Indiana Dunes

Climate Change Adaptation Plan

INDIANA LAKE MICHIGAN COASTAL PROGRAM

Save the Dunes

FIELD MUSEUM

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE

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Indiana Dunes Climate Change Adaptation Plan

Executive Summary

The Indiana Dunes National Lakeshore is one of the most floristically rich U.S. national parks, situated within a narrow band at the southern tip of Lake Michigan. Embedded within this unique national park is the Indiana Dunes State Park, which consists of 2,182 acres of similar primitive and exceptional landscape. A wide range of habitats and plant species are found in these parks, where a dune and swale succession progresses from the shore inland and habitats include abundant plant species, from boreal and prairie to Eastern deciduous forest. These habitats are also home to many types of animals and the lake provides habitat for numerous aquatic species. In addition, both the state and national parks provide year-round recreational opportunities.

The successional habitats that exist in the parks depend on natural disturbance processes (e.g., wind, shoreline erosion, fire, etc.) to sustain their rich plant communities and the range of animals they support. As human development fragmented the landscape and suppressed wildfires, oak habitats have flourished and invaded other habitats, bringing with it a decrease in plant species. In some areas, dunes and wetlands have been damaged by human traffic or changes in hydrology. Restoration and conservation activities have reversed some of the harm, but the delicate habitats that have endured despite their human neighbors for over a century are now being stressed by climate change.

Recent studies from the National Park Service Climate Response Program found that temperature, precipitation, and indications of the onset of spring relative to historic values (1901-2012) are already exposing the Indiana Dunes region to climate impacts. One-fifth of the length of the park's lakeshore is highly vulnerable to lake level changes. Rising temperatures are expected to make habitats less hospitable to some species, especially boreal plants, and forest compositions will change as habitats for many tree species are driven northward. Like most of the Midwest US, precipitation in Indiana Dunes is expected to become characterized by fewer but heavier rain events, with an overall decrease in precipitation during the summer and an increase during the winter months. Winter precipitation will shift away from snow, falling in the form of rain more and more, and Lake Michigan may eventually have less ice cover. The number of days within the growing season has increased and is expected to continue doing so by as much as a month's time by the middle of the century, with the expectation of earlier springs and later autumns. Land managers at state and national parks are being encouraged to "manage for change", especially as climate forces impose an increasing amount of stress on these natural areas. The US National Park System (NPS) has developed a Natural Resource Adaptation Strategy aimed at making the parks more resilient to climate change through enhancing specific elements. The elements include availability of climate refugia (habitats that persist as climate changes), landscape corridors that allow plants and animals to move to more suitable locations, healthy populations with sufficient genetic diversity to adapt, blocks of natural landscape large enough to be resilient to large-scale disturbances and long-term changes, and fewer additional threats and stressors.

Adaptation options assembled in this plan range from resisting impacts to embracing an evolution in habitats that results in a suite of ecosystem functions that are better suited to future conditions. Land managers will benefit from carefully assessing goals in conjunction with environmental monitoring and climate forecasts to prioritize actions. Shifts in growing seasons will necessitate changing the timing of some activities, such as prescribed fire. In addition, managers may need to adapt the nature of the burn (intensity and duration) to hotter and drier conditions, and adjust fire management protocols to create refugia, new habitats, and to preserve vulnerable species (e.g., boreal, etc.).

Coordinating with regional planners will enable managers to enhance corridors in the fragmented landscape that will allow plants and animals to migrate. Infrastructure at the parks will need to be improved, and this is an opportunity to re-evaluate park structures and roads that are better suited to future conditions. The parks will benefit from adding to their monitoring activities to create a "watch list" of southern invasive species that will be moving into the area, and connecting with other land managers to share information about best management practices for controlling their current invasive species. Finally, park managers may want to consider creating messaging systems that advise area residents, staff, and visitors about climate related threats such as extreme heat, flooding, an increase in the number of ticks, more wildlife encounters, etc.

Building resiliency in natural habitats under a rapidly shifting climate requires thoughtful but deliberate actions. The depth of commitment, knowledge, and cooperation among the many experts in the region is an asset that can be leveraged through continued communication and coordinated planning. To that end, this adaptation plan will benefit from regular evaluation and updates in order to assess new impacts and vulnerabilities and to fine-tune adaptation strategies that are specific to the Indiana Dunes region.

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OVERVIEW

Photo: Katherine Moore Powell

Introduction

The ecological and cultural significance of the unique array of habitats associated with the Indiana Dunes has been understood for well over a century. While efforts to protect and restore this beautiful and species rich area are ongoing, changes in the local climate have already left their mark. On the endangered species list since 1992, the Karner blue butterfly (*Lycaeides melissa samuelis*) became extirpated from the region when a combination of an early spring and protracted summer drought in 2012 caused the breeding cycles to fail (USFWS 2012; Harvey Keagle 2015). In 2014, a study conducted by the National Park Service found that climate change has already been affecting the National Lakeshore, the park is vulnerable to future climate stress, and climate change impacts will affect all aspects of park management.

This climate change adaptation plan was developed in 2017 with funding from the Indiana Department of Natural Resources Lake Michigan Coastal Program and National Oceanic and Atmospheric Administration. Guidance for the development of the plan was provided by The Field Museum, Save the Dunes, and from the regional advisory committee comprised of organizations associated with the Indiana Dunes Ecosystem Alliance (IDEA) - the National Park Service (NPS), Indiana Department of Natural Resources (DNR), U.S. Geological Survey (USGS), The Nature Conservancy (TNC), Shirley Heinze Land Trust (SHLT), and the National Parks Conservation Association (NPCA). Climate change vulnerability assessments for habitats in the region were developed through local workshops, webinars, and meetings with a diverse set of regional experts and additional information was gathered from scientific studies and cutting edge, downscaled climate model projections for the state of Indiana from the Purdue Climate Change Research Center (http://www.purdue.edu/discoverypark/climate/).

Recent climate trends show that the Indiana Dunes region has already been experiencing increasing temperatures and precipitation over the past century, and spring is occurring earlier in the year. A high level summary of the projected Impacts to this region includes increasing air, water, and soil temperatures and seasonal changes in rainfall patterns that will drive a shift away from mesic dominated habitats to more xeric ecosystems. The highly fragmented landscape presents additional challenges to organisms as they attempt to adapt to these shifts by seeking refugia or migrating to other regions. The location of these habitats at the southern end of Lake Michigan impedes faunal movement north and the migration paths east and west present very different climate regimes. To the west, the Chicago area is one of the largest urban landscapes in the world. As a result, there will be transitions in ecological communities with a cascading effect on phenological events and migrating organisms, especially from the neo-tropical regions. Finally, extreme weather events, such as floods and droughts, are expected to increase, and cool and moist microclimates will become drier and warmer, stressing vulnerable boreal relict species, such as white pine (*Pinus strobus*), likely leading to the loss of some species.

The natural and built environments are physically close and fragmented within the Indiana Dunes region, creating distinct challenges to conserving the unique habitats that exist there. The changing climate will further test the enduring relationship between conservation and industrial stress that mark this region’s history. Furthermore, future climate projections indicate an increase in both variability and extremes with increasing uncertainty towards the end of this century. Consequently, the adaptation strategies presented in this plan are aimed at building resiliency specifically for this set of diverse ecosystems given an array of new challenges that are expected to emerge under a rapidly shifting climate system.

Climate Impacts

Habitats within the Indiana Dunes park boundaries are directly and indirectly influenced by increasing temperatures (Figure 1) and other climate impacts that affect migration patterns and ecological range shifts throughout the U.S. Midwest. Therefore, climate trends and projections are summarized at the regional scale before focus narrows to state, county, and park boundaries scale.

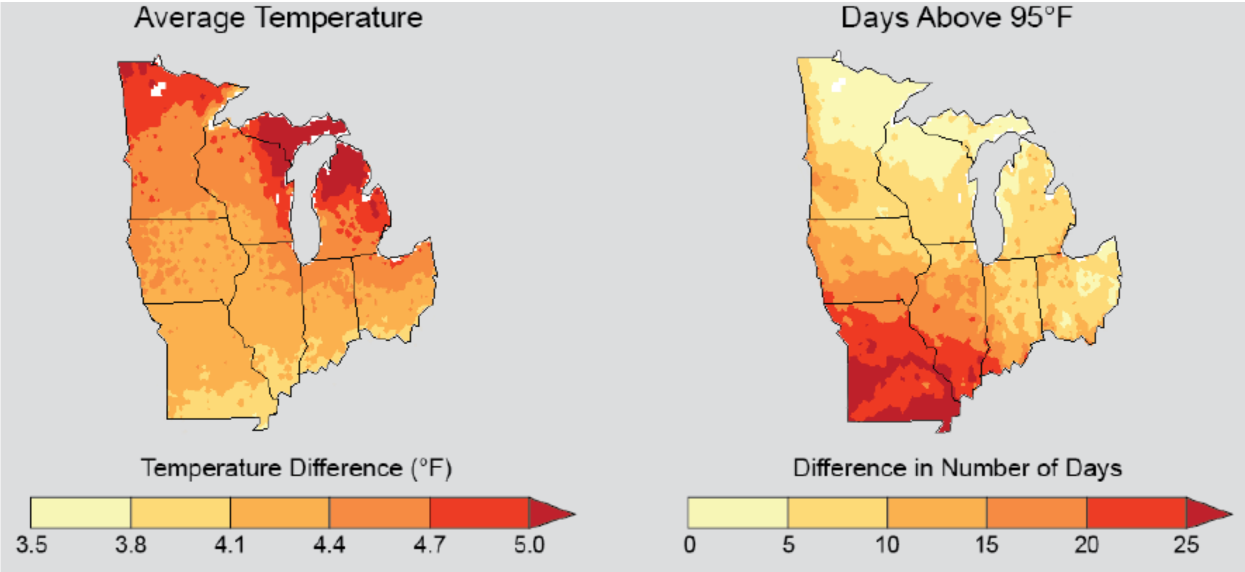


Figure 1. From the Third National Climate Assessment - Projected increase in annual average temperatures (left) and number of hottest days (right) by mid-century (2041-2070) as compared to the 1971-2000 period (Pryor et al. 2014).

Climate Impacts in the Midwest

National Climate Assessment

Regional historic trends and climate model projections for the Midwest region were compiled in the Third National Climate Assessment (Pryor et al. 2014). The analysis concluded that extremes in temperature and precipitation play a crucial role in the threats expected to this region.

Ecosystems in the Indiana Dunes region will be most affected by these two key messages from the National Climate Assessment:

The composition of the region's forests is expected to change as rising temperatures drive habitats for many tree species northward.

Extreme rainfall events and flooding have increased during the last century, and these trends are expected to continue.

Natural forest systems in the Midwest are particularly vulnerable to multiple stresses – climate change, land-use change, and increasing numbers of invasive species. Native tree habitat in the Midwest U.S. is shrinking as warming pushes these species northward and southern species encroach. The habitat ranges of oak trees, and some pine, commonly found in the southern Midwest region are projected to expand their ranges northward.

Extreme precipitation (defined as a daily amount that occurs once in 20 years) will impact many areas of the Midwest. Analyzing the spatial variation in projected precipitation changes in the Midwest region (Figure 2), the areas surrounding Northwest Indiana will also have increasing precipitation, inundating their watersheds and compounding runoff and infiltration issues in the Indiana Dunes region.

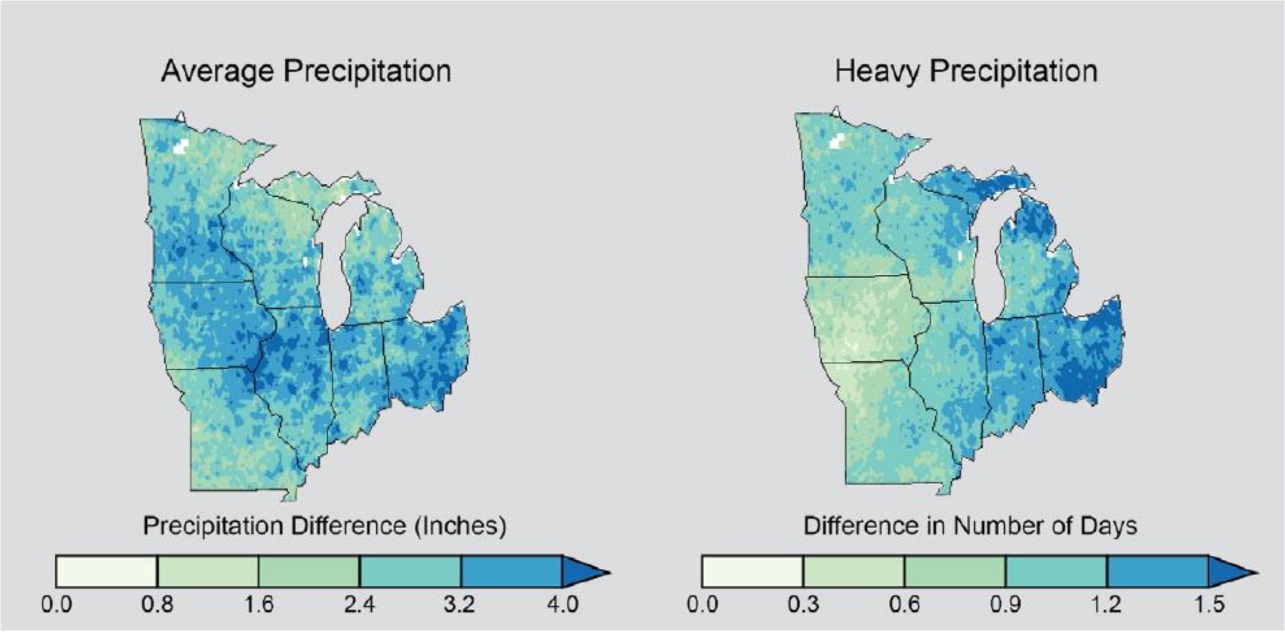


Figure 2. From the Third National Climate Assessment - Projected precipitation changes in total annual average precipitation (left) and the number of days with very heavy precipitation (right, the top 2% of all rainfalls each year) for mid-century (2041-2070) relative to the end of the last century (1971-2000) under continued emissions (Pryor et al. 2014).

According to the National Climate Assessment, species that are particularly vulnerable to climate change were found to possess the following traits or conditions:

- ✓ Found in isolated habitats
- ✓ Occur near their physiological tolerance limits
- ✓ Have specific habitat requirements
- ✓ Have low reproductive rates or limited dispersal capability
- ✓ Are dependent on interactions with specific other species
- ✓ Have low genetic variability

Lake Michigan Water Levels and Ice Cover

Although there is much interest in climate change research surrounding the U.S. Great Lakes region, these lakes are often omitted from global climate models due in part to dataset discontinuity between federal and state agencies, particularly because the US–Canadian border runs through much of the region. Nevertheless, the Indiana Geological Survey and Great Lakes Environmental Research Laboratory (GLERL) provided resources for past trends and model projections of the Lake Michigan-Huron system from which we drew meaningful information on future water levels and ice cover that can impact the coastal areas of Northern Indiana.

Lake Michigan has a long geologic time record of lake level fluctuations, with two quasi-periodic 30-year and 160-year fluctuations apparent for the last ~4,700 years (Lewis et al. 2010).

There are also indications of long-term lake-level changes that mirror past climate events suggesting that water changes in Lake Michigan is influenced by regional weather forces.

The Lake Michigan-Huron system historical records records (1860 to present;

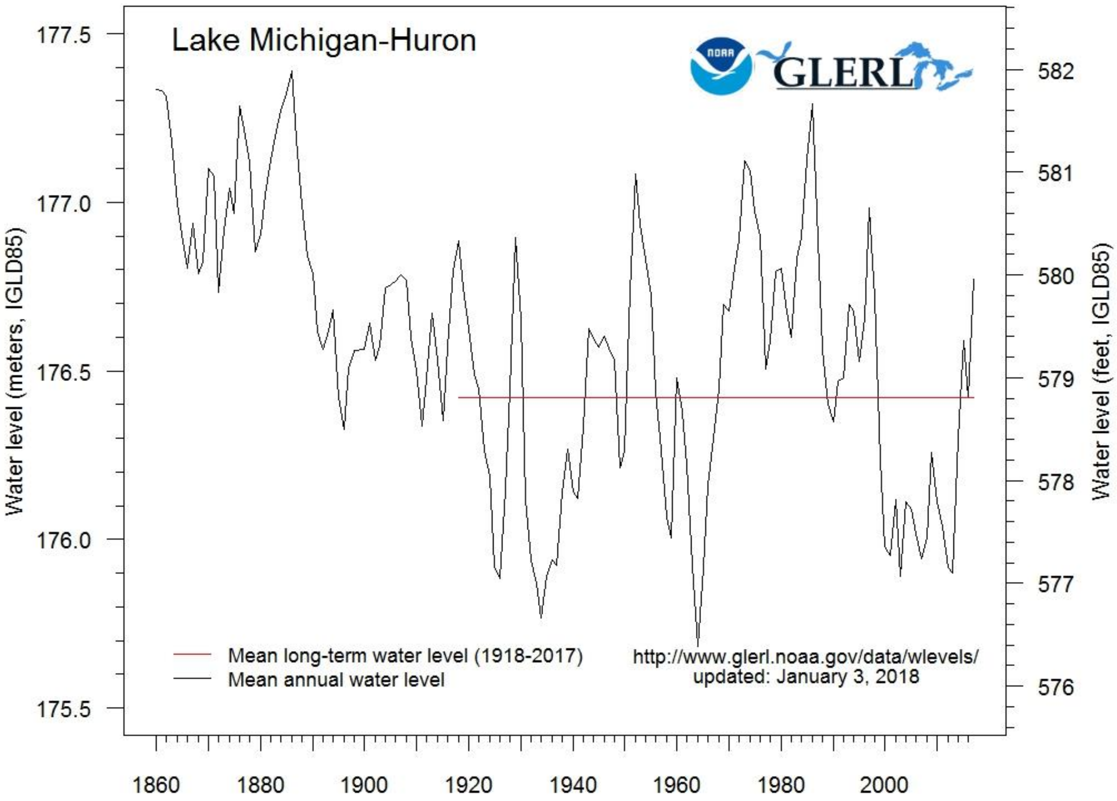


Figure 3. Water level changes over time (1860-2017) for the Lake Michigan-Huron system (source: NOAA GLERL).

Threats

Ice cover on the Great Lakes is extremely variable from year to year (Figure 4), and long-term trends are sometimes difficult to discern in light of that variability. There is a strong natural interannual variability in percent ice cover that may be related to large scale climate oscillations (Arctic, North American, and El Nino). Average ice cover across the Great Lakes declined for much of the 1970s, 1980s, and 1990s, however the trend was less pronounced in the 2000s (Wang et al. 2011). High percentage ice cover returned in 2014 and 2015, demonstrating the long-term variability in Great Lakes ice cover – variability that may increase with climate change.

The relationship between evaporation and lake ice is also complex, and also often misunderstood – lake ice does not cap evaporation. Once the lake is cool enough to ice over, the majority of evaporation has already occurred for that season (Clites et al. 2014). This relationship has been made more complicated by general increases in surface water temperature on the lakes. It is expected that, towards the end of this century, the warmer surface water will lead to a reduction of ice cover on the lakes.

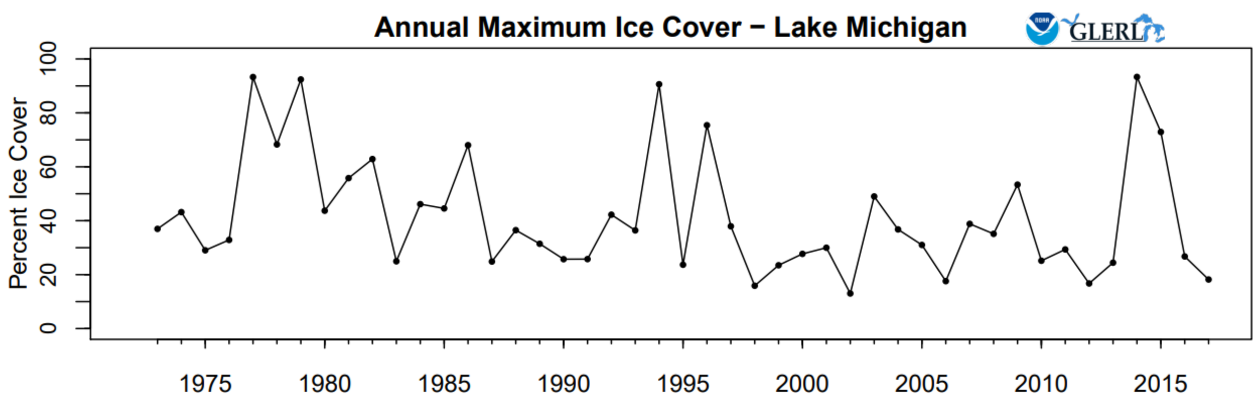


Figure 4. The maximum annual ice cover on Lake Michigan (as a percent) from 1973 – 2017 (source: NOAA GLERL).

The key messages regarding the trends and projections related to Lake Michigan hydrology and climate (Burnett et al. 2003; Notaro, Bennington, and Vavrus 2015) are thus summarized:


Surface water temperatures increasing faster than air temperatures


Lake Michigan ice cover stayed basically the same since the early 1980's


Lake-effect snow trends extremely variable for Northwest Indiana


Winter downwind precipitation will shift to be more rain than snow

Climate Impacts in Indiana

The Indiana Climate Change Assessment provides statistically downscaled climate model forecasts for the state of Indiana. Changes in temperature and precipitation vary considerably from north to south (Figure 5 and Figure 6) generally following latitudinal gradients. The forecasted variation in changes could also be attributed to the proximity of areas in Northwest Indiana that border the southern tip of Lake Michigan, which has a moderating effect on air temperature and contributes to the quantity and form of precipitation. Precipitation in Indiana is expected to become characterized by fewer but heavier rain events, with an overall decrease in precipitation during the summer and an increase during the winter months.

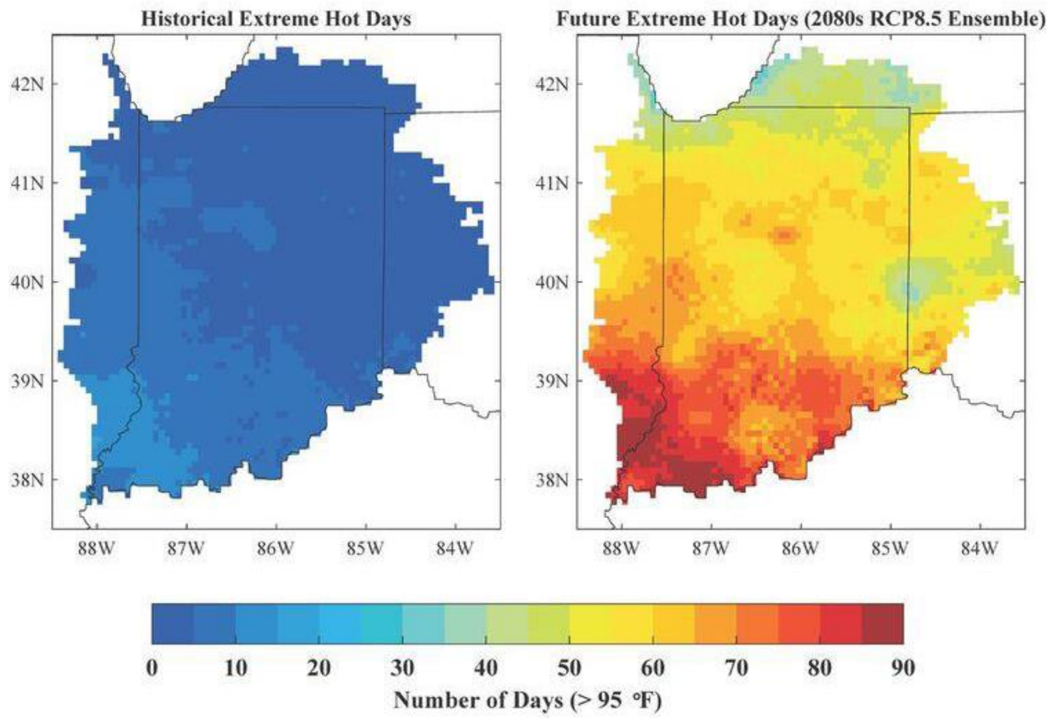


Figure 5. Climate model forecast for Indiana showing extreme hot days for the 2080's (Byun and Hamlet 2018).

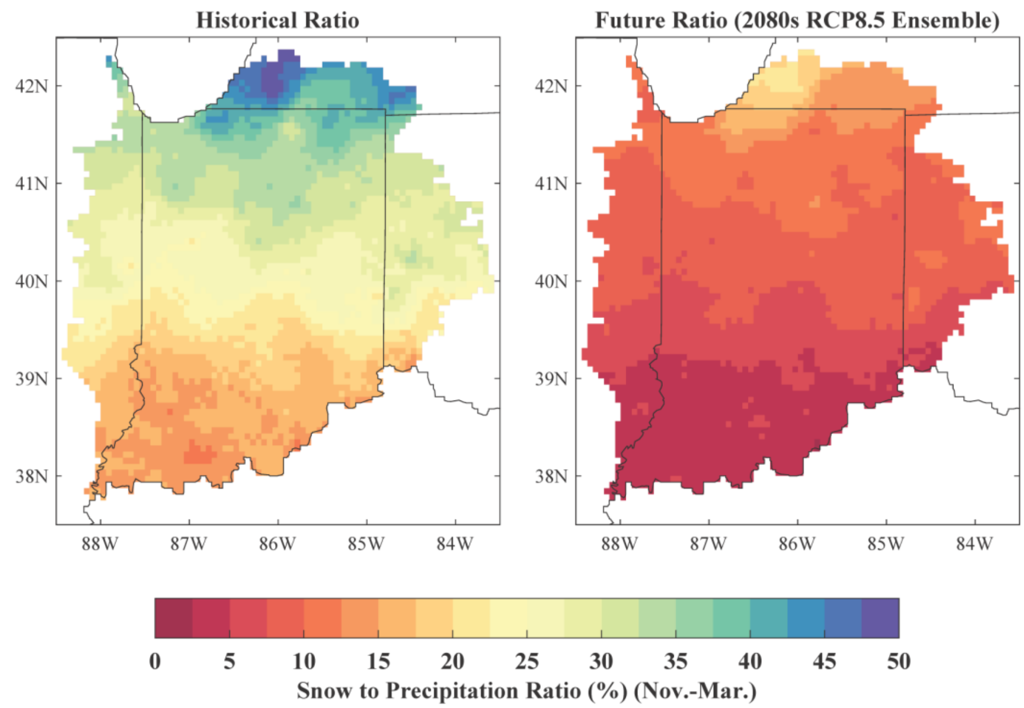


Figure 6. Climate model forecast for Indiana showing snow to rain ratio to the 2080's (Byun and Hamlet 2018).

Threats

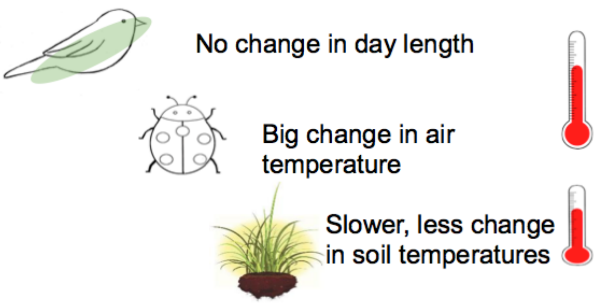
Current Climate Threats to the Indiana Dunes Region

Recent Climate Trends

The National Park Service Climate Change Response Program evaluated the climate trends and vulnerabilities at the Indiana Dunes National Lakeshore (Gonzalez 2014) and conducted an analysis of recent (past 10, 20, and 30 year windows) temperature, precipitation, and indications of the onset of spring relative to historic values (1901-2012) to describe the park's exposure (Monahan et al. 2016; Fisichelli et al. 2015; Monahan and Fisichelli 2014b). Climate change exposure was defined as "extreme" when climate values for recent decades exceeded 95% of the historical values. The panel on the right summarizes the findings from those studies (see Appendix B: NPS Climate Change Assessments), and relevant climate impacts for specific habitats within the Indiana Dunes region are included in each chapter under the TERRESTRIAL COMMUNITIES section.

Phenological Mismatch

Phenological mismatch is a term that describes out of sync life cycle associations between organisms (e.g., predator-prey, migration, breeding) that occurs when changes in individual phenology shift at different rates (Hurlbert and Liang 2012). This mismatch is currently occurring in the Indiana Dunes region because the triggers for life cycle events in many plants and animals are differentially affected by climate change. For example, most birds track photoperiods (day length) to trigger migration and other life cycles events, while most insect phenology is linked to air temperature changes, and vegetation life cycle events are more dependent on soil temperatures. Since air temperature is increasing faster than soil temperatures and day length is not changing, these are expected to become increasingly out of phase with each other.



ALREADY HAPPENING…

EARLIER SPRINGS

First leaf and first bloom happening much earlier

GETTING WARMER

Temperature is increasing about 0.5º F per century

GETTING WETTER

Precipitation is increasing 18% per century, with the biggest increase in winter

LOSING SPECIES

The Karner blue butterfly extirpated in 2012; boreal and rare species likely vulnerable

STILL TO COME...

1 MONTH LONGER GROWING SEASON

Last spring / first fall freeze dates add 29 to 36 more days by 2050

GETTING HOTTER!

33 to 45 more days above 90°F / plant heat zone goes from 5 to 7 by 2050

WINTER / SPRING GETTING WETTER

14 to 22% increase in precipitation and 17 to 23% increase in runoff by 2050

1 MONTH LESS SNOW

24 to 36 fewer days of snow cover by 2050

Projected Climate Impacts to the Indiana Dunes Region

Climate Projections

The panel on the left summarizes the most recent downscaled model forecasts for Porter County, Indiana, generated from the Indiana Climate Change Impacts Assessment. These projections are based on a moderate / high emission scenario (RCP 4.5 / 8.5), and focuses on the mid-range future time period of the 2050's, or the 30-yr average from 2041 to 2070 (Appendix A: Indiana Climate Change Impacts Assessment).

In addition to an increase in mean values, there will be greater overall variability. Air temperatures, for example, are expected to vary considerably, seasonally within the same year and from year to year. This variability affects long-term breeding success of some species, like birds. Furthermore, interaction effects between temperature and precipitation can complicate ecological impacts – a warm fall in conjunction with a large rain event causing an unusual floral bloom event very late in the season.

Climate change has been referred to as a "threat amplifier", exacerbating concurrent or existing threats that natural communities face and increasing their vulnerability to these threats (Fischlin et al. 2007). The field of conservation ecology is in the initial phases of developing general "rules of thumb" of how species and communities are likely to respond to the most direct aspects of climate change (i.e., changes in air or water temperature) by integrating the observed changes in our ecosystems with ecological theory (Dietz and Bidwell 2012).

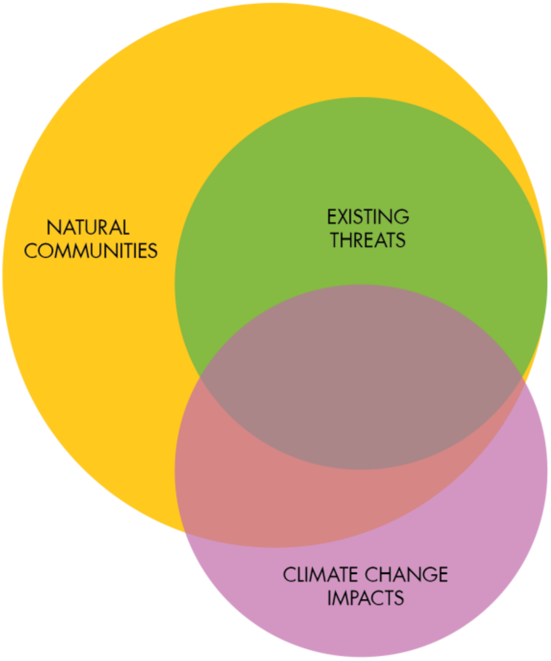


Figure 7. From the Chicago Wilderness Biodiversity Recovery Plan: Climate Change Update (climatechicagowilderness.org).

Land Management Goals

Key Natural Processes

The central theme of this plan is to guide actions that will promote and support truly durable and resilient populations of all living organisms inhabiting the Indiana Dunes Region. Fundamental to achieving this is an understanding that actions will require, above all else, the protection and rehabilitation of ecological habitats and the natural processes that sustain them. Many of the natural elements and processes have been substantially altered by human activity since European settlement. They all influence the remnant natural communities that survived conversion of our landscape to farming and urban development. Of greatest importance today are continuing changes in *hydrology* and *water quality*, the suppression of *fire*, and changes in *competition*, primarily the impact of invasive species resulting from human alteration of the environment and natural processes.

Natural processes that provide the dynamic mix of nurture and stress needed to maintain ecological health in habitats:

- ✓ Water availability
- ✓ Groundwater and soil moisture
- ✓ Watershed and stream hydrology
- ✓ Floodplain processes of inundation, channel movement, etc.
- ✓ Water quality, including chemistry, nutrient content, clarity, etc.
- ✓ Soil: structure, fertility, permeability, erosion, and sedimentation
- ✓ Sunlight and microclimates: shade, shelter, weather, and climate
- ✓ Fire: its inhibition or promotion of various species
- ✓ Competition and natural balances: food-webs, herbivory, and predation
- ✓ Habitat size and connectivity: genetic flow and survival, corridors for migration and dispersal, and habitat diversity
- ✓ Pollination and seed dispersal

Conservation Targets

Priority Areas and Native Habitats

Aligning the key natural processes needed to establish healthy habitats with priority conservation targets is essential to guide specific land management goals and strategies. Thus, the Indiana Dunes Ecosystem Alliance identified six priority areas – Cowles Bog, Great Marsh, Indiana Dunes State Park, Inland Marsh, Miller Woods, and Tolleston Dunes (Figure 8) – as well as conservation targets, specific goals, and strategies for habitats within these priority areas. Furthermore, all habitats within the priority areas is categorized as belonging to one of three main groups: Nearshore, Stabilized Dune or Wetland (Table 1).

By the end of 2015, 1077 acres of black oak savanna in Miller Woods, Tolleston Dunes, and the Indiana Dunes State Park were restored. In addition, extensive restoration in the Great Marsh section of the Cowles Bog unit were ongoing. In order to maintain this restoration work, it will be necessary to have consistent land management, including prescribed fire and invasive species removal.

Goals

Table 1. The Indiana Dunes Ecosystem Alliance (IDEA) six priority areas and their main habitat groups.

Nearshore Habitats	***Stabilized Dune Habitats***	***Wetland Habitats***
- Active dunes and foredunes - Interdunal wetlands: o Lagoons, ponds o Pannes	- Oak savanna - Dune and swale - Woodland, forested dune - Mesophytic forest	- Wet mesic savanna - Mesic prairie - Bog - Fen - Shrub swamp - Wet mesic upland forest - Emergent marsh

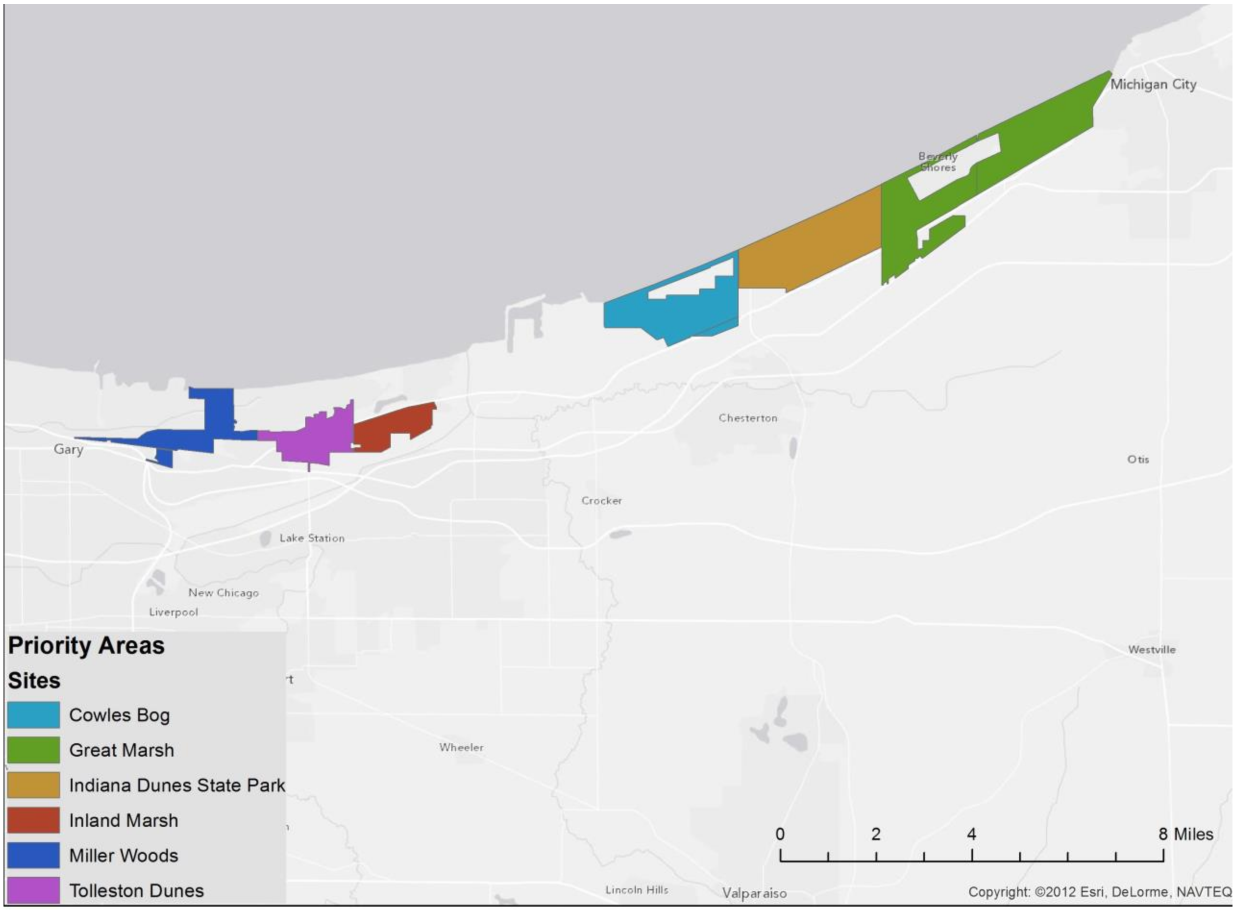


Figure 8. A map of priority areas as designated by the Indiana Dunes Ecosystem Alliance (IDEA, 2016).

Landscape fragmentation and lack of resources are the main issues that continue to impact the habitats in the Indiana Dunes region, and therefore IDEA set goals to draw more resources to various sites and to engage nearby residents in stewardship of the ecological resources of this area. IDEA proposed conducting a detailed assessment of necessary resources (e.g., funding, staff, equipment, fire, etc.) to maintain high quality habitats, and create an informative presentation and a written summary that highlights the unique ecology and importance of this area and what neighbors can do to protect it. In addition, it would be advantageous to enhance funding opportunities with endowments and work with neighboring businesses, utilities, and other regional planners in order to understand their priorities, share IDEA priorities, and seek collaboration.

Interesting or Rare Habitats and Species

Several interesting or rare habitats and species were identified by scientists from the U.S. Geological Survey and land managers from the National Lakeshore and State Park (Pavlovic and Bowles 1996). There was substantial interest in considering these habitats more deliberately when making planning, purchasing, and operating decisions within the state and federal parks because these could be particularly vulnerable as certain climate impacts are experienced (e.g., droughts, extreme heat, extreme precipitation, etc.).

Shrub swamp habitats emerged as important to consider when doing restorations for a few reasons. These are wetland systems populated by woody vegetation, are less biodiverse than other wetlands, and buttonbush (*Cephalanthus occidentalis*) and other native that provide cover for many birds. Within the Indiana Dunes State park, these habitats also contain dead ash trees, a consequence of emerald ash borer activity. Interestingly, removal of woody vegetation could expose seed banks for rare habitats.

Disjunct coast plains (Reznicek 1994) are sand deposits associated with postglacial lakes and drainage channels that migrated westward after glaciation from the Atlantic coastal plain and are dependent on drawdowns for germination of their dormant seeds. They have sandy, gravelly, or peaty emergent shores of shallow, soft-water ponds and small lakes with fluctuating water levels, or sometimes sandy, periodically flooded swales. The flora is composed of herbs and graminoids.

Ephemeral or vernal pools are small, temporary pools of water that provide ideal habitat for amphibians and some plants. Vernal pools are dependent on specific seasonal precipitation patterns – sufficient rainfall in the spring followed by a drying up in the summer. Seasonal shifts in rainfall brought on by climate change could disrupt these systems, so in July 2017, vernal pools in the Cowles Bog region of the Indiana Dunes National Lakeshore were assessed to determine their vulnerability.

Interesting or rare habitats and species in the Indiana Dunes region:

- ✓ Shrub Swamps
- ✓ Disjunct Coastal Plain
- ✓ Ephemeral or Vernal Pools
- ✓ Boreal Relict Species

Boreal relict species (e.g., white pine, jack pine, bearberry, etc.) occur in discontinuous patches throughout the region. This vegetation is better adapted to climate found in regions to the north and are being stressed by increasing temperatures and thus may require more management to maintain in the long run.

Goals

Current and Expected Vulnerabilities in the Indiana Dunes Region

Shorelines and Nearshore Regions

Lake Michigan waves and water currents affect beach profiles and coastal erosion along the shore, while wind and major storm events drives the development of the Indiana Dunes iconic sand dune complex. Changes in theses natural processes, along with lake level changes, can strongly influence the future evolution of the shoreline and resilience of the habitat succession further inland.

Recently, the National Park Service conducted an Environmental Impact Study at the Indiana Dunes National Lakeshore which resulted in the Shoreline Restoration and Management Plan (National Park Service 2014). The study analyzed shoreline segments, reviewed the history of shoreline changes and management activities, and modeled the impacts of future storm events. The study determined areas that were eroding or accreting, or were dynamically stable, and outlined alternative management actions to consider for maintaining the nearshore areas. Increases in surface water temperature in Lake Michigan can alter wave heights and longshore currents, increasing erosion of beach areas. As the lake levels increase or decrease, the amount of beach area will grow or shrink, affecting the establishment of vegetation and the amount of harm from human recreational activities.

A 2007 USGS study determined the susceptibility of the shoreline to future lake-level using a coastal change potential index, or CPI (Pendleton, Thieler, and Williams 2007). The CPI utilized geomorphology, regional coastal slope, rate and direction (e.g., rise and fall) of relative lake-level change, historical shoreline change rates, annual ice cover and mean significant wave height. The CPI highlights those regions where the physical effects of lake-level and coastal change might be the greatest. This approach combines the coastal system's potential for change with its natural ability to adapt to changing environmental conditions, yielding a quantitative, although relative, measure of the park's natural susceptibility to the effects of lake-level variation.

The study concluded that one-fifth of the length of park lakeshore has a very high lake level change potential making these areas vulnerable, most to the east of Burns Harbor, and areas from Dune Acres to Michigan City (Figure 9). See Appendix C for more specific physical impacts, analysis, and the study’s generated maps for the Indiana Dunes region.

Vulnerabilities

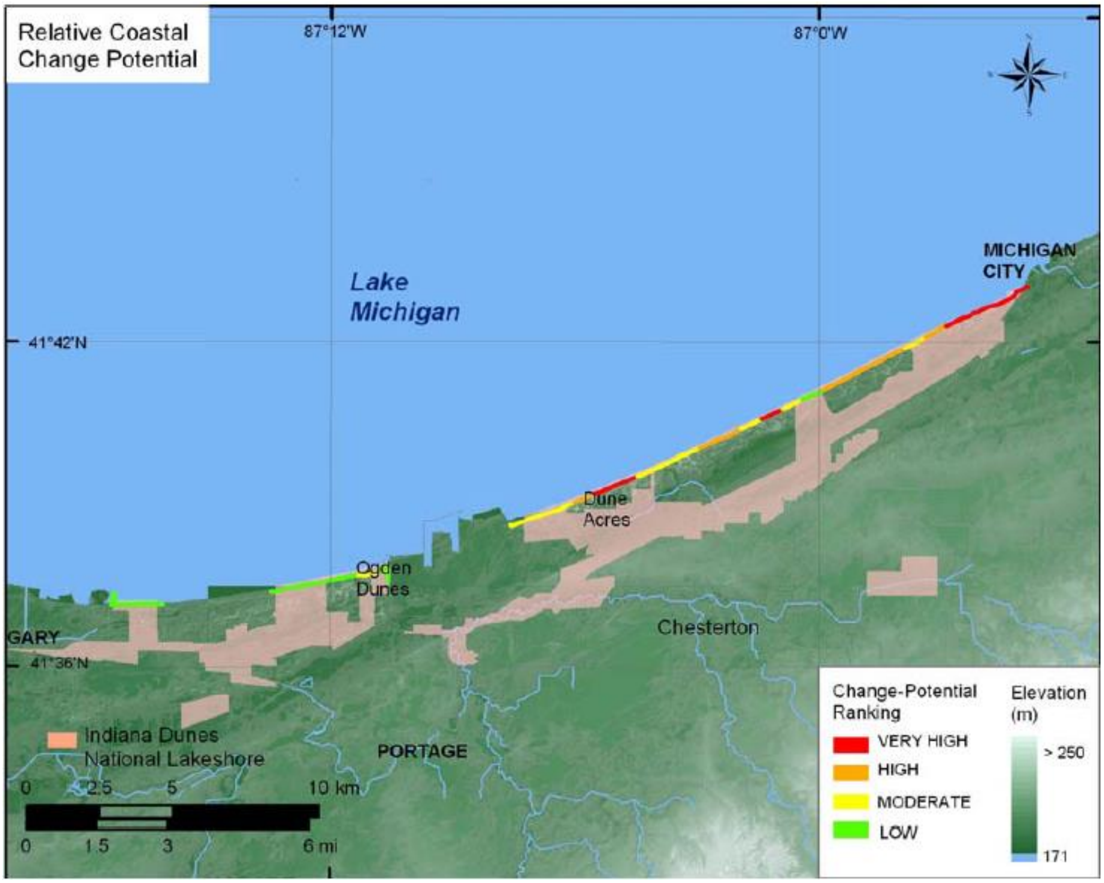


Figure 9. Relative Coastal Change-potential for Indiana Dunes National Lakeshore. The relative coastal change-potential index (CPI) is determined from the six variables - geomorphology, regional coastal slope, rate and direction (i.e., rise and fall) of relative lake-level change, historical shoreline change rates, annual ice cover and mean significant wave height. (Pendleton, Thieler, and Williams 2007; Appendix C: Coastal Change-Potential Assessment)

Invasive and Non-native Species

A considerable amount of human and capital resources are currently devoted to controlling invasive species in the state and federal parks. Future climate regimes will likely increase these challenges as invasives are capable of adapting their life cycles to earlier and more variable spring timing compared to the native species (Fisichelli et al. 2015). Of particular concern are several invasive plant species that have been extremely problematic to control in recent years (see box below).

The invasive subspecies of *Phragmites* (*Phragmites australis* spp. *australis*) is a large perennial grass that has invaded many of the wetland habitats in the Indiana Dunes region. It grows quickly and in dense communities, with extensive root systems and a tall, thick canopy which blocks the sun from other wetland plants – all effectively displacing native plant communities and compounding restoration efforts. In addition, substantial resources are needed to control the non-native grass, utilizing a combination of chemical, mechanical, and hydrologic methods, usually together. Yet a recent study of land managers found that while $4.6 million was spent annually between 2005 and 2009 to control *Phragmites* on over 80,000 hectares in the United States, there was no significant relationship between the expenditures and success (Kowalski et al. 2015).

Oriental bittersweet is a woody vine originally from Asia. This species is largely dispersed through the floral trade and then dispersed locally by birds. It resprouts from rootsuckers that result in large clone patches, and in the Indiana Dunes region, Oriental bittersweet infiltrates forests where it smothers the native host plants and girdles trees (Leicht-Young and Pavlovic 2012).

Many invasive plants have symbiotic relationships with fungal endophytes and understanding these relationships may improve the management techniques used to control the plants by disrupting host plant/endophyte interactions (Clay et al. 2016; Kowalski et al. 2015). In 2013, the U.S. Geological Survey and the Great Lakes Commission initiated the Phragmites Symbiosis Collaborative, or PSC, (https://www.greatlakesphragmites.net) to advance research on microbial-based approaches for the control of *Phragmites*. The website is a good resource for reviewing the pros and cons of all currently used management techniques for controlling and monitoring *Phragmites*.

Invasive species currently threatening habitats in the Indiana Dunes region:

- ✓ Common reed (*Phragmites australis* spp. *Australis*), a large perennial grass
- ✓ Oriental bittersweet (*Celastrus orbiculatus*), a woody vine
- ✓ Black locust (*Robinia pseudoacacia*), a deciduous tree
- ✓ Japanese barberry (*Berberis thunbergii*), a deciduous shrub
- ✓ Garlic mustard (*Alliaria petiolata*), a herbaceous biennial plant
- ✓ Purple loosestrife (*Lythrum salicaria*) is a herbaceous perennial plant
- ✓ Bush or Amur honeysuckle (*Lonicera maackii*), a deciduous shrub
- ✓ Spotted Knapweed (*Centaurea maculosa*), a perennial flowering plant
- ✓ Japanese or Asian Knotweed (*Fallopia japonica*), an herbaceous perennial plant
- ✓ Narrow-leaved cattail (*Typha angustifolia*) and hybrid cattail (*Typna x glauca*), a large herbaceous perennial plant
- ✓ Crownvetch (*Securigera varia*), a legume vine
- ✓ Glossy buckthorn (*Rhamnus frangula*), a shrub

Vulnerabilities

Landscape Fragmentation

Fragmented habitats have a lower overall biodiversity and decreased resilience to disturbance because species are unable to migrate into or out of inappropriate habitats or maintain the genetic diversity found in larger populations (Opdam and Wascher 2004). As changes in community composition and structure occur under climate change, organisms are differently affected - birds can seek out new habitats, while plants and some animals are less capable of relocation.

Habitat fragmentation has been an issue in the Indiana Dunes region for decades and could seriously limit adaptation options if not considered carefully as part of the land management planning process. The fragmented landscape reduces wildlife corridors that can greatly improve biodiversity and adaptation options. In addition, the landscape is made up of a mosaic of industrial, municipal, and natural areas that are in close proximity to each other, acting to aggravate existing issues that threaten natural area restoration and conservation. For example, regional hydrology and water quality continue to be modified and stressed by local industry, particularly the steel mills and the multiple railway lines that cross through the entire region. Local industry also contributes to poor air quality and, along with emissions from car and truck traffic, adds to regional nitrogen deposition, which has the potential to boost vegetation blooms when accompanied by heavy rains and higher atmospheric CO_2. Transportation right-of-ways (ROWs), storm water management structures (e.g., ditches, man-made channels), and runoff from urban development help to promote the introduction and establishment of non-native species.

Threats to Humans

People who live near, work around and within, or visit the parks have several exposures that were identified given the future climate scenarios. Higher spring and summer temperatures increase physical stresses on the human body, and the projected extreme temperatures could pose severe health crises, particularly in young children, the elderly, or those with illnesses. Personnel doing work outside, such as park managers, rangers, and seasonal interns, are expected to become increasingly susceptible to heat stress. Seasonal shifts in and heavier rainfall events along with increasing temperatures in the region are conducive to greater reproduction of disease vectors such as ticks and mosquitoes (Wuebbles and Hayhoe 2004), creating health risks for those who live and work in the area. The timing and numbers of visitors to the park will shift with early spring onset and longer falls, but there could also be a decrease in winter tourism as lake effect precipitation shifts away from snow. Law enforcement (LE) or Resource and Visitor Protection personnel for the parks could have increased workload due to heat-related incidents, an expanded visitor season, and overall increase in peak visitation numbers. Increasing flooding or decreasing water quality could affect fishing permits, or boating and other recreation that depends on healthy streams, canals, and lake access.

Annual park maintenance activities are expected to be affected by longer growing seasons and increase in visitation, as well as indirect meteorological events that are influenced by increasing surface water temperatures on Lake Michigan. Wind driven sand dune movement affects parking lot clearing activities in the spring.

Aging infrastructure at the park requires significant resources to improve or maintain, but can also affect the ability of park personnel to access areas of the park to perform other duties. An increase in the magnitude and duration of precipitation events can cause road washouts, and in conjunction with an increases in Lake Michigan water levels, can trigger flooding that makes roads impassable, in addition to disrupting or destroying habitat.

Adaptation Options and Strategies

Adaptation Categories

Climate change adaptation options will generally fall under three categories: resistance, resilience, and transition. These categories denote a balance between the response to climate change impacts and the future ecosystem conditions – a land management trajectory. Resistance preserves an unchanging ecosystem by protecting it from disturbance, resilience enhances the ability of an ecosystem to absorb disturbance and return to its original condition, and transition enables a system to adaptively respond to changing conditions. It's important to consider land management goals and choose the adaption options that are aligned with those goals. Accordingly, resistance and resilience activities emphasize management for the persistence of existing habitats, while transition actions promote ecosystem change Figure 10).

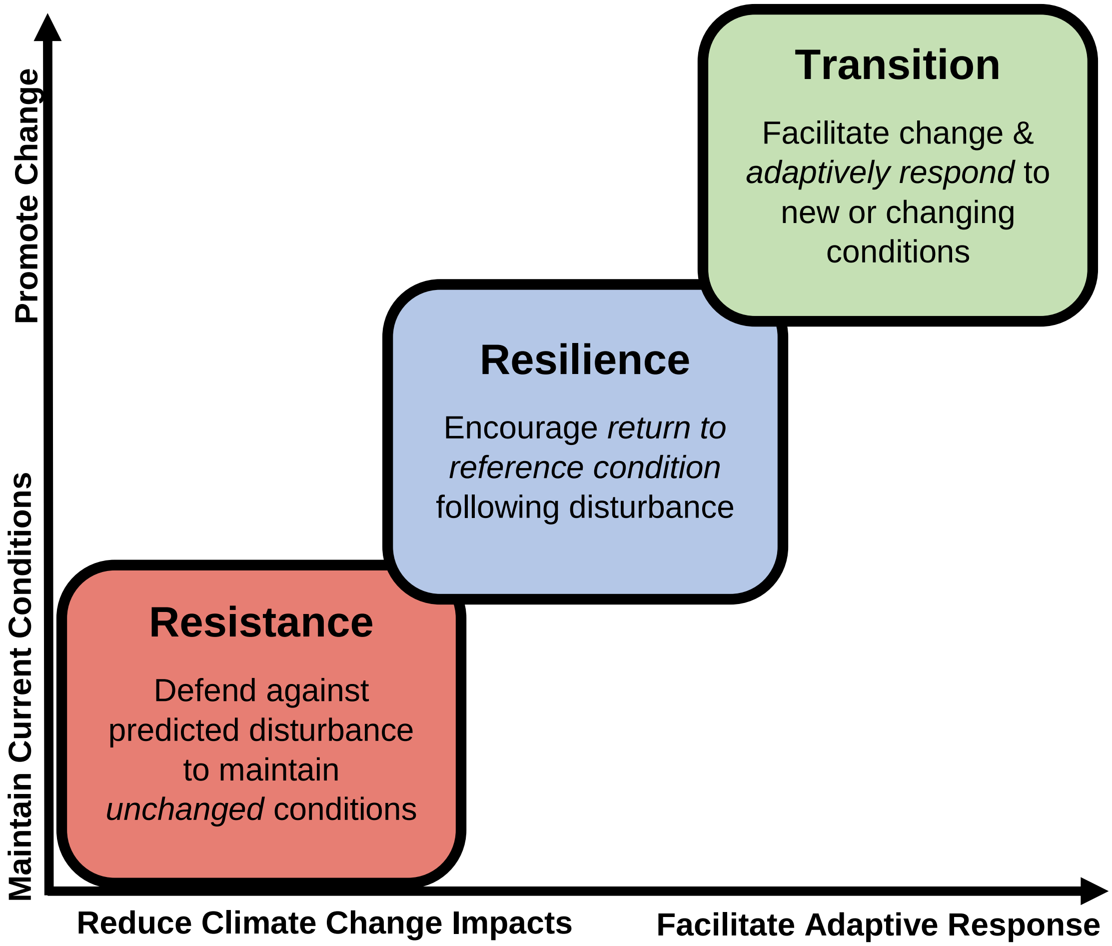


Figure 10. Climate change adaptation options are categorized by the balance between response to impacts and the resulting future conditions. Figure modified from the USDA Climate Change Response Framework.

Land management goals for specific habitats must be aligned with the adaptation options best able to address the region's climate change vulnerabilities. To assess the success of the adaptation choices, it is crucial to regularly monitor the habitats, determine the effectiveness of the actions that are taken, and adjust ongoing and future actions where appropriate. This may require changes in land management goals and assessing the appropriate climate change adaptation category.

This plan presents a set of proposed adaptation strategies assembled from the researchers and land managers who contributed to the project. It is intended to be a guide for land management into the future and to reflect the wealth of knowledge and resources found in the region. It is not a recommendation or endorsement for preferred actions. Local expertise and updated information will need to be combined with the information in this plan in order to select appropriate actions.

Resistance to climate change involves strategies that preserve an unchanging ecosystem by protecting it from disturbance. Choosing resistance as the primary adaptation option makes sense only when land management goals clearly state a preference for high-value systems or species that are vulnerable to climate change impacts (e.g., boreal species). These strategies may only be feasible in the short term as maintaining ecosystem protections may require significant resources that will continue to increase and may even reach a threshold that causes the ecosystem to eventually collapse. For example, choosing to protect the Karner blue butterfly and to enable it to resist future disturbance in the Indiana Dunes may require substantial resources and ultimately fail anyway as the ecosystem reaches a threshold from which it cannot recover.

Resilience involves strategies that enhance the ability of an ecosystem to absorb disturbance to climate change and recover, returning to prior conditions after a disturbance. Choosing resilience as the primary adaptation option makes sense when land management goals are aligned with preserving the current ecosystem functions (e.g., high biodiversity). Future habitats may not look exactly like the current ones, but they will be similar in composition and function. Managing the ecosystem to cope with climate disturbance may not be resource intensive at first, but the system may not be able to recover from ever increasing disturbances long term.

Transition actions intentionally accommodate change and enable an ecosystem to respond in a deliberate way to disturbances. Choosing transition as the primary adaptation option makes sense when land management goals embrace an evolution in habitats that results in a suite of ecosystem functions that are better suited to future conditions. The ecosystem complexes that exist in the Indiana Dunes may allow for adaptive strategies that maintain desired functions and values even as individual habitats are altered. Transition strategies are long term in nature and require that actions take place before climate change impacts occur.

NOTE: Adaptation options that are presented in the tables throughout this plan will be divided by type and then arranged to go from resistance, to resilience, and finally transitional strategies. Some options can span all three categories depending on how specific actions are applied.

Example:

Resistance – create and maintain refugia

Resilience – enhance biodiversity

Transitional – created, deeper wetlands

Adaptations

Shifts in Land Management Paradigm

The future of the biodiversity comprising the many ecosystems in the Indiana Dunes is of immense concern as the impacts of climate change are uncertain. Additionally, the range of land management activities (i.e., controlling invasive species, restoring native vegetation, maintaining ecosystem health) that are needed to achieve long-term biodiversity conservation goals frequently exceeds the resources that are available. Therefore, the land management focus at the Indiana Dunes may need to shift perspective in response to climate change in order to restore certain habitats, such as prairies.

For example, much thought has been put into how to increase prescribed burning, but with drier and hotter conditions there is the possibility of more frequent and hotter fires occurring. The need to allow space for flexible thinking about how fire is used in the future is crucial. Additionally, park managers should be selecting target habitats across the whole spectrum of habitat systems, not just individual habitats (e.g., the gradient of wetland-prairie-savanna).

To respond to these impacts, and given the resource limitations of the parks, the Indiana Dunes region would benefit from a change in land management paradigm that recognizes ecosystem function that is better suited to the changing moisture regimes. In addition, it is important to determine how to prioritize rare habitats and species moving forward. To achieve these outcomes, land managers may employ a combination of heavily managed to hands-off approaches. High quality or rare habitats and species will require intervention to allow them to persist, while other areas will need to have a directed transformation approach to improve habitat resiliency.

The impacts from climate change will require us to think of the land management goals for the region through a different lens. For example, how important are the boreal relics and which ones need to be able to shift north because the gradient north is important? How important is jack pine in the successional process at the dunes, and is it necessary to have this species for succession to occur? Jack pine exists in the Indiana Dunes region because they are long-lived and they have persisted because of the moderating effect of the Great Lakes. What role do they play structurally, and what is the importance of letting them leave the area to join the healthy, robust systems to the north. Though the species may be rare in the Indiana Dunes region, that doesn’t mean it is rare everywhere. Is there a reason we are conserving it in this region?

Changes in habitats in the region have already presented viable options and new challenges for rethinking management goals. For example, emergent marsh habitat that was being maintained by reducing woody cover in willow and button bush dominated systems could instead shift to trying to save the shrubs in these habitats. Assuming a habitat has been a shrub swamp and wet for a long time, then it could be possible that beaver dams are already contributing to keeping these habitats wet.

This new approach, however, results in questions about what to do with the beaver since simply targeting beaver for reduction may upset the hydrology that supports the buffer and natural solution to keeping wetlands hydrated. Yet there are important differences between habitats in the state and national parks. Large portions of the Indiana Dunes State Park are and were wetlands prior to increased beaver activity within the dunes ecosystem. The current strategy is to control beaver populations within the nature preserves as they have negative impacts on visitor use and safety of the property (i.e., flooding of trails and roadways).

Given the complexity of the current habitats and the climate impacts expected in this region, a wide variety of habitats and niches should enable changes to occur while promoting resiliency in the landscape. On the other hand, habitat and species redundancy is equally important for promoting resiliency. For example, habitat disturbance, such as blowouts, would not result in a total loss if the species or habitat exists elsewhere.

Prescribed Fire

Should the parks shift their burn regime? Are the only options to wait for first frost, or go ahead and burn as usual and see how that affects habitats? The many fire related issues and the questions they raise make it clear that land managers would benefit from not only considering how a changing climate will affect their current burn regimes, but by rethinking how prescribed fire is used as a strategy to attain new conservation goals under climate change.

Climate change has already increased fire risk in North America, particularly in the western forests where there will be an increase in the number of years with high fire danger, an increase in the length of season with fire risk and an increase of extreme events during the fire season that could result in larger, more intense and more frequent fires. While Midwest forests are not expected to suffer from the worst of these extremes, increasing temperatures and shifts in precipitation have the potential to profoundly influence the use of prescribed fire.

There is a backlog of areas that need to be burned in the Indiana Dunes region due in part to shifting and shrinking seasonal burn windows. Fire suppression, especially in forests, disproportionally favors certain species and reduces overall biodiversity (Nowacki and Abrams 2008). Fire-adapted ecosystems depend on disturbance of natural fire regimes to maintain the complexity and competition needed to remain resilient.

Increasing temperatures and shifts in precipitation have the potential to profoundly influence the use of prescribed fire in the Indiana Dunes region. There must be adequate soil moisture to protect the root zone of plants and soil microorganisms during a fire and the fire should be controlled to preserve a thin layer of organic material in order to minimize erosion in the area. Prescribed burning during periods of drought can be difficult because plants are more stressed than usual and the fire can spread to unintended areas. Increasing temperatures bring an increase in fire intensity, which can drive a system from savanna to prairie. The burn plan for the Indiana Dunes State Park, for example, has weather conditions that must be met – ambient air temp 70°F – because burning at or above 80°F will kill canopy trees and will change the structure of the savanna, shifting marginal savannas into prairies and creating larger openings than were intended. Finally, it is possible there will be phenological mismatches between plants and animals that could impact animal populations that are dependent on the vegetation (e.g., pollinators, birds, etc.).

A paleoecology study of white pine and oak forests in northwest Wisconsin found that wildfire frequency and intensity may increase with climate change but future fire regimes will also be strongly influenced (dampened) by habitat fragmentation and modern fire-containment capability (see box below, Duveneck et al. 2014). The effect of alternative management regimes and climate adaptation efforts on different soil types may be the most significant predictor of future forest composition changes.

A paleoecology study of white pine and oak forests in northwest Wisconsin (Duveneck et al. 2014) found that wildfire frequency and intensity may increase with climate change but future fire regimes will also be strongly influenced (dampened) by habitat fragmentation and modern fire-containment capability. Principles include:

- ✓ Soil attributes and the landscape context constraining fire behavior shape forest response to climate changes and disturbance even at very local scales
- ✓ Soil differences are important influences on vegetation response to climate change
- ✓ Encourage stratification of forest research and monitoring across soil types to develop consistent baseline and trend data

In the Indiana Dunes region, prescribed fire can be used in forests to target ladder fuels and understory competition. It may be beneficial to encourage drought-adapted species in areas that are vulnerable to drier conditions in the future. In addition to targeting forest composition, fire is used to maintain prairie and dune and swale habitats and to combat invasive species in many wetlands in the area. Prairie and oak savannas have been opened up in recent years, and fire will continue to play an important role in maintaining an open canopy.

Climate change is already shifting burn windows seasonally, so it may be necessary to burn earlier in the spring in order to minimize shifts in the community structure. Prescribed fire in late autumn is usually based on the first signs of winter (e.g., the first frost, oak leaf drop). This means that historically a burn would occur in mid-November, but the first frost is increasingly occurring later in the year. Shifts in prescribed burning may need to line up with late season precipitation. Furthermore, leaving small patches unburned, especially in microhabitats, can create climate refugia.

Using prescribed fire, land managers can balance protecting some areas with accommodating an evolution in habitat structure that is a more drought and fire-tolerant community. These approaches would facilitate the gradients or continuum of habitats that are more resilient, biodiverse, and better suited to future climate conditions.

Landscape Connectivity

Managing landscape connections can enhance biodiversity and ecosystem resilience by improving species range shifts and expanding the sizes of ecological communities, which withstand disturbances more effectively (Opdam and Wascher 2004). Different species and habitat types will have specific requirements – birds are more mobile than trees, for example, so the selection of specific actions to be taken in the Indiana Dunes region will benefit from determining the alignment with land management goals.

The Northwest Indiana Regional Planning Commission (NIRPC) has increasingly been taking climate change forecasts and impacts into consideration during region-wide planning. Additionally, an innovative geographical information system (GIS) project using CircuitScape software is being conducted by the USGS Lake Michigan Research Station. The maps generated specifically for the Indiana Dunes region and used during the adaptation planning workshops show regional landscape pinch points, redundant pathways, and potential connectivity (Figure 11). Continuing this and other connectivity mapping projects will greatly improve the information needed by land managers. Identifying the best migration corridors is the first step in selecting actions that can improve biodiversity and make habitats more resilient. Restoring native vegetation in degraded patches of a wider landscape matrix can fill in areas that currently block or inhibit movement. In addition, expanding current nature reserves that are adjacent to smaller habitat blocks can greatly improve connectivity. Finally, park managers and area planners could reach out to municipalities, residents, and other developed properties in contact with park boundaries to modify easements to retain native vegetation and improve overall connectivity.

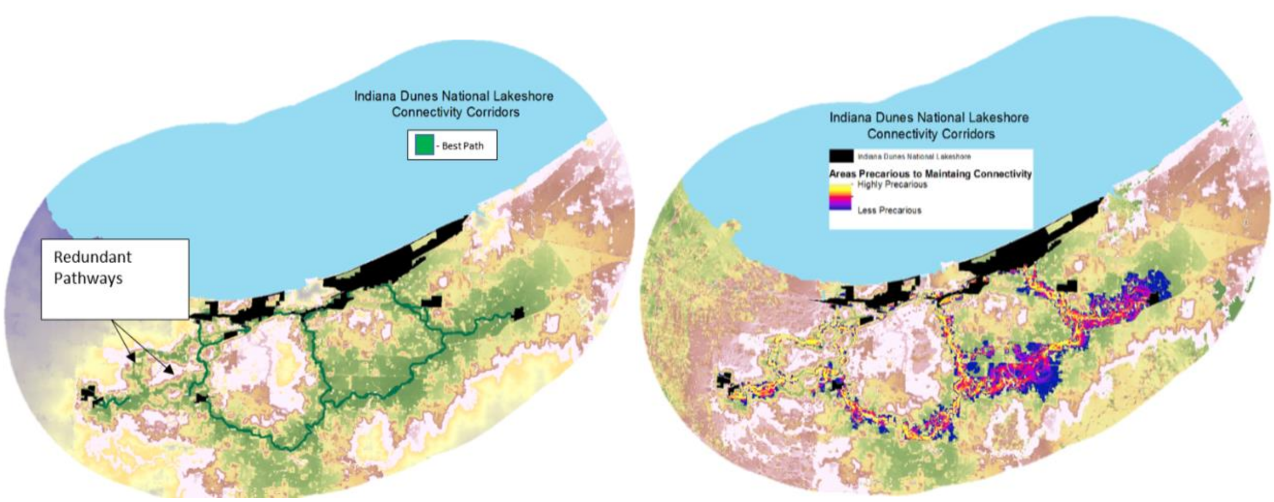


Figure 11. CircuitScape generated maps for the Indiana Dunes region, used during Workshop II for the adaptation planning process (courtesy Lindsay Hunt, U.S. Geological Survey).

Infrastructure and Park Management

Park managers would benefit from being more nimble when dealing with big changes. The goal would be to become less reactive to individual incidents and take a big picture perspective. To achieve this, it is important to assess resource needs that are also changing – are we adequately prepared? Consider the Wildland-Urban Interface (WUI), or zone between natural and developed areas. What is emphasized for stewardship? What are the current drains to annual resources? For example, beaver management tends to demand a lot of time and money, but the end goal could be better defined in collaboration with other long-term stewardship goals, especially as climate impacts add to management needs. The public looks to the park for answers regarding increased wildlife issues, etc., and planning would contribute to finding those answers.

There may also be a need for significant changes to infrastructure in order to maintain a safe and enjoyable experience for staff, visitors, and residents of nearby communities. Roads that are washed out or vulnerable to future flooding would benefit from repair, redesign and/or relocation to allow staff to access natural areas. Regional hydrology has been significantly altered with industrialization and development over several decades, therefore a return to a regional, natural flow regime is extremely unlikely. It would be beneficial to upgrade culverts and ditches to manage a wider range of flow levels that are likely with the projected increase in heavy rainfall events.

Park managers may consider preparing for and communicating to the public and surrounding communities the many threats to human health posed by the changing climate. For example, extreme heat during the summer months will affect hikers and beach goers, there are increasing risks from tick-borne diseases, and interactions with wildlife are increasing as well. Information should include how to best decrease exposure to these threats and how the park staff can assist visitors.

Regional Adaptation Options

NOTE: Adaptation options that are presented in the tables throughout this plan will be divided by type and then arranged to go from resistance, to resilience, and finally transitional strategies. Some options can span all three categories depending on how specific actions are applied.

Example:

Resistance – create and maintain refugia

Resilience – enhance biodiversity

Transitional – created, deeper wetlands

Table 2. Adaptation Options and Strategies for the entire Indiana Dunes Region

Adaptation Option	Strategies
Utilize downscaled climate model outputs	The Indiana Climate Change Assessment modeling project is ongoing and may have regular updates. Explore data output and model analyses from other regional universities and research centers.
Re-prioritize restoration and conservation projects	Combine regular environmental monitoring with research reviews and climate model forecasts to re-prioritize projects.
Monitor and communicate environmental conditions	Set up a system of alerts and actions (e.g., close trails, stay inside) to protect staff, residents, and visitors from extreme conditions (e.g., flooding events, heat stress). Monitor threats from wildlife and be proactive in communicating to the local community the appropriate responses.
Adjust staff planning	Connect with university or non-profit studies of tourism shifts expected in the area due to climate change and incorporate the results into personnel planning.
Increase seasonal park staff	As the growing season shifts and gets longer, more personnel are needed to control invasive plants, clear trails and roads, manage an increase in visitation, etc.
Coordinate land management planning within the region	Continue and increase coordination between local, state, federal, and non-profit agencies to ensure land management strategies are synchronized and landscape connectivity is improved: ❖ NIRPC 2040 Regional Comprehensive Plan targets regional stakeholders to integrate transportation, land use, economic, and environmental objectives. ❖ The Nature Conservancy, Shirley Heinze Land Trust, U.S. Army Corps of Engineers, and others have land acquisitions and/or restoration work in neighboring or nearby areas. ❖ Chicago Wilderness Green Infrastructure Vision (GIV), targeted at improving hydrology and biodiversity (e.g., wildlife corridors, pollinator habitats, etc.) throughout the tri-state region (Northwest Indiana, Chicago, and Southwest Wisconsin).

Table 2. Adaptation Options and Strategies for the entire Indiana Dunes Region (continued)

Adaptation Option	Strategies
Expand regional mapping projects	Expand USGS CircuitScape GIS mapping project to include migration paths and range shift into and out of the Indiana Dunes parks and immediately surrounding communities. Update mapping of constricted corridors for migration as regional planning and land purchases change landscape connectivity. Connect mapping projects to other regional mapping for wildlife corridors, green infrastructure, and stormwater projects.
Adjust infrastructure planning	Work with researchers to improve modeling the impacts to infrastructure, and consider the best available science to minimize impacts or improve durability over the lifespan of the infrastructure.
Modify the *timing* and *nature* of prescribed fire	Assess the timing of prescribed fire as the growing season shifts earlier and later. Adapt the nature of the burn (intensity and duration) to the new climate conditions. Adjust fire management protocols to create refugia, to create new habitats, and to preserve vulnerable species (e.g., boreal, etc.)

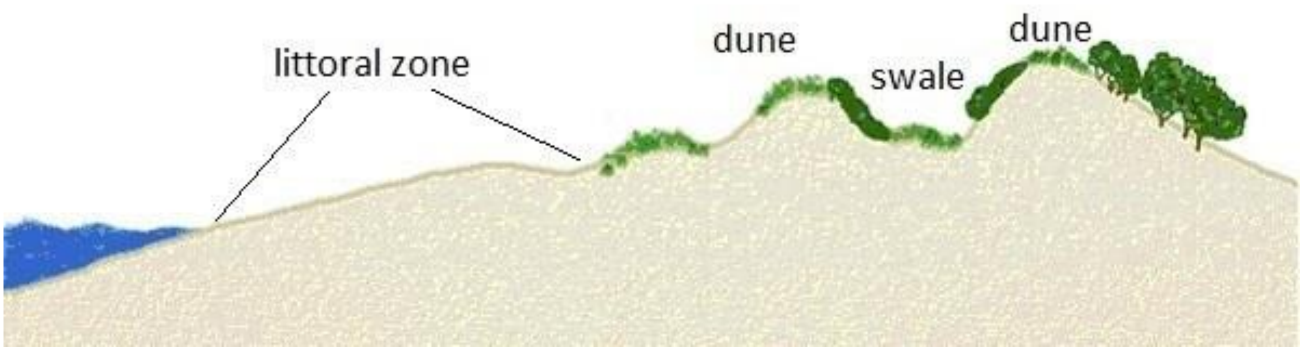
TERRESTRIAL COMMUNITIES

Dune and Swale Complex

There are several distinct communities that encompass the ecological succession of the dune and swale complex of the Indiana Dunes region including:

- Foredune
- Interdunal wetlands
- Forested dune ridges and swales
- Lagoons

These communities can be found in Miller Woods, Cowles Bog and the Indiana Dunes State Park. Near shore Interdunal wetlands, like pannes, are an extremely rare wetland community threatened by the invasion of non-native or invasive plant species that could be further threatened by climate impacts. In addition, cool microhabitats that act as a refuge for boreal species could be threatened by increasing temperatures.



Climate Scenarios Relevant to Dune and Swale Habitats

Warmer temperatures
- ✓ Warmer, drier conditions in the growing season
- ✓ Plant heat zone shifting from 5 to 7

Wetter winter / spring and drier summer
- ✓ 14 to 22% increase in winter / spring precipitation
- ✓ 17 to 23% increase in winter / spring runoff
- ✓ Longer dry periods between precipitation events

Lake Michigan surface water temperatures increasing
- ✓ Less shelf ice
- ✓ Lake level changes, an increase in variability

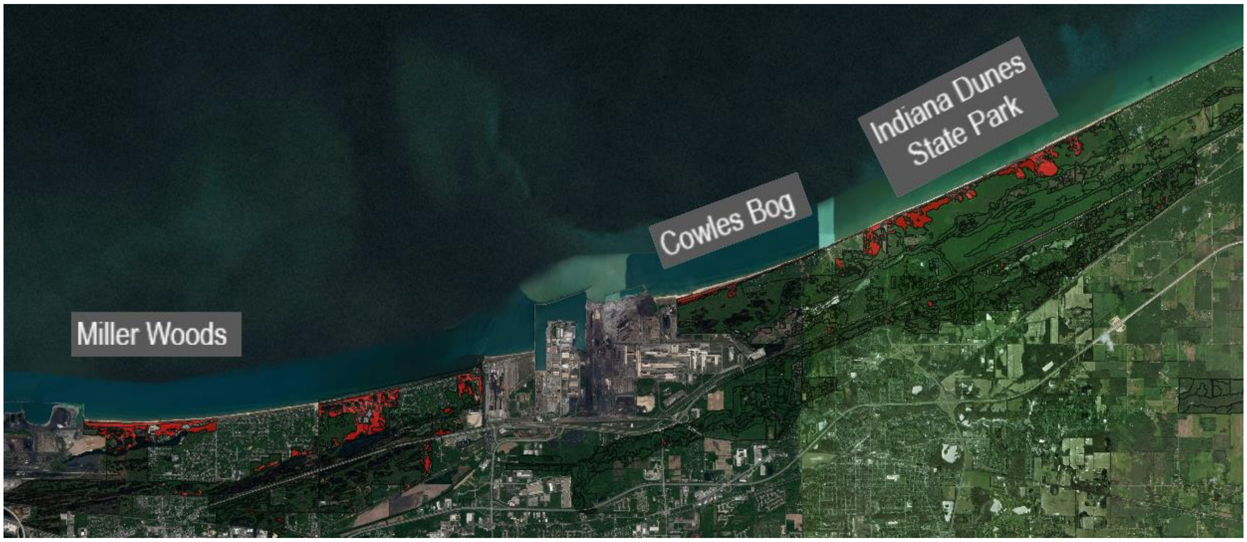


Figure 12. Dune and Swale Habitats in the Indiana Dunes Region

Climate Impacts and Vulnerabilities

Table 3. Projected Climate Impacts and Vulnerabilities for Dune and Swale Habitats

Direct Impacts

Climate Stressor	Impacts / vulnerabilities
Increase in air temperature and seasonal shifts in precipitation	Higher air temperatures could favor Phragmites invasions in swales, increasing the difficulty in controlling the spread. Some areas could shift to a more drought tolerant plant community structure, including more C_4 (warm season) grasses. Swale tree productivity could be negatively affected by extreme heat and seasonal precipitation shifts.
Increase in mean air temperature	Plant species with preferred lower temperature ranges will suffer – white pines and other boreal relics are more vulnerable to heat.
Extreme air temperatures	Temperatures could exceed the tolerance range for some species (e.g., bumblebees).
Drought and heat	Some wetlands may dry up, especially pannes and vernal pool habitats, and adjacent wetlands influence those inside the parks: ❖ A panne in Marquette Park is outside the National Lakeshore boundary, but the city has few resources to manage and maintain this habitat.
Change in lake water levels	There could be a loss of beach area and / or foredune habitats.
Increase in winter air temperature and loss of lake ice	Loss of beach ice can result in an increase in soil erosion, blowing sand farther inland. Strong winds cause an increase in wave height along the coast, increasing beach erosion.

Table 3. Projected Climate Impacts and Vulnerabilities for Dune and Swale Habitats (continued)

Indirect Impacts

Climate Stressor	Impacts / vulnerabilities
Increase in air temperature and seasonal shifts in precipitation	There may be a loss of microhabitats that typically occur along the slopes between dune and swale. Unchecked growth of some invasive plants can destabilize sand banks. ❖ Japanese knotweed is taking over areas near West Beach in Miller Woods. The loss of trees in swale habitat decreases canopy cover and leaf litter needed to maintain vernal pools habitats.
Increase in air temperature, seasonal shifts in precipitation, extreme temperatures	Endemic plants already weakened by predation from insects and/or birds are more vulnerable to other climate impacts. ❖ Pitcher's thistle, *Cirsium pitcher* (Figure 13) is endemic to the Great Lakes region. Confined to open sandy soils along the lakefront, it is currently stressed by insects and birds. It is vulnerable to the loss of mutualistic insect-plant interactions, such as pollination. Some pollinators, such as bees, are negatively affected by increases in air temperature, especially extreme heat, decreasing their populations and activities and reducing Pitcher's thistle reproduction.

Figure 13. Pitcher's Thistle (photo: Environmental Protection Agency)

Adaptation Options

NOTE: Adaptation options that are presented in the tables throughout this plan will be divided by topics (Ecology, Hydrology, etc.) and then arranged to go from resistance, to resilience, and finally transitional strategies. Some options can span all three categories depending on how specific actions are applied.

Example:

Resistance – create and maintain refugia

Resilience – enhance biodiversity

Transitional – created, deeper wetlands

Table 4. Adaptation Options and Strategies for Dune and Swale Habitats

Ecology

Adaptation Option	Strategies
Monitor ecosystem for climate change impacts	Design and implement a monitoring protocol to evaluate climate change effects on local plants and animals (e.g., US Geological Survey Natural Resources Protection Program, The Nature Conservancy Conserving Nature's Stage, etc.).
Increase microhabitat sizes for refugia	Maintain large microhabitat patches that provide a range of moisture and temperature gradients to allow species to find appropriate microclimates for survival when faced with increased temperatures, changes in precipitation, wind, etc.
Seed bank vulnerable plant species	Store genetic material, or seeds, of white pines and other boreal relict species (e.g., US Geological Survey and NPS, Chicago Botanic Garden, etc.).
Use assisted migration to preserve climate sensitive species	Use assisted migration and other tools to guide the strategic framework for maintaining climate sensitive species in highly fragmented or isolated areas, or for which suitable habitat may no longer occur (i.e., Vitt et al. 2010).
Distribute native / early establishing plants to help stabilize sand dunes	Continue to incubate and distribute seeds for use in stabilizing dunes.
Monitor species range shifts that impact the region	Implement early detection and rapid removal - a "watch list" - of coming species, such as non-native, exotic, or invasives from areas to the south.
Replace lost trees with native species	Plant native trees along river/stream banks and riverine areas, especially where significant loss of trees has occurred.
Modify canopy thinning operations	Some tree canopy and understory growth is needed to maintain the shade that sustains vernal pools and other wetlands that are breeding areas for amphibians, etc. Less "thinned" habitat can serve as refugia from extreme heat and provide a gradient of microhabitats. Leave some areas untouched during thinning activities (e.g., mechanical cutting, prescribed fire, etc.) to preserve these types of habitats.

Table 4. Adaptation Options and Strategies for Dune and Swale Habitats (continued)

Ecology (continued)

Adaptation Option	Strategies
Use redundant planting strategies to enhance survivability	Plant seedlings or seeds for a target species at a variety of locations that offer different conditions (e.g., shading, slope, soil type, etc.) to increase the odds for some protection and thus survival after a disturbance. ❖ Intentionally plant Pitcher's thistle in areas nearby to increase redundancy in areas with more appropriate habitat, since some current habitat is changing to more little bluestem and less open sand.
Intentionally enhance disjunct coast plain habitats	Open up areas with the sand deposits associated with postglacial lakes and drainage channels. These disjunct coastal plains have sandy, gravelly, or peaty emergent shores of shallow, soft-water ponds and small lakes with fluctuating water levels, and the flora is composed of herbs and graminoids (Reznicek 1994).
Consider planting hybrid cultivars	Use hybridized cultivars in areas where they are better suited to future climate stresses, like new water and temperature ranges (e.g., Marram grass, etc.).

Landscape Connectivity

Adaptation Option	Strategies
Coordinate land management actions with regional stakeholders	Work closely with regional planning groups and municipalities to ensure coordination of purchasing and land management actions in property that is adjacent to the parks.
Utilize river corridors to provide large-scale connectivity	Improve the connectivity of wildlife corridors by reviewing land management actions that utilize rivers to connect similar habitat throughout the region.

Hydrology

Adaptation Option	Strategies
Coordinate river-related actions to improve large-scale hydrology	Coordinate land management actions with other stakeholders in the region that have access to rivers in developing a region or large-scale hydrology plan.
Fill ditches to modify hydrology and keep wetlands hydrated	Fill ditches to re-route surface water flow back over the land and allow for more infiltration. ❖ The Nature Conservancy land managers have had success filling ditches in areas to the south of the region.
Redesign landscape to alleviate flooding issues	Identify and map where there are issues of flooding and where high quality restorations are taking place and redesign landscapes to alleviate these issues.

Table 4. Adaptation Options and Strategies for Dune and Swale Habitats (continued)

Hydrology (continued)

Adaptation Option	Strategies
Incentivize wetland creation	Work with planning and policy agencies to create or restore wetlands. Ensure wetlands are part of the gradient of habitats in an urban-to-natural ecosystem paradigm.
Use equipment to create deeper vernal pools	Dig out areas to create a deeper and wider than natural basin in order to retain more water during higher precipitation events and/or bring them in contact with groundwater. This could be a good pilot project at several sites and/or working with US Army Corps of Engineers for mitigation opportunities.

Infrastructure and park management

Adaptation Option	Strategies
Monitor weather and air quality	Set up a regular system of alerts and actions (e.g., close trails, stay inside) to take to protect staff, residents, and visitors from extreme conditions (e.g. flooding events, heat stress).
Increase seasonal staff	As the growing season shifts and becomes longer, more personnel are needed to control invasive plants, clear trails and roads, and manage an increase in visitation.
Evaluate future personnel scheduling based on changing demographics	Connect with university or non-profit studies of tourism shifts expected in the area related to climate change and incorporate the results into personnel planning.
Redesign park structures to alleviate flooding issues	Identify and map where there are issues of flooding and where there are high quality restorations going on and redesign park structures (e.g., roads, bridges, buildings, etc.) to alleviate these issues. Remove or redesign roads as a raised structure so that flooding will not affect the wetlands.
Incorporate climate model projections into infrastructure lifespan	Work with researchers to improve modeling the impacts to infrastructure, and consider the best available science to minimize impacts or improve durability over the lifespan of the infrastructure.

Figure 14. Dune and swale habit from the Miller Woods trail looking north towards Lake Michigan (left) and a foredune from the Cowles Bog trail looking west towards Burns Harbor (right). Photo credit: Katherine Moore Powell.

Prairie and Oak Savanna Continuum

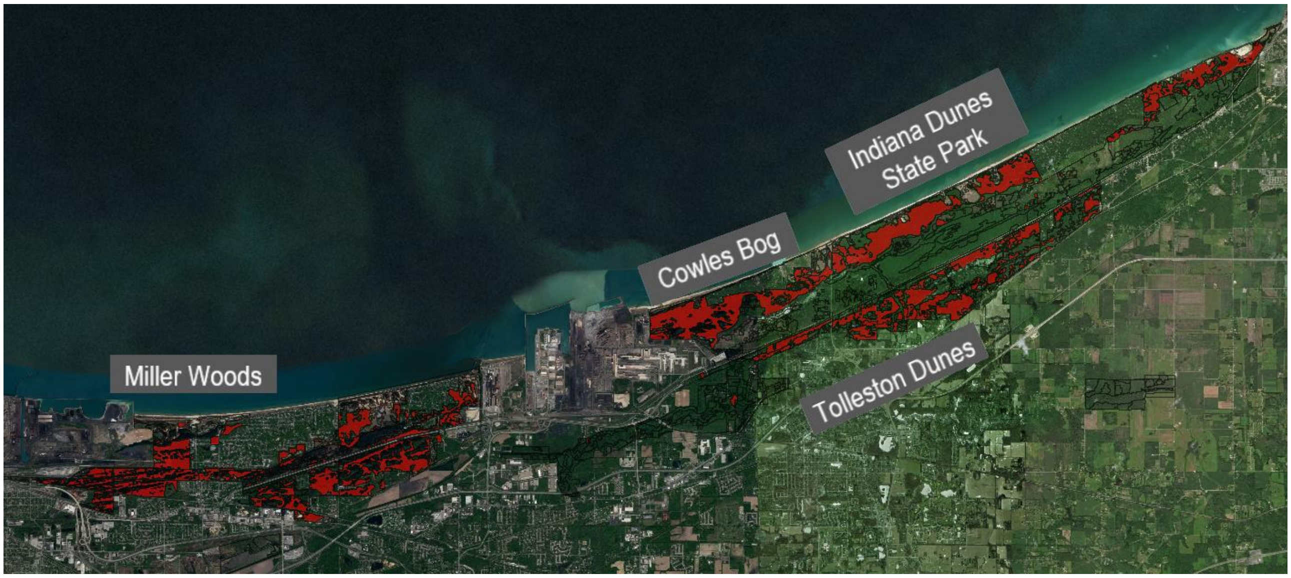


Figure 15. Prairie and Oak Savanna Habitats in the Indiana Dunes Region

The oak savanna complex exists further from the shores of Lake Michigan in the Indiana Dunes region, and these habitats are on a soil moisture continuum with prairies at the drier end of the spectrum. They are divided into:

- Prairie
- Oak savanna
- Woodlands/forested dunes

Prairie and oak savanna habitats are found in Miller Woods, Tolleston Dunes, Cowles Bog and the Indiana Dunes State Park. The IDEA group set a priority to establish relationships with adjacent landowners and municipalities to acquire the remaining parcels of savanna habitat that are located in the Inland Marsh/Tolleston Dunes region and are within and adjacent to the park boundary.

Figure 16. Trail through Miller Woods oak savanna and view of Mnoke Prairie (photos: Katherine Moore Powell, left, and Alex Zaideman, right)

Climate Scenarios Relevant to Prairie and Oak Savanna Habitats

Extended growing season – earlier springs and later falls

Warmer temperatures
- ✓ Warmer, drier conditions in the growing season
- ✓ Plant heat zone goes from 5 to 7

Wetter winter / spring and drier summer
- ✓ 14 to 22% increase in precipitation
- ✓ 17 to 23% increase in winter / spring runoff
- ✓ Longer dry periods

Climate Impacts and Vulnerabilities

Table 5. Projected Climate Impacts and Vulnerabilities for Prairie and Oak Savanna Habitats

Direct Impacts

Climate Stressor	Impacts / vulnerabilities
Increase in mean air temperature	Few boreal species are currently present in savanna habitats, and warmer conditions could mean a further decrease or loss of boreal species, such as Trailing arbutus (*Epigaea repens* L.), and shinleaf (*Pyrola elliptica*).
Later “first frost” in fall	The “first frost” date is usually associated with tree leaf drop in late fall, currently occurring in mid-October in the region. This date sets up the timing for prescribed burns in the fall would mean putting fire on the ground in mid-November; if first frost occurs in November then may lose the fall prescribed fire season/burn window.
Change in freeze-thaw cycles and shifts in precipitation	Some plant species, particularly boreal, depend on longer and colder frost periods to maintain frozen soils and minimize root damage. Furthermore, shifts in seasonal precipitation can change the amount of soil moisture and, along with habitat exposure, can influence the duration of frozen ground. For example, resurrection fern (*Pleopeltis polypodioides*) occurs on exposed soil, pure sand / pure rock environments which are vulnerable to changes in freeze-thaw and precipitation.
Extreme air temperatures, drought	The frequency and duration of drought periods in summer may be increasing the possibility of higher intensity fires, which could reduce oak establishment and change savanna structure. ❖ Miller Woods savanna complex is likely maintained by a higher frequency of prescribed burns that are currently used.

Indirect Impacts

Climate Stressor	Impacts / vulnerabilities
Habitat shift from mesic to xeric	Although white oaks are traditionally more prevalent in mesic savanna, the dominant trees currently in savanna habitats are black oaks, and conditions could continue to shift away from white oak trees. In response to restoration activities and seasonal precipitation shifts, the woodland to prairie community transitions may include an increase in C_4 or warm season grasses because they have a higher water use efficiency. There may be a shift to drier, sand savannas with fewer willows, shrubs, and less woody encroachment into the habitat.

Table 5. Projected Climate Impacts and Vulnerabilities for Prairie and Oak Savanna Habitats (continued)

Indirect impacts (continued)

Climate Stressor	Impacts / vulnerabilities
Habitat shift from mesic to xeric	There are moisture dependent species, such as amphibians like the northern leopard frog (*Lithobates pipiens*), that will need adaptation to maintain populations.
Loss of habitat and microhabitats	The overgrowth of understory and lack of fire has limited open canopies in the savanna habitats. ❖ Red-headed woodpeckers prefer the more open canopies and the savanna habitats because their fly catching activities requires that type of space. ❖ There may be phenological mismatch or loss of habitat for violets and associated regal fritillary butterfly (*Speyeria idalia).*
Introduced invasives through railway and management activities	Invasive species that are introduced to the area via land management activities may further increase exposures and vulnerabilities in those habitats. ❖ Japanese stilt grass has been established in southern Indiana, but is now found in Jasper county on a fire break. It was possibly introduced on ATVs with fire equipment. Managers will need to watch that more invasives are not brought in through Allen County. ❖ The railroad line goes right through the Miller Woods unit and can therefore introduce invasives via the right-of-way (ROW).

Adaptation Options

NOTE: Adaptation options that are presented in the tables throughout this plan will be divided by topics (Ecology, Hydrology, etc.) and then arranged to go from resistance, to resilience, and finally transitional strategies. Some options can span all three categories depending on how specific actions are applied.

Example:

Resistance – create and maintain refugia

Resilience – enhance biodiversity

Transitional – created, deeper wetlands

Table 6. Adaptation Options and Strategies for Prairie and Oak Savanna Habitats

Ecology

Adaptation Option	Strategies
Seed bank vulnerable plant species	Store genetic material, or seeds, of white pines and other boreal relict species (e.g., US Geological Survey and NPS, Chicago Botanic Garden, etc.).
Increase microhabitat sizes for refugia	Maintain large microhabitat patches that provide a range of moisture and temperature gradients to allow species to find appropriate microclimates for survival when faced with increased temperatures, changes in precipitation, wind, etc.
Monitor ecosystem for climate change impacts	Design and implement a monitoring protocol to evaluate climate change effects on local plants and animals (e.g., US Geological Survey Natural Resources Protection Program, The Nature Conservancy Conserving Nature's Stage, etc.).
Use assisted migration to preserve climate sensitive species	Use assisted migration and other tools to guide the strategic framework for maintaining climate sensitive species in highly fragmented or isolated areas, or for which suitable habitat may no longer occur (i.e., Vitt et al. 2010).
Monitor species range shifts that impact the region	Implement early detection and rapid removal - a "watch list" - of coming species, such as non-native, exotic, or invasives from areas to the south.
Modify canopy thinning operations	Some tree canopy and understory growth is needed to maintain the shade that sustains vernal pools and other wetlands that are breeding areas for amphibians, etc. Less "thinned" habitat can serve as refugia from extreme heat and provide a gradient of microhabitats. Leave some areas untouched during thinning activities (e.g., mechanical cutting, prescribed fire, etc.) to preserve these types of habitats.
Balance management of white and black oak trees	Currently habitats are managed to keep white oak saplings and reduce scrub black oak, however black oaks are a xeric species that will do quite well in hotter and drier conditions. Shift management priorities to balance both tree species. Do more intentional plantings of both tree species; identify native saplings and avoid removing them. Prepare area around black oak trees before prescribed fires.

Table 6. Adaptation Options and Strategies for Prairie and Oak Savanna Habitats (continued)

Ecology (continued)

Adaptation Option	Strategies
Use redundant planting strategies to enhance survivability	Plant seedlings or seeds for a target species at a variety of locations that offer different conditions (e.g., shading, slope, soil type, etc.) to increase the odds for some protection and thus survival after a disturbance.

Prescribed Fire

Adaptation Option	Strategies
Modify the *timing* of prescribed fire	Assess the timing of prescribed fire as the growing season shifts earlier and later. For example, do not wait for leaves to drop in the fall to conduct a prescribed burn.
Modify the *nature* of burns	Adapt the nature of prescribed burns (intensity and duration) to the new climate conditions. For example, it may be necessary to decrease fire intensity when burning earlier in the spring since there may not be as much biofuel on the ground at this time. ❖ Woodland to prairie transitions may include an increase in C_4 or warm season grasses, which have more vertical fuels.
Apply prescribed fire to new areas	Apply prescribed fire to new areas to completely change the habitat structure: ❖ For example, use prescribed burn to open canopy on northeast slopes of Tolleston Dunes.
Create non-burn areas	Incorporate non-burn areas in fire management units to create refugia for amphibians, invertebrates, and some boreal plant species. For example, Trailing arbutus is a rare plant species that occurs in litter but favors exposed sites where the plants are not smothered by leaf litter. It is sensitive to abrupt environmental disturbances.

Infrastructure and park management

Adaptation Option	Strategies
Increase seasonal staff	As the growing season shifts and becomes longer, more personnel are needed to control invasive plants, clear trails and roads, and manage an increase in visitation.
Monitor weather and air quality	Set up a regular system of alerts and actions (e.g., close trails, stay inside) to take to protect staff, residents, and visitors from extreme conditions (e.g. flooding events, heat stress).

Table 6. Adaptation Options and Strategies for Prairie and Oak Savanna Habitats (continued)

Infrastructure and park management (continued)

Adaptation Option	Strategies
Evaluate future personnel scheduling based on changing demographics	Connect with university or non-profit studies of tourism shifts expected in the area related to climate change and incorporate the results into personnel planning.
Incorporate climate model projections into infrastructure lifespan	Work with researchers to improve modeling the impacts to infrastructure, and consider the best available science to minimize impacts or improve durability over the lifespan of the infrastructure.

Forest Complex

This complex exists further from the shores of Lake Michigan in the Indiana Dunes region, and is divided into:

- Floodplain forest
- Wet/mesic forest

Studies on the impact to forests in the U.S. Great Lakes region found that for the highest emission scenarios, forest productivity and diversity are closely related and species diversity declines. These studies suggest that land management strategies that maintain a diversity of tree species will be increasingly important for the adaptive capacity of forests in this area (Duveneck et al. 2014; Duveneck, Scheller, and White 2014).

The Indiana Dunes host some very unique forest habitats that benefit a variety of wildlife species. For example, the cerulean warbler (*Setophaga cerulea*) is a canopy dwelling bird that migrates from South America to breed in this region. Though it has been spotted in the greater Chicago region, it only breeds within the parks. The forest canopy structure is important to its breeding as it requires large patches to breed, exactly the type of habitat that is currently found in the Indiana Dunes park boundaries.

Climate Scenarios Relevant to Forest Habitats

Extended growing season – earlier springs and later falls

Warmer temperatures
- ✓ Warmer, drier conditions in the growing season
- ✓ Plant heat zone goes from 5 to 7

Wetter winter / spring and drier summer
- ✓ 14 to 22% increase in precipitation
- ✓ 17 to 23% increase in winter / spring runoff
- ✓ Longer dry periods

Climate Impacts and Vulnerabilities

Table 7. Projected Climate Impacts and Vulnerabilities for Forest Habitats

Direct impacts

Climate Stressor	Impacts / vulnerabilities
Increase in mean air temperature	Warmer climate conditions could mean a further decrease or loss of boreal species, such as Trailing arbutus (*Epigaea repens* L.) and shinleaf (*Pyrola elliptica*).
Later "first frost" in fall	The "first frost" date is usually associated with tree leaf drop in late fall, currently occurring in mid-October in the region. This date sets up the timing for prescribed burns in the fall. would mean putting fire on the ground in mid-November; if first frost occurs in November then may lose the fall prescribed fire season/burn window.
Change in freeze-thaw cycles and shifts in precipitation	Some plant species, particularly boreal, depend on longer and colder frost periods to maintain frozen soils and minimize root damage. Furthermore, shifts in seasonal precipitation can change the amount of soil moisture and, along with habitat exposure, can influence the duration of frozen ground. For example, resurrection fern (*Pleopeltis polypodioides*) occurs on exposed soil, pure sand / pure rock environments which are vulnerable to changes in freeze-thaw and precipitation.
Extreme air temperatures, drought	The frequency and duration of drought periods in summer may be increasing the possibility of more intense fires.
Shifts in precipitation	Wet or mesic forests are vulnerable to seasonal precipitation shifts and landscape fragmentation that disrupts natural hydrology.

Table 7. Projected Climate Impacts and Vulnerabilities for Forest Habitats (continued)

Indirect impacts

Climate Stressor	Impacts / vulnerabilities
Habitat shift from mesic to xeric	The species composition in forested landscapes are expected to change, with some tree species increasingly moving north, some tree species eventually leaving the area entirely, and new tree and understory species migrating to the area from the south. Moisture dependent species, such as amphibians like the northern leopard frog (*Lithobates pipiens*), will need adaptation to maintain populations.
Amplified stresses from urbanization	Climate change is expected to worsen current stresses, such as urbanization, landscape fragmentation, and threats from invasive plant species. ❖ Oriental bittersweet (*Celastrus orbiculatus*) infiltrates forests where it smothers the native host plants and girdles trees (Leicht-Young and Pavlovic 2012).
Introduced invasives through railway and management activities	Invasive species that are introduced to the area via land management activities may further increase exposures and vulnerabilities in those habitats. ❖ Japanese stilt grass has been established in southern Indiana, but is now found in Jasper county on a fire break. It was possibly introduced on ATVs with fire equipment. Managers will need to watch that more invasives are not brought in through Allen County. ❖ The railroad line goes right through the Miller Woods unit and can therefore introduce invasives via the right-of-way (ROW). ❖ The imminent double tracking that will increase rail transportation to the area could also increase pressure from visitors and bring in more invasive plant species
Amplified stresses from wildlife	Increase in beaver, muskrat, deer populations puts a strain on resource needs and fertility management options. If forage or other food sources flourish due to increasing temperatures and/or precipitation, efforts to control these populations could be made more difficult or even impossible.

Adaptation Options

NOTE: Adaptation options that are presented in the tables throughout this plan will be divided by topics (Ecology, Hydrology, etc.) and then arranged to go from resistance, to resilience, and finally transitional strategies. Some options can span all three categories depending on how specific actions are applied.

Example:

Resistance – create and maintain refugia

Resilience – enhance biodiversity

Transitional – created, deeper wetlands

Table 8. Adaptation Options and Strategies for Forest Habitats

Ecology

Adaptation Option	Strategies
Seed bank vulnerable plant species	Store genetic material, or seeds, of white pines and other boreal relict species (e.g., US Geological Survey and NPS, Chicago Botanic Garden, etc.).
Prioritize resources	Identify early spring resources and manage to maintain these, particularly for those species that have limited range (e.g., deer).
Increase microhabitat sizes for refugia	Maintain large microhabitat patches that provide a range of moisture and temperature gradients to allow species to find appropriate microclimates for survival when faced with increased temperatures, changes in precipitation, wind, etc.
Monitor ecosystem for climate change impacts	Design and implement a monitoring protocol to evaluate climate change effects on local plants and animals (e.g., US Geological Survey Natural Resources Protection Program, The Nature Conservancy Conserving Nature's Stage, etc.).
Monitor species range shifts that impact the region	Implement early detection and rapid removal - a "watch list" - of coming species, such as non-native, exotic, or invasives from areas to the south.
Prioritize high quality habitats	Prioritize high quality wooded communities and maintain appropriate density of woody species present in them through active, restoration-focused management.
Use redundant planting strategies to enhance survivability	Plant seedlings or seeds for a target species at a variety of locations that offer different conditions (e.g., shading, slope, soil type, etc.) to increase the odds for some protection and thus survival after a disturbance.
Promote biodiversity	Promote regional tree diversity through management in natural areas and planting in urban systems to increase resiliency of regional forest.

Table 8. Adaptation Options and Strategies for Forest Habitats (continued)

Ecology (continued)

Adaptation Option	Strategies
Use assisted migration to preserve climate sensitive species	Use assisted migration and other tools to guide the strategic framework for maintaining climate sensitive species in highly fragmented or isolated areas, or for which suitable habitat may no longer occur (i.e., Vitt et al. 2010).

Prescribed Fire

Adaptation Option	Strategies
Modify the *timing* of prescribed fire	Assess the timing of prescribed fire as the growing season shifts earlier and later. For example, do not wait for leaves to drop in the fall to conduct a prescribed burn.
Modify the *nature* of burns	Adapt the nature of prescribed burns (intensity and duration) to the new climate conditions. For example, it may be necessary to decrease fire intensity when burning earlier in the spring since there may not be as much biofuel on the ground at this time.
Apply prescribed fire to new areas	Apply prescribed fire to new areas to completely change the habitat structure.
Create non-burn areas	Incorporate non-burn areas in fire management units to create refugia for amphibians, invertebrates, and some boreal plant species. For example, Trailing arbutus is a rare plant species that occurs in litter but favors exposed sites where the plants are not smothered by leaf litter. It is sensitive to abrupt environmental disturbances.

Infrastructure and park management

Adaptation Option	Strategies
Monitor weather and air quality	Set up a regular system of alerts and actions (e.g., close trails, stay inside) to take to protect staff, residents, and visitors from extreme conditions (e.g. flooding events, heat stress).
Increase seasonal staff	As the growing season shifts and becomes longer, more personnel are needed to control invasive plants, clear trails and roads, and manage an increase in visitation.
Evaluate future personnel scheduling based on changing demographics	Connect with university or non-profit studies of tourism shifts expected in the area related to climate change and incorporate the results into personnel planning.
Incorporate climate model projections into infrastructure lifespan	Work with researchers to improve modeling the impacts to infrastructure, and consider the best available science to minimize impacts or improve durability over the lifespan of the infrastructure.

Wetland Complex

This complex consists of some of the most iconic habitats associated with the Indiana Dunes, including:

- Bogs
- Marshes
- Fens
- Shrub swamps
- Sedge meadows
- Pannes

Wetlands have been modified extensively by humans. However, recent beaver activity has further impacted the hydrology in the region, to the benefit of the wetlands by damming waterways and keeping the wetlands wet. There is a concern that this ecosystem engineering by beavers is not happening in the places that align with the long term land management goals. As climate change brings heavier precipitation events, beaver activity and other factors that impact the viability of many wetlands will be of particular importance.

Climate Scenarios Relevant to Wetland Habitats

Warmer temperatures
- ✓ Warmer, drier conditions in the growing season
- ✓ Plant heat zone goes from 5 to 7

Wetter winter / spring and drier summer
- ✓ 14 to 22% increase in precipitation
- ✓ 17 to 23% increase in winter / spring runoff
- ✓ Longer dry periods

Climate Impacts and Vulnerabilities

Table 9. Projected Climate Impacts and Vulnerabilities for Wetland Habitats

Direct impacts

Climate Stressor	Impacts / vulnerabilities
Increase in water temperature	An increase in evaporation can hurt water quality in wetlands, reduce water levels, and negatively impact aquatic plants and animals.

Table 9. Projected Climate Impacts and Vulnerabilities for Wetland Habitats (continued)

Direct impacts (continued)

Climate Stressor	Impacts / vulnerabilities
Decrease in precipitation, droughts	Vernal pools and amphibian habitats could be negatively impacted by drying up.
Shifts in seasonal precipitation	The timing of wetland wet and dry cycles may negatively impact organisms that depend them for life cycle events (e.g., breeding, migration). ❖ Migrating birds, such as heron, would be impacted if the timing of hydrology changed. So wetlands that dry up annually anyway would only be an issue if they dry up earlier in the year, for example.
Increase in winter air and soil temperatures	If soil is not frozen, then as snow melts there will be less water on the surface because it will be able to infiltrate into the soil easier.

Indirect impacts

Climate Stressor	Impacts / vulnerabilities
Urban development divert surface water hydrology	Urban development outside of park boundaries can modify hydrology and increase other wetland vulnerabilities.
Changing habitat	The combination of drier conditions and land management activities could create new issues. ❖ Wetlands dry enough to create areas of exposed mud, this could allow invasives, like phragmites, to spread farther and become even more difficult to control. ❖ Shrub swamps or wetlands with a shrub component have been exaggerated by fire suppression. If they dry up and management becomes more consistent with the use of fire, the shrub component could be lost.
Changing hydrology	Some wetland habitats are dependent on hydrological fluctuations - land use change along with changing vegetation and shifts in precipitation may intensify or disrupt water fluctuations. ❖ A coastal plain disjunct habitat depends on hydrological fluctuations that create mud flats.
Changing wildlife populations	If forage or other food sources flourish due to increasing temperatures and/or precipitation, the resulting increase in beaver, muskrat, deer and other wildlife populations can put a strain on resource needs and limit fertility management options.

Adaptation Options

NOTE: Adaptation options that are presented in the tables throughout this plan will be divided by topics (Ecology, Hydrology, etc.) and then arranged to go from resistance, to resilience, and finally transitional strategies. Some options can span all three categories depending on how specific actions are applied.

Example:

Resistance – create and maintain refugia

Resilience – enhance biodiversity

Transitional – created, deeper wetlands

Table 10. Adaptation Options and Strategies for Wetland Habitats

Ecology

Adaptation Option	Strategies
Prioritize charismatic ecosystems	Fens, pannes, and bogs are imperiled and unique to the area and therefore could be a management priority.
Seed bank vulnerable plant species	Store genetic material, or seeds, of white pines and other boreal relict species (e.g., US Geological Survey and NPS, Chicago Botanic Garden, etc.).
Invest in long-term invasive species eradication	Invasive species utilize limited resources and make native habitat more vulnerable to climate impacts. Fighting some invasive species will take at least a decade and require coordination among stakeholders across jurisdictions. Funding and planning should account for the long-term nature and investment in fighting invasives, including the follow-up needed to ensure they will not return. ❖ A large stand of phragmites is a 10-year process to control. Short term money and only one year spent fighting has resulted in lost resources and no progress. Funding sources such as GLRI (Great Lakes Restoration Initiative) have been hugely instrumental in providing long-term resolutions.
Replace lost trees with native species	Plant native trees along river/stream banks and riverine areas, especially where significant loss of trees has occurred.
Use assisted migration to preserve climate sensitive species	Use assisted migration and other tools to guide the strategic framework for maintaining climate sensitive species in highly fragmented or isolated areas, or for which suitable habitat may no longer occur (i.e., Vitt et al. 2010).
Monitor ecosystem for climate change impacts	Design and implement a monitoring protocol to evaluate climate change effects on local plants and animals (e.g., US Geological Survey Natural Resources Protection Program, The Nature Conservancy Conserving Nature's Stage, etc.).

Table 10. Adaptation Options and Strategies for Wetland Habitats (continued)

Ecology (continued)

Adaptation Option	Strategies
Intentionally enhance shrub swamp habitats	Wetland systems populated by woody vegetation, are less biodiverse than other wetlands, and buttonbush (*Cephalanthus occidentalis*) provide good habitat for native birds. Within the Indiana Dunes State park, these habitats also contain dead ash trees, a consequence of emerald ash borer activity. Interestingly, removal of woody vegetation could expose seed banks for rare habitats.
Use redundant planting strategies to enhance survivability	Plant seedlings or seeds for a target species at a variety of locations that offer different conditions (e.g., shading, slope, soil type, etc.) to increase the odds for some protection and thus survival after a disturbance.
Consider planting hybrid cultivars	Use hybridized cultivars in areas where they are better suited to future climate stresses, like new water and temperature ranges (e.g., Marram grass, etc.).
Modify canopy thinning operations	Some tree canopy and understory growth is needed to maintain the shade that sustains vernal pools and other wetlands that are breeding areas for amphibians, etc. Less "thinned" habitat can serve as refugia from extreme heat and provide a gradient of microhabitats. Leave some areas untouched during thinning activities (e.g., mechanical cutting, prescribed fire, etc.) to preserve these types of habitats.
Monitor species range shifts that impact the region	Implement early detection and rapid removal - a "watch list" - of coming species, such as non-native, exotic, or invasives from areas to the south. ❖ Engage local communities to identify invasives upstream of wetlands (e.g., carp, phragmites, and other plant species).
Create habitat gradients	Develop a complex of wetlands that are interconnected and represent wetness gradients, so that a range of wetness exists and different wetlands will be vulnerable to drying out at different times and under different conditions.
Plan for created wetlands	Dig out areas to create deeper and wider wetlands than naturally occurring. This will allow some habitats to retain more water during higher precipitation events and/or bring the wetland in contact with groundwater.

Table 10. Adaptation Options and Strategies for Wetland Habitats (continued)

Landscape Connectivity

Adaptation Option	Strategies
Coordinate land management actions with regional stakeholders	Work closely with regional planning groups and municipalities to ensure coordination of purchasing and land management actions in property that is adjacent to the parks.
Utilize river corridors to provide large-scale connectivity	Improve the connectivity of wildlife corridors by reviewing land management actions that utilize rivers to connect similar habitat throughout the region.

Hydrology

Adaptation Option	Strategies
Coordinate river-related actions to improve large-scale hydrology	Coordinate land management actions with other stakeholders in the region that have access to rivers in developing a region or large-scale hydrology plan.
Redesign landscape to alleviate flooding issues	Identify and map where there are issues of flooding and where high quality restorations are taking place and redesign landscapes to alleviate these issues.
Fill ditches to modify hydrology and keep wetlands hydrated	Filling ditches re-routes surface water flow back over the land and allows for more infiltration. ❖ Land managers with The Nature Conservancy (TNC) have done this in the county south of the Indiana Dunes with success.
Use equipment to create deeper vernal pools	Dig out areas to create a deeper and wider than natural basin in order to retain more water during higher precipitation events and/or bring them in contact with groundwater. This could be a good pilot project at several sites and/or working with US Army Corps of Engineers for mitigation opportunities.
Incentivize wetland creation	Work with planning and policy agencies to create or restore wetlands. Ensure wetlands are part of the gradient of habitats in an urban-to-natural ecosystem paradigm.

Infrastructure and park management

Adaptation Option	Strategies
Monitor weather and air quality	Set up a regular system of alerts and actions (e.g., close trails, stay inside) to take to protect staff, residents, and visitors from extreme conditions (e.g. flooding events, heat stress).
Increase seasonal staff	As the growing season shifts and becomes longer, more personnel are needed to control invasive plants, clear trails and roads, and manage an increase in visitation.

Table 10. Adaptation Options and Strategies for Wetland Habitats (continued)

Infrastructure and park management (continued)

Adaptation Option	Strategies
Evaluate future personnel scheduling based on changing demographics	Connect with university or non-profit studies of tourism shifts expected in the area related to climate change and incorporate the results into personnel planning.
Redesign park structures to alleviate flooding issues	Identify where there are issues of flooding and where there are high quality restorations going on and redesign park structures (e.g., roads, bridges, buildings, etc.) to alleviate these issues. Remove or redesigning roads (raised structure) so that flooding will not impact the wetlands.
Incorporate climate model projections into infrastructure lifespan	Work with researchers to improve modeling the impacts to infrastructure, and consider the best available science to minimize impacts or improve durability over the lifespan of the infrastructure.

AQUATIC COMMUNITIES

All aquatic communities in the Indiana Dunes region, including waterways (e.g., streams, rivers, ditches, etc.) and water bodies (e.g., inland lakes, ponds, Lake Michigan, etc.), are likely to be impacted by the expected increase in water temperature and shift toward more extreme precipitation events. These impacts will manifest themselves in a variety of ways, with some affecting aquatic communities across the board and others tending to be more community-specific.

Figure 17. Port of Indiana - Burns Harbor (photo: Google Maps)

This category is inclusive of specific water routes and the associated aquatic communities within the Indiana Dunes Focus Area, including:

- Deep River
- Burns Waterway
- Salt Creek
- East Branch of Little Calumet River
- Dunes Creek
- Kintzele Ditch
- Lake Michigan

Climate Scenarios Relevant to Aquatic Communities

Warmer temperatures
- ✓ Warmer, drier conditions in the growing season

Wetter winter / spring and drier summer
- ✓ 14 to 22% increase in winter / spring precipitation
- ✓ 17 to 23% increase in winter / spring runoff
- ✓ Longer dry periods between precipitation events

Lake Michigan surface water temperatures increasing
- ✓ Less shelf ice
- ✓ Lake level changes, an increase in variability

Climate Impacts and Vulnerabilities

Table 11. Projected Climate Impacts and Vulnerabilities for Aquatic Communities

Direct impacts

Climate Stressor	Impacts / vulnerabilities
Increase in water temperature	An increase in water temperature and evaporation can hurt water quality and disrupt water chemistry.
Increase in precipitation	An increase in runoff would also create a flashy watershed regime that can flush nutrients and transport pollutants into Lake Michigan.
Increase in extreme precipitation events	Extreme precipitation events could impact waterway infrastructure - testing the engineered limits and reducing the lifespan (e.g., culverts, bridges, boat launches, etc.)
Increase in lake water level	An increase in the level of water on Lake Michigan can decrease the shoreline and outlet areas, increasing the threat of overbank flow and flooding from waterways inland. ❖ Modifies storm water mitigation in the area due to a rise in the water table near the coast. ❖ Changes in nearshore sand dynamics and dune building processes by moving the distance to the shoreline further out in the lake (lake level decrease) or closer inland (lake level increase) ❖ Loss of shoreline structures.

Table 11. Projected Climate Impacts and Vulnerabilities for Aquatic Communities (continued)

Indirect impacts

Climate Stressor	Impacts / vulnerabilities
Urban development divert surface water hydrology	Developments outside of park boundaries can add to changing hydrology and intensify flashy watershed regimes. ❖ Local changes in waterway navigability and impacts to recreation, boating and fishing
Increase in invasive species introduction	Changes in hydrology and use of waterways also increases the introduction of invasives by improving water flow pathways and enabling “hitchhikers” via watercraft.

Adaptation Options

NOTE: Adaptation options that are presented in the tables throughout this plan will be divided by topics (Ecology, Hydrology, etc.) and then arranged to go from resistance, to resilience, and finally transitional strategies. Some options can span all three categories depending on how specific actions are applied.

Example:

Resistance – create and maintain refugia

Resilience – enhance biodiversity

Transitional – created, deeper wetlands

Table 12. Adaptation Options and Strategies for Aquatic Communities

Ecology

Adaptation Option	Strategies
Conserve, connect, and restore high quality habitat	Protect and conserve property that includes critical cooler-water fish habitat areas, reconnect high quality habitats, protect belt-width-based river corridors (e.g., corridors defined by the lateral extent of the river meanders), and restore floodplains.
Invest in long-term invasive species eradication	Remove in-stream barriers (dams and undersized culverts) and re-establish in-stream flows to restore aquatic habitats. This strategy should be well researched and designed to minimize the potential for the spread of invasives and disease vectors. Locations should be carefully and strategically selected to reflect areas that would benefit the most under both current as well as future conditions.
Monitor species range shifts that impact the region	Implement early detection and rapid removal - a “watch list” - of coming species, such as non-native, exotic, or invasives from areas to the south.
Promote aquatic biodiversity	Promote biological diversity by managing for invasives and maintaining in-stream habitat diversity.
Restore riparian vegetation	Design riparian restoration projects to endure stream flows of increased magnitude and variability will enhance long-term restoration success and improve the quality of the aquatic ecosystem. Use native planting near/around lakes and ponds to help with runoff from communities.

Table 12. Adaptation Options and Strategies for Aquatic Communities (continued)

Ecology (continued)

Adaptation Option	Strategies
Regulate land use near waterways	Work with land use planners to minimize additional development on parcels of land adjacent to rivers and streams. Optimally, try to acquire floodplains and nearby lands that are not currently publicly owned or ensure they are placed in protected status. Recharge areas need to be included in these types of planning activities to provide baseflow to streams beyond that from effluent discharges. Buffers should be encouraged along rivers and conservation easements. Work with the agricultural community to discuss alternatives to current water-use for their crops; determine if there are efficient water systems; reduce pesticides, insecticides, and nutrients that flow into the nearby waterways. Guide growth and incentivize Smart Growth/low impact development to reduce nonpoint source pollution. Supervise / monitor lakeshore development.

Hydrology

Adaptation Option	Strategies
Acquire hydrologic baselines	Increase monitoring to improve information on water flows, water quality, water temperature, and higher sedimentation rates thus enabling river managers to prioritize actions and evaluate effectiveness.
Develop environmentally sustaining baseflows	Forge partnerships and develop mechanisms to ensure environmentally sustainable flows (e.g., the amount of water needed in a watercourse to maintain healthy ecosystems) for rivers and streams in basins that experience water stress. Encourage greater use of seasonal and long-term projections for streamflows in water management decisions to more proactively protect and restore flows for fish habitat.
Regulate water consumption	Communicate with regulators about regulating human water consumption in the area - increase water use efficiency and conservation.

Table 12. Adaptation Options and Strategies for Aquatic Communities (continued)

Infrastructure and park management

Adaptation Option	Strategies
Monitor weather and air quality	Set up a regular system of alerts and actions (e.g., close trails, stay inside) to take to protect staff, residents, and visitors from extreme conditions (e.g. flooding events, heat stress).
Evaluate future personnel scheduling based on changing demographics	Connect with university or non-profit studies of tourism shifts expected in the area related to climate change and incorporate the results into personnel planning.
Redesign park structures to alleviate flooding issues	Identify and map where there are issues of flooding and where there are high quality restorations going on and redesign park structures (e.g., roads, bridges, buildings, etc.) to alleviate these issues. Remove or redesigning roads (raised structure) so that flooding will not impact the wetlands.
Incorporate climate model projections into infrastructure lifespan	Work with researchers to improve modeling the impacts to infrastructure, and consider the best available science to minimize impacts or improve durability over the lifespan of the infrastructure. Use Variable Infiltration (VIC) model coupled with MODFLOW to determine if there are benefits to nearby agricultural areas that restore (reclaim) habitat and provide more ecosystem services in the form of storm water management.
Develop education outreach	Develop educational programs that target lake and waterways recreational users, particularly for boaters due to accidental transport and introduction of invasive species by boats (e.g., invasive aquatic weeds, zebra mussels, etc.) Develop education for aquatic gardeners. Many aquatic garden plants are semi-tropical, but may be able to survive or become invasive under future conditions caused by climate change.

CLIMATE CHANGE INFORMATION SOURCES

US Global Change Research Program (USGCRP) - Conducts state-of-the-art research to understand the interactive processes that influence the total Earth system—which includes the atmosphere, oceans, land, ice, ecosystems, and people. The National Climate Assessment is the product of their research.
https://www.globalchange.gov/climate-change

NOAA Climate.gov - Promotes public understanding of climate science and climate-related events through videos, stories, images, and data visualizations:
http://www.noaa.gov/climate

Great Lakes Integrated Sciences and Assessments program (GLISA) – Great Lakes region of a NOAA national network focusing on adaptation to climate change by integrating information from a wide array of scientific fields, helping to develop collaborations between entities with similar goals, and lending climate information support to decision makers throughout the region.
http://glisa.umich.edu/

Great Lakes Environmental Research Laboratory (GLERL) - Conduct scientific research on the Great Lakes and coastal ecosystems; develop and transition products and services; and share knowledge and information to advance science, service and stewardship.
https://www.glerl.noaa.gov/

National Park Service Climate Change Response Program - a cross-disciplinary program that provides guidance, training, technical expertise, project funding, and educational products that support our actions to preserve the natural and cultural resources and values of the National Park Service.
https://www.nps.gov/orgs/ccrp/index.htm

USDA US Forest Service Climate Change Resource Center – A website with numerous guides regarding the science of climate change, as well as responding to climate change and adaptation planning.
https://www.fs.fed.us/science-technology/climate-change

NASA Global Climate Change – Super informative, fun, and cool maps, videos, and graphs of climate science.
https://climate.nasa.gov/

iClimate.org – Indiana State Climatology reports.
https://iclimate.org/

Indiana Climate Change Impacts Assessment - Led by the Purdue Climate Change Research Center (PCCRC), this assessment provides the latest scientific research to help Hoosiers understand and prepare for the impacts of a changing climate.
https://ag.purdue.edu/indianaclimate/

Conservation Gateway, The Nature Conservancy – A hub with conservation planning tools and models (Conserving Nature's Stage or CNS, LANDFIRE, etc.).
http://www.conservationgateway.org/Pages/default.aspx

Audubon Birds and Climate Change in our National Parks - On average, one-quarter of bird species found in a given national park could be completely different by 2050 if carbon emissions continue at their current pace. New research about birds and the impact from Climate Change is highlighted, along with interactive graphics and regionally specific data.
http://www.audubon.org/climate/national-parks

Climate Change Knowledge Exchange (CAKE) - Aims to build a shared knowledge base for managing natural and built systems in the face of rapid climate change. It is intended to help build an innovative community of practice with directories of experts and case studies.
http://www.cakex.org/

Chicago Wilderness Climate Action – A source for biodiversity plans, climate change assessments and adaptation options focused on the natural areas within the Chicago Wilderness region, including the Indiana Dunes region.
http://www.chicagowilderness.org/?page=Climate

NIRPC 2040 Comprehensive Regional Plan – a comprehensive vision for sustainable growth and revitalization of Lake, Porter and LaPorte Counties.
http://www.nirpc.org/2040-plan/

Phragmites Symbiosis Collaborative, or PSC
https://www.greatlakesphragmites.net

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Appendix A: Indiana Climate Change Impacts Assessment

Background

The Purdue Climate Change Research Center (PCCRC) led the development of the Indiana Climate Change Impacts Assessment (IN CCIA) from 2016 to 2018. The IN CCIA is a multi-institution collaboration involving over 100 experts from across Indiana with the objective to bring together the best available climate change research into a series of reports that are designed to help Hoosiers better understand climate change-related risks so they can prepare for challenges and capitalize on opportunities. The target outcomes are to increase dialogue about climate change across the state, provide Indiana decision makers with accessible, credible climate change impact information, and to build a network of experts & stakeholders to support ongoing assessment efforts and knowledge sharing.

Dr. Alan Hamlet of the University of Notre Dame, a co-lead of the IN CCIA Climate Working Group, presented some of the early results from the downscaled model forecasts from this project during the first workshop at the Indiana Dunes National Park Headquarters on April 27, 2017. The models used the output from the CMIP5 global climate model inter-comparison project, filtered for appropriate regional variables related to the Great Lakes (Byun and Hamlet 2018). The radiative forcing used were representative concentration pathways (RCP) 4.5 and 8.5.

Graphs

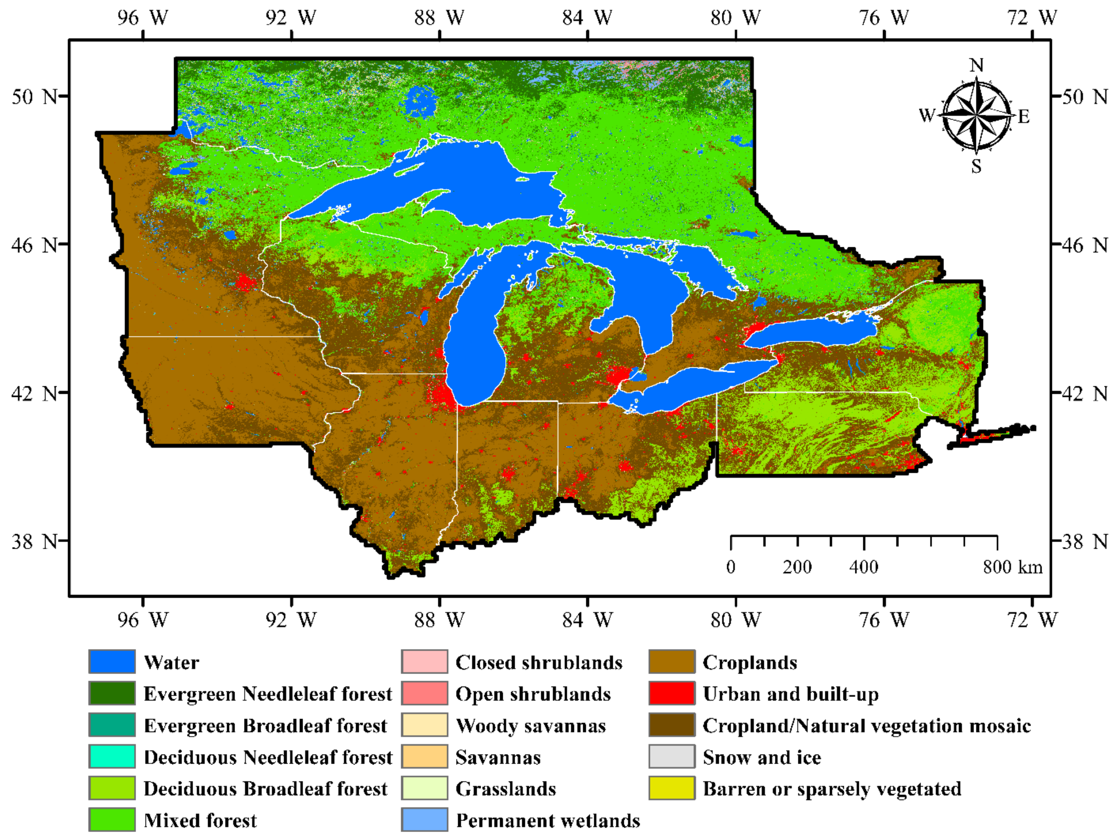


Figure 18. Study Doman (5 X 7 km resolution)

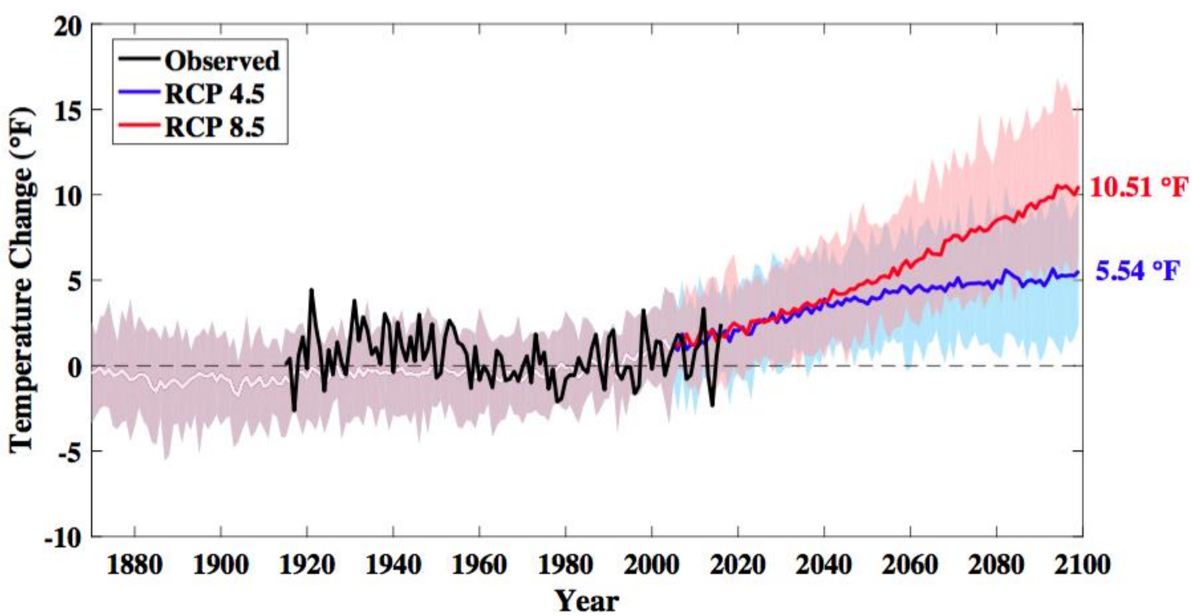


Figure 19. Trajectory of annual mean temperature change for Indiana. The historical reference period is 1971 to 2000. Heavy black line shows Indiana's annual temperature from historical observations (1915 to 2013). Each shaded area represents 95 percent of climate model projections. The most extreme projections are omitted, and colored-lines show the average projection of the 31 remaining models. (Byun and Hamlet 2018).

There is high confidence in the temperature projections, high confidence in the annual/winter/spring precipitation projections, and lower confidence in the summer and fall precipitation projections.

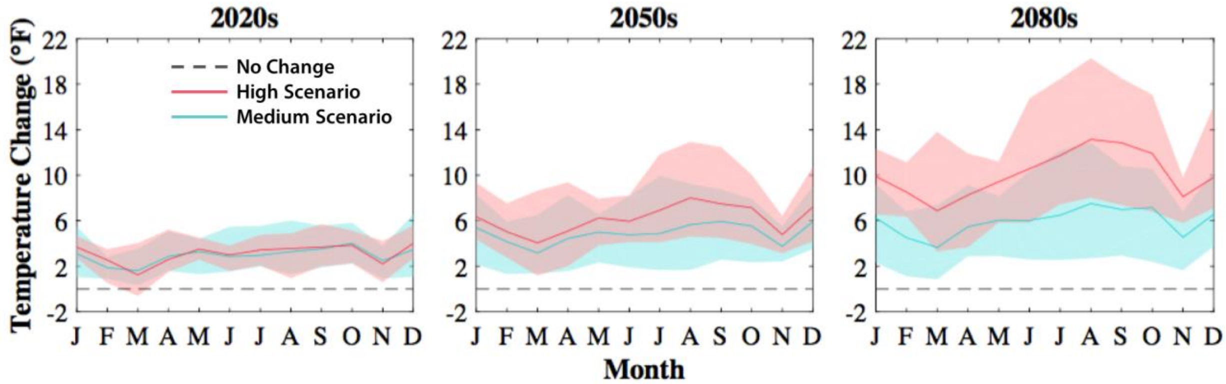


Figure 20. Projected changes in monthly average temperature for Indiana for the 2020s (2011-2040), 2050s (2041-2070), and 2080s (2071-2100), relative to a 1971 to 2000 historical baseline. The solid red and blue lines show the 10-model average for the high and medium emissions scenarios, respectively. The shaded areas show the range of results across the 10 climate models (Byun and Hamlet 2018).

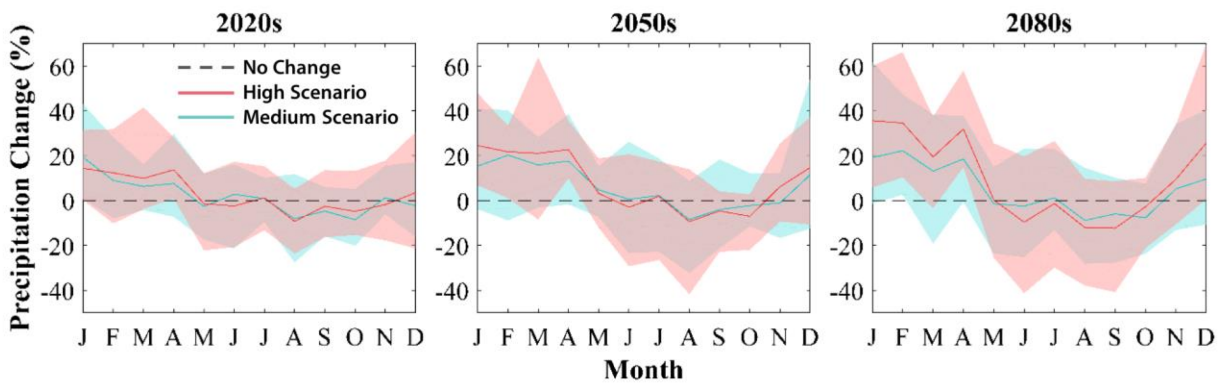
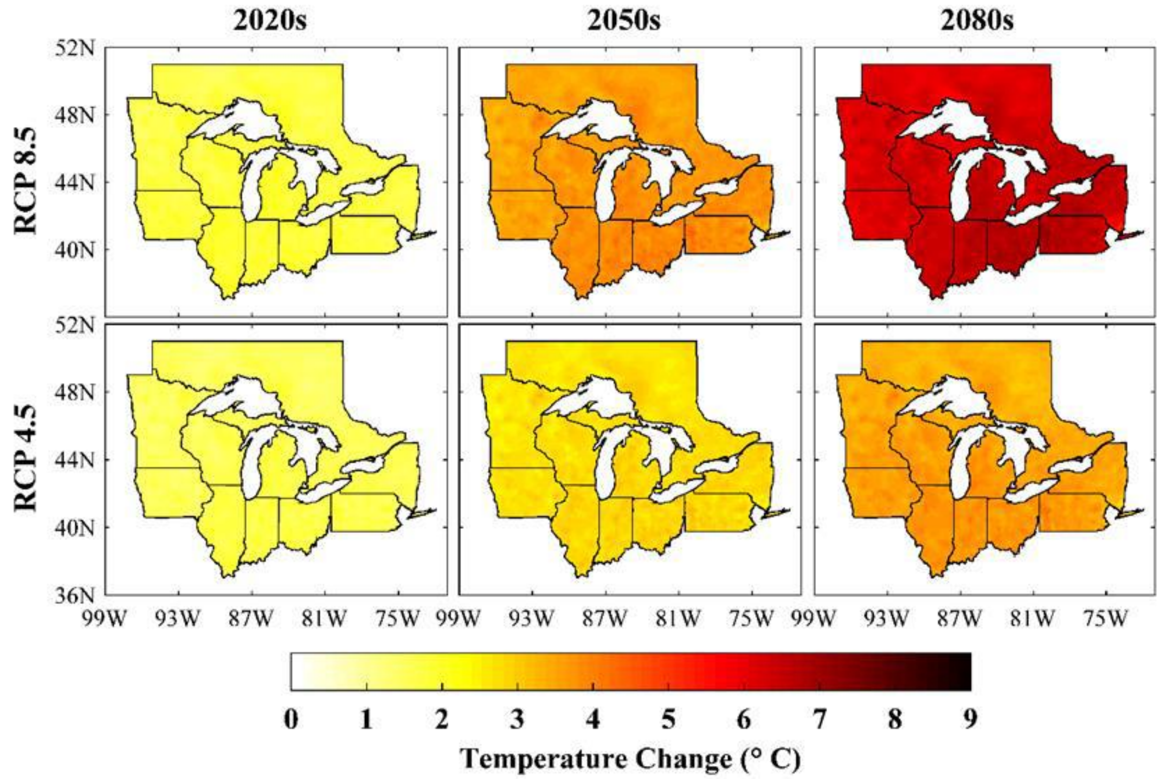
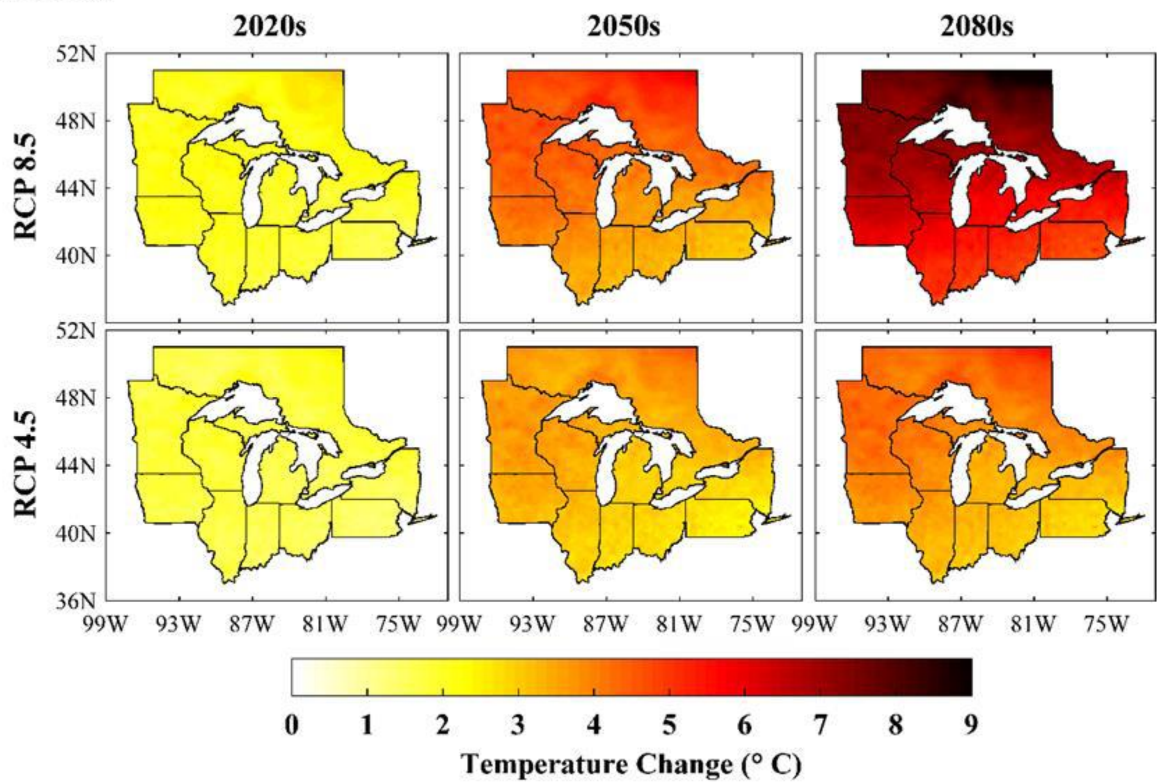


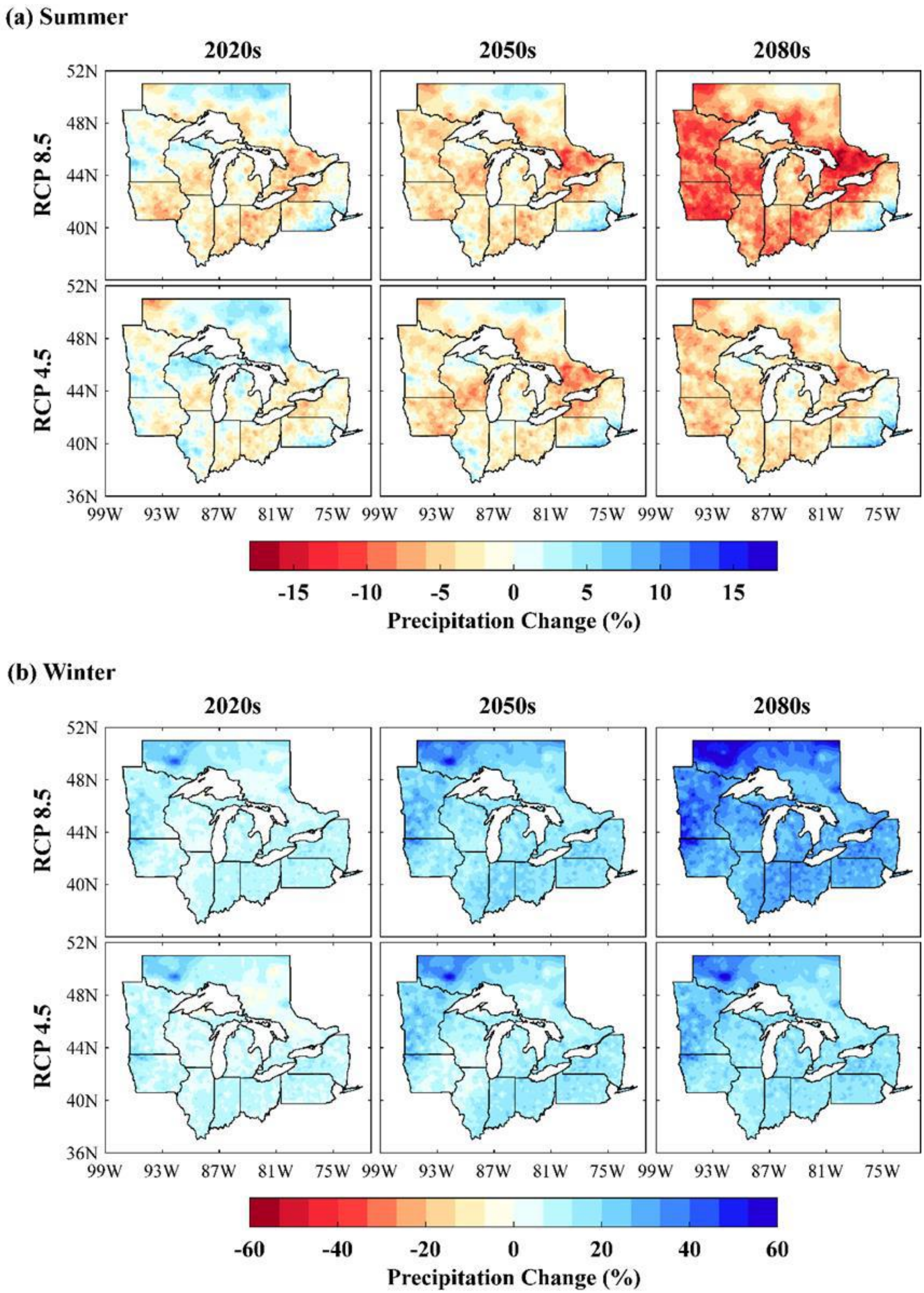
Figure 21. Projected changes in monthly average precipitation for Indiana for the 2020s (2011-2040), 2050s (2041-2070), and 2080s (2071-2100), relative to a 1971 to 2000 historical baseline. The solid red and blue lines show the 10-model average for the high and medium emissions scenarios, respectively. Shaded areas show the corresponding range of results across the 10 climate models (Byun and Hamlet 2018).

(a) Summer

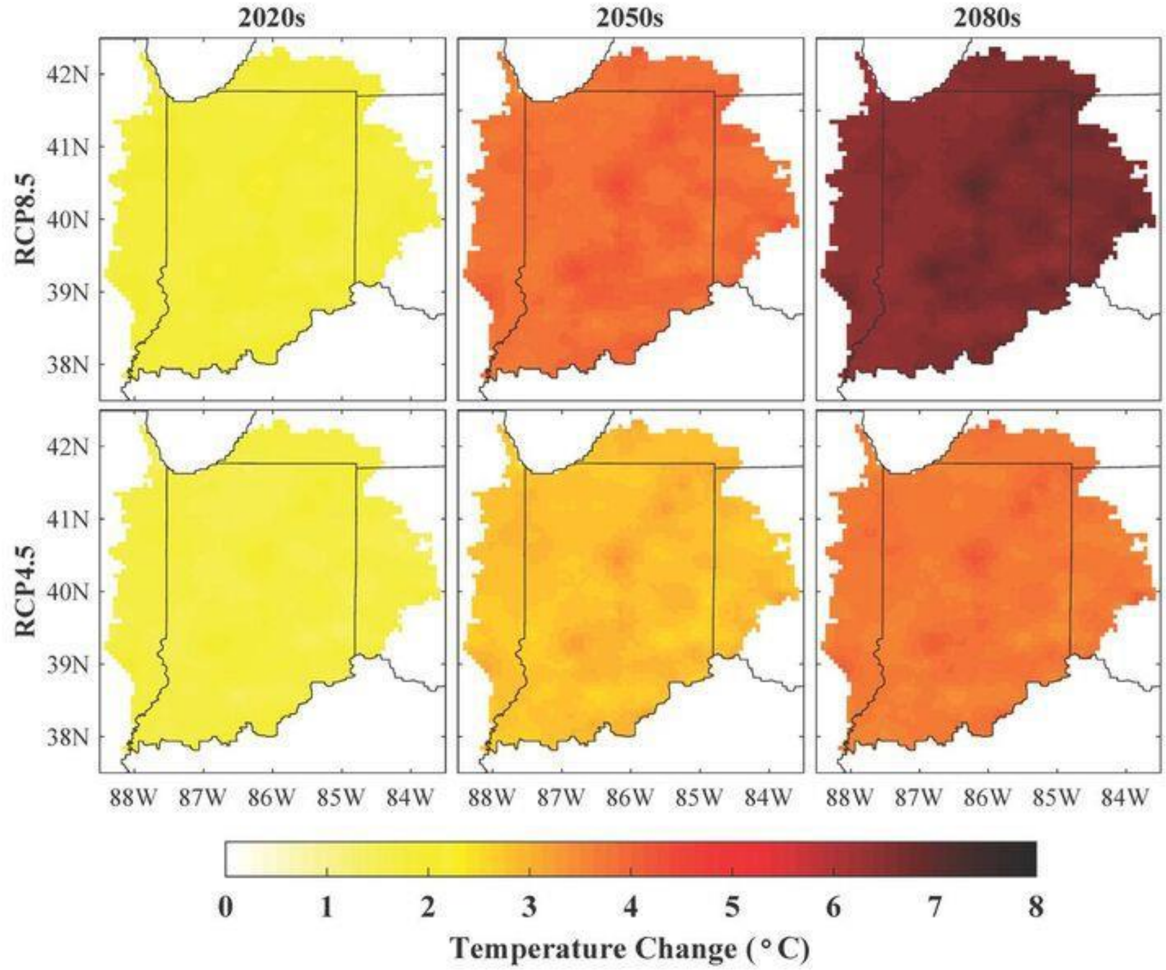


(b) Winter

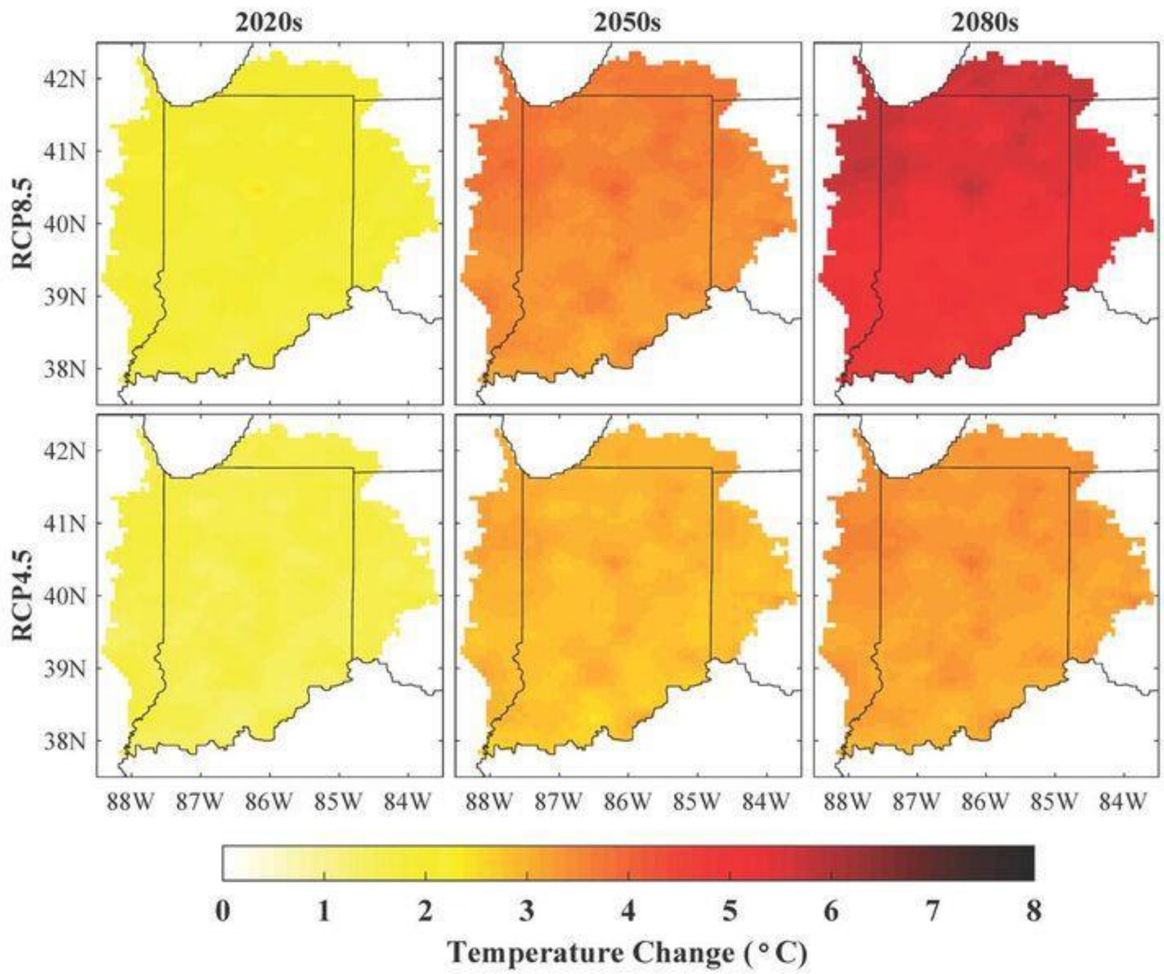


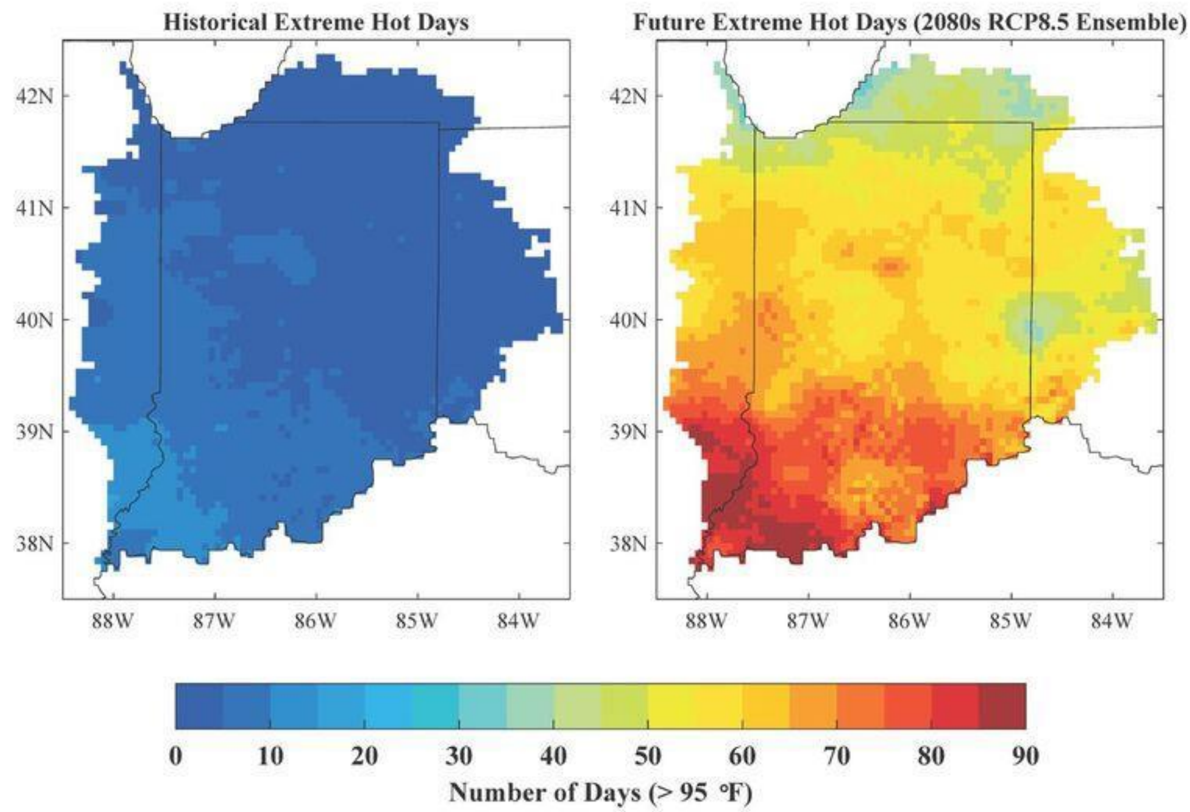

(a) Summer
2020s
2050s
2080s
RCP 8.5
RCP 4.5
52N
48N
44N
40N
36N
99W
93W
87W
81W
75W
-15
-10
-5
0
5
10
15
Precipitation Change (%)
(b) Winter
2020s
2050s
2080s
RCP 8.5
RCP 4.5
-60
-40
-20
0
20
40
60
Precipitation Change (%)

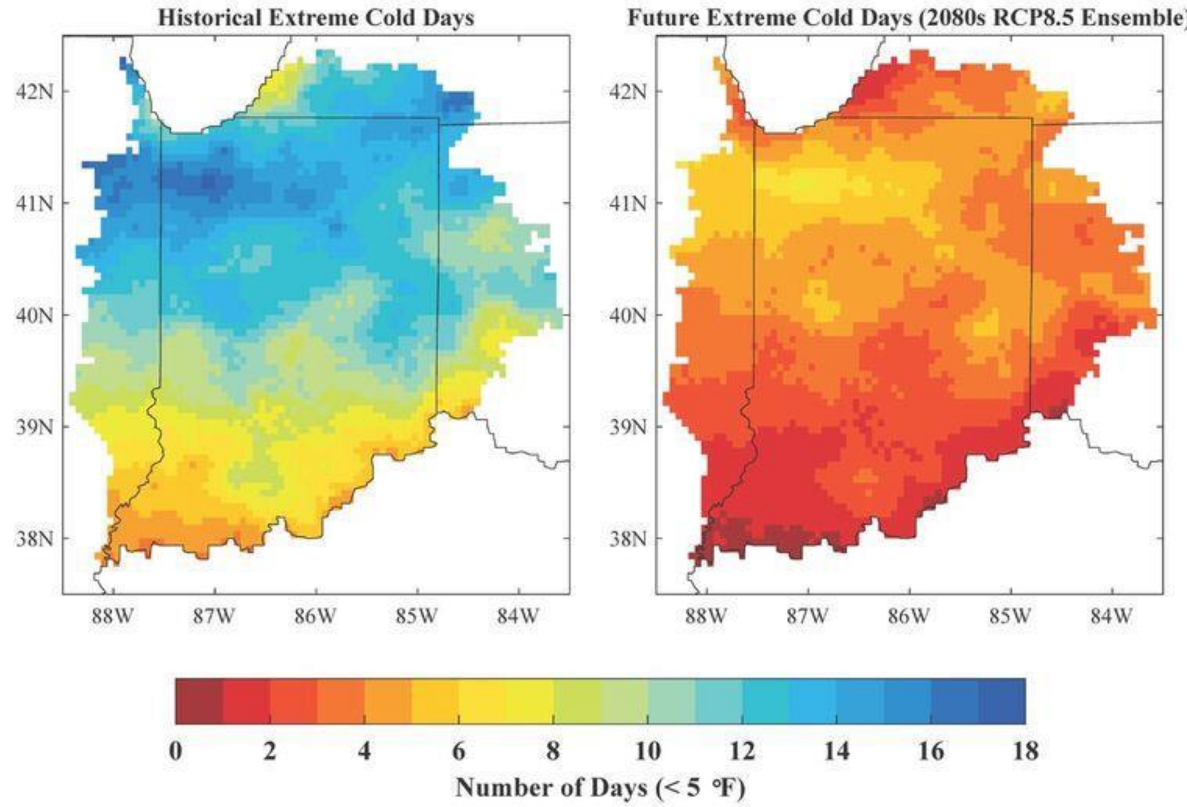
Summer


2020s
2050s
2080s
RCP8.5
RCP4.5
42N
41N
40N
39N
38N
88W
87W
86W
85W
84W
0
1
2
3
4
5
6
7
8
Temperature Change (° C)

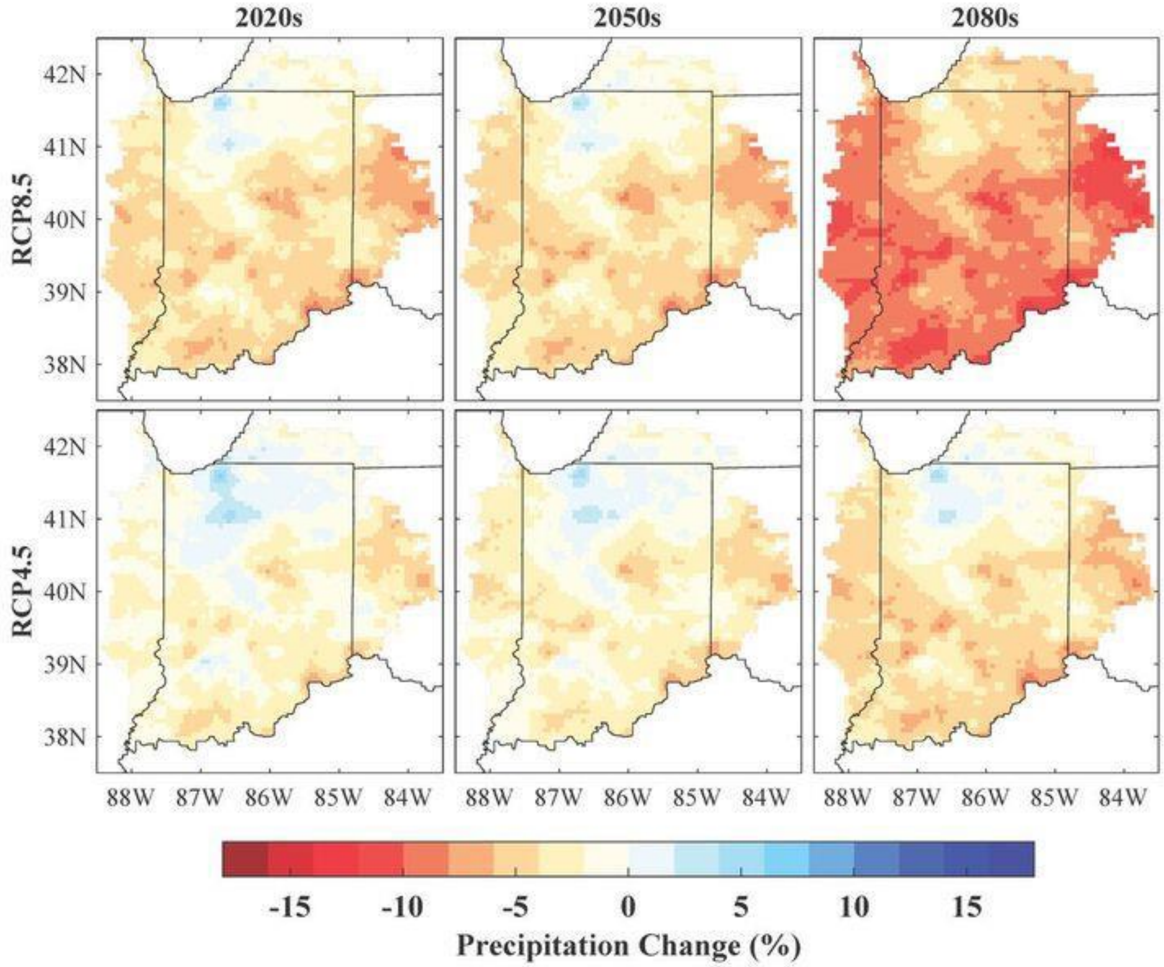
Winter


2020s
2050s
2080s
RCP8.5
RCP4.5
42N
41N
40N
39N
38N
88W
87W
86W
85W
84W
0
1
2
3
4
5
6
7
8
Temperature Change (° C)

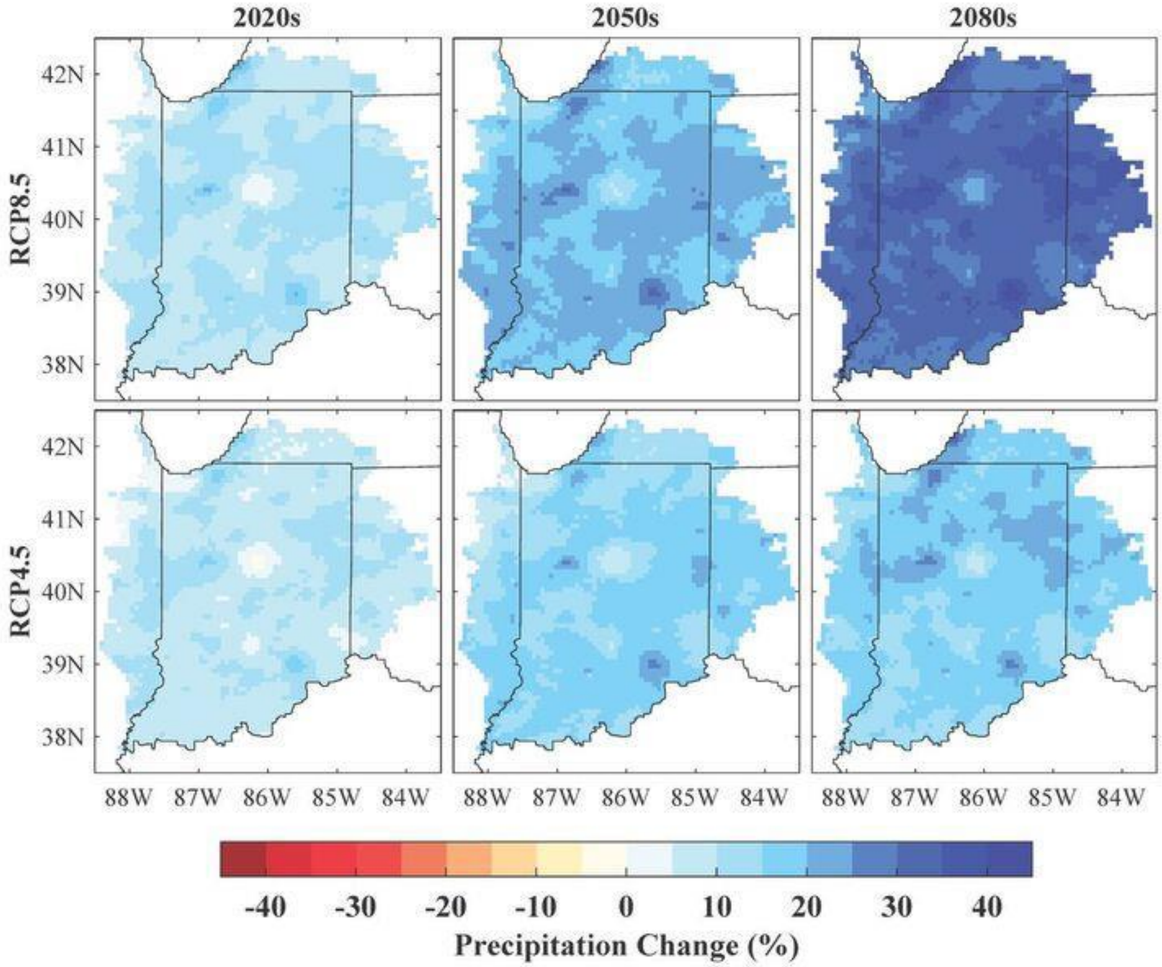

Historical Extreme Hot Days
Future Extreme Hot Days (2080s RCP8.5 Ensemble)
42N
41N
40N
39N
38N
88W
87W
86W
85W
84W
0
10
20
30
40
50
60
70
80
90
Number of Days (> 95 °F)

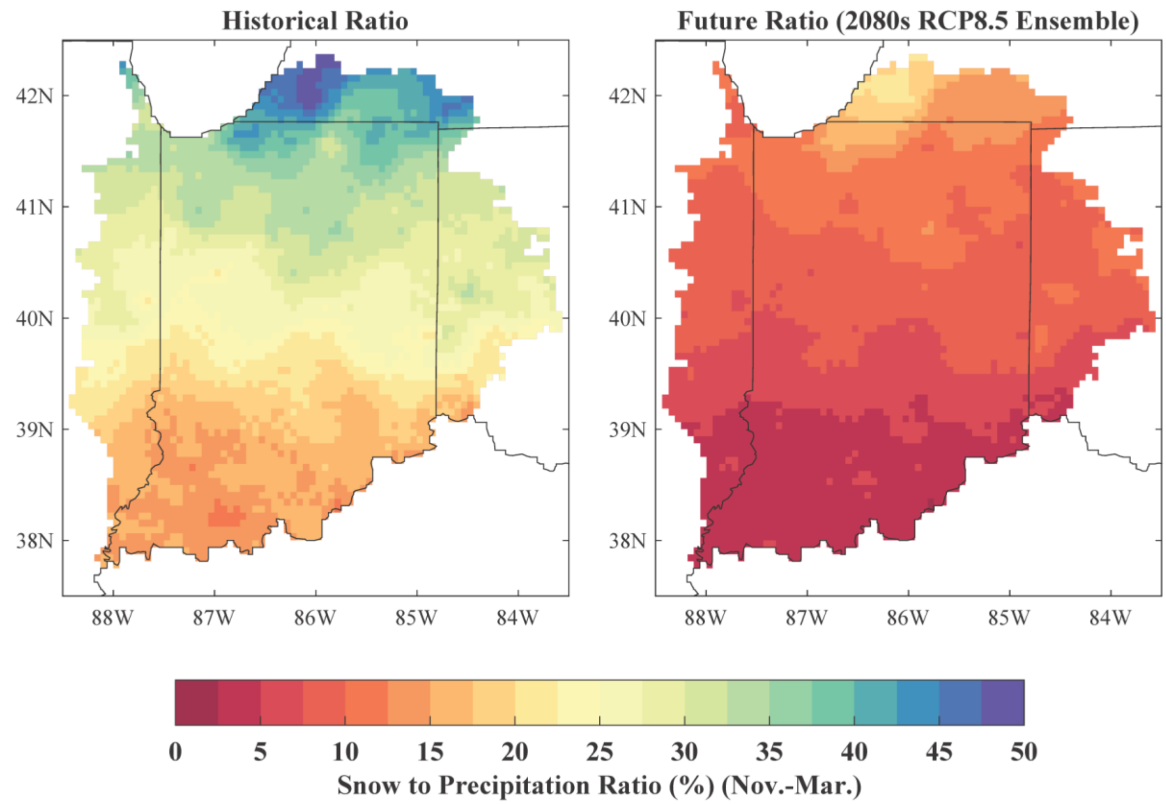

Historical Extreme Cold Days
Future Extreme Cold Days (2080s RCP8.5 Ensemble)
42N
41N
40N
39N
38N
88W
87W
86W
85W
84W
0
2
4
6
8
10
12
14
16
18
Number of Days (< 5 °F)

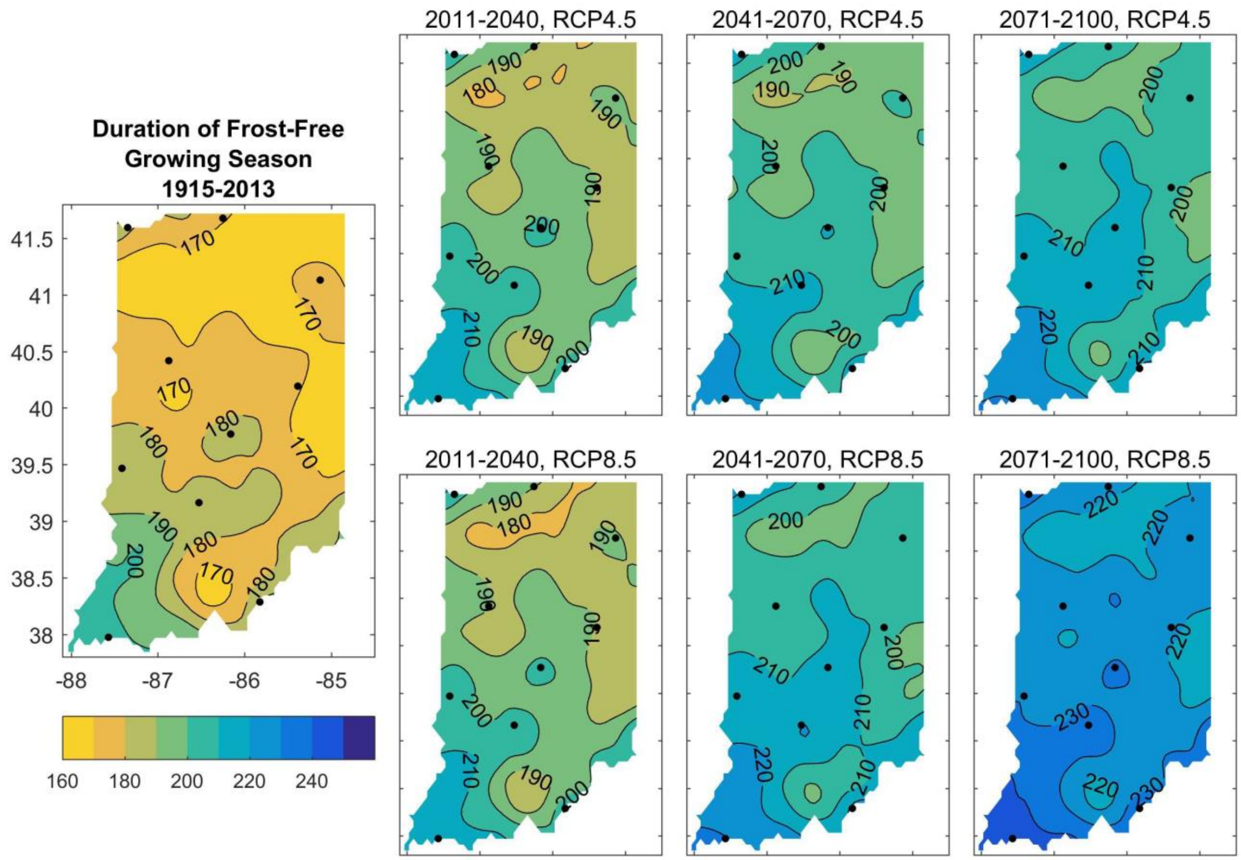
Summer Precipitation Changes

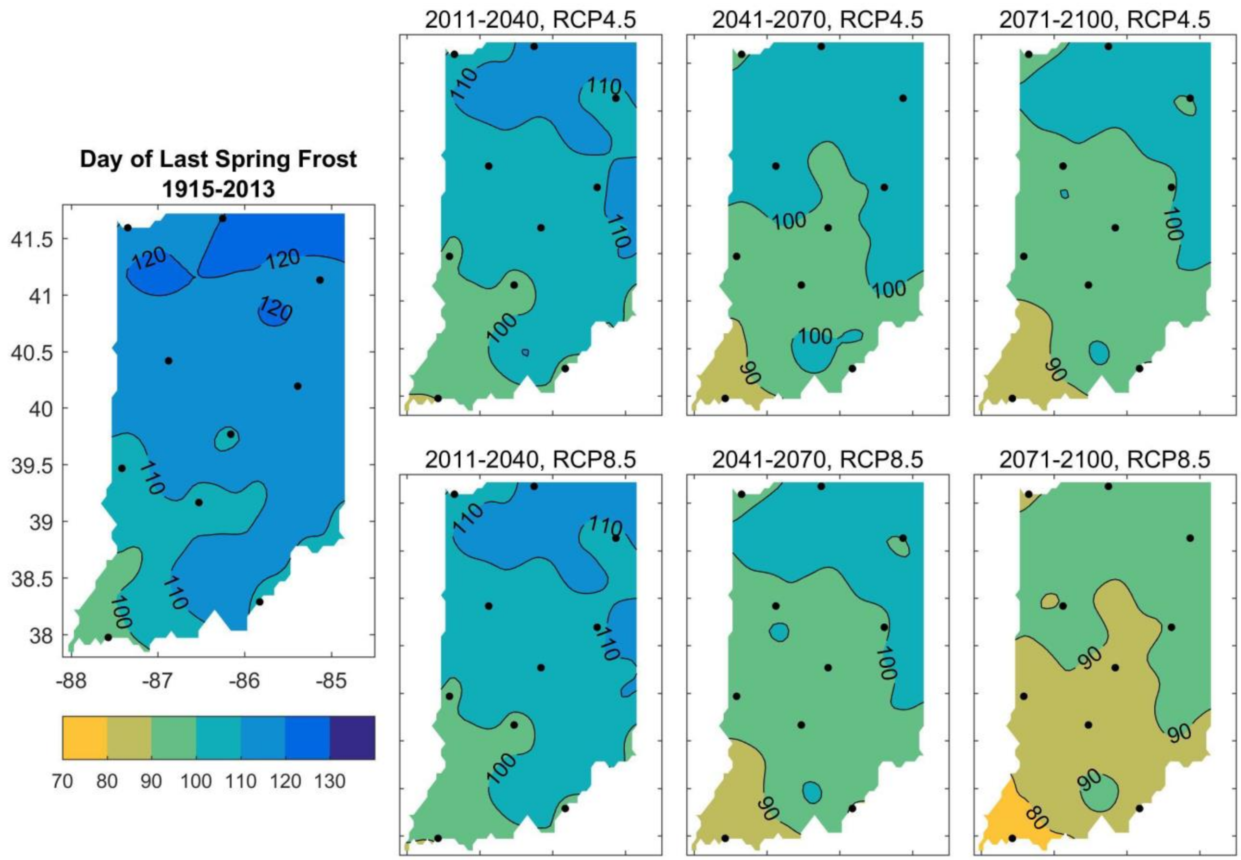


Winter Precipitation Changes

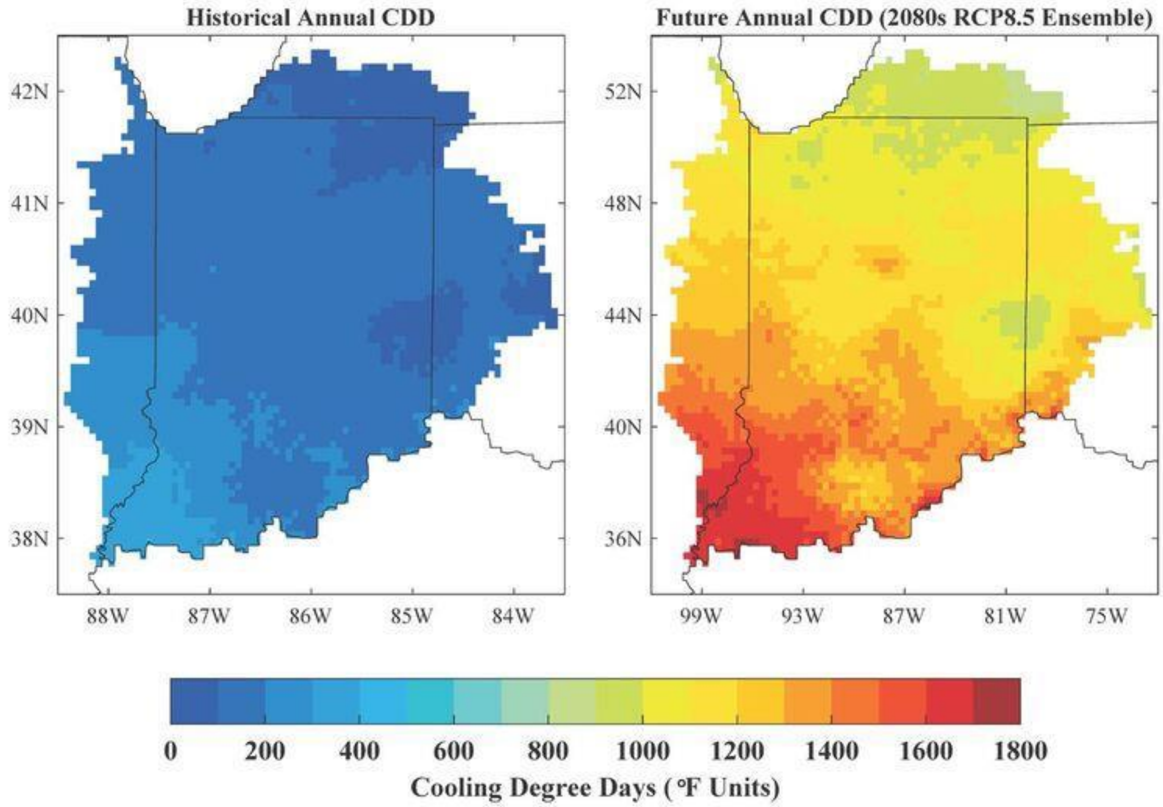


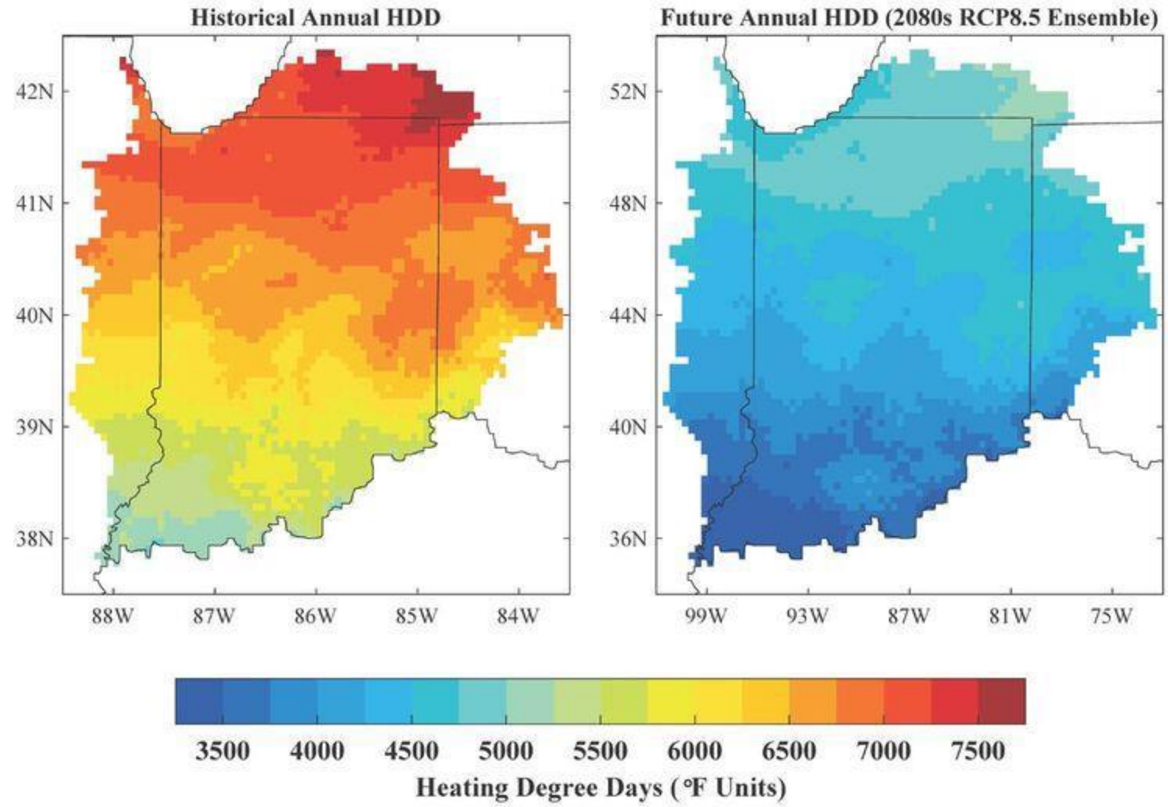

Historical Ratio
Future Ratio (2080s RCP8.5 Ensemble)
42N
41N
40N
39N
38N
88W
87W
86W
85W
84W
0
5
10
15
20
25
30
35
40
45
50
Snow to Precipitation Ratio (%) (Nov.-Mar.)


Duration of Frost-Free
Growing Season
1915-2013
2011-2040, RCP4.5
2041-2070, RCP4.5
2071-2100, RCP4.5
2011-2040, RCP8.5
2041-2070, RCP8.5
2071-2100, RCP8.5
41.5
41
40.5
40
39.5
39
38.5
38
-88
-87
-86
-85
160
180
200
220
240



Day of Last Spring Frost
1915-2013
2011-2040, RCP4.5
2041-2070, RCP4.5
2071-2100, RCP4.5
2011-2040, RCP8.5
2041-2070, RCP8.5
2071-2100, RCP8.5
41.5
41
40.5
40
39.5
39
38.5
38
-88
-87
-86
-85
70 80 90 100 110 120 130


Historical Annual CDD
Future Annual CDD (2080s RCP8.5 Ensemble)
42N
41N
40N
39N
38N
88W
87W
86W
85W
84W
52N
48N
44N
40N
36N
99W
93W
87W
81W
75W
0
200
400
600
800
1000
1200
1400
1600
1800
Cooling Degree Days (°F Units)


Historical Annual HDD
Future Annual HDD (2080s RCP8.5 Ensemble)
42N
41N
40N
39N
38N
88W
87W
86W
85W
84W
52N
48N
44N
40N
36N
99W
93W
87W
81W
75W
3500
4000
4500
5000
5500
6000
6500
7000
7500
Heating Degree Days (°F Units)

Indiana Dunes Region – Preliminary Model Output

These data are from analysis conducted as part of the Indiana Climate Change Impacts Assessment (www.IndianaClimate.org). Results shown are multi-model averages for Porter County, Indiana. This document was compiled by Melissa Widhalm at the Purdue Climate Change Research Center (PCCRC).

Climate projections are based on statistically downscaled data generated for the Midwestern United States. Historical climate data are based on gridded observations that include a precipitation gage undercatch correction (Chiu et al., in review). Hydrologic simulations were conducted using the Variable Infiltration Capacity (VIC) model (Cherkauer et al., in prep).

Projections are for three future periods, which are based on 30-year averages for 2011 to 2040 (called 2020s), 2041 to 2070 (called 2050s), and 2071 to 2100 (called 2080s). Variables with the superscript “C” have a historical period covering 1915-2013 (unless otherwise noted) and future simulations are based on a 10-model ensemble. Variables w/the superscript “W” have a historical period covering 1984-2013 and future simulations are based on a 6-model ensemble. Additional details about the model ensembles are available at http://www.crc.nd.edu/~kbyun/CMIP5_IN_CCIA.html.

Two greenhouse gas emissions scenarios are included for three future time periods. “Moderate” refers to emissions scenario RCP 4.5, which represent relatively ambitious emissions reductions resulting in radiative forcing being stabilized shortly after 2100. “High” refers to emissions scenario RCP 8.5, which is consistent with no policy changes to reduce emissions. Also referred to a the “business as usual” scenario where greenhouse gas concentrations in the atmosphere continue to grow over time.

Please contact Melissa Widhalm (mwidhalm@purdue.edu, 765-494-8191) for questions about this document.

References:

Byun, K. and A.F. Hamlet, 2018: Projected Changes in Future Climate over the Midwest and Great Lakes Region Using Downscaled CMIP5 Ensembles, International Journal of Climatology, (accepted).

Chiu, C.-M., A. F. Hamlet, K. Byun, 2018: An Improved Meterological Driving Data Set for the Great Lakes Region Incorporating Precipitation Gauge Undercatch Corrections (in review).

Cherkauer, K., L. Bowling, I. Chaubey, N. Chin, D. Ficklin, S. Kines, C. Lee, G. Pgnotti, S. Rahman, S., Singh, F. Valappil, and T. Williamson, in prep: Climate Change Impacts and Strategies for Water Resource Management in Indiana. Planned submission to *Climatic Change*

Hamlet, A., K. Byun, S. Robeson, M. Widhalm, and M. Baldwin, in prep: Impacts of Climate Change on the State of Indiana: Future Projections Based on Statistical Downscaling. Planned submission to *Climatic Change*

Porter County, Indiana – ANNUAL

Variable	Historical	2020s (moderate/high)	2050s (moderate/high)	2080s (moderate/high)
Avg T[w]	50°F	53°F / 56°F	55°F / 56°F	56°F / 60°F
Length of growing season[c]	171 days	191 / 191	200 / 207	206 / 224
Freeze/thaw days (Tmin < 26F AND Tmax > 43F)[c]	11 days	10 / 10	10 / 10	10 / 9
Hottest day of the year[c]	96°F	100°F / 101°F	103°F / 105°F	105°F / 110°F
Coldest night of the year[c]	-11°F	-8°F / -7°F	-5°F / -4°F	-4°F / 0°F
Days above 90 F[c]	15 days	34 / 36	48 / 60	60 / 94
Days below 5 F[c]	15 days	10 / 9	7 / 6	6 / 4
Plant Hardiness Zone[c]	(1976-2005) 5b	6a / 6a	6b / 6b	6b / 7a
Plant Heat Zone[c]	5	6 / 7	7 / 7	7 / 8
Days when Tmin > 68F[c]	14 days	27 / 29	39 / 49	48 / 76
% change in annual precip relative to historical period[w]	---	3% / 5%	7% / 8%	6% / 9%
Potential Evapotranspiration (PET)[w]	1027 mm/day	1078 / 1083	1102 / 1122	1132 / 1207
Actual Evapotranspiration (Annual)[w]	739 mm/day	769 / 767	781 / 786	783 / 798
% change in total runoff relative to historical period[w]	---	2% / 0%	9% / 10%	6% / 10%
Days w/ snowcover[w]	75 days	60 / 59	51 / 44	48 / 33

Porter County, Indiana – WINTER

Variable	Historical	2020s (moderate/high)	2050s (moderate/high)	2080s (moderate/high)
Avg T[w]	27°F	30°F / 30°F	32°F / 33°F	32°F / 37°F
% change in annual precip relative to historical period [w]	---	10% / 9 %	14% / 14%	20% / 32%
Potential Evapotranspiration (PET)[w]	92 mm/day	96 / 97	98 / 100	100 / 107
Actual Evapotranspiration[w]	62 mm/day	62 / 61	61 / 61	61 / 65
Total runoff[w]	---	10% / 6%	20% / 20%	23% / 37%
Days w/ snowcover [w]	60 days	49 / 48	43 / 37	41 / 29

Porter County, Indiana – SPRING

Variable	Historical	2020s (moderate/high)	2050s (moderate/high)	2080s (moderate/high)
Avg T[w]	49°F	51°F / 51°F	52°F / 53°F	53°F / 56°F
Last Spring Freeze[c]	Apr 28	Apr 19 / Apr 19	Apr 14 / Apr 11	Apr 11 / Apr 3
% change in annual precip relative to historical period[w]	---	8% / 11%	16% / 22%	13% / 21%
Potential Evapotranspiration (PET)[w]	296 mm/day	305 / 305	311 / 314	319 / 331
Actual Evapotranspiration[w]	187 mm/day	195 / 195	200 / 203	203 / 211
Total runoff[w]	---	7% / 7%	17% / 23%	13% / 22%
Days w/ snowcover[w]	11 days	9 / 9	7 / 6	6 / 4

Porter County, Indiana – SUMMER

Variable	Historical	2020s (moderate/high)	2050s (moderate/high)	2080s (moderate/high)
Avg T[w]	71°F	74°F / 75°F	76°F / 78°F	78°F / 83°F
% change in annual precip relative to historical period[w]	---	1% / -1%	2% / 1%	0% / -6%
Potential Evapotranspiration (PET)[w]	428 mm/day	447 / 449	455 / 463	468 / 502
Actual Evapotranspiration[w]	349 mm/day	361 / 360	364 / 364	363 / 362
Total runoff[w]	---	-6% / -9%	-5% / -4%	-9% / -16%

Porter County, Indiana – FALL

Variable	Historical	2020s (moderate/high)	2050s (moderate/high)	2080s (moderate/high)
Avg T[w]	53°F	56°F / 56°F	58°F / 59°F	59°F / 64°F
First Fall Freeze[c]	Oct 15	Oct 26 / Oct 26	Oct 30 / Nov 3	Nov 2 / Nov 11
% change in annual precip relative to historical period[w]	---	0% / -3%	3% / 1%	-2% / -1%
Potential Evapotranspiration (PET)[w]	211 mm/day	230 / 232	237 / 245	246 / 267
Actual Evapotranspiration[w]	141 mm/day	152 / 151	157 /159	156 / 160
Total runoff[w]	---	-7% / -12%	-3% / -9%	-12% / -16%
Days w/ snowcover[w]	4 days	2 / 2	1 / 1	2 / 1

Appendix B: NPS Climate Change Assessments

In 2014, NPS Ecologists Bill Monahan and Nicholas Fisichelli conducted an assessment of the recent climate change exposure of national parks, and produced a Resource Brief for the Indiana Dunes National Lakeshore. During the same year, NPS Climate Change Scientist Patrick Gonzalez produced a climate change trends and vulnerabilities report for the Indiana Dunes. Included in this appendix are the combined data and graphs from both of the analyses.

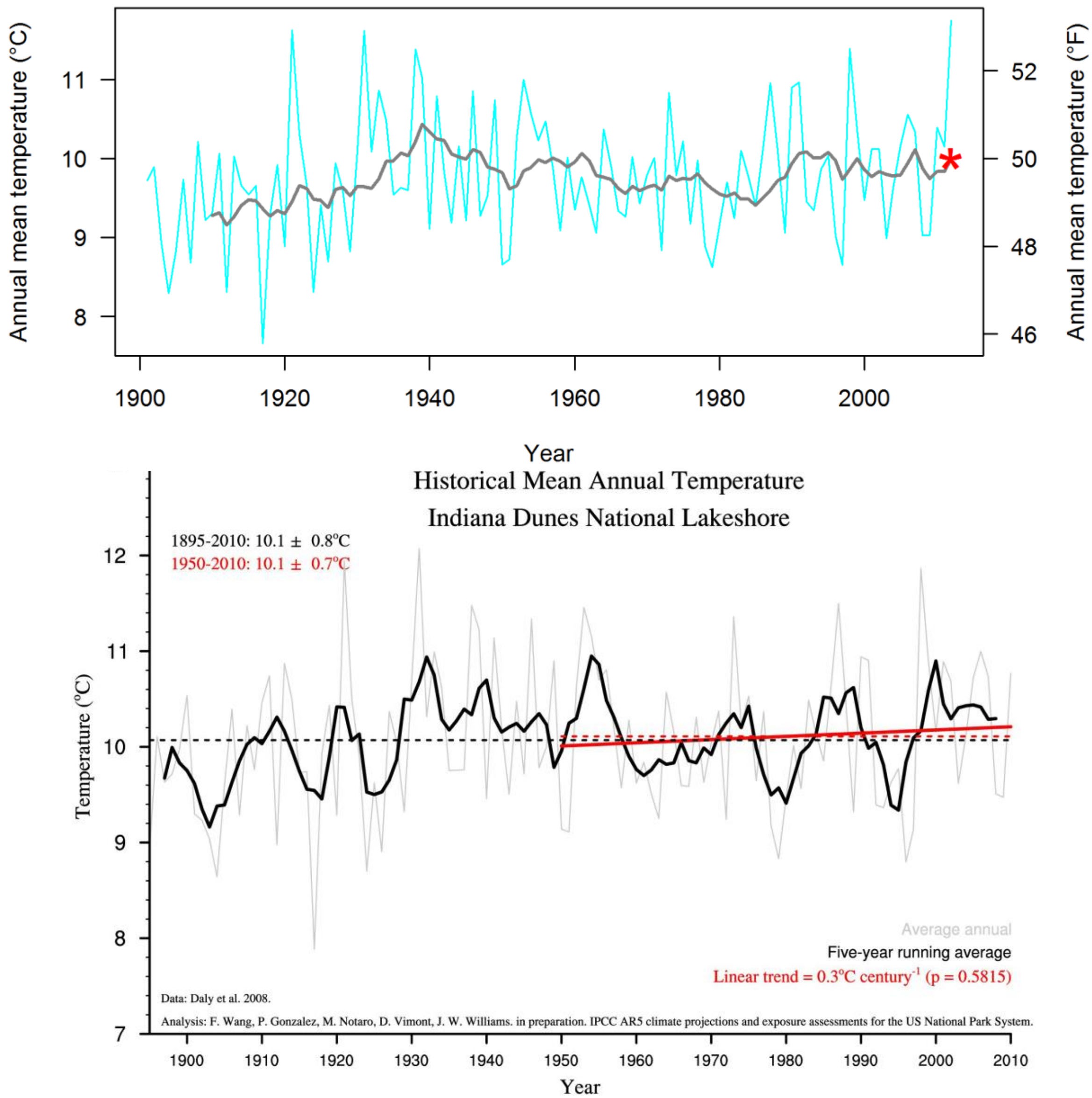
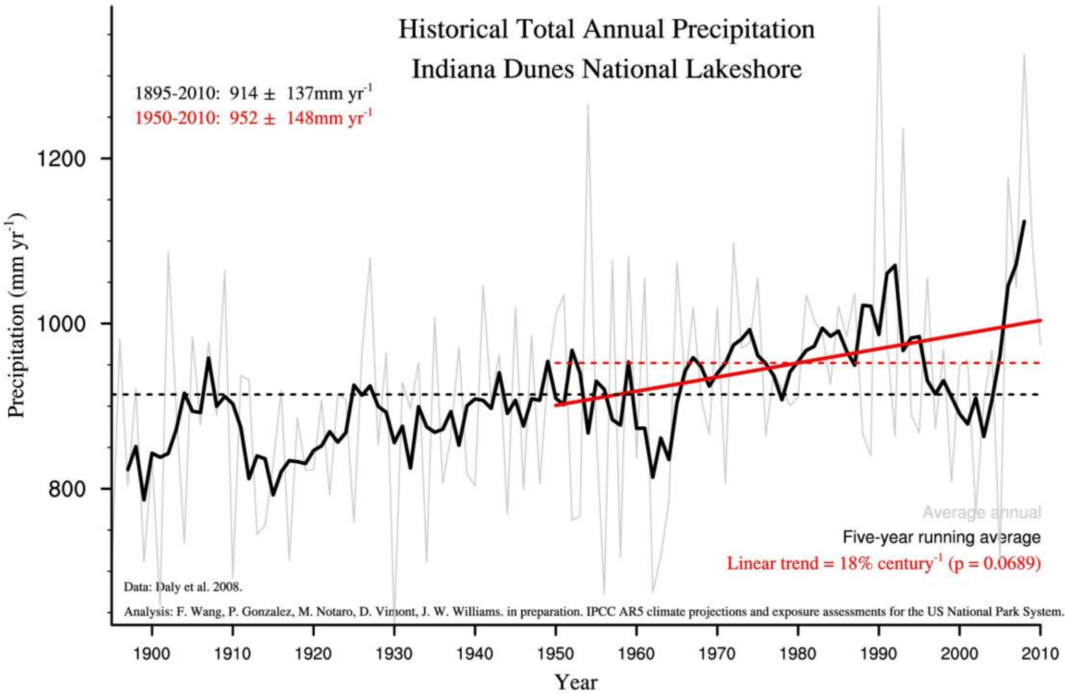


*Figure 22. Graphs showing the temperature trends over the last century at the Indiana Dunes National Lakeshore - from WB Monahan and Fisichelli (2014), top, and Gonzalez (2014), bottom. The light blue and light grey in each graph tracks the annual variability. The dark grey line in the top graph shows a 10-year **moving** average, while the black line in the bottom graph shows a 5-year **running** average and thus shows more variability. In addition, the Gonzalez (bottom) graph includes trend lines, and in particular focusing on the rate of temperature increase for the 1950 – 2010 (red line).*



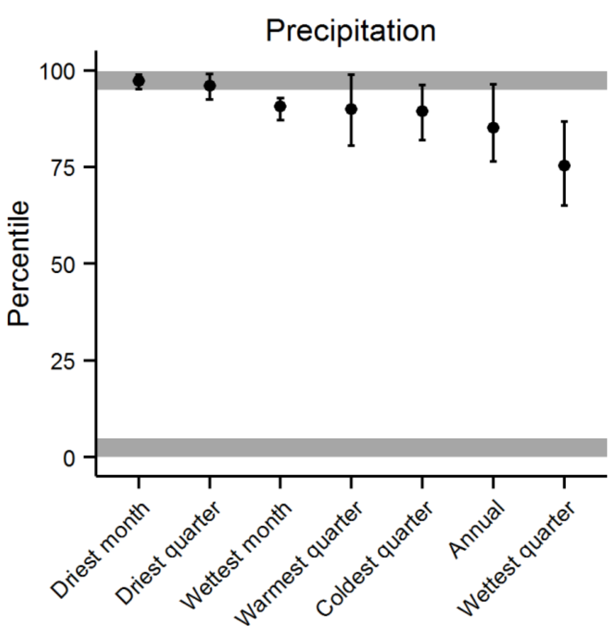


Figure 23. The time series graph from Gonzalez (2014) showing the precipitation trend over the past century, top, and the plot from Monahan and Fisichelli (2014), bottom, showing the average recent percentiles (dots) and ranges (bars) across the 10, 20, and 30-year intervals (moving windows). Values for the driest month (February) and quarter (winter DJF) exceeded 95% of the historical range of conditions, the horizontal grey bar.

	1950-2010	2000-2050	2000-2100
Historical			
Temperature	+0.3°C (0.5°F.)/century		
Precipitation	+18%/century		
Projected (compared to 1971-2000)			
Low emissions (IPCC RCP 4.5)			
Temperature		+2.5°C (4.5°F.)	+3.2°C (5.8°F.)
Precipitation		+7%	+8%
High emissions (IPCC RCP 6.0)			
Temperature		+2.0°C (3.6°F.)	+3.6°C (6.5°F.)
Precipitation		+6%	+9%
Highest emissions (IPCC RCP 8.5)			
Temperature		+3.1°C (5.6°F.)	+5.4°C (9.7°F.)
Precipitation		+8%	+11%

Figure 24. Table of temperature trends and projections from Gonzalez (2014).

Appendix C: Coastal Change-Potential Assessment of Indiana Dunes National Lakeshores to Lake-Level Changes

In a USGS study in 2007, a change-potential index (CPI) was used to map the susceptibility of the shoreline to future lake-level change within Apostle Islands, Indiana Dunes, and Sleeping Bear Dunes National Lakeshores (NL) along Lake Superior and Lake Michigan (Pendleton, Thieler, and Williams 2007). The CPI in the Great Lakes setting ranks the following in terms of their physical contribution to lake-level related coastal change: geomorphology, regional coastal slope, rate and direction (e.g., rise and fall) of relative lake-level change, historical shoreline change rates, annual ice cover and mean significant wave height. The rankings for each input variable were combined, and an index value calculated for 1-minute bins covering the parks. The CPI highlights those regions where the physical effects of lake-level and coastal change might be the greatest. This approach combines the coastal system's potential for change with its natural ability to adapt to changing environmental conditions, yielding a quantitative, although relative, measure of the park's natural susceptibility to the effects of lake-level variation. The CPI provides an objective technique for evaluation and long-term planning by scientists and park managers. The areas within these Great Lakes parks that are likely to experience the most lake-level-related coastal change are areas of unconsolidated sediment where regional coastal slope is low and wave energy is high. Maps included in this appendix represent the analyses and results for the Indiana Dunes National Lakeshore only.

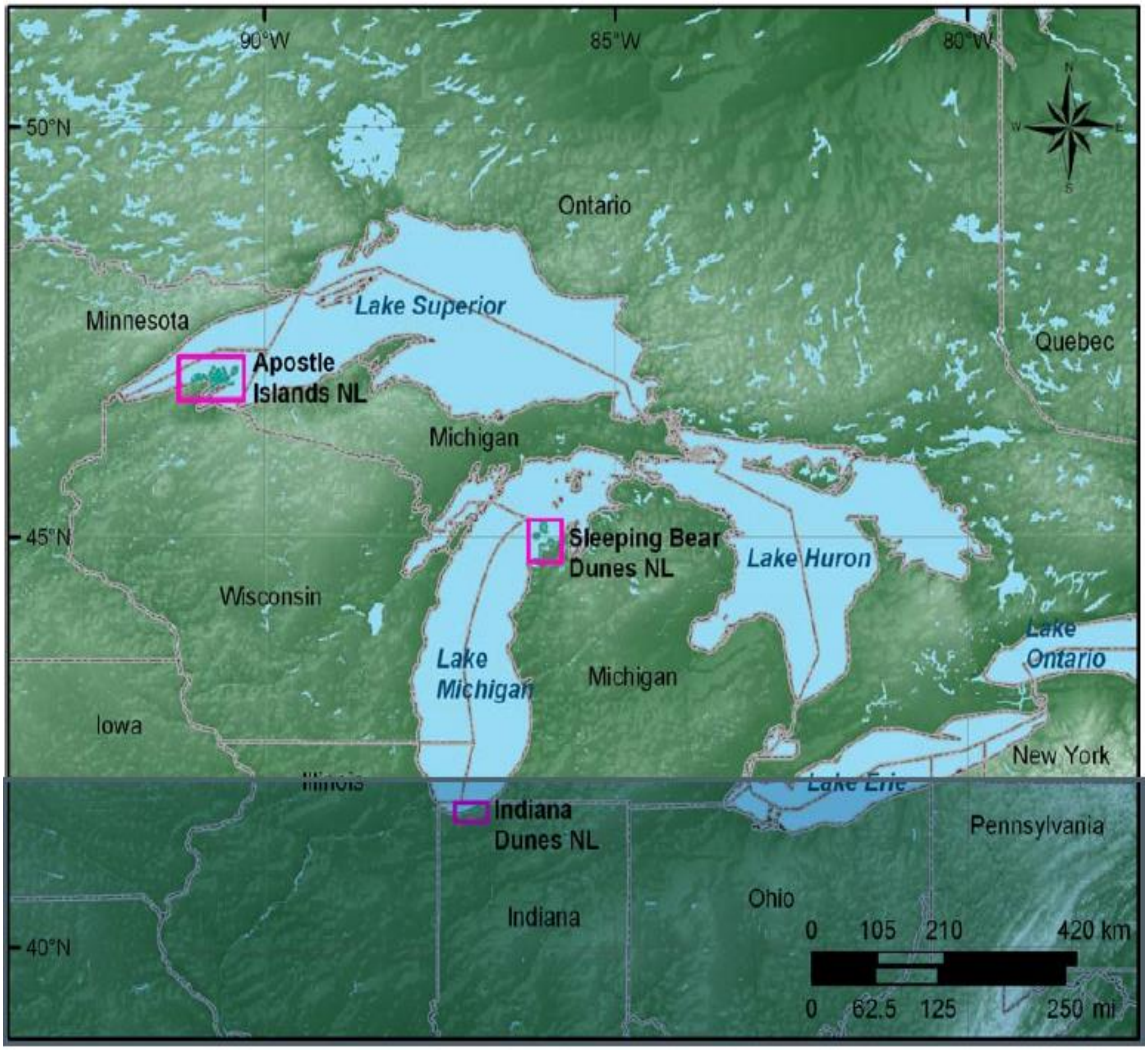


Figure 25. Location of Great Lakes National Lakeshores: Sleeping Bear Dunes, MI; Indiana Dunes, IN; and Apostle Islands, WI.

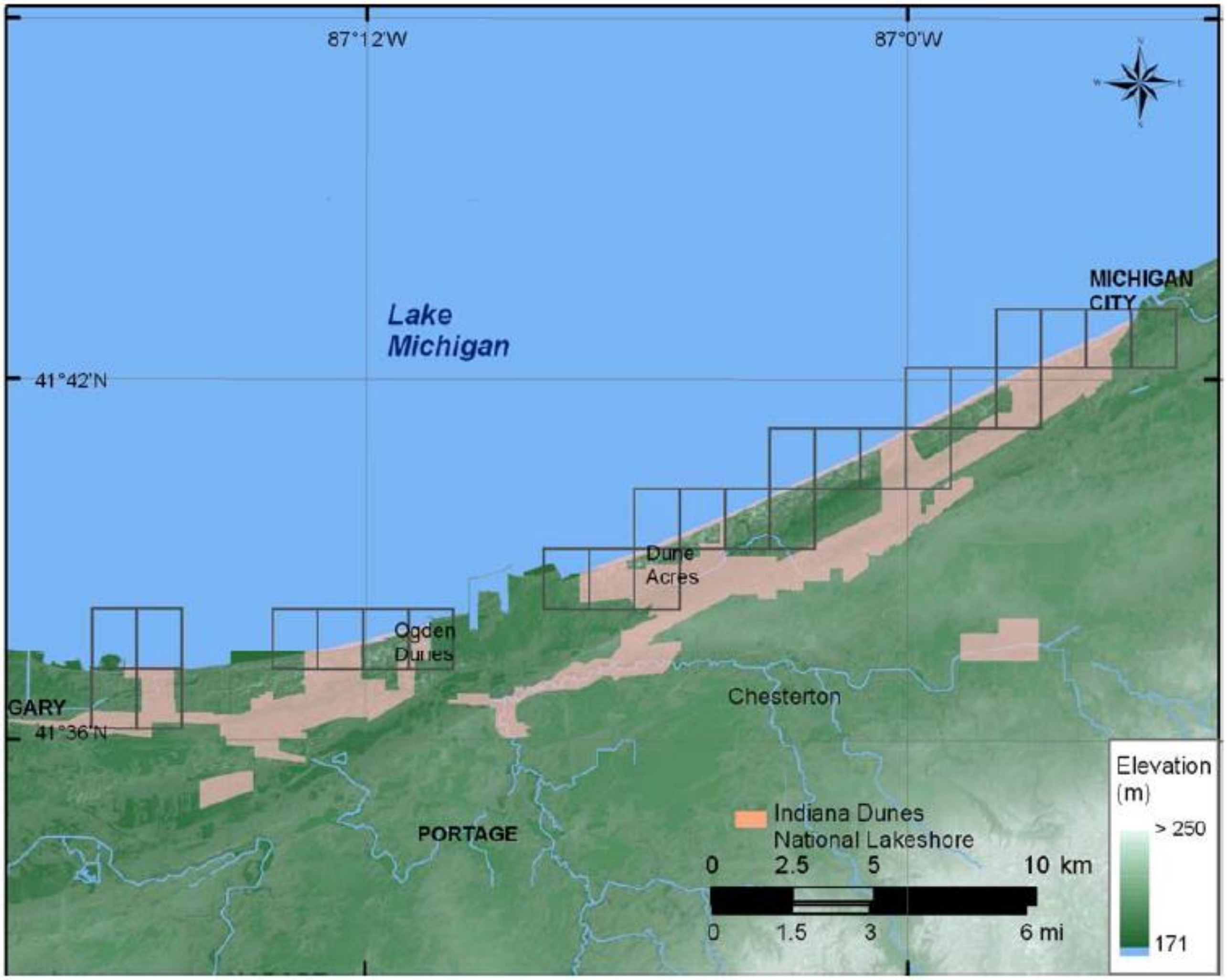


Figure 26. Shoreline grid for the Indiana Dunes NL. Each cell is approximately 1-minute and represents a shoreline segment for which each variable is defined.

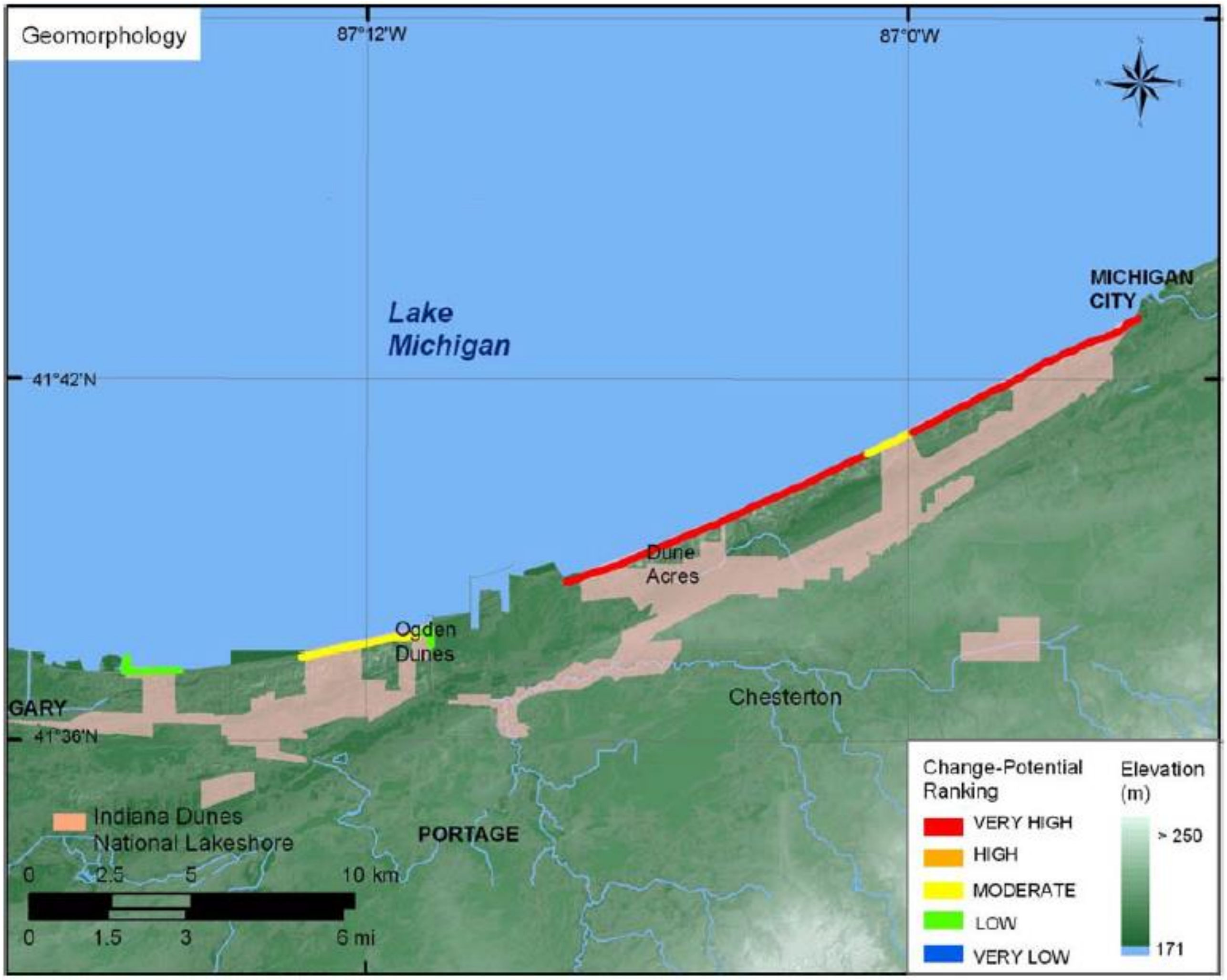


Figure 27. Lakeshore geomorphology for Indiana Dunes National Lakeshore. The colored shoreline represents the variation in coastal geomorphology within the park. High change-potential geomorphology includes gravel and sand beaches not immediately backed by bluffs. Moderate change-potential geomorphology consists of alluvial fans and beaches backed by bluffs. Low change-potential geomorphology includes medium bluffs and rock outcrops.

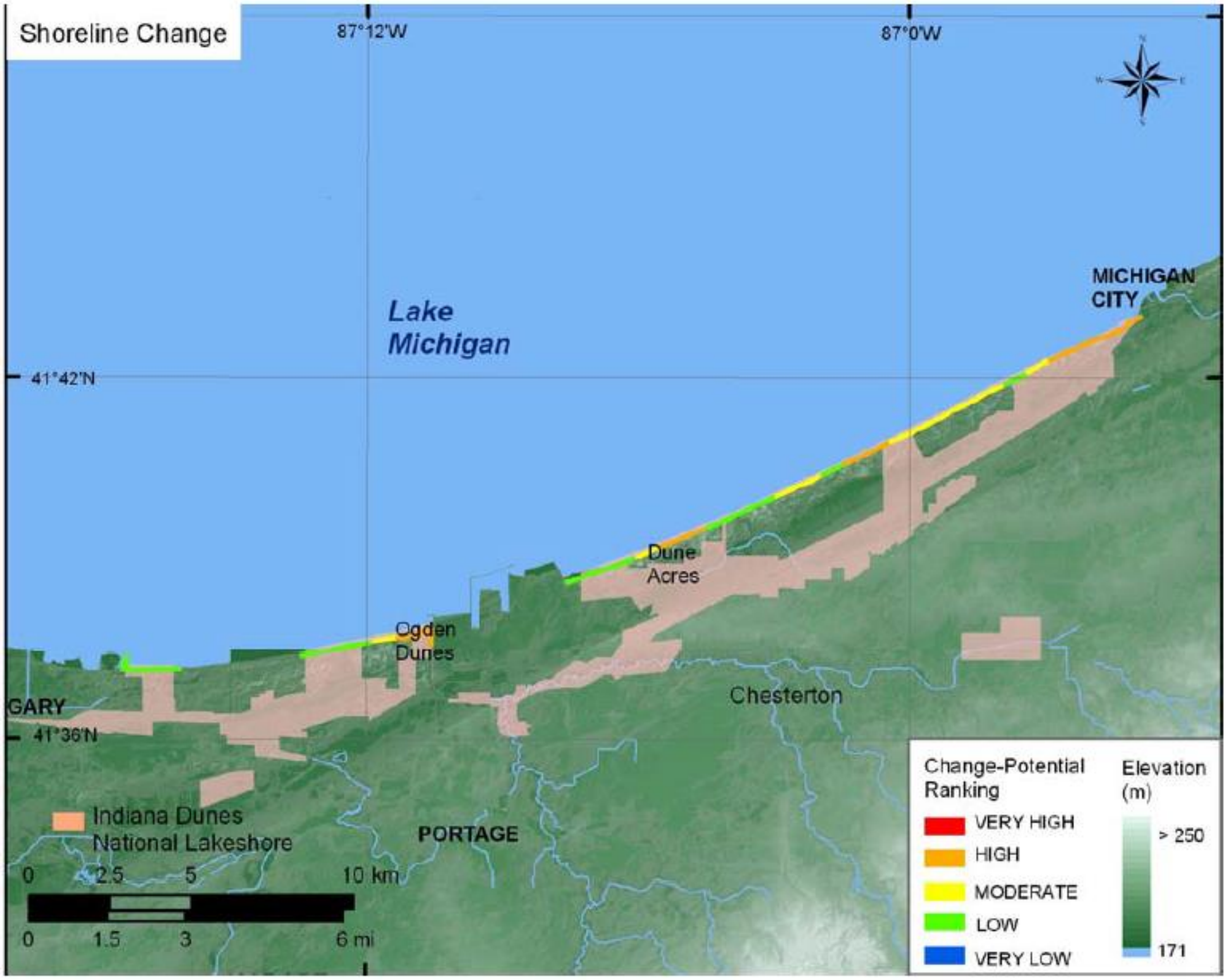


Figure 28. Shoreline change for Indiana Dunes National Lakeshore. The colored shoreline represents the rate of shoreline change.

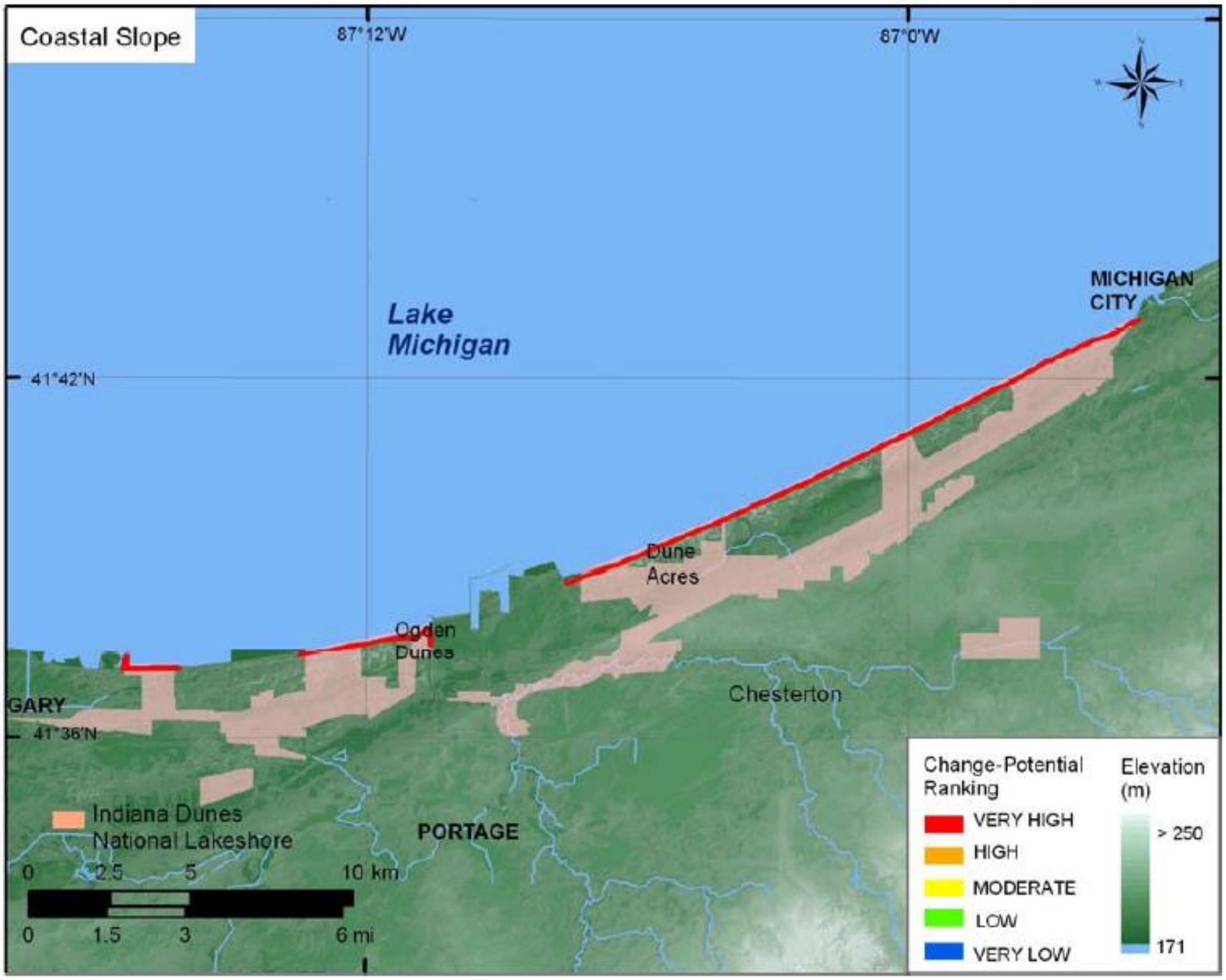


Figure 29. Regional coastal slope for Indiana Dunes National Lakeshore. The colored shoreline represents the regional slope of the land, 5 km landward and lakeward of the shoreline.

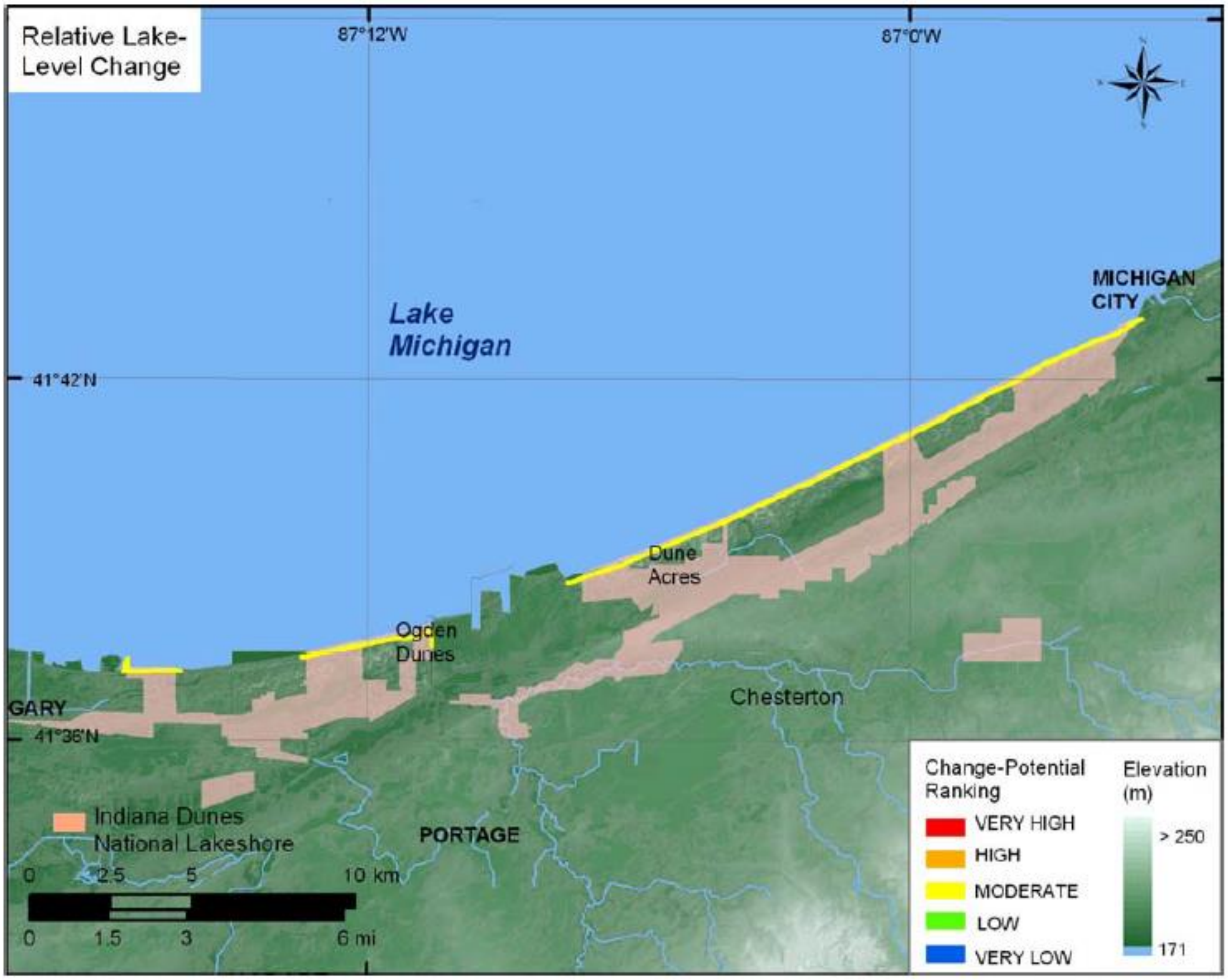


Figure 30. Rate of relative lake-level change for Indiana Dunes National Lakeshore.

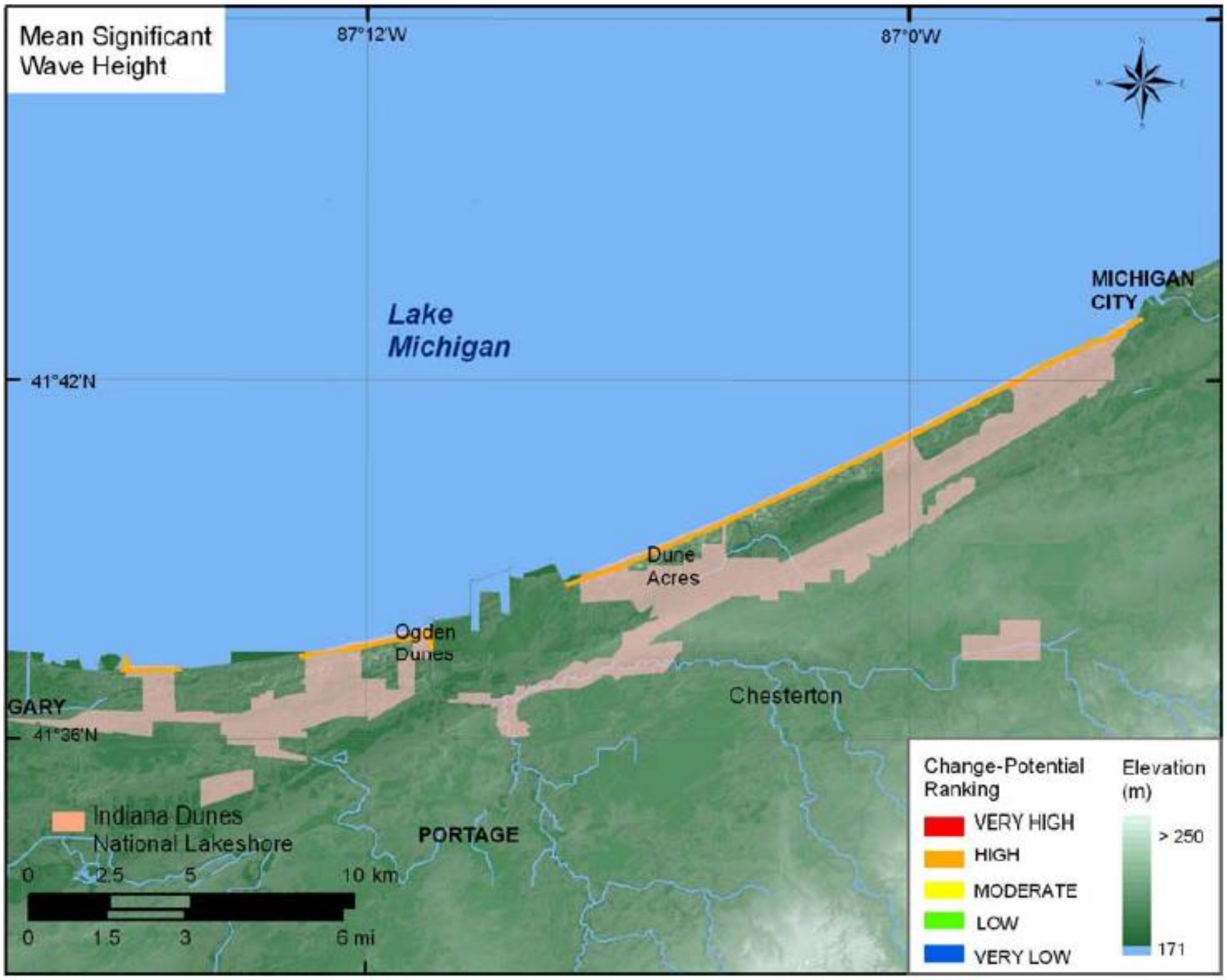


Figure 31. Mean significant wave heights for Indiana Dunes National Lakeshore. The colored shoreline rep

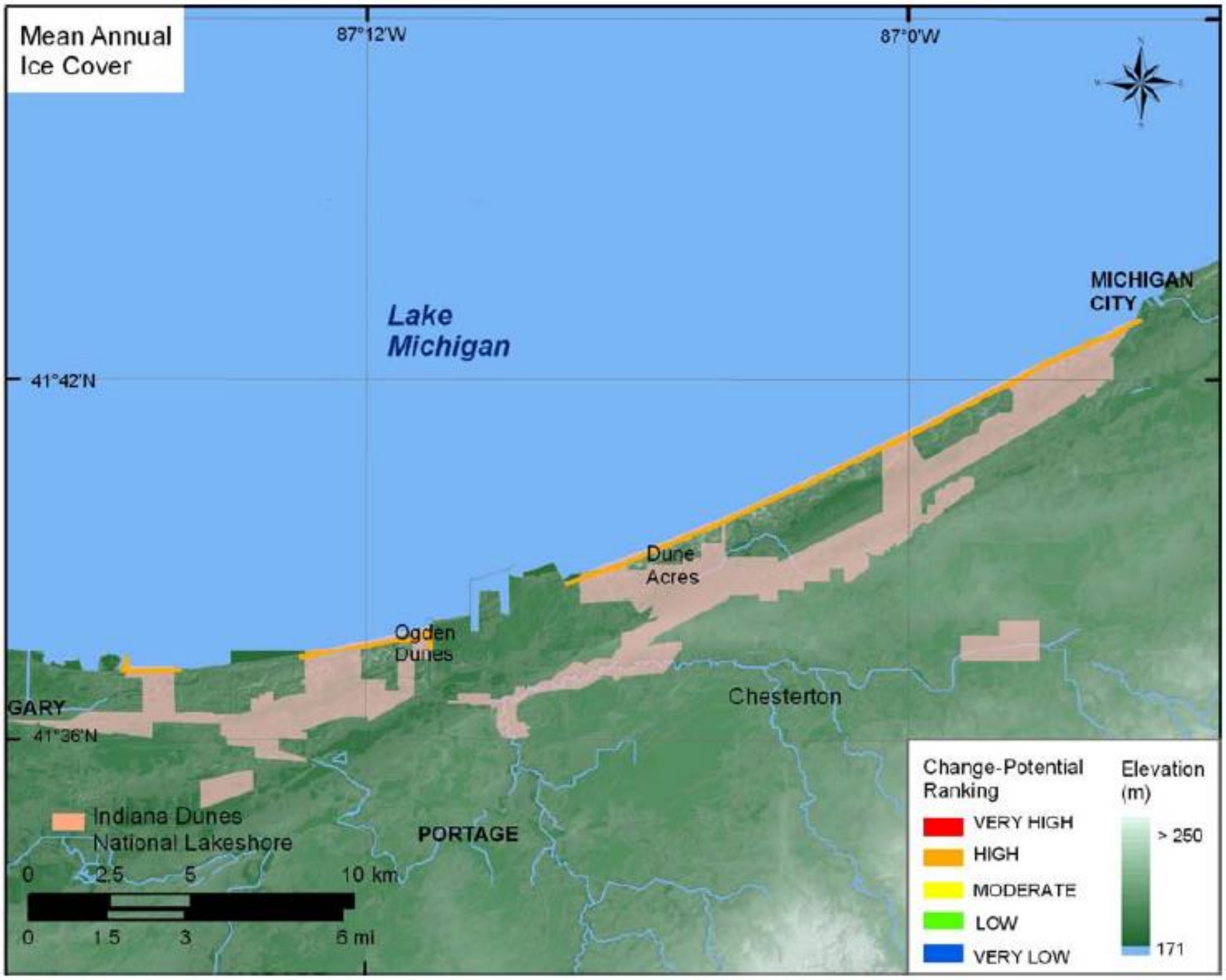


Figure 32. Mean Annual Ice Cover for Indiana Dunes National Lakeshore.

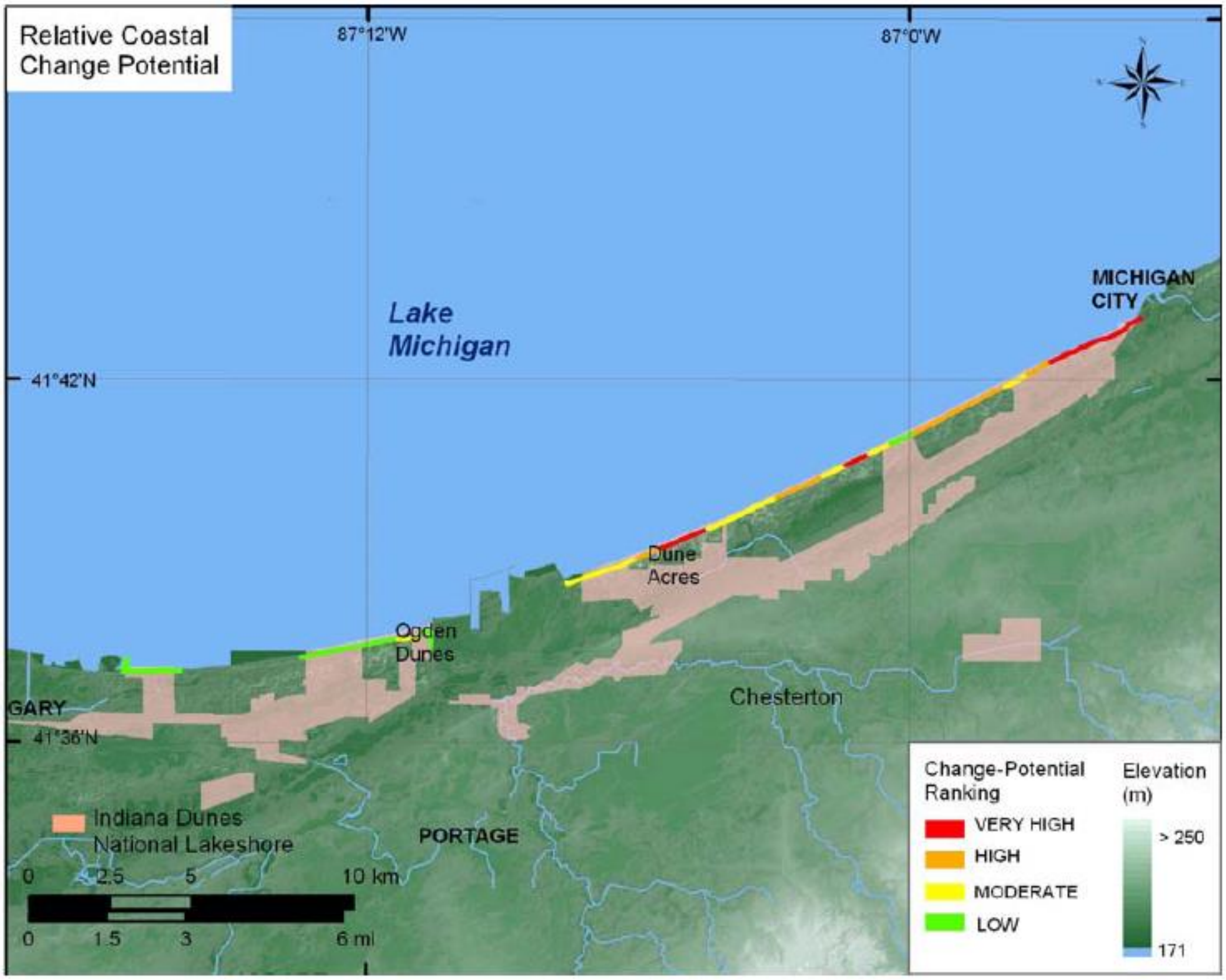


Figure 33. Relative Coastal Change-potential for Indiana Dunes National Lakeshore. The colored shoreline represents the relative coast change-potential index (CPI) determined from the six variables. The very high change-potential shoreline is located along sandy stretches of coast where shoreline recession rates are highest. The low change-potential shoreline is located along bluffs where shoreline is lower.