Levels
Changes in Great Lakes water levels will not likely impact this system. However, lower Great Lakes water levels may increase the potential habitat for floodplain forest along river deltas.

Appendix 27. Summary of Climate Change Vulnerability Assessment for Floodplain Forest (Continued).

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels would be detrimental to floodplain forest.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how floodplain forest will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetlands systems. It remains unclear whether the increase in winter precipitation will be in snow or rain. The change in the timing of precipitation will impact floodplain forests.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact floodplain forest.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Invasive plant competition will likely be exacerbated by climate change. Floodplain forest is currently threatened by emerald ash borer. A climate change induced increase in emerald ash borer would be devastating to ash and floodplain forest.

Adaptation strategies
Reduce stressors to current southern hardwood swamps by controlling invasive species.

Appendix 28. Summary of Climate Change Vulnerability Assessment for Great Lakes Marsh.

GREAT LAKES MARSH

The vulnerability of Great Lakes marsh will vary depending on the region of the state with marsh systems in the southern lower peninsula and the thumb being vulnerable due to high levels of fragmentation, shoreline development, and invasive species competition. In other words, where these systems are currently stressed, Great Lakes marsh will likely be vulnerable to climate change. The vulnerability of the system as a whole will likely depend on whether the Great Lakes water levels lower or rise. If Great Lakes water levels decline, Great Lakes marsh could potentially increase in area.

Increased Air and Surface Temperature

Great Lakes marsh could potentially benefit from increased air and surface temperature with increased plant productivity. However, increased air and surface temperature could also be detrimental for Great Lakes marsh by increasing the prevalence of woody encroachment (especially invasives) within this open wetland system. Also increased temperatures would likely result in increased water temperatures, which can lead to eutrophication.

Longer Growing Season

Great Lakes marsh could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season could also be detrimental for Great Lakes marsh if it allows for the increase in the prevalence of woody encroachment (especially invasives) within this open wetland system.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

Great Lakes marsh is restricted to the Great Lakes. This system will not likely experience latitude range expansion or contraction due to climate change.

Ability to Disperse

Great Lakes marsh is a wetland ecosystem with a high capacity to move. This wetland has historically tracked the natural fluctuations of the Great Lakes water levels. In recent years, MNFI ecologists have noted the increase in area and number of Great Lakes marsh in northern Michigan as Great Lakes water levels have dropped. However, the ability of this system to disperse is limited in the southern part of the state where shoreline development and fragmentation are prevalent.

Appendix 28. Summary of Climate Change Vulnerability Assessment for Great Lakes Marsh (Continued).

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)
It is unclear if Great Lakes marsh would be negatively impacted or benefited by increased frequency or intensity of extreme events. Great Lakes marsh could potentially benefit from increased fire, flooding and wind events but could also be negatively impacted by extreme droughts. Flash flooding events could increase detrimental impacts from sedimentation and pollution.

Great Lakes Lower Water Levels
Lower Great Lakes levels would likely result in the increase of Great Lakes marsh, especially in the northern portion of its range. As noted above, in recent years, MNFI ecologists have noted the increase in area and number of Great Lakes marsh in northern Michigan as Great Lakes water levels have dropped. However, where invasive species are prevalent, lower water levels could result in increased levels of invasive species in coastal wetlands.

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels could potentially be detrimental to Great Lakes marsh. Drier marshes might be more susceptible to invasive species and woody encroachment.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how Great Lakes marsh will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetlands systems. As noted above, drier marshes might be more susceptible to invasive species and woody encroachment. It remains unclear whether the increase in winter precipitation will be in snow or rain. Also, if ice cover decreases in the winter, Great Lakes marsh will be impacted as winter wave activity will change.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact Great Lakes marsh with increased encroachment from woody species and invasives.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Great Lakes marsh is currently stressed by invasive plants (i.e., *Phragmites australis*, *Typha angustifolia*, and *Typha* X*glauca*), especially in southern lower Michigan. Invasive plant competition will likely be exacerbated by climate change, especially in the southern Lower Peninsula.

Adaptation strategies
Reduce stressors to current Great Lakes marsh by controlling invasive species.

Establish rolling easements to allow for long-term fluctuations of coastal ecosystems across space and time.

Appendix 29. Summary of Climate Change Vulnerability Assessment for Interdunal Wetland.

INTERDUNAL WETLAND

Interdunal wetland is an already imperiled wetland community that will likely be vulnerable to climate change, especially in the southern portion of its range where it is currently threatened by invasive species and shoreline development and fragmentation.

Increased Air and Surface Temperature

Interdunal wetland could potentially benefit from increased air and surface temperature with increased plant productivity. However, increased air and surface temperature could also be detrimental for interdunal wetland by increasing the prevalence of woody encroachment (especially invasives) within this open wetland system. Also increased temperatures would likely result in increased water temperatures, which can lead to eutrophication.

Longer Growing Season

Interdunal wetland could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season could also be detrimental for interdunal wetland if it allows for the increase in the prevalence of woody encroachment (especially invasives) within this open wetland system.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

Interdunal wetland is restricted to the Great Lakes. This system will not likely experience latitude range expansion or contraction due to climate change.

Ability to Disperse

Interdunal wetland is a wetland ecosystem with a moderate capacity to move through space and time. This wetland has historically tracked the natural fluctuations of the Great Lakes water levels. In recent years, MNFI ecologists have noted the development of new interdunal wetlands in northern Michigan as Great Lakes water levels have dropped. However, the ability of this system to disperse is limited in the southern part of the state where shoreline development and fragmentation are prevalent.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

It is unclear if interdunal wetland would be negatively impacted or benefited by increased frequency or intensity of extreme events. Interdunal wetland could potentially benefit from increased fire, flooding and wind events but could also be negatively impacted by extreme droughts. Flash flooding events could increase detrimental impacts from sedimentation and pollution. Increased wind along the shoreline could be detrimental for interdunal wetlands if increased sand movement results in wetlands being buried by sand.

Appendix 29. Summary of Climate Change Vulnerability Assessment for Interdunal Wetland (Continued).

Great Lakes Lower Water Levels
Lower Great Lakes levels would likely result in the increase of interdunal wetland, especially in the northern portion of its range. As noted above, in recent years, MNFI ecologists have noted the development of new interdunal wetland in northern Michigan as Great Lakes water levels have dropped. However, where invasive species are prevalent, lower water levels could result in increased levels of invasive species in coastal wetlands.

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels could potentially be detrimental to interdunal wetland. Drier interdunal wetlands might be more susceptible to invasive species and woody encroachment.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how interdunal wetlands will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetlands systems. As noted above, drier wetlands might be more susceptible to invasive species and woody encroachment. It remains unclear whether the increase in winter precipitation will be in snow or rain and how the timing of precipitation will change.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact interdunal wetland with increased encroachment from woody species and invasives.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Interdunal wetland is currently stressed by invasive plants in southern lower Michigan. Invasive plant competition will likely be exacerbated by climate change, especially in the southern Lower Peninsula.

Adaptation strategies
Reduce stressors to current interdunal wetland by controlling invasive species.

Establish rolling easements to allow for long-term fluctuations of coastal ecosystems across space and time.

Appendix 30. Summary of Climate Change Vulnerability Assessment for Lakeplain Oak Openings.

LAKEPLAIN OAK OPENINGS
Lakeplain oak openings is an already imperiled wetland community that will likely be vulnerable to climate change due to the sensitivity of this ecosystem to hydrology and the current high levels of fragmentation, shoreline development, and invasive species competition.

Increased Air and Surface Temperature
Lakeplain oak openings could potentially benefit from increased air and surface temperature with increased plant productivity. However, increased air and surface temperature could also be detrimental for lakeplain oak openings by increasing the prevalence of woody encroachment (especially invasives).

Longer Growing Season
Lakeplain oak openings could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season could also be detrimental for lakeplain openings if it allows for the increase in the prevalence of woody encroachment (especially invasives). This might occur since a longer growing season could mean that water table levels would be drawn down for longer periods of time during the growing season.

Phenological Change
It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction
A suitable climatic envelope for lakeplain oak openings could expand to the north following climate change.

Ability to Disperse
The ability of this system to disperse is limited by shoreline development and fragmentation and the limited extent of the current distribution of lakeplain oak openings.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)
Increased fire, flooding, windthrow, and drought would likely benefit this system.

Great Lakes Lower Water Levels
Lower Great Lakes levels could potentially benefit lakeplain oak openings. However, where invasive species are prevalent, lower water levels could result in increased levels of invasive species in coastal wetlands. Benefits to this natural community type from lower Great Lakes water levels are unlikely to be realized due to the fragmentation and degradation of the lakeplain landscapes where this system occurs.

Appendix 30. Summary of Climate Change Vulnerability Assessment for Lakeplain Oak Openings (Continued).

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels could potentially be detrimental to lakeplain oak openings. Some lakeplain oak openings are dependent on high water tables to limit woody encroachment. Changes in hydrology could result in woody species encroachment (including invasives). Specific physiographic setting of lakeplain oak openings will likely determine if changes in groundwater and surface water levels are beneficial or detrimental.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how lakeplain oak openings will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetlands systems but positive impacts on savanna ecosystems. As noted above, some lakeplain oak openings might be more susceptible to invasive species and woody encroachment. It remains unclear whether the increase in winter precipitation will be in snow or rain and how the timing of precipitation will change.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate may benefit lakeplain oak openings.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Lakeplain oak openings are currently stressed by invasive plants. Invasive plant competition will likely be exacerbated by climate change.

Adaptation strategies
Reduce stressors to current lakeplain oak openings by controlling invasive species and implementing prescribed fire.

Restore numerous lakeplain oak openings across its range to increase the resilience of the type.

Appendix 31. Summary of Climate Change Vulnerability Assessment for Lakeplain Wet Prairie.

LAKEPLAIN WET PRAIRIE

Lakeplain wet prairie is an already imperiled wetland community that will likely be highly vulnerable to climate change due to the sensitivity of this ecosystem to hydrology and the current high levels of fragmentation, shoreline development, and invasive species competition.

Increased Air and Surface Temperature

Lakeplain wet prairie could potentially benefit from increased air and surface temperature with increased plant productivity. However, increased air and surface temperature could also be detrimental for lakeplain wet prairie by increasing the prevalence of woody encroachment (especially invasives) within this open wetland system.

Longer Growing Season

Lakeplain wet prairie could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season could also be detrimental for lakeplain wet prairie if it allows for the increase in the prevalence of woody encroachment (especially invasives) within this open wetland system. This might occur since a longer growing season could mean that water levels would be drawn down for longer periods of time during the growing season.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

Lakeplain wet prairie could expand to the north following climate change.

Ability to Disperse

The ability of this system to disperse is limited by shoreline development and fragmentation and the limited extent of the current distribution of lakeplain wet prairie.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Increased fire and flooding would likely benefit this system but increased drought events may negatively impact lakeplain wet prairie. Flash flooding events could increase detrimental impacts from sedimentation and pollution.

Great Lakes Lower Water Levels

Lower Great Lakes levels could potentially benefit lakeplain wet prairie. However, where invasive species are prevalent, lower water levels could result in increased levels of invasive species in coastal wetlands. Benefits to this natural community type from lower Great Lakes water levels are unlikely to be realized due to the fragmentation and degradation of the lakeplain landscapes where this system occurs.

Appendix 31. Summary of Climate Change Vulnerability Assessment for Lakeplain Wet Prairie (Continued).

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels could potentially be detrimental to lakeplain wet prairie. Drier lakeplain wet prairies might be more susceptible to invasive species and woody encroachment.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how lakeplain wet prairie will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetlands systems. As noted above, drier lakeplain wet prairie might be more susceptible to invasive species and woody encroachment. It remains unclear whether the increase in winter precipitation will be in snow or rain and how the timing of precipitation will change.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact lakeplain wet prairie with increased encroachment from woody species and invasives.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Lakeplain wet prairie is currently stressed by invasive plants. Invasive plant competition will likely be exacerbated by climate change.

Adaptation strategies
Reduce stressors to current lakeplain wet prairies by controlling invasive species and implementing prescribed fire.

Restore numerous lakeplain wet prairies across its range to increase the resilience of the type.

Appendix 32. Summary of Climate Change Vulnerability Assessment for Lakeplain Wet-Mesic Prairie.

LAKEPLAIN WET-MESIC PRAIRIE

Lakeplain wet-mesic prairie is an already imperiled wetland community that will likely be highly vulnerable to climate change due to the sensitivity of this ecosystem to hydrology and the current high levels of fragmentation, shoreline development, and invasive species competition.

Increased Air and Surface Temperature

Lakeplain wet-mesic prairie could potentially benefit from increased air and surface temperature with increased plant productivity. However, increased air and surface temperature could also be detrimental for lakeplain wet-mesic prairie by increasing the prevalence of woody encroachment (especially invasives) within this open wetland system.

Longer Growing Season

Lakeplain wet-mesic prairie could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season could also be detrimental for lakeplain wet-mesic prairie if it allows for the increase in the prevalence of woody encroachment (especially invasives) within this open wetland system. This might occur since a longer growing season could mean that water levels would be drawn down for longer periods of time during the growing season.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

Lakeplain wet-mesic prairie could expand to the north following climate change.

Ability to Disperse

The ability of this system to disperse is limited by shoreline development and fragmentation and the limited extent of the current distribution of lakeplain wet-mesic prairie.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Increased fire and flooding would likely benefit this system but increased drought events may negatively impact lakeplain wet-mesic prairie. Flash flooding events could increase detrimental impacts from sedimentation and pollution.

Great Lakes Lower Water Levels

Lower Great Lakes levels could potentially benefit lakeplain wet-mesic prairie. However, where invasive species are prevalent, lower water levels could result in increased levels of invasive species in coastal wetlands. Benefits to this natural community type from lower Great Lakes water levels are unlikely to be realized due to the fragmentation and degradation of the lakeplain landscapes where this system occurs.

Appendix 32. Summary of Climate Change Vulnerability Assessment for Lakeplain Wet-Mesic Prairie (Continued).

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels could potentially be detrimental to lakeplain wet-mesic prairie. Drier lakeplain wet-mesic prairies might be more susceptible to invasive species and woody encroachment.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how lakeplain wet-mesic prairie will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetlands systems. As noted above, drier lakeplain wet-mesic prairie might be more susceptible to invasive species and woody encroachment. It remains unclear whether the increase in winter precipitation will be in snow or rain and how the timing of precipitation will change.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact lakeplain wet-mesic prairie with increased encroachment from woody species and invasives.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Lakeplain wet-mesic prairie is currently stressed by invasive plants. Invasive plant competition will likely be exacerbated by climate change.

Adaptation strategies
Reduce stressors to current lakeplain wet-mesic prairies by controlling invasive species and implementing prescribed fire.

Restore numerous lakeplain wet-mesic prairies across its range to increase the resilience of the type.

Appendix 33. Summary of Climate Change Vulnerability Assessment for Mesic Northern Forest.

MESIC NORTHERN FOREST

Mesic northern forest is likely vulnerable to climate change. This community has a widespread distribution in Michigan but is currently stressed by invasive species and deer herbivory. Predicted climate change will likely be detrimental to the canopy cohort of this system.

Increased Air and Surface Temperature

Mesic northern forest will likely be negatively impacted by increased air and surface temperature, which will likely shift floristic composition and result in the decline of species diversity.

Longer Growing Season

A longer growing season will likely be detrimental to mesic northern forest, likely causing a shift in floristic composition and a decline of species diversity. In addition, longer growing seasons can allow for increased tree pests, especially for conifers.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

With climate change, the current range of mesic northern forest will likely contract northward.

Ability to Disperse

Mesic northern forest has a widespread distribution in northern Michigan. In forested landscapes, mesic northern forest has a high ability to disperse. In the southern portion of its range, the dispersal ability of mesic northern forest is limited due to fragmentation.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Mesic northern forest will likely be negatively impacted by increased frequency or intensity of extreme events. Mesic northern forest will likely be negatively impacted by increased fire, drought, flooding and wind events.

Great Lakes Lower Water Levels

Changes in Great Lakes water levels will not likely impact this system.

Reduction in Regional Groundwater and Surface Water Levels

The reduction in regional groundwater and surface water levels could potentially be detrimental to mesic northern forest. Important attributes of mesic northern forest that are linked to ground water and surface water (i.e., vernal pools and seeps) would be negatively impacted.

Appendix 33. Summary of Climate Change Vulnerability Assessment for Mesic Northern Forest (Continued).

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how mesic northern forest will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on mesic northern forest. It remains unclear whether the increase in winter precipitation will be in snow or rain. If snow cover decreases, then winter deer browse pressures will likely increase and this system will be very negatively impacted. In addition, decreased snow cover and therefore insular could lead to increased root damage due to soil freezing (more frequent freezing of the root zone).

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact mesic northern forest.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Invasive plant competition will likely be exacerbated by climate change. As noted above, mesic northern forest is currently stressed by high deer herbivory levels, which has locally limited the regeneration capacity of components of this system (i.e., hemlock and yellow birch). Higher levels of deer and winter deer browse pressure will be very detrimental to this system. Mesic northern forest is also currently stressed by invasive pests (especially beech bark disease). Increased pests would be detrimental to mesic northern forest.

Adaptation strategies
Reduce stressors to current mesic northern forest by controlling invasive species and reducing deer densities.

Protect numerous mesic northern forests across its range to increase the resilience of the type.

Appendix 34. Summary of Climate Change Vulnerability Assessment for Mesic Southern Forest.

MESIC SOUTHERN FOREST
Mesic southern forest is likely slightly vulnerable to climate change. This community has a widespread distribution in Michigan but is currently stressed by invasive species and deer herbivory. Predicted climate change will likely exacerbate the current threats to this system.

Increased Air and Surface Temperature
It is not clear how mesic southern forest will be impacted by increased air and surface temperature. Mesic southern forest could potentially benefit from increased air and surface temperature with increased plant productivity. However, increased air and surface temperature could also be detrimental for floodplain forest by increasing the prevalence of invasive plants and pests.

Longer Growing Season
Mesic southern forest could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season could also be detrimental for mesic southern forest if it allows for the increase in invasive plants and invasive pests.

Phenological Change
It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction
With climate change, the current range of mesic southern forest will likely expand northward.

Ability to Disperse
Mesic southern forest has a widespread distribution in southern Michigan. In forested landscapes, mesic southern forest has a high ability to disperse. However, throughout the majority of its range, mesic southern forest has limited dispersal ability due to high levels of fragmentation.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)
Mesic southern forest will likely be negatively impacted by increased frequency or intensity of extreme events. Mesic southern forest will likely be negatively impacted by increased fire, drought, flooding and wind events.

Great Lakes Lower Water Levels
Changes in Great Lakes water levels will not likely impact this system.

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels could potentially be detrimental to mesic southern forest. Important attributes of mesic southern forest that are linked to ground water and surface water (i.e., vernal pools and seeps) would be negatively impacted.

Appendix 34. Summary of Climate Change Vulnerability Assessment for Mesic Southern Forest (Continued).

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how mesic southern forest will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on mesic southern forest. It remains unclear whether the increase in winter precipitation will be in snow or rain. If snow cover decreases, then winter deer browse pressures will likely increase and this system will be very negatively impacted. Decreased snow cover and therefore insular could lead to increased root damage due to soil freezing (more frequent freezing of the root zone).

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact mesic southern forest.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Invasive plant competition will likely be exacerbated by climate change. As noted above, boreal forest is currently stressed by high deer herbivory levels, invasive plants, and invasive pests. Higher levels of deer and winter deer browse pressure will be very detrimental to this system. Increased pests and invasive plants would be detrimental to mesic northern forest.

Adaptation strategies
Reduce stressors to current mesic southern forest by controlling invasive species and reducing deer densities.

Protect numerous mesic southern forest examples across its range to increase the resilience of the type.

Appendix 35. Summary of Climate Change Vulnerability Assessment for Northern Hardwood Swamp.

NORTHERN HARDWOOD SWAMP
Northern hardwood swamp is likely highly vulnerable to climate change. As a groundwater or surface water-fed, ecosystem with organic soils, this community is especially sensitive to changes in soil moisture and hydrology. In addition, northern hardwood swamp is dominated by black ash, which will likely be decimated as emerald ash borer spreads (this spread will likely be exacerbated by climate change).

Increased Air and Surface Temperature
It is not clear how northern hardwood swamp will be impacted by increased air and surface temperature.

Longer Growing Season
A longer growing season will likely be detrimental to northern hardwood swamp. Longer growing seasons can allow for increased tree pests.

Phenological Change
It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction
With climate change, the current range of northern hardwood swamp could contract to where precipitation is greater than evapotranspiration.

Ability to Disperse
Although northern hardwood swamp has a widespread distribution in Michigan, the capacity of northern hardwood swamp to disperse is limited because the community is restricted to a specific hydrologic and geologic setting.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)
Northern hardwood swamp will likely be negatively impacted by increased frequency or intensity of extreme events. Northern hardwood swamp will likely be negatively impacted by fire, drought, flooding and wind events.

Great Lakes Lower Water Levels
Changes in Great Lakes water levels will not likely impact this system.

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels would be very detrimental to northern hardwood swamp.

Appendix 35. Summary of Climate Change Vulnerability Assessment for Northern Hardwood Swamp (Continued).

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how northern hardwood swamps will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetlands systems. It remains unclear whether the increase in winter precipitation will be in snow or rain.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact northern hardwood swamp.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Invasive plant competition will likely be exacerbated by climate change. As noted above, northern hardwood swamp is currently threatened by emerald ash borer. A climate change induced increase in emerald ash borer would be devastating to black ash and northern hardwood swamp.

Adaptation strategies
Reduce stressors to current northern hardwood swamp by controlling invasive pests.

Appendix 36. Summary of Climate Change Vulnerability Assessment for Rich Conifer Swamp.

RICH CONIFER SWAMP

Rich conifer swamp is likely highly vulnerable to climate change. As a groundwater-fed, ecosystem with organic soils, this community is especially sensitive to changes in soil moisture and hydrology. In addition, rich conifer swamp is currently stressed across its range by high deer herbivory levels, which has locally limited the regeneration capacity of this system.

Increased Air and Surface Temperature

Rich conifer swamp will likely be negatively impacted by increased air and surface temperature with plant productivity of hardwood competition increasing.

Longer Growing Season

A longer growing season will likely be detrimental to rich conifer swamp with hardwood competition being imparted a competitive advantage over the current conifer canopy dominants. In addition, longer growing seasons can allow for increased tree pests.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

With climate change, the current range of rich conifer swamp could contract to where precipitation is greater than evapotranspiration.

Ability to Disperse

Although rich conifer swamp has a widespread distribution in Michigan, the capacity of rich conifer swamp to disperse is limited because the community is restricted to a specific hydrologic and geologic setting. The dispersal ability of rich conifer swamp is also limited by the failure of cedar to regenerate in landscapes where deer densities are high.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Rich conifer swamp will likely be negatively impacted by increased frequency or intensity of extreme events. Rich conifer swamp will likely be negatively impacted by fire, drought, flooding and wind events.

Great Lakes Lower Water Levels

Changes in Great Lakes water levels will not likely impact this system.

Reduction in Regional Groundwater and Surface Water Levels

The reduction in regional groundwater and surface water levels would be very detrimental to rich conifer swamp.

Appendix 36. Summary of Climate Change Vulnerability Assessment for Rich Conifer Swamp (Continued).

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how rich conifer swamps will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetlands systems. It remains unclear whether the increase in winter precipitation will be in snow or rain. If snow cover decreases, then winter deer browse pressures will likely increase and this system will be very negatively impacted.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact rich conifer swamp.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Invasive plant competition will likely be exacerbated by climate change. As noted above, rich conifer swamp is currently stressed across its range by high deer herbivory levels, which has locally limited the regeneration capacity of this system. Higher levels of deer and winter deer browse pressure will be very detrimental to this already stressed system. Increased pests that impact conifer species would be detrimental to rich conifer swamp.

Adaptation strategies
Reduce stressors to current rich conifer swamps by controlling invasive species and reducing deer densities.

Rich conifer swamps provide unique microclimates and can function as climate refugia.

Appendix 37. Summary of Climate Change Vulnerability Assessment for Southern Hardwood Swamp.

SOUTHERN HARDWOOD SWAMP

Southern hardwood swamp is likely vulnerable to climate change. As a groundwater or surface water-fed, ecosystem with organic soils, this community is especially sensitive to changes in soil moisture and hydrology. In addition, southern hardwood swamp is currently stressed by invasive species, a threat that will likely be exacerbated by climate change.

Increased Air and Surface Temperature

It is not clear how southern hardwood swamp will be impacted by increased air and surface temperature. Southern hardwood swamp could potentially benefit from increased air and surface temperature with increased plant productivity. However, increased air and surface temperature could also be detrimental for southern hardwood swamp by increasing the prevalence of invasive plants and pests.

Longer Growing Season

Southern hardwood swamp could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season could also be detrimental for southern hardwood swamp if it allows for the increase in invasive plants and invasive pests.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

With climate change, the current range of southern hardwood swamp could expand.

Ability to Disperse

Although southern hardwood swamp has a widespread distribution in Michigan, the capacity of southern hardwood swamp to disperse is somewhat limited because the community is restricted to a specific hydrologic and geologic setting.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Southern hardwood swamp will likely be negatively impacted by increased frequency or intensity of extreme events. Southern hardwood swamp will likely be negatively impacted by fire, drought, flooding and wind events.

Great Lakes Lower Water Levels

Changes in Great Lakes water levels will not likely impact this system.

Reduction in Regional Groundwater and Surface Water Levels

The reduction in regional groundwater and surface water levels would be very detrimental to southern hardwood swamp.

Appendix 37. Summary of Climate Change Vulnerability Assessment for Southern Hardwood Swamp (Continued).

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how southern hardwood swamps will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetlands systems. It remains unclear whether the increase in winter precipitation will be in snow or rain.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact southern hardwood swamp.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Invasive plant competition will likely be exacerbated by climate change. Southern hardwood swamp is currently threatened by emerald ash borer. A climate change induced increase in emerald ash borer would be devastating to ash and southern hardwood swamp.

Adaptation strategies
Reduce stressors to current southern hardwood swamps by controlling invasive species.

Appendix 38. Summary of Climate Change Vulnerability Assessment for Wet-Mesic Flatwoods.

WET-MESIC FLATWOODS

Wet-mesic flatwoods is an already imperiled wetland community that will likely be vulnerable to climate change due to the sensitivity of this ecosystem to hydrology and the current high levels of fragmentation, shoreline development, hydrologic alteration, and invasive species competition. High levels of species diversity within this type increase its adaptive capacity, however many of the current examples of wet-mesic flatwoods have been degraded by anthropogenic disturbance and have already experienced reduced floristic complexity.

Increased Air and Surface Temperature

It is not clear how wet-mesic flatwoods will be impacted by increased air and surface temperature. Wet-mesic flatwoods could potentially benefit from increased air and surface temperature with increased plant productivity. However, increased air and surface temperature could also be detrimental for wet-mesic flatwoods by increasing the prevalence of invasive plants and pests.

Longer Growing Season

Wet-mesic flatwoods could potentially benefit from a longer growing season with increased plant productivity. However, a longer growing season could also be detrimental for wet-mesic flatwoods if it allows for the increase in the prevalence of woody encroachment (especially invasives). This might occur since a longer growing season could mean that water table levels would be drawn down for longer periods of time during the growing season.

Phenological Change

It is not clear how potential climate driven changes in phenology will impact this community.

Latitude Range Expansion or Contraction

A suitable climatic envelope for wet-mesic flatwoods could expand to the north following climate change, however, this system is restricted in range to a specific hydrologic and physiographic context.

Ability to Disperse

The ability of this system to disperse is limited by its restricted hydrologic and physiographic setting as well as shoreline development and fragmentation and the limited extent of the current distribution of wet-mesic flatwoods.

Increased Frequency or Intensity of Extreme Events (e.g., fire, drought, windstorms, and floods)

Wet-mesic flatwoods will likely be negatively impacted by increased frequency or intensity of extreme events. Wet-mesic flatwoods will likely be negatively impacted by increased fire, drought, flooding and wind events.

Appendix 38. Summary of Climate Change Vulnerability Assessment for Wet-Mesic Flatwoods (Continued).

Great Lakes Lower Water Levels
Changes in Great Lakes water levels will not likely impact this system. Lower Great Lakes levels could potentially benefit wet-mesic flatwoods. However, where invasive species are prevalent, lower water levels could result in increased levels of invasive species in coastal wetlands. Benefits to this natural community type from lower Great Lakes water levels are unlikely to be realized due to the fragmentation and degradation of the lakeplain landscapes where this system occurs.

Reduction in Regional Groundwater and Surface Water Levels
The reduction in regional groundwater and surface water levels could potentially be detrimental to wet-mesic flatwoods. Changes in hydrology could result in woody species encroachment (including invasives) and shifts in species composition.

Wetter Winters and Springs and Drier Summers and Falls
It is unclear how wet-mesic flatwoods will be impacted by wetter winters and springs and drier summers and falls. Drier summers and falls will likely have negative impacts on wetlands systems. As noted above, some wet-mesic flatwoods might be more susceptible to invasive species and woody encroachment. It remains unclear whether the increase in winter precipitation will be in snow or rain and how the timing of precipitation will change.

Overall Drier Climate (>evaporation and evapotranspiration and drier soils)
A drier climate will likely negatively impact wet-mesic flatwoods.

Increased Levels of Invasive Plants, Pests, Pathogens, Grazers, and Browsers
Wet-mesic flatwoods is currently stressed by invasive plants and pests. Impacts from invasives will likely be exacerbated by climate change. A climate change induced increase in emerald ash borer would be devastating to ash, which is an important canopy species in wet-mesic flatwoods.

Adaptation strategies
Reduce stressors to current wet-mesic flatwoods by controlling invasive species, implementing prescribed fire, and restoring hydrological processes where they have been degraded.

Restore numerous wet-mesic flatwoods across its range to increase the resilience of the type.