

GREAT LAKES NATIONAL PARKS IN PERIL THE THREATS OF CLIMATE DISRUPTION

Pictured Rocks National Lakeshore



*At stake are the resources and values
that make our national parks the
special places that Americans love.*

the
**ROCKY
MOUNTAIN
CLIMATE**
Organization



Principal Authors
Stephen Saunders
Dan Findlay
Tom Easley

The Rocky Mountain Climate Organization

Contributing Author
Theo Spencer
Natural Resources Defense Council

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The Rocky Mountain Climate Organization (RMCO) works to reduce climate disruption and its impacts. We do this in part by spreading the word about what a disrupted climate can do to us and what we can do about it. Visit www.rockymountainclimate.org to learn more about our work.

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The Rocky Mountain Climate Organization
P.O. Box 270444, Louisville, CO 80027
1633 Fillmore St., Suite 412, Denver, CO 80206
303-861-6481
www.rockymountainclimate.org



Natural Resources Defense Council
40 West 20th Street, New York, NY 10011
212-727-2700 / Fax 212-727-1773
www.nrdc.org

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Natural Resources Defense Council

About the Authors

Stephen Saunders is president of RMCO and former Deputy Assistant Secretary of the U.S. Department of the Interior over the National Park Service and U.S. Fish and Wildlife Service. Dan Findlay is a program officer at RMCO. Tom Easley is director of programs at RMCO and a former statewide programs manager at the Colorado State Parks agency. Theo Spencer is a senior advocate in NRDC's Climate Center.

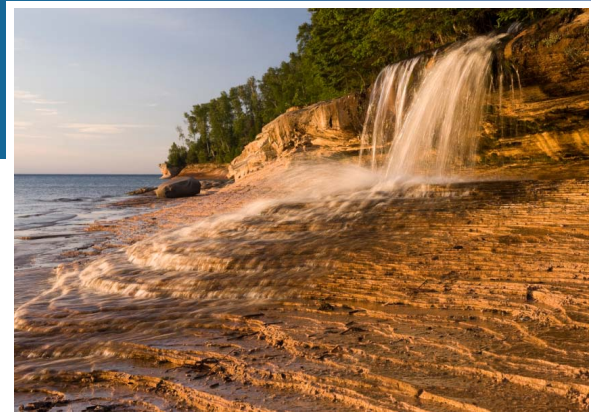
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EXECUTIVE SUMMARY



Sleeping Bear Dunes NL

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Human disruption of the climate is the greatest threat ever to America’s national parks. This report details the particular threats that a changed climate poses to our Great Lakes national parks—those within the lakes or on their shores.

Seven units of the national park system on the shores of the lakes contain some of the most spectacular, nationally significant resources along the Great Lakes coastline. This report focuses primarily on the five largest of these parks, all on lakes Michigan and Superior: Indiana Dunes National Lakeshore (NL) in Indiana; Sleeping Bear Dunes NL, Pictured Rocks NL, and Isle Royale National Park (NP) in Michigan; and Apostle Islands NL in Wisconsin. (See pages 1-3.)

The threats of climate disruption to the national parks in the Great Lakes are also **threats to the region’s economy**. (See pages 4-6). The five parks featured in this report together drew more than four million visitors in 2010. Visitor spending in 2009

totaled more than \$200 million and supported nearly 3,000 jobs. These economic benefits are at risk as a changing climate threatens the special resources that draw vacationing families and others to these parks.

The parks face **more heat and other climate changes**. (See pages 7-14.) For this report, the Rocky Mountain Climate Organization (RMCO) analyzed temperature records for the two weather stations in the U.S. Historical Climatology Network (USHCN) in the immediate vicinity of Great Lakes national parks. As shown in the figure on the following page, for those parks 2001-2010 was the hottest decade in the period of temperature

Spending and Jobs from Visitors to Great Lakes National Parks in 2009				
	(Visitors In 2010)	Visitors In 2009	Total Visitor Spending	Total Jobs Supported
Indiana Dunes NL	(2,150,345)	1,944,568	\$54,878,000	542
Sleeping Bear Dunes NL	(1,280,932)	1,165,836	\$107,165,000	1,803
Pictured Rocks NL	(499,281)	448,215	\$18,199,000	300
Apostle Islands NL	(156,945)	170,202	\$18,203,000	301
Isle Royale NP	(15,793)	14,653	\$1,798,000	26
Totals	(4,103,296)	3,743,474	\$200,243,000	2,972

Table ES-1. Sources: NPS and Stynes (2010).

measurements. Near Indiana Dunes, the last decade was 1.6°F hotter than the 20th century average temperature. Near Pictured Rocks the last decade was 2.7° hotter. Both were above the 1.5° by which temperatures for the planet as a whole exceeded its 20th century average.

RMCO also obtained new projections of changes in annual and (as shown in the table on the following page) summer temperatures in the featured parks, for mid-century (2040-2069) and late century (2070-2099), based on two possible futures—with lower or medium-high emissions of heat-trapping

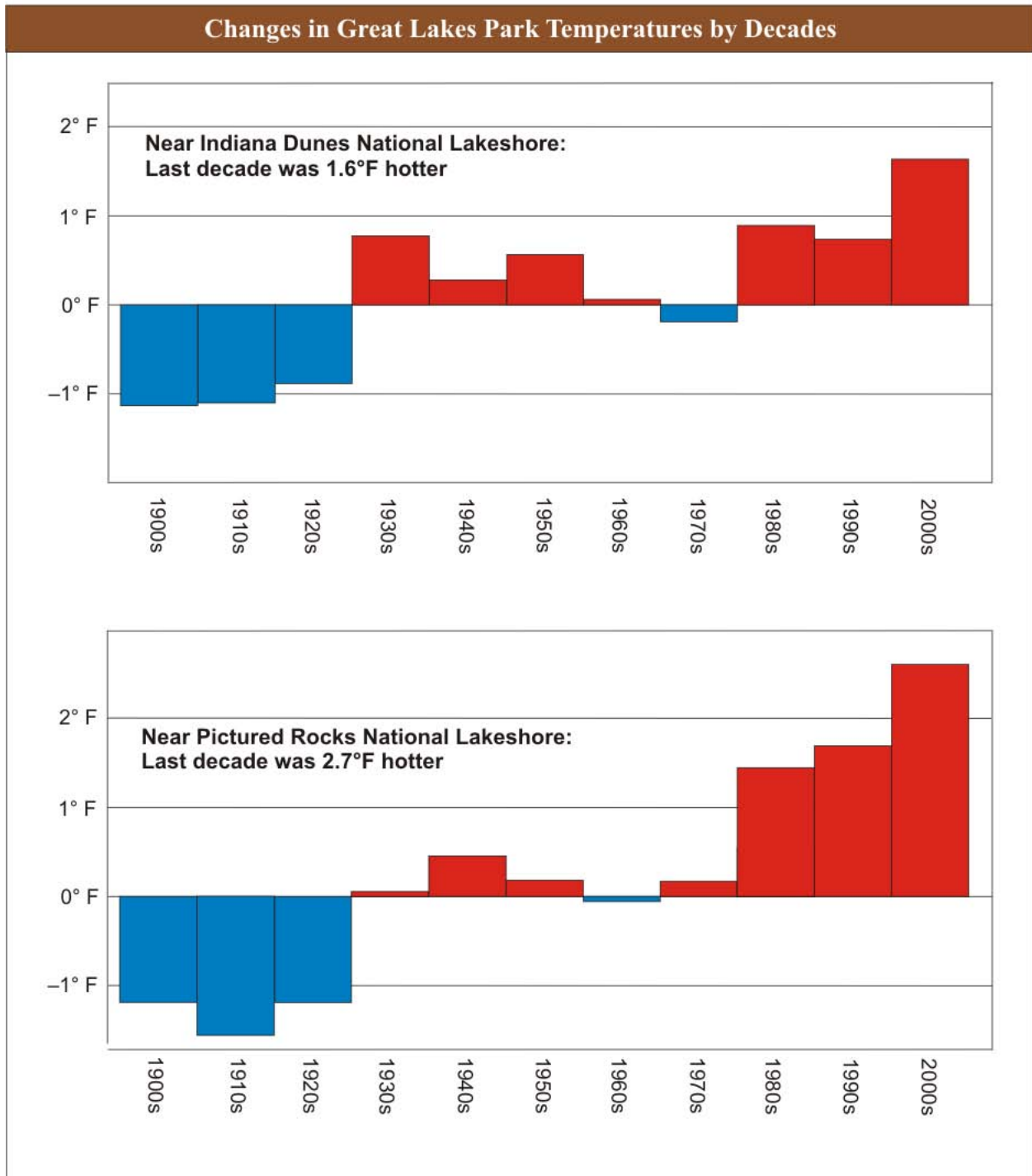


Figure ES-1. Average temperatures 1901 through 2010, by decade (e.g., 1901-1910), compared to corresponding 1901-2000 averages, for high-quality weather stations near the identified national parks. Data from the U.S. Historical Climatology Network. Analysis by the Rocky Mountain Climate Organization.

Hotter Future Average Summers in Great Lakes Parks with Medium-High Emissions

National Park	2040-2069	2070-2099
<p>Indiana Dunes NL</p> <p>Average projection</p> <p>Effect of average projection</p> <p>Range of projections</p>	<p>+5.0° (to 76.7°)</p> <p>As hot as recent summers in Raleigh, NC (76.9°)</p> <p>+2.7° (to 74.4°) to +9.5° (81.2°)</p>	<p>+8.6° (to 80.3°)</p> <p>As hot as recent summers in Gainesville, FL (80.2°)</p> <p>+4.9° (to 76.6°) to +15.4° (87.1°)</p>
<p>Sleeping Bear Dunes NL</p> <p>Average projection</p> <p>Effect of average projection</p> <p>Range of projections</p>	<p>+4.5° (to 71.1°)</p> <p>As hot as recent summers in Chicago (71.1°)</p> <p>+2.0° (to 68.6°) +8.6° (75.2°)</p>	<p>+7.7° (to 74.3°)</p> <p>As hot as recent summers in Lexington, KY (74.4°)</p> <p>+3.6° (to 70.2°) to +13.7° (80.3°)</p>
<p>Pictured Rocks NL</p> <p>Average projection</p> <p>Effect of average projection</p> <p>Range of projections</p>	<p>+4.4° (to 66.1°)</p> <p>As hot as recent summers just north of Green Bay (Oconto, WI, 66.1°)</p> <p>+1.5° (to 63.2°) to +8.4° (70.1°)</p>	<p>+8.4° (to 70.1°)</p> <p>As hot as recent summers just north of Chicago (Lake Villa, IL, 70.0°)</p> <p>+5.0° (to 66.7°) to +14.3° (76.0°)</p>
<p>Apostle Islands NL</p> <p>Average projection</p> <p>Effect of average projection</p> <p>Range of projections</p>	<p>+5.2° (to 68.3°)</p> <p>As hot as recent summers in Lansing, MI (68.3°)</p> <p>+2.7° (to 65.8°) to +9.5° (72.6°)</p>	<p>+8.2° (to 71.3°)</p> <p>As hot as recent summers in central IN (Elwood, 71.3°)</p> <p>+4.3° (to 67.4°) to +14.2° (77.3°)</p>
<p>Isle Royale NP</p> <p>Average projection</p> <p>Effect of average projection</p> <p>Range of projections</p>	<p>+4.6° (to 65.7°)</p> <p>As hot as recent summers in the Upper Peninsula of MI (Alpena, 65.6°)</p> <p>+2.5° (to 63.6°) to +8.2° (69.3°)</p>	<p>+7.9° (to 69.0°)</p> <p>As hot as recent summers in southernmost WI (Kenosha, 69.0°)</p> <p>+4.2° (to 65.3°) to +13.1° (74.2°)</p>

Table ES-2. Projected increases in June-July-August average temperatures in degrees Fahrenheit with a medium-high emissions scenario (identified on page 14), compared to 1971-2000. Data from the World Climate Research Program's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset and the National Climatic Data Center. Analysis by RMC0.

pollutants. These projections illustrate that how much the climate changes will depend in large part on whether future emissions are limited. In every case, the scenario with higher emissions yields greater temperature increases than the scenario with lower emissions. At Indiana Dunes, for example, the average result from 16 climate models is for annual average temperatures in the park to get 4.7°F hotter near century's end with lower emissions, but 8.0° hotter with medium-high future emissions.

RMCO also obtained projections of future summer temperature changes. Visitation to the parks is much higher in summer than in other seasons, so future summer temperatures could particularly affect park visitors. As the table on the previous page shows, the average of the projections with medium-high future emissions is for summers in Indiana Dunes to become as hot by late in this century (2070-2099) as summers in Gainesville, Florida, have been in recent history (1971-2000). Summers in Sleeping Bear Dunes could become as hot as those in Lexington, Kentucky, recently have been. Obviously, the experience of visiting these parks in summer would be fundamentally different. The effects on park resources and values, too, would be profound.

Other projected climate changes in the Great Lakes parks include increases in annual precipitation levels and shifts in some winter precipitation from snow to rain. Projections for summers include decreases in rainfall and increases in evaporation from soil and water bodies, leading to drier as well as hotter summers.

The parks are at risk of **disruption of their ecosystems**. (See pages 15-21.) Water temperatures in the Great Lakes have already gone up. (See the next page for more information on this and other changes that are already underway and are consistent with projections of a changed climate.) Scientists project that lake waters could get 2° to 12°F hotter in this century.

Higher air and water temperatures already are reducing winter ice cover on the Great Lakes, a trend expected to accelerate. Lake Michigan may have some winters with no ice cover in as soon as ten years, and Lake Superior may typically be ice-free in about three decades. Another study projects that by the end of the century ice could last 76 days less around Apostle Islands and Isle Royale and 80 days less around Pictured Rocks.

With less ice and more open waters, the lakes will have more waves in winter than before, especially during strong storms, increasing erosion threats to park shorelines and structures. The park staff at Sleeping Bear Dunes has expressed concern that the park's signature perched dunes, atop towering bluffs above the shorelines, could be vulnerable to accelerated loss from increased erosion, resulting from a loss of winter ice and snow cover that keeps the dunes's sand from blowing away and from more



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Sleeping Bear Dunes NL

waves undercutting the bluffs on which the dunes perch.

An altered climate is projected to lower the water levels of the Great Lakes by disrupting the current balance of water entering the lakes through inflows and precipitation and leaving through outflows and evaporation. One projection is that by before the century's end lake levels could drop by about 10 inches with lower future emissions of heat-trapping gases, 11 inches with medium emissions, and 16 inches with medium-high emissions. One effect could be that docks and boat ramps in the national parks could become unusably far above the lake surface.

In a hotter climate, the forested areas in the Great Lakes parks may no longer meet the habitat requirements of the spruce-fir forests now found there, or of individual species including quaking aspen, paper birch, northern white cedar, balsam fir, and sugar maple.

Increases in temperature and other climate changes may promote the spread into the parks of invasive plant species that can crowd out native plants. Particularly at risk is Indiana Dunes, which, with more than 1,100 native flowering plants, has some of the greatest biological diversity of any national park. One projected invader of the region's parks is kudzu, a highly aggressive, fast-growing Asian vine that has long plagued much of the southeastern United States but has been kept out of the Great Lakes region by cold winters. Kudzu is now projected to reach Indiana Dunes in another decade and spread farther north after that.

The Great Lakes parks also face a **loss of wildlife**. (See pages 22-28.) In Isle Royale, the moose population has declined, as have the numbers of the wolves that depend on them as prey (see the next page). Other park mammals at risk as the climate changes include lynx and martens. Birds at risk of being eliminated from the parks include common loons and ruffed grouse, iconic birds of the Great Lakes and the North Woods. Also at risk are warblers,

PROJECTED CHANGES ARE ALREADY UNDERWAY

Already underway in the Great Lakes region and its national parks are many changes consistent with human-caused climate change.

- **The Great Lakes national parks are now hotter, with temperatures that have gone up more in the last decade than the global average.** According to a new analysis done for this report, near Indiana Dunes NL the last decade was 1.6°F above the 20th-century average temperature. Near Pictured Rocks NL, the last decade was 2.7°F above the 20th century average. For both, the increases are greater than for the planet as a whole. (See page 9.)
- **The amount of rain falling in heavy storms in the Midwest increased by 31% over the past century.** This is the second highest increase of any region of the country and well above the national average of 22%. (See page 14)
- **Winds over the Great Lakes already are stronger than they used to be.** Lake Superior wind speeds have increased by 12% since 1985. (See page 14.)
- **The waters in the Great Lakes are hotter, with their temperatures having increased more in recent decades than air temperatures have.** Lake Superior's summer water temperatures rose about 4.5°F from 1979 to 2006, roughly double the rate at which summer air temperatures have gone up over the surrounding land. (See page 15.)
- **Great Lakes waters now separate into different temperature layers earlier in the year and this stratification lasts longer.** In Lake Superior, the temperature layers now occur two weeks earlier than 30 years ago—about half a day earlier per year. (See page 15.)
- **The lakes are now covered by less ice in winter.** From the 1970s through 2002, ice cover in the center of the lakes shrank by more than 30%. Through 2009, ice cover across the entire surface of the lakes has fallen 15%. (See page 16.)
- **The ice forms later in the season and disappears earlier.** Around Apostle Islands, since 1975 the ice cover has formed about 12 days later per decade and melted away three days earlier. (See page 16.)
- **In Isle Royale NP, the moose population is down to about 515, half the park's long-term average.** Temperatures higher than moose can tolerate could be responsible—as in nearby northwest Minnesota, where the moose population has crashed in the past two decades from 4,000 to fewer than 100 animals, coinciding with higher temperatures. Also, warmer winters in Isle Royale enable enough ticks to overwinter and cause such a large loss of blood among the moose that they are more vulnerable to the park's wolves. (See pages 22-23.)
- **Isle Royale's wolf population has fallen, too.** The park's moose make up 90% of the wolves's prey, and declines in the moose population threaten the wolves. The park now has only 16 wolves in two packs, compared to 24 wolves in four packs a few years ago. (See pages 22-23.)
- **Botulism outbreaks linked to high water temperatures and low lake levels now kill hundreds to thousands of birds a year in Sleeping Bear Dunes NL.** So many dead birds cover the park's beaches that a new employee and volunteers work from June through November to clean up the bird carcasses. (See page 24.)
- **Because of warmer winters, birds already are wintering farther to the north.** In Indiana Dunes NL, sightings of wintering and migrating evening grosbeaks have declined markedly. From 1975 through 1997, in most years there were 50 or more sightings of evening grosbeaks in the park. From 1998 on, only twice have there been as many as 20 sightings and in most years there have not been any. (See page 26.)
- **In Indiana Dunes, populations of the endangered Karner blue butterfly have declined in years of low snow cover.** Snow may be crucial in protecting butterfly eggs on the ground and letting them survive through the winter. (See pages 27-28.)
- **In 2010, a tick of the type that carries Lyme disease was confirmed at Isle Royale for the first time**—a fact apparently being reported publicly for the first time in this report. Cold temperatures previously prevented the ticks that carry Lyme disease from reaching so far north, but their spread into the region had been projected as the climate gets hotter. (See page 31.)
- **The Lyme disease ticks also apparently have spread to nearby Grand Portage National Monument for the first time.** (See page 31.)

which in this region may reach their greatest concentration in the United States. One study has projected that nearly all breeding warbler species in the region's national parks face potential local eliminations or population declines. Native coldwater fish species could be eliminated from the Great Lakes or forced into northern portions of their current ranges.

On the other hand, mosquitoes and biting flies may become more numerous in the parks as a consequence of a hotter climate.

Climate changes may lead to a **loss of visitor enjoyment** in the region's parks. (See pages 29-33.) Summers may often become intolerably hot or even dangerous for outdoor activities people enjoy in the parks, such as dune climbing and hiking. A loss of snow cover and lake ice in winter is expected to diminish opportunities for ice fishing, skiing, and other outdoor winter recreation, including popular hikes over the frozen surface of Lake Superior to visit scenic ice formations in Apostle Islands's sea caves. Hotter temperatures will promote the formation of more ground-level ozone, an air pollutant that harms people's health. Particularly affected could be visitors to Indiana Dunes and Sleeping Bear Dunes, which already exceed federal health-based air quality standards for ozone. Higher temperatures also are promoting the spread into the region of

disease-carrying insects and an extension of the pollen season, affecting those with seasonal allergies. More wildfires and stronger storms may also disrupt vacations to the region's national parks.

An altered climate poses new risks in the Great Lakes parks of a **loss of cultural resources**— the archaeological and historical resources that contribute to and help us understand our national heritage. (See pages 34-35.) Vulnerable to increased erosion are the many historic lighthouses in these parks, along with other culturally significant structures and sites on park shorelines.

To prevent these threats to the resources and values of the Great Lakes national parks, and to reduce the threats when they cannot be prevented altogether, **tackling climate disruption** is needed. (See pages 36-37.) Parks should be managed to preserve their resources at risk, to adapt to coming changes, and to provide visible leadership in addressing climate change. Ultimately, of course, we need to curtail emissions of climate-changing pollutants enough to reduce their impacts, in parks and everywhere else. Action by the federal government is uniquely important to reduce emissions of heat-trapping pollutants enough that climate disruption does not overwhelm these national parks or any other special places.



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Pictured Rocks NL

INTRODUCTION

Human disruption of the climate is the greatest threat ever to America's national parks.¹ This report details the particular threats that a changed climate poses to our Great Lakes national parks—those within the lakes or on their shores.

The whole planet and our entire nation face the consequences of how we people are disrupting the climate and its natural cycles. But the Great Lakes national parks deserve particular attention. What could happen to them illustrates how, if we do not limit our pollution of the atmosphere with heat-trapping gases, the places many Americans most love may never be the same.

"I believe climate change is fundamentally the greatest threat to the integrity of our national parks that we have ever experienced.

Jon Jarvis, Director, National Park Service²

The Great Lakes and the land bordering them is a special region. The lakes themselves hold nearly 20% of the world's and 95% of our nation's total supply of fresh surface water. The United States' coastline along the lakes, 10,900 miles long, is the nation's longest. The area that drains into the lakes is home to one tenth of all Americans and one quarter of all Canadians. Millions of people from the region and beyond rely on the lakes and their shores for beach-going, camping, hiking, sightseeing, wildlife watching, fishing, hunting, swimming, boating, and other forms of recreation. This recreation is an important mainstay of the regional economy.

There are seven units of the national park system on the shores of the lakes, containing some of the most spectacular, nationally significant resources along the Great Lakes coastline. This report focuses primarily on the five largest of these parks, all on the shores of lakes Michigan and Superior. (This report, as the National Park Service does, refers to national lakeshores and national monuments as national parks. Congress has provided that they all are part of a single national park system, as expressions of our country's single national heritage.)



Sleeping Bear Dunes NL

The national parks on the Great Lakes, like those across the country, face their greatest threat ever from the impacts of human-caused climate change.

At stake are special places set aside so current and future generations can enjoy the best of the natural and cultural resources of the Great Lakes region.

"By the mid-20th century, urban centers and industry dotted much of the shoreline of the Great Lakes, and public places for recreation and ecological preservation were dwindling. Congress had to act quickly to preserve some of the region's unique features for the future. In 1958, the National Park Service completed a survey of nearly 5,500 miles of Great Lakes shoreline, titled "Our Fourth Shore," which identified opportunities for preservation. The report strongly urged that several special places along Lake Superior and Lake Michigan be acquired and preserved for the enjoyment of future generations. In answer to this recommendation, Congress created a new kind of national park—a national lakeshore."

National Parks Conservation Association³

Indiana Dunes National Lakeshore (NL) in Indiana is the most-visited of these parks, with over two million visitors per year. Its 15,000 acres of beaches, dunes, wetlands, prairies, and forests are at the southern end of Lake Michigan, between Gary and Michigan City, only a short trip from Chicago. The lakeshore's beaches are the main draw for most visitors, but it also offers extraordinary natural resources, especially for being surrounded by urban areas. With some 1,100 types of flowering plant species, its biological diversity is among the highest of any national park. As many bird species have been observed here as in Everglades National Park, world-famous for its bird life.

Sleeping Bear Dunes National Lakeshore in Michigan, the second most-visited of these parks (with more than one million visitors per year), is one of the most beautiful natural areas in Michigan's Lower Peninsula. The coastal dunes for which the park is named rise 450 feet above Lake Michigan. The lakeshore also offers 65 miles of shoreline along with lakes, streams, wetlands, forests, and the Manitou Islands—all adding up to what the lakeshore calls "the best nature escape in the Midwest."⁴

Pictured Rocks National Lakeshore, also in Michigan, is named after multicolored sandstone cliffs that stretch for 12 of the lakeshore's 42 miles of shoreline. The park's natural beaches are major draws to visitors, as are more than 100 miles of trails along the coast and through forests and wetlands. As in many national parks, wildlife is a major attraction, with sightings possible of deer, moose, black bears, wolves, fishers, minks, or martens.

Apostle Islands National Lakeshore in Wisconsin includes 21 islands and 12 miles of coastline on its mainland unit, along with waters of Lake Superior. Its unique blend of cultural and natural resources includes six still-active lighthouses. Boating, camping, hiking, fishing, and wildlife viewing are among the park's most popular activities.

Isle Royale National Park (NP), in Michigan but closer to Minnesota than to the mainland of its own state, is comprised of one large island surrounded by more than 400 small islands, plus submerged lands extending 4-1/2 miles into Lake Superior. Accessible only by boat or seaplane, the park is one of the remotest and wildest spots in the contiguous United States, which is its major attraction for those who make the effort to go there. Despite its remote nature, Isle Royale has the highest backcountry overnight use per acre of any national park.

These national parks and their resources are threatened by human-caused climate change. Indiana Dunes was identified by the Rocky Mountain Climate Organization and the Natural Resources Defense Council in an October 2009 report as one of the 25 units of the national park system most endangered by climate change.⁵ The other parks face comparable risks. Summers in these parks, now

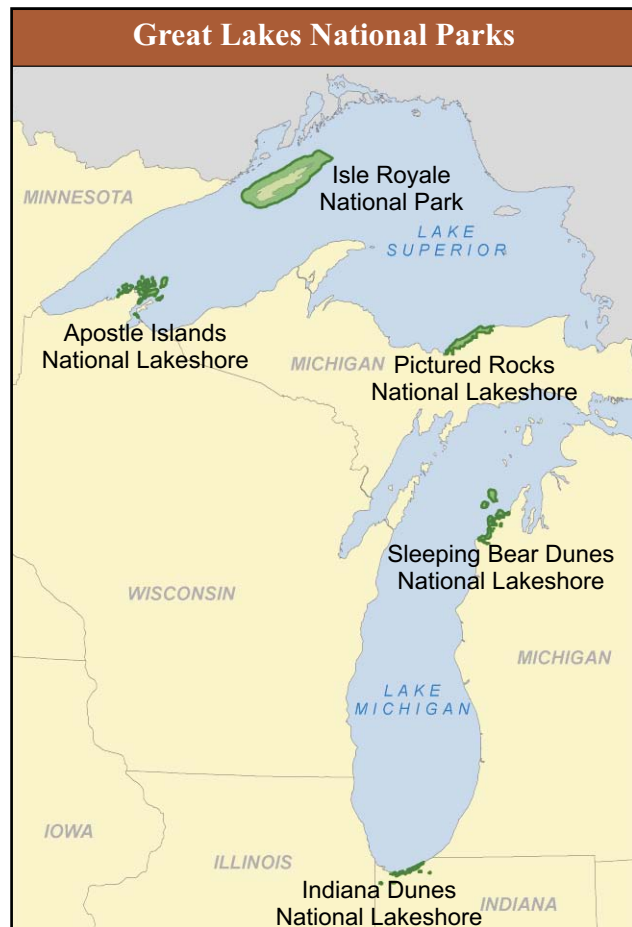


Figure 1. National parks featured in this report.

generally mild and pleasant, could become as hot as those in the Deep South today. Ecosystems could be disrupted. Wildlife species now found there, from wolves, moose, and martens to loons, grouse, and warblers, could disappear from the parks. Air quality in the parks will be polluted more often to levels that threaten people's health. Opportunities for boating, fishing, and other forms of recreation could be compromised. Wildfires could become more frequent and widespread.

Grand Portage National Monument on the Minnesota shore close to Isle Royale NP faces similar risks, and impacts to its wildlife and cultural resources are covered in this report. Perry's Victory and International Peace Memorial on Lake Erie in Ohio and Keweenaw National Historical Park near Lake Superior in Michigan were not considered for this report. Likely facing similar risks from a changed climate, but not bordering the lakes and so beyond the scope of this report, are other national conservation units that certainly are important to the Great Lakes region and its economy. Prominent among these are Boundary Waters Canoe Area, a part of Superior National Forest, and Voyageurs National Park, both in Minnesota.

“The Great Lakes region is experiencing climatic changes including increased air and water temperatures, changes in precipitation patterns, and a reduction in winter ice. These changes have resultant effects on the natural ecosystems and cultural resources within and surrounding the lakes, as well as area recreational opportunities.”

National Park Service⁶

The consequences of climate disruption on the special places of the Great Lakes, beginning with the five national parks featured in this report, could be not just ecological but economic. These parks draw over four million people each year. Their spending adds more than \$200 million to local economies and sustains about 3,000 jobs. Harm to the resources that support this spending and these jobs illustrate how climate disruption threatens our economy.

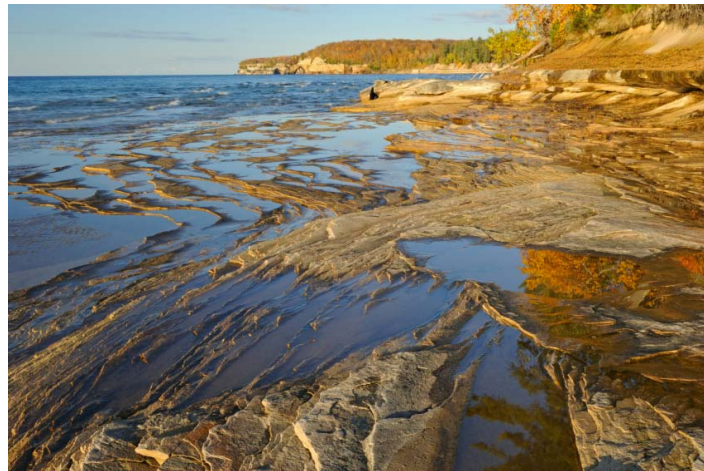
This report summarizes what is known about the possible impacts, now and in the future, on these national parks from human emissions of heat-trapping pollutants. The report contains new analyses of how much hotter the parks have become in recent years and new local projections from climate models

of how temperatures may change in the parks as a result of human-caused climate change. Other information is drawn from government and scientific reports, journal articles, and other publications, and also from the authors’s consultations with scientists and other professionals of the National Park Service and other federal agencies who work in the Great Lakes region and its parks.

A common thread throughout the information presented in this report is that the extent to which these national parks will be affected by human alteration of the climate will be determined by future levels of heat-trapping pollutants. If we humans continue with high levels of heat-trapping emissions, the consequences on these special places will be drastic. If we reduce emissions, the worst impacts can be avoided. And the sooner we curtail our pollution, the better—for these national parks and for our enjoyment of them, as well as for the planet as a whole.

“Climate change could be the most important issue we will face in the Great Lakes national parks in the coming decades.”

Bob Krumenaker, Superintendent
Apostle Islands National Lakeshore⁷



Pictured Rocks NL

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THE GREAT LAKES ECONOMY AT RISK

The threats of climate disruption to the national parks in the Great Lakes are also threats to the region's economy. The five parks featured in this report together drew more than four million visitors in 2010, contributing greatly to the economy of the region by generating more than \$200 million in visitor spending and supporting nearly 3,000 jobs in 2009. These economic benefits are at risk as a changing climate threatens the special resources that draw vacationing families, sightseers, campers, boaters, wildlife watchers, and others to these parks.

Calculations of the economic benefits of the Great Lakes parks come from a Michigan State University researcher who annually compiles that data for all national parks. Results from the latest report, based on 2009 visitation levels, are in Table 1. The table also shows that more visitors came to the parks in 2010, so the economic benefits last year presumably were also higher.



Apostle Islands NL

NPS

Studies of national park visitors in other areas suggest that the effects of a disrupted climate may lead to a reduction in park visitation levels.

If the Great Lakes parks become less attractive to visitors, that would threaten \$200 million in spending and about 3,000 jobs in the region.

Spending and Jobs from Visitors to Great Lakes National Parks in 2009				
	(Visitors In 2010)	Visitors In 2009	Total Visitor Spending	Total Jobs Supported
Indiana Dunes NL	(2,150,345)	1,944,568	\$54,878,000	542
Sleeping Bear Dunes NL	(1,280,932)	1,165,836	\$107,165,000	1,803
Pictured Rocks NL	(499,281)	448,215	\$18,199,000	300
Apostle Islands NL	(156,945)	170,202	\$18,203,000	301
Isle Royale NP	(15,793)	14,653	\$1,798,000	26
Totals	(4,103,296)	3,743,474	\$200,243,000	2,972

Table 1. Sources: NPS and Stynes (2010).⁸

“Surveys show that approximately 80% of [Indiana Dunes] visitors are not from the local area. That means some 1.6 million of these visits are from people outside Northwest Indiana contributing to the local economy through tourism spending.”

Costa Dillon, superintendent, Indiana Dunes NL⁹

How climate change may affect tourism patterns has not yet been studied much. An altered climate could lead to increased visitation in the Great Lakes parks. Warmer springs and falls could be expected to extend the tourism season. The parks could be much hotter in summer, when visitation levels are highest, but they may still be cooler than other areas and so could still offer relative escapes from summer heat.

But it is far from certain that summer visitation levels would remain as high as now. There has so far been very little research on what effect large increases in summer temperatures could have on people’s interest in visiting national parks and similar places, where visitors typically are outside, with little access to air conditioning, and often are engaged in physical activities.¹⁰ The one study of whether higher temperatures could affect future national park visitation was focused on Rocky Mountain National Park in Colorado.¹¹ Although western mountains are obviously very different from the Great Lakes, Rocky Mountain is a relatively cool park which draws visitors both from nearby major metropolitan areas and from afar, with nearly all of its visitation during summers—which offers some similarity to the Great Lakes parks. The Rocky Mountain study showed that visitation to the park generally goes up with warmer temperatures, but that visitation to the park slowed as temperatures got hotter and hotter and even declined by 7.5% during one summer of very high temperatures (with 60 days over 80°F). Similarly, projections of future visitation levels to Rocky Mountain based on surveys of current visitors showed that moderate increases in temperature could lead to increased visitation, by perhaps 10 to 14%. But in a very hot future, visitation could decline, by perhaps 9% compared to current levels, with a comparable drop in local tourism-related jobs. These results make intuitive sense. Up to a point, more people may go to a cooler, mountain park to escape higher temperatures. But as temperatures get too hot, outdoor recreation even in the mountains becomes less pleasant, and people may find other ways to get a break from the heat.

A similar pattern might hold for visitation to beaches and other features of the Great Lakes parks



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as the future gets hotter. As explained in the next section, new climate projections obtained for this report by the Rocky Mountain Climate Organization show with medium-high future emissions of heat-trapping pollutants, summers in Indiana Dunes could get as hot by the end of the century as those in Gainesville, Florida, have been. Another study suggests that with higher future emissions summers in Indiana Dunes could become as hot as those in Key West. (See pages 11-13.) Changes of that magnitude could be enough to affect visitation patterns. June, July, and August are currently Indiana Dunes’s busiest months.¹² But in Key West, those are three of the four slowest months of the year for tourism.¹³

Changes in the character of the natural resources and visitor experiences in the Great Lakes parks also might affect visitation. This question, again, has received little attention among social researchers. In Canada, however, researchers have surveyed visitors to that country’s national parks to evaluate how climate change might affect visitation.¹⁴ Visitors were asked if they would return more often, less often, or as often if conditions degraded in the ways expected to result from human alteration of the climate. Examples of such changes included altered plant communities, changes to animal populations (such as moose), warmer lakes, more wildfire, and loss of fishing—all of which are among the impacts projected for the Great Lakes parks. Other conditions in the scenarios used in the Canadian surveys, however, would not apply to the Great Lakes national parks. The results, shown in Table 2 on the following page, suggest that climate-change effects could cause visitation to the Canadian parks to drop, perhaps sharply. At the least, this suggests a need for additional research on how climate change may alter patterns of tourism and outdoor recreation.

Visitor Survey in Waterton Lakes National Park, Canada Effects of Climate-Change Impacts on Future Visitation

Scenario 1	Scenario 2	Scenario 3
Description of Environmental Conditions Used in Survey		
No current mammal species lost, 15 new species move in	6 current mammal species lost, 44 new species move in	12 current mammal species lost, 42 new species move in
No change in numbers of grizzly bears, moose, bighorn sheep	Small declines in numbers of grizzly bears, moose, bighorn sheep	Moderate declines in numbers of grizzly bears, moose, bighorn sheep
No change in number of glaciers (currently 30)	10 glaciers lost (out of 30)	All 30 glaciers lost
Forests make up 70% of park, grasslands 15%, meadows and tundra 15%	Forests make up 65% of park, grasslands 25%, meadows and tundra 10%	Forests make up 55% of park, grasslands 44%, meadows and tundra 1%
No rare plant species lost	5 rare plant species lost	10 rare plant species lost
No change in forest fires	Moderate increase in forest fires	Large increase in forest fires
10% change of campfire ban	33% chance of campfire ban	75% chance of campfire ban
Fishing catch rate up 10%	Fishing catch rate up 15%	Fishing catch rate down 20%
Lakes 3.6°F warmer	Lakes 7.2°F warmer	Lakes 12.6°F warmer
Identified Effects on Frequency of Future Visitation		
0% would not visit again	3% would not visit again	19% would not visit again
2% would visit less often	14% would visit less often	38% would visit less often
89% would visit as often	78% would visit as often	43% would visit as often
10% would visit more often	5% would visit more often	0% would visit more often

Table 2. Reactions of visitors to Waterton Lakes National Park, Canada, to three scenarios of future park conditions resulting from climate change. Sources: D. Scott and B. Jones (2006), and D. Scott, B. Jones, and J. Konopek (2007).¹⁵

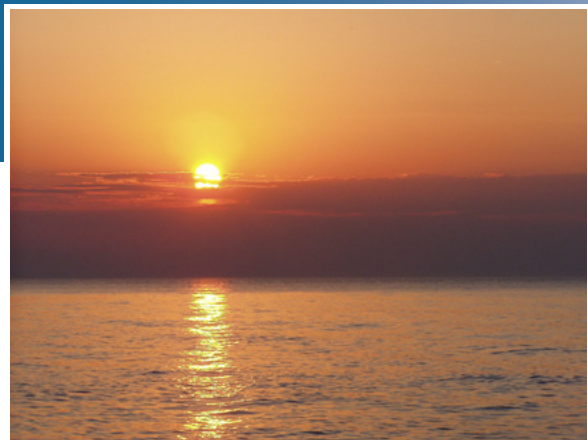
MORE HEAT AND OTHER CLIMATE CHANGES

Humans, mostly by our use of fossil fuels, have added to the atmosphere extra heat-trapping gases, which are already changing the climate. A congressionally mandated 2009 report by the U.S. government's Global Change Research Program (USGCRP) began:

Observations show that warming of the climate is unequivocal. The global warming observed over the past 50 years is due primarily to human-induced emissions of heat-trapping pollutants.¹⁶

This echoes the Intergovernmental Panel on Climate Change (IPCC), which says there is more than a 90% likelihood that humans have caused most of the temperature increases over the last 50 years.¹⁷ The USGCRP and the IPCC also report that the world would have cooled since 1950 from natural factors, except they were trumped by heat-trapping pollution.¹⁸

Figure 2 shows the trend in global temperatures. The last decade, 2001-2010, was 1.0°F above the 20th century average.¹⁹ The year 2010 tied with 2005 as the hottest on record, nine of the ten hottest years have been since 2001, and 34 straight years have been above the 20th century average.²⁰



Indiana Dunes NL

Great Lakes national parks have gotten hotter, by more than the global average.

Future summers could get much hotter—in Indiana Dunes, as hot by the end of this century as Florida summers have been, unless emissions are limited.

Stronger storms in the Midwest already drop 31% more rain, and storms are forecast to continue getting stronger.

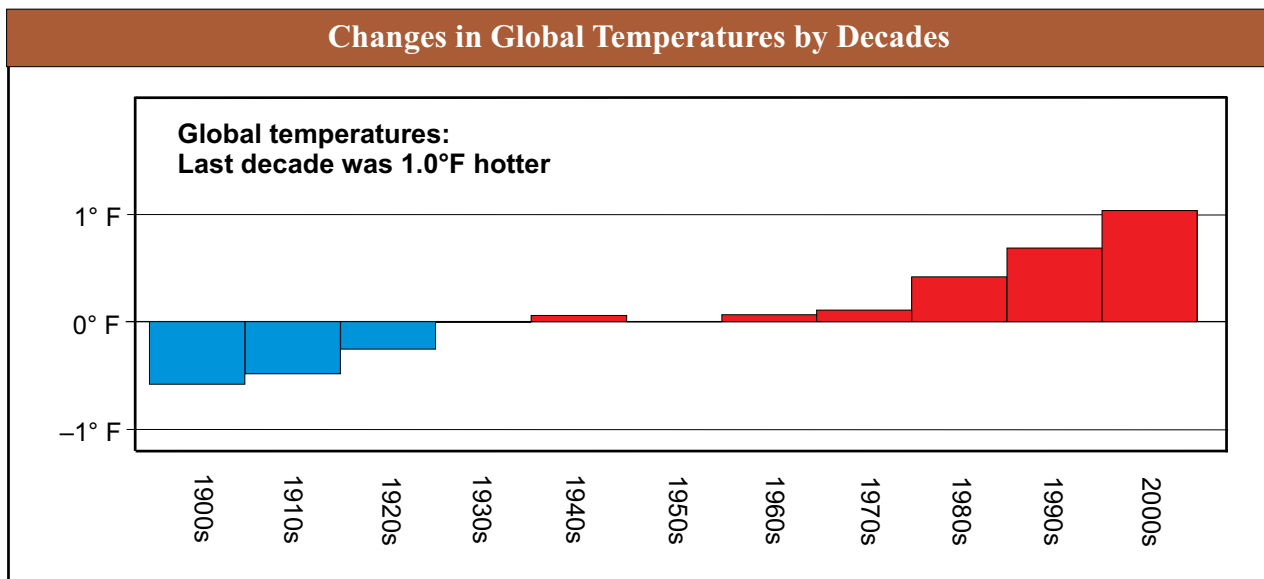


Figure 2. Average global surface temperatures, 1901 through 2010, by decade (for example, 1901-1910), compared to 1901-2000 averages. Data from the National Climatic Data Center.²¹ Analysis by the Rocky Mountain Climate Organization; see the Appendix for details.

Compared to an earlier, cooler baseline of the late 19th century, the last decade represents an even larger temperature change, of 1.4°F.²² That climate change already causes major impacts on natural, social, and economic systems, as detailed in this and many other reports. It also is a large step toward triggering dangerous human interference with Earth's climate, the avoidance of which is the central commitment of a 1992 international treaty entered into by the United States and 193 other nations. The parties to that agreement last year reaffirmed that avoiding dangerous climate interference requires meeting a goal of holding global average temperatures to no more than 3.6°F (2.0°C) above pre-industrial temperatures, and also agreed to reexamine that goal in the light of the current best available scientific evidence, which now suggests that the goal perhaps should be revised to be as low as 2.7°F (1.5°C) above pre-industrial levels.²³ In short, the planet is already about 40% to 50% of the way toward what is now believed to be unacceptable human disruption of the climate.

The climate of the Great Lakes region, too, is already being changed, along with that of the world as a whole. A study in 2006 for the International Joint Commission on the Great Lakes found recent regional trends of higher temperatures, shorter winters, and hotter summers, all consistent with the projected effects of heat-trapping pollution and strongly supporting the conclusion that in the Great Lakes region "a new climate, quite distinct from that present at the turn of the century, is already in place."²⁴ Other studies have also found in the region as a whole and in individual states increases in temperature and other climate changes consistent with scientific projections of how human emissions of heat-trapping pollution will alter the region's climate.²⁵

TEMPERATURE INCREASES IN GREAT LAKES NATIONAL PARKS

For this report, the Rocky Mountain Climate Organization (RMCO) prepared a parallel analysis to the global temperature trend shown in Figure 2 for the two weather stations in the U.S. Historical Climatology Network (USHCN) in the immediate vicinity of Great Lakes national parks. That Network is a collection of weather stations with long-term data records that have been reviewed for reliability in detecting long-term climate trends. Only two of the featured parks, Indiana Dunes NL and Pictured Rocks NL, are located near existing USHCN stations. Additionally, no other weather station in or near any of the featured parks has a complete record of length to reliably detect a long-term trend. The two USHCN stations, in short, present the best picture of how temperatures have changed in the area of these national parks. (See the Appendix for details of these weather stations and the methodology used for this analysis.)

That new RMCO analysis, presented in Figure 3 on the following page, shows that these two parks have experienced more of a rise in temperature than has the globe as a whole. For both, the last decade (2001-2010) was the hottest in the period of temperature measurements. Near Indiana Dunes, the last decade was 1.6°F hotter than the 20th century average temperature, and near Pictured Rocks the last decade was 2.7° hotter. For the area of both national parks, the last decade's temperatures exceeded their averages for the last century by a larger margin than for the planet as a whole—0.6°F more for Indiana Dunes and 1.7° more for Pictured Rocks.

GREAT LAKES CLIMATE-CHANGE ASSESSMENTS

Major sources of information on climate change and its effects on the Great Lakes region include:

- *Confronting Climate Change in the Great Lakes Region: Impacts on our Communities and Ecosystems*, a 2003 report by the Union of Concerned Scientists and the Ecological Society of America;²⁶
- *Global Climate Change Impacts in the United States*, a 2009 report by the U.S. government's interagency Global Change Research Program—a national assessment on how climate change may affect the United States (and the clearest such statement yet), which contains information specific to the Midwest region;²⁷
- A 2010 special edition of the *Journal of Great Lakes Research* with 11 articles on climate change in the Great Lakes region, including projections of future climate change by a group of scientists led by Katharine Hayhoe of Texas Tech University;²⁸ and
- *Wisconsin's Changing Climate: Impacts and Adaptation*, a 2011 report by the Wisconsin Initiative on Climate Change Impacts, a joint project of the Nelson Institute for Environmental Studies at the University of Wisconsin-Madison and the Wisconsin Department of Natural Resources.²⁹

Changes in Great Lakes Park Temperatures by Decades

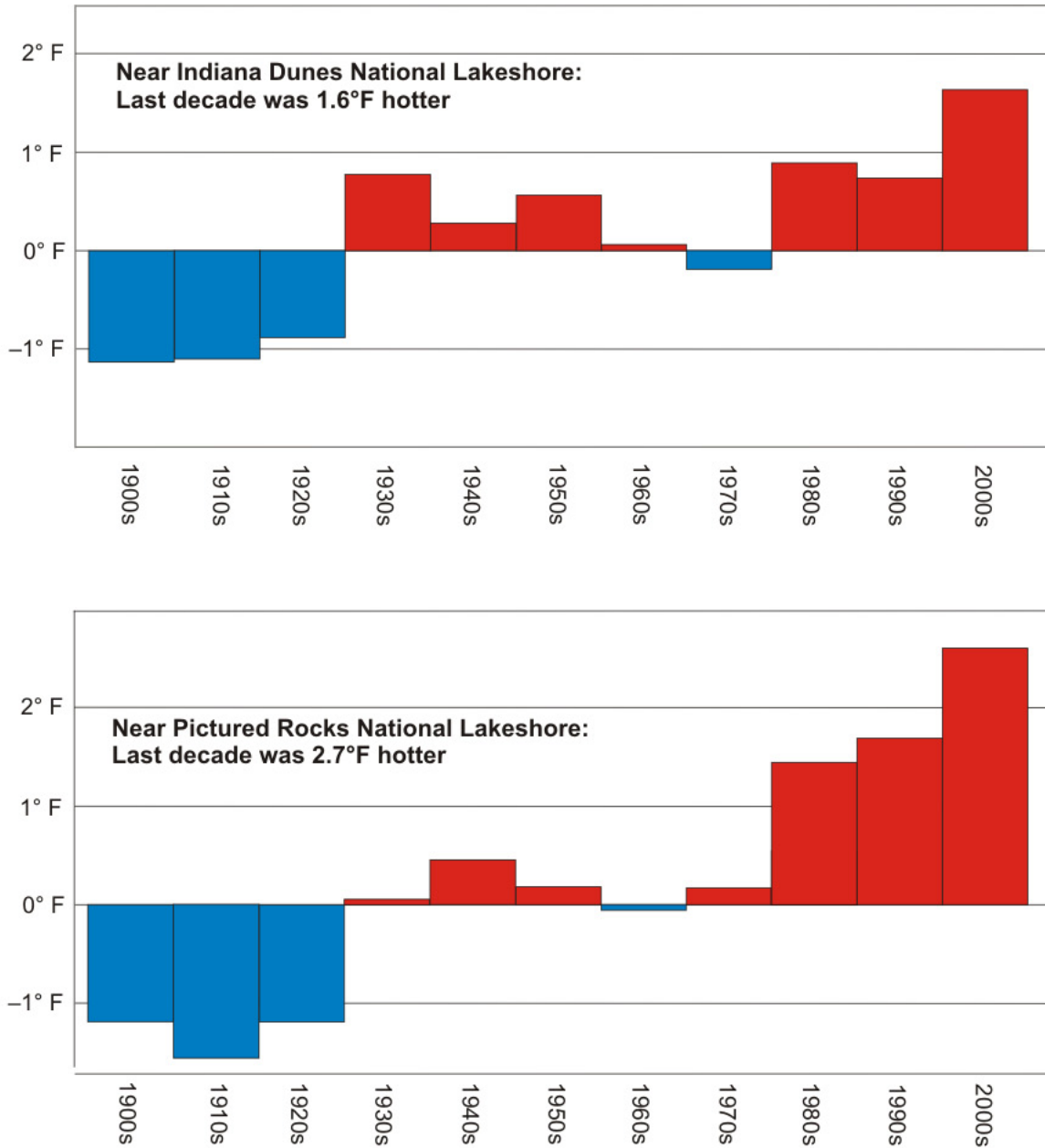


Figure 3. Average temperatures 1901 through 2010, by decade (e.g., 1901-1910), compared to corresponding 1901-2000 averages, for high-quality weather stations near the identified national parks. Data from the U.S. Historical Climatology Network.³⁰ Analysis by the Rocky Mountain Climate Organization. See the Appendix for details on sources and methodology.

Both of the Great Lakes national parks that have adequate long-term data have had greater recent temperature increases than the worldwide average.

FUTURE ANNUAL TEMPERATURES IN GREAT LAKES NATIONAL PARKS

With respect to future temperatures, RMCO obtained for this report new “downscaled” climate projections of how much hotter annual average temperatures in the featured Great Lakes national parks may get as a result of human emissions of heat-trapping gases. Table 3 presents the results. Projections were made

for two different possible futures: one scenario with a lower level of future emissions of heat-trapping pollutants and the other with medium-high emissions. (See page 14 for information on these scenarios.) For each scenario, results were produced from 16 global climate models and for two 30-year time periods, in mid-century and near the century’s end.

The projections in Table 3 illustrate that how much the climate changes depends in large part on whether

Hotter Future Average Annual Temperatures in Great Lakes National Parks				
	Lower Future Emissions		Medium-High Future Emissions	
	2040-2069	2070-2099	2040-2069	2070-2099
Indiana Dunes NL				
Average of projections	+3.4°	+4.7°	+4.6°	+8.0°
Range of projections	+1.9° to +4.8°	+2.5° to +6.1°	+2.8° to +6.3°	+4.5° to +10.8°
Sleeping Bear Dunes NL				
Average of projections	+3.5°	+4.6°	+4.5°	+7.6°
Range of projections	+2.0° to +5.0°	+2.5° to +6.7°	+2.9° to +6.3°	+4.8° to +11.3°
Pictured Rocks NL				
Average of projections	+3.5°	+4.7°	+4.5°	+7.7°
Range of projections	+1.7° to +5.0°	+2.5° to +6.9°	+2.6° to +6.3°	+4.0° to +11.3°
Apostle Islands NL				
Average of projections	+3.7°	+4.8°	+4.7°	+8.1°
Range of projections	+2.1° to +5.3°	+2.7° to +7.2°	+2.8° to +6.6°	+5.4° to +11.6°
Isle Royale NP				
Average of projections	+3.6°	+4.8°	+4.6°	+8.0°
Range of projections	+2.1° to +5.1°	+2.4° to +7.4°	+3.1° to +6.4°	+5.2° to +11.4°

Table 3. Projected future annual average temperatures compared to 1971-2000 annual temperatures, in degrees Fahrenheit. Data from 16 climate models in the World Climate Research Program’s (WCRP’s) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset.³¹ Emissions scenarios are identified on page 14. Analysis by the Rocky Mountain Climate Organization. See the Appendix for details on the ranges of the projections from individual models, sources, and methodology.

or not future emissions are limited. In every case the scenario with higher emissions yields greater temperature increases than the scenario with lower emissions. For Indiana Dunes, for example, the average result from the 16 models is for the park to get 4.7°F hotter late in the century with lower emissions, but 8.0° hotter with medium-high future emissions.

Other conclusions are also evident from the information in Table 3. First, the different models produce different projections; the table shows the ranges, from the smallest projected temperature increases to the largest. The difference among today's models on how sensitive the climate will be to particular atmospheric concentrations of heat-trapping gases is one reason why these (or any) projections of future temperature changes should be taken as suggestions of future changes, not definitive predictions. Further, models also are less reliable in estimating future local conditions than in estimating future global averages.³²

Second, every model shows the parks will be hotter in the future—a consistent projection for each park, in each time period, and under either emissions scenario.

Third, for either emissions scenario, the increases in temperature are projected to be greater later in the century, from the lasting, cumulative effect of both pollutants already in the atmosphere and those newly emitted. This characteristic of heat-trapping pollution is why scientists tell us that reductions in emissions made sooner will do more to limit climate change than reductions made later.³³

These new RMCO projections for the Great Lakes parks are generally consistent with other projections of future climate for the Great Lakes region. The U.S. government's 2009 national assessment report on climate-change impacts estimated that with lower future emissions areas including the Great Lakes parks would become 4° to 5°F hotter by 2080-2099, compared to 1961-1990 levels. With medium-high emissions, the increases would be 8° to 10°, among

the greatest increases anywhere in the contiguous United States.³⁴

Also, in 2010, Katharine Hayhoe of Texas Tech University, who has played a leading role in several regional climate-change projections and assessments, and four colleagues published a study with projections of temperature and other climate changes in the Great Lakes region, as part of a comprehensive special edition on regional climate change of the *Journal of Great Lakes Research* (see page 8). They used the same database as RMCO for its new projections as well as the same 16 climate models, the same 1971-2000 baseline, the same medium-high emissions scenario, and the same late-century period (2070-2099) to project changes in average annual temperatures. For each of the land areas closest to the borders of the Great Lakes, their study projects an increase of between 7.65° to 8.55°F in average temperature.³⁵ That matches well with RMCO's corresponding projections for our featured parks, shown in the far-right column of Table 3—namely, the average projected increases of 8.0°, 7.6°, 8.1°, 7.7°, and 8.0°F for those parks.

FUTURE SUMMER TEMPERATURES IN GREAT LAKES NATIONAL PARKS

For this report, RMCO also obtained projections of future summer temperatures for the five parks studied here. Temperatures could increase more in summer than in other seasons if future emissions are at the upper end of current scenarios, according to at least two studies.³⁶ Also, the national parks in the Great Lakes region are visited much more in summer than in other seasons, as are most parks across the country. As a result, these summer temperature projections better indicate how most future visitors to the parks may be affected by an altered climate.

As Table 4 on the following page shows, the average of the projections with the scenario for medium-high future emissions is for summers in Indiana Dunes to become as hot by late in this century (2070-2099) as summers in Gainesville, Florida, have been in recent history (1971-2000). Summers in Sleeping Bear Dunes could become as hot as those in Lexington, Kentucky, recently have been. Obviously, the experience of visiting these parks in summer would be fundamentally different. The effects on park resources and values, too, would be profound.

“National parks that have special places in the American psyche will remain national parks, but their look and feel may change dramatically.”

U.S. Climate Change Science Program³⁷



NPS

Pictured Rocks NL

Hotter Future Average Summers in Great Lakes Parks with Medium-High Emissions

National Park	2040-2069	2070-2099
<p>Indiana Dunes NL</p> <p>Average projection</p> <p>Effect of average projection</p> <p>Range of projections</p>	<p>+5.0° (to 76.7°)</p> <p>As hot as recent summers in Raleigh, NC (76.9°)</p> <p>+2.7° (to 74.4°) to +9.5° (81.2°)</p>	<p>+8.6° (to 80.3°)</p> <p>As hot as recent summers in Gainesville, FL (80.2°)</p> <p>+4.9° (to 76.6°) to +15.4° (87.1°)</p>
<p>Sleeping Bear Dunes NL</p> <p>Average projection</p> <p>Effect of average projection</p> <p>Range of projections</p>	<p>+4.5° (to 71.1°)</p> <p>As hot as recent summers in Chicago (71.1°)</p> <p>+2.0° (to 68.6°) +8.6° (75.2°)</p>	<p>+7.7° (to 74.3°)</p> <p>As hot as recent summers in Lexington, KY (74.4°)</p> <p>+3.6° (to 70.2°) to +13.7° (80.3°)</p>
<p>Pictured Rocks NL</p> <p>Average projection</p> <p>Effect of average projection</p> <p>Range of projections</p>	<p>+4.4° (to 66.1°)</p> <p>As hot as recent summers just north of Green Bay (Oconto, WI, 66.1°)</p> <p>+1.5° (to 63.2°) to +8.4° (70.1°)</p>	<p>+8.4° (to 70.1°)</p> <p>As hot as recent summers just north of Chicago (Lake Villa, IL, 70.0°)</p> <p>+5.0° (to 66.7°) to +14.3° (76.0°)</p>
<p>Apostle Islands NL</p> <p>Average projection</p> <p>Effect of average projection</p> <p>Range of projections</p>	<p>+5.2° (to 68.3°)</p> <p>As hot as recent summers in Lansing, MI (68.3°)</p> <p>+2.7° (to 65.8°) to +9.5° (72.6°)</p>	<p>+8.2° (to 71.3°)</p> <p>As hot as recent summers in central IN (Elwood, 71.3°)</p> <p>+4.3° (to 67.4°) to +14.2° (77.3°)</p>
<p>Isle Royale NP</p> <p>Average projection</p> <p>Effect of average projection</p> <p>Range of projections</p>	<p>+4.6° (to 65.7°)</p> <p>As hot as recent summers in the Upper Peninsula of MI (Alpena, 65.6°)</p> <p>+2.5° (to 63.6°) to +8.2° (69.3°)</p>	<p>+7.9° (to 69.0°)</p> <p>As hot as recent summers in southernmost WI (Kenosha, 69.0°)</p> <p>+4.2° (to 65.3°) to +13.1° (74.2°)</p>

Table 4. Projected increases in June-July-August average temperatures, in degrees Fahrenheit, from 16 climate models assuming medium-high future emissions (see page 14), compared to 1971-2000 June-July-August temperatures. Data from the WCRP's CMIP3 multi-model dataset and the National Climatic Data Center.³⁸ Analysis by RMC0. See the Appendix for details on the ranges of the projections from individual models, sources, and methodology.

Future Summer Temperature Increases, Areas Including Great Lakes Parks Projections by Hayhoe and Colleagues

	Lower Future Emissions		Higher Future Emissions	
	2040-2069	2070-2099	2040-2069	2070-2099
Average of projections	+4.1° to +5.9°	+5.0° to +6.8°	+6.8° to +8.6°	+11.3 to +13.1°

Table 5. Projected summer temperature increases in degrees Fahrenheit in areas containing the featured Great Lakes national parks, from a broader regional analysis. Projections from three climate models, compared to 1961-1990, with emission scenarios as identified on page 14. Source: Hayhoe and others.⁴¹

The RMCO projections of changes in average summer temperatures for the national parks are generally consistent with other projections for summer temperatures in the region. The closest comparison is, again, from the Great Lakes climate-change study by Hayhoe and others, summarized in Table 5, above. For this part of their study, they used a lower and a higher emissions scenario—the latter assuming more future emissions than the medium-high scenario used by RMCO. (See page 14 for more on these scenarios.) The projections by Hayhoe and others are that with higher future emissions, summers along the Great Lakes could get extraordinarily hotter—about 11 to 13°F hotter, as shown in the right-hand column of Table 5.³⁹ While the RMCO projections with medium-high emissions show that summers in Indiana Dunes, for example, could get 8.6°F hotter, making them like those of Gainesville, Florida, the projections by Hayhoe and others with higher emissions show that Indiana Dunes summers could get about 12.6°F hotter, like those of Key West.⁴⁰

The good news is that summers in Indiana Dunes need not get as hot as those of either Gainesville or Key West. According to the RMCO climate projections, if future emissions of heat-trapping pollution are held to the levels in a lower-emissions scenario, Indiana Dunes would still get hotter—but only as hot as those of Knoxville, not like those in Florida. Summers in Sleeping Bear Dunes would get as hot as those of central Indiana (Elwood), not like those of Lexington. (See the Appendix for details.) Emissions can be held even lower than this (see page 14), yielding even lower future summer temperature increases in the Great Lakes parks and preserving more of their natural character.

With summers as hot as those of Gainesville, Florida (with medium-high future emissions) or Key West (with higher emissions), Indiana Dunes would be fundamentally changed. The only way to reliably avoid that is to reduce future emissions of heat-trapping gases.

PRECIPITATION CHANGES

Most climate projections are that in the Great Lakes region overall precipitation levels will increase, particularly late in the century.⁴² In the study by Hayhoe and others, only two of 21 separate climate projections indicate decreases in annual precipitation.⁴³ Models also consistently project that the expected precipitation increases will be concentrated in winter and spring.⁴⁴

Some winter precipitation is also expected to shift from snowfall to rainfall.⁴⁵ More rain already falls now in winter than before, a trend expected to accelerate. Since 1980, almost three out of four winters have seen below-average snowfall. By the end of the century, the number of snow days per year in the region is expected to decrease by about 30% to nearly 50% with lower future emissions, or about 45% to 60% with higher emissions.⁴⁶ The Wisconsin climate-change assessment (see page 8) says that by mid-century there will be significant statewide decreases in snowfall, snowpack, and snow cover.⁴⁷ In the region's national parks, these changes can have major effects on, for example, winter recreation (see page 30) and wildlife (see pages 23-24).

Summers in the region may well become drier as well as much hotter. The latest regional climate-change projections, those done in 2010 by Hayhoe and others, have mixed results on whether regional precipitation in summer will increase or decrease—but the range of the projections is from relatively modest possible increases in summer precipitation to a decrease of about 50%.⁴⁸ In other studies, the average of projections with medium-high future emissions is for decreased summer precipitation in the region.⁴⁹ Even if summer precipitation levels stay about the same, ecosystems would be drier in summer, as hotter temperatures would increase the take-up of water by vegetation and, perhaps, evaporation from bodies of water and soil.⁵⁰

A shorthand summary is that the climate of the Great Lakes region may well shift to warmer, wetter winters and hotter, drier summers.

STRONGER STORMS AND WINDS

Already, downpours are heavier than they used to be. Over the past century, the amount of rain falling in heavy storms increased by 31% in the Midwest—the second highest in any region of the country, and well above the national average of 22%.⁵¹ Stronger downpours and more flooding can affect the ecosystems of the region's parks (see pages 15-21) and the enjoyment of park visitors (pages 29-33).

The U.S. government's 2009 national assessment says this trend very likely will continue, with more frequent and heavier downpours and more flooding.⁵² The Wisconsin climate-change assessment released

in 2011 says that storms producing at least three inches of rainfall could be 40% more frequent by mid-century and about 50% more frequent by late in the century.⁵³

Already, winds over the Great Lakes are stronger than they used to be. One study found a general trend toward higher average wind speeds at a variety of locations throughout lakes Superior, Michigan, and Huron.⁵⁴ Another study reported that Lake Superior wind speeds have increased by 12% since 1985 and are continuing to increase by nearly 5% per decade.⁵⁴ These increases in winds over Lake Superior are greater than in those over land in the region.⁵⁶

FUTURE EMISSIONS OF HEAT-TRAPPING GASES

How much more the climate will change depends on future levels of heat-trapping pollutants. In making projections of future changes, scientists use scenarios that assume different types of futures, based on such factors as population levels and energy use and the emission levels that could result. These scenarios illustrate how we can limit future climate change.

The emission scenarios now in widest use were developed in the 1990s and used in the 2007 reports by the Intergovernmental Panel on Climate Change (IPCC). In this report, the IPCC scenarios are identified in these ways:

- "Higher" future emissions: scenario A1F1;
- "Medium-high" emissions: scenario A2;
- "Medium" emissions: A1B; and
- "Lower" emissions: B2.⁵⁷

The new RMCO projections in this report use the medium-high and lower scenarios. No scenario with higher emissions is available on the database used to obtain those projections. As a result, the RMCO projections are skewed toward the low end of possible future emissions.

Future emissions could be above even the current higher-emissions scenario. In some recent years, actual emissions have exceeded all of the current scenarios, and new scenarios are being developed to reflect this and other realities.⁵⁸

On the other hand, future emissions could be lower than in the current scenarios, none of which assume new policies to ward off climate change. With new policies designed to reduce heat-trapping pollution, many of the possible consequences

identified in this report may be avoided. We can, in fact, realize a better future—if we choose to.

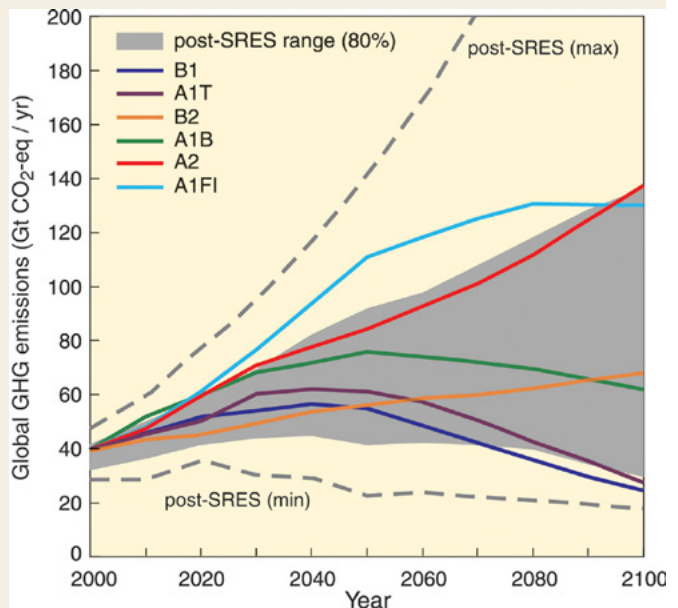


Figure 4. Selected current emissions scenarios, including those cited in this report. Those used in the new RMCO projections are A2 ("medium-high") and B1 ("lower"). Dashes indicate the range of new ("post-SRES") scenarios being developed, with the gray area representing the middle 80th percentile of that range. As the figure shows, the "medium-high" scenario used for the RMCO projections is actually slightly below the middle of the range of the new scenarios being developed. Figure from the IPCC.⁵⁹

DISRUPTION OF ECOSYSTEMS



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Sleeping Bear Dunes NL

Already, water temperatures in the Great Lakes are higher and winter ice cover is forming later and disappearing earlier. Increased waves and erosion result, threatening lakeshore dunes and other park resources.

Lake levels may fall as much as two feet, depending on future emission levels.

Already, northern trees are shifting farther to the north. The types of forests found in the Great Lakes parks are expected to change, with some northern trees disappearing and southern trees moving in.

Higher water temperatures could lead to significant changes in the fish species present in the lakes (see page 27) and also contribute to more dead zones of oxygen-depleted waters in the lakes.⁶³ In Lake Erie, where pollution (not water temperature) has sometimes caused such oxygen-poor zones to develop, the consequences include greenish-brown, murky lake water and green, slimy, rotting algae covering beaches.⁶⁴ Dead zones also can cause fish kills.⁶⁵

Less Lake Ice

Winter ice cover on the Great Lakes is distinctive, beautiful, and ecosystem-shaping. But higher air and water temperatures already are reducing winter ice, a trend expected to continue and accelerate.

Scientists have measured a decline in winter ice, with the greatest changes occurring in the centers of the lakes, where the water is deeper and normally

The Great Lakes themselves, their shores, and inland ecosystems, including forests, lakes, streams, and wetlands, are at risk as heat-trapping gases change the climate.

THE GREAT LAKES

The well-named Great Lakes—the largest group of lakes in the world, both by volume of water and surface area—are unquestionably the defining feature of the entire region. The lakes however, already are changing, with hotter water, less ice in winter, and stronger winds. The lakes are projected to become smaller, with lower water levels and smaller surface areas.

Hotter Water

Water temperatures in the Great Lakes have increased even more in recent decades than air temperatures have. Lake Superior's summer temperatures rose about 4.5°F from 1979 to 2006, roughly double the rate at which summer air temperatures have gone up over the surrounding land; water temperatures in Lake Michigan and Lake Huron, too, have gone up more than air temperatures.⁶⁰

In recent years, the temperature of Lake Superior's water in summer has gone up about twice as much as air temperatures.

The Great Lakes are expected to continue getting hotter as a result of human-caused climate change. Early projections suggested that water temperatures could get 2° to 12°F hotter in this century, and projections with newer climate models suggest the temperature increases could be even greater.⁶¹

One consequence of hotter waters is an earlier onset and longer duration of the natural separation of lake waters into layers of different temperatures. This stratification already has been occurring earlier in lakes Michigan, Huron, and Superior, with the onset in Lake Superior two weeks earlier now than 30 years ago—about half a day earlier per year.⁶² (For the effects on fish, see page 27.)

colder. According to a calculation by the National Oceanic and Atmospheric Administration (NOAA), since the 1970s ice cover in the centers of the lakes through 2002 has fallen more than 30% and total ice cover across the lakes has fallen 15% through 2009.⁶⁶

Ice also is forming later in the season and disappearing earlier. Around Apostle Islands, since 1975 the ice cover has formed about 12 days later and melted away three days earlier per decade.⁶⁷

Scientists project that the loss of ice in the Great Lakes will accelerate. Lake Michigan may have some

Already, winter lake ice cover is 15% lower than in the 1970s. Around Apostle Islands, the period of ice cover is getting shorter by about 15 days per decade.

winters with no ice cover in as soon as ten years. By midcentury, ice-free winters could be the norm, with average ice cover falling to near zero.⁶⁸ Lake Superior could be ice-free in a typical winter in about three decades.⁶⁹ Another study projects that by the end of the century ice could last 76 days less on parts of Lake Superior near Apostle Islands and Isle Royale, 80 days less in the area near Pictured Rocks, and 75 days less in Whitefish Bay.⁷⁰

A loss of ice affects the ecosystems of the Great Lakes and the region's parks. With less ice and more open waters, the lakes will have more waves in winter than before, especially during strong winter storms. Park shorelines and structures will have more risk of erosion.⁷¹ Also, because snow and ice cover protect dunes, beaches, and other shoreline features from erosion by keeping them effectively frozen in place, they may be at greater risk of erosion in the future.⁷²

The park staff at Sleeping Bear Dunes has expressed concern to the authors that the park's signature perched dunes, atop towering bluffs above the shorelines, could be vulnerable to increased erosion and accelerated loss. The threat arises from the combined effects of less winter ice and snow cover to protect the dunes's sand from blowing away and of increased wave action that could undercut the

A lack of lake ice leads to more winter waves, which can increase shoreline erosion. National Park Service staff has expressed concern that erosion of lakeshore dunes could accelerate as a result.

bluffs on which the dunes perch.⁷³ Huge dunes, of course, are the namesake features of not only that park but also of Indiana Dunes NL.

More wave action resulting from less lake ice cover also could increase the removal of sediment from some places and its deposition elsewhere. In Sleeping Bear Dunes, this process is adding between five and ten feet of sediment each year around some docks. Most of the sediment appears to be added during storm events. Docks previously surrounded by open water are now engulfed in sediment, which could require more frequent, larger-scale, and expensive NPS dredging near affected docks and other park infrastructure.⁷⁴

With less ice to reflect the sun's warming rays, lake surfaces absorb more heat than they used to. The loss of winter ice therefore helps to explain how water temperatures in the lakes have increased faster than the region's air temperatures.

Ice loss also can affect park wildlife. According to NPS staff at Sleeping Bear Dunes, a reduction in the scouring action of lake ice along shorelines may be increasing shoreline vegetation, cutting into the open beach habitat required for nesting by the park's endangered piping plovers (see page 26). As another example, the eggs of some fall-spawning fish may be lost to increased winter waves (see page 27).

Less lake ice would also reduce opportunities for ice fishing and visiting the ice formations at Apostle Islands's sea caves (see page 30). Increased winter evaporation from open water also can cause heavier lake-effect snow inland, affecting the entire region.⁷⁵

Lower Lake Levels

Most climate projections suggest that an altered climate will disrupt the current balance of water entering the lakes through inflows and precipitation and leaving through outflows and evaporation, lowering the water levels of the lakes. The causes could include increased take-up of water by plants in a hotter future, reducing runoff into waterways that flow into the lakes. Evaporation could increase from soil and waterways in the Great Lakes basin and from the lakes themselves, the latter in part because less winter ice exposes the water to evaporation for longer stretches.⁷⁶

Estimates of future Great Lake levels vary. A recent study by James Angel and Kenneth Kunkel used 23 climate models to project changes in lake levels by 2080-2094, for lower, medium, and medium-high future emissions.⁷⁷ The averages of the projections for each scenario are presented in Table 6. For all



Indiana Dunes NL

**Projected Declines in Lakes Michigan and Huron by 2080-2094
Projections by Angel and Kunkel**

	Lower Future Emissions	Medium Future Emissions	Medium-High Future Emissions
Average of projections	9.8 inches	11.0 inches	16.0 inches

Table 6. Source: Angel and Kunkel.⁷⁸

scenarios, the average projection is for declining lake levels, with greater declines if future emissions are greater. With lower and medium emissions, nearly three-quarters of all individual model results are for lower lake levels; with medium-high emissions, more than three-quarters are. As is the case with the new temperature projections by the Rocky Mountain Climate Organization in the previous section, this study did not use any scenario at the higher end of the current range of emissions, so the Angel-Kunkel results do not indicate how much the lake levels may go down if future emissions are on a higher path.

The regional climate projections by Hayhoe and colleagues also included projections of changed lake levels, using fewer model runs but a wider range of emissions scenarios. With a higher-emissions scenario, the average of their projections is for a drop of a foot and a half in lake levels by the end of the century.⁷⁹ As their study notes, that result is for the average decline across all the lakes, and significant variability—even on the order of several feet—from lake to lake or during certain time periods is likely.

These studies underscore that, as with higher temperatures and other climate-change impacts, how much the levels of the lakes change appears to depend on what is done to limit future emissions of heat-trapping pollutants.

“Under a lower emissions scenario, water levels in the Great Lakes are projected to fall no more than 1 foot by the end of the century, but under a higher emissions scenario, they are projected to fall between 1 and 2 feet. The greater the temperature rise, the higher the likelihood of a larger decrease in lake levels.”

Global Climate Change Impacts in the United States⁸⁰

The National Park Service itself has not yet assessed in detail how declines in levels of the Great Lakes may affect particular park resources and visitor experiences of them. In very general terms, the Service has said that decreasing lake levels will have an impact on park buildings and facilities, such

as docks, boat ramps, and ferry landings, which as currently built may be inadequate for changed future conditions. For example, docks and boat ramps may be too high as lake levels decline.⁸¹ The NPS has also stated that shallower water may prevent access by deeper-draft boats at docks and anchorages and expose new navigational hazards such as sandbars.⁸² In conversation with the authors of this report, the superintendent of Apostle Islands, Bob Krumenaker, has elaborated that when lake levels have recently been low, the lakeshore’s docks have not been usable for some boaters visiting the park, prompting understandable visitor complaints. Krumenaker has also said that in recent years the NPS, when replacing park docks, has begun installing docks that will be usable with low lake levels. More extensive changes, such as extending docks farther into the lake to make them more fully accessible in low water, would be more expensive and may not be feasible with expected future NPS budgets, he says.⁸³ (For more on possible effects on boaters, see page 32.)



NPS

Apostle Islands NL

The U.S. Geological Survey (USGS), in partnership with the NPS, has assessed the possible effects of lake-level declines on the shorelines of Indiana Dunes, Sleeping Bear Dunes, and Apostle Islands, much as the USGS has evaluated possible effects of sea-level rise on some coastal national parks.⁸⁴ For the three Great Lakes parks, the USGS identified the likelihood of changes in shorelines based on six factors: erosion and accretion (build-up) rates,



Apostle Islands NL

coastal slopes, relative projected lake-level changes, average wave weights, average ice cover, and geologic stability or susceptibility to changes.

- At Indiana Dunes, nearly half of the 15-mile shoreline has a high or very high potential of shoreline change. The vulnerable areas, mostly in the eastern portions of the lakeshore, include Central Beach, and the beaches below Mt. Baldy.⁸⁵
- At Sleeping Bear Dunes, 60% of its 64 miles of coastline has a high to very high potential for shoreline change.⁸⁶ Vulnerable areas include Platte Point Beach; Peterson Beach, “one of the most beautiful and secluded beaches in the lakeshore,” according to the NPS; Glen Haven Beach in Sleeping Bear Bay; and North Bar Lake, near the park visitor center.⁸⁷
- At Apostle Islands, nearly half of the 160 miles of shoreline is rated as having a high to very high potential for shoreline change.⁸⁸ The most vulnerable areas are on the islands (not the park’s mainland unit), including Outer Island, Stockton Island, Michigan Island, Long Island, Cat Island, Ironwood Island, South Twin Island, and Devils Island, especially along sandy beaches where wave heights are highest.

FORESTS AND OTHER PLANT COMMUNITIES

Forests comprise key ecosystems in all the featured Great Lakes national parks. These forests face a multitude of threats from human-caused climate change.

Changes in Forest Types

Higher temperatures alone are likely to affect forests in the Great Lakes parks, as across the country. In a hotter climate, areas that now meet the habitat

requirements of certain tree species likely will no longer do so, and new areas that now cannot support particular species will become suitable for them.

Already, forest compositions seem to be shifting. U.S. Forest Service researchers analyzing tree seedling densities have concluded that in the eastern United States more than 70% of northern tree species have moved their ranges to the north, with more seedlings growing at the northern ends of their previous ranges and fewer at the southern ends.⁸⁹

An expected continuation of this trend threatens the current forest types in the Great Lakes parks. As the U.S. government’s 2009 national assessment of climate change impacts puts it, there would be “major changes in the character of U.S. forests and the types of forests that will be most prevalent in different regions.”⁹⁰ At risk in the southern Great Lakes region, including Indiana Dunes, are forests dominated by oaks and hickories. Farther north, including the areas of the other Great Lakes national parks, are northern hardwood forests featuring sugar maple, American beech, and American basswood, and boreal forests dominated by white spruce, balsam fir, and to a lesser extent eastern hemlocks.

“Climate warming alone is projected to drive significant changes in the range and species composition of forests and other ecosystems. Generally, tree species are expected to shift their ranges northward or upslope, with some current forest types such as oak-hickory expanding, others such as maple-beech contracting, and still others such as spruce-fir disappearing from the United States altogether.”

National Academy of Sciences⁹¹

One study used climate and vegetation models to project that in the eastern half of the United States, including the Great Lakes region, the suitable habitat for most tree species will move to the north, by 60 to over 300 miles for several species. Quaking aspen, paper birch, northern white cedar, balsam fir, sugar maple, and other species may have their suitable habitat move outside the United States and into Canada.⁹² In the Great Lakes region, boreal spruce-fire forests are expected to diminish or perhaps disappear altogether.⁹³ Scientists caution, though, that these broad-scale projections cannot fully reflect how types of forests may change. More forest disturbances such as those expected from insect infestations and wildfires may lead to more abrupt changes than models suggest. Or, because trees are long-lived and may tolerate conditions different from those in which they now live, changes in forest composition may take longer than models suggest.⁹⁴

“Although people’s worries about global climate change most often focus on things like summer heat, drought, flooding, rising sea levels, and polar bears, there’s another big worry that isn’t so well publicized—the effects of all these changes on plants, particularly trees. People and animals can walk, run, swim, or fly to a more suitable habitat, but trees can’t escape the heat.”

Dennis May, U.S. Forest Service⁹⁵

Disruption by Invasive Plants

In the Great Lakes parks, as elsewhere, an altered climate is likely to worsen the threats posed to natural plant communities by non-native invasive plants. Invasive plants are by definition aggressive spreaders, which have spread from their historical range into new territory where they damage the economy or the ecosystem. They typically thrive in a wide range of environmental conditions and can out-compete native plants for water, nutrients, and other essentials. The changes in local conditions expected from an altered climate often would give the invaders an extra edge in competing against native plants.

Indiana Dunes NL, in particular, has an astonishing range of native plants that is at risk as a changed climate promotes the spread of invasive plants. The park features some of the greatest biological diversity found anywhere in the national park system. More than 1,100 native species of flowering plants and ferns have been documented, and about 30% of Indiana’s state-listed rare, threatened, and endangered species live there.⁹⁶ In any setting, this would be a biological gem. Not far from a heavily urbanized and industrial area, this is a true wonder.

The natural biological diversity of Indiana Dunes is already threatened by invasive plants, which now

number about one fifth of the park’s plants. A hotter climate would promote the spread into the park of even more invasive plants from elsewhere. One suggestion of the extent of the possible changes is a projection that the plant hardiness zone of the region—a classification based on average minimum winter temperatures, and widely used by gardeners to pick locally suitable plants—could shift by 2070-2099 to become like that of present-day southern Illinois with lower future emissions of heat-trapping gases, or like that of northern Alabama with higher future emissions.⁹⁷

The other Great Lakes parks are also vulnerable to more invasive species. Already in Sleeping Bear Dunes, fully 25% of the plants present are non-native, and in Isle Royale about 15% are.

One particular invasive species found in all five featured parks is spotted knapweed, which is particularly successful in the shifting sands of dunes and other disturbed areas.⁹⁸ Another invasive plant already infesting Indiana Dunes is oriental bittersweet, the “kudzu of the north.” Coming behind it is the real kudzu, a highly aggressive, fast-growing Asian vine which has long infested much of the southeastern United States and has already spread into southern Indiana and Illinois. Kudzu’s already-extraordinary growth rate accelerates when atmospheric carbon dioxide levels are higher. In earlier times, cold winters would have kept this invasive weed from moving farther north, as it is confined to areas where winter temperatures do not drop more than a few degrees below zero. Climate models suggest that continued warming of winters will move that temperature barrier to the north. Kudzu could reach northern Indiana, central Wisconsin, and central Michigan in another decade, and spread farther North after that.⁹⁹

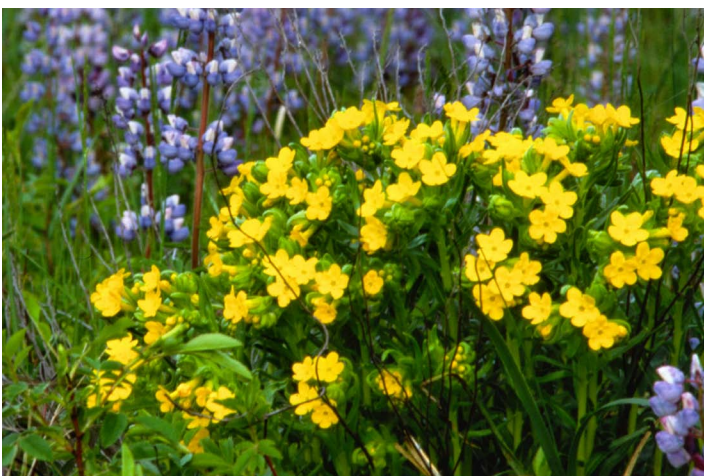
“By the end of this century, plants now associated with the Southeast are likely to become established throughout the Midwest.”

Global Climate Change Impacts on the United States¹⁰⁰

Stronger downpours and increased flooding (see page 14) can also promote the spread of invasive plant species. In Indiana Dunes in September 2008, 14 inches of rainfall in three days flooded for almost a year the park’s Howes Prairie ecosystem, suppressing the natural prairie vegetation and enabling hybrid cattail and purple loosestrife to invade and become established in the prairie for the first time.

Disruption by Insects

Warmer winters, hotter and drier summers, and longer insect growing seasons have already



Indiana Dunes NL

contributed significantly to several major insect outbreaks that have changed forests in the United States and Canada over the past several decades. Further climate change is expected to promote more outbreaks of this type.¹⁰¹ The Great Lakes region and its parks are vulnerable to these threats, too.¹⁰²

Two examples illustrate how parks are threatened by a loss of the deep cold of winter that naturally serves to hold the populations of some insects in check. The first is gypsy moths, which as adults defoliate more hardwood forests than any other insect in North America, can kill trees, and can increase the incidence of stress-related tree diseases. According to a recent study about climate change impacts on ecosystems around southern Lake Michigan, there is “great concern” about the possible consequences of the spread of gypsy moths in the region as winters continue to warm, allowing more moths to overwinter and extending their feeding and breeding seasons.¹⁰³

The second example is a looming threat to eastern hemlocks, found in Apostle Islands, Pictured Rocks, and Sleeping Bear Dunes national lakeshores, from the hemlock woolly adelgid, a tree-killing insect from Asia that is spreading north as warmer winters keep it from being held in check by cold temperatures.¹⁰⁴ Adelgids attach themselves to the needles of hemlocks and feed on their sap. Eastern hemlocks have evolved no defenses to this foreign invader, and infested trees are usually deprived of so much nutrition that they die within a few years.¹⁰⁵ Once the adelgids arrive in an area, “complete hemlock mortality is inevitable.”¹⁰⁶ Eastern hemlocks are already being completely eliminated in more southerly areas now infested by the adelgids, such as Shenandoah National Park in Virginia, where eastern hemlocks are a key tree species.¹⁰⁷ Adelgids have not yet infested the Great Lakes region, but warmer winters are expected to enable the insects to spread into the region, including its national parks with eastern hemlocks.¹⁰⁸ Both the U.S. government’s 2009 national assessment of climate-change impacts and an earlier U.S. government report on ecosystem effects of climate change identified the possible spread of the adelgid into northern forests as an example of how a hotter climate can promote ecosystem disruption.¹⁰⁹

“Spruce beetle, pine beetle, spruce budworm, and woolly adelgid (which attacks eastern hemlocks) are just some of the insects that are proliferating in the United States, devastating many forests. These outbreaks are projected to increase with ongoing warming.”

Global Climate Change Impacts on the United States¹¹⁰



US Forest Service

Hemlock woolly adelgids, covered by the white woolly substance after which they are named.

INLAND WATERS AND WETLANDS

Also vulnerable to climate change are the inland lakes, streams, and wetlands of the Great Lakes region—the greatest concentration of small water bodies in the world for an area of such size.¹¹¹

Lakes and streams are likely to be most affected in summer, as a result of hotter summers (see pages 11-12), which would increase both take-up of water by plants and evaporation from water bodies and the soil, and an expected regional decrease in average summer precipitation (see pages 13-14) and therefore lower run-off into the lakes and streams. Possible consequences include lower summer streamflows, more headwater streams going dry, more perennial streams becoming intermittent, and groundwater recharge being reduced.¹¹²

Wetlands face similar threats from a loss of water in summer. Wetlands could become drier, shrink, become fragmented, or even disappear entirely, particularly where the local topography will not allow them to migrate in response to changed conditions. In some cases, too, lower water levels in the Great Lakes could diminish or sever waterway connections between the inland wetlands and the lakes themselves.¹¹³ Some unique types of wetlands, such as northern peatlands, bogs, and fens, which do not occur farther south, could be entirely lost to the region due to projected climate changes.¹¹⁴

The Great Lakes parks have many lakes, streams, and wetlands that are vulnerable. Sleeping Bear Dunes, Pictured Rocks, and Isle Royale alone have 85 named lakes and nearly 400 unnamed lakes.¹¹⁵ Some of the streams in the Great Lakes national parks may not maintain connections with the Great Lakes under a disrupted climate, which would eliminate important spawning areas for fish such as the native brook trout.¹¹⁶ Potentially vulnerable wetlands in and near the Great Lakes parks include those of

Sevenmile Creek, Hurricane River, and Miner’s River at Pictured Rocks; Cowles Bog, Pinhook Bog, and Great Marsh at Indiana Dunes; and the 27 wetlands present on Stockton Island in the Apostle Islands.

In addition, culturally important wetlands, such as wild-rice wetland beds in the Apostle Islands that are still harvested by indigenous peoples, could dry up or become non-navigable. (See page 35.)



Otter Creek meeting Lake Michigan, Sleeping Bear Dunes NL

LOSS OF WILDLIFE



US Fish & Wildlife Service (FWS)

Gray wolf

The number of moose on Isle Royale has dropped, in part because of their vulnerability to heat. The park's wolves, which depend on the moose for food, are vulnerable and also in decline.

Already, mammal populations in the region's forests have become dominated by southern rather than northern species.

Already, hotter lake waters are contributing to disease outbreaks killing hundreds to thousands of birds a year in Sleeping Bear Dunes.

The latest inventory, from the winter of 2010-2011, shows both populations are down. The park now has 16 wolves in two packs, compared to 24 wolves in four packs a few years ago. Moose number about 515, for the third year in a row only about half the park's long-term average.¹¹⁸

The decline in moose numbers appears to be driven by higher temperatures and their consequences. As John Vucetich, one of the co-directors of the wolf-moose study, says, "The weather is now the most significant factor. We seem to have moved from a predator-controlled system to a climate-controlled system."¹¹⁹

The first key climate-related factor is heat itself. Moose, adapted to cold climates, are stressed by high temperatures. Heat stress likely causes energy loss and malnutrition among the moose, making them more vulnerable to diseases.¹²⁰

Today's higher temperatures already seem to be taking a toll. In nearby northwest Minnesota, researchers at the Department of Natural Resources have documented that the moose population has

For visitors to the national parks around the Great Lakes, as to parks around the country, the highlight of their trip can be the wildlife they see there. But a changed climate could mean a loss of some wildlife species now found in the Great Lakes national parks.

Some species found in these parks could go completely extinct. The Intergovernmental Panel on Climate Change warns that just 4° to 5°F of higher temperatures could leave 20 to 30% of plant and animal species in climatic conditions far outside those of their current ranges, making them "likely to be at increasingly high risk of extinction."¹¹⁶ Even more common could be major populations shifts, so that some wildlife species now present in the Great Lakes parks may no longer be found there, or persist only in greatly reduced numbers.

Some of these changes could already be underway. Moose, creatures of the cold North, are in decline in Isle Royale NP, and a hotter climate seems to be a cause. The wolves in that park that are dependent on them also have declining numbers. Hotter lake waters appear to be facilitating disease outbreaks that are claiming thousands of birds in Sleeping Bear Dunes. Range shifts among birds already appear to have some species disappearing from Great Lakes parks where they used to be regulars.

MAMMALS

Lucky visitors to Isle Royale may see the island's famed wolves or moose. The very lucky at Grand Portage National Monument might see lynx, or those at Isle Royale or Pictured Rocks might see martens—both special species of the North. A sighting of any of those mammals may be remembered for a lifetime. But the populations of these four mammals in these parks are threatened by a disrupted climate.

Wolves and Moose

Isle Royale's populations of wolves and moose are inextricably linked. The only predators of the moose on the island are the wolves, and the moose make up about 90% of the wolves's food. A 52-year-old study of their relationship, now operated by researchers from Michigan Technology University, is the longest-running predator/prey study in the world.



©2006 Todd VerBeek

Moose, Isle Royale NP

crashed in the past two decades from 4,000 to fewer than 100 animals, coinciding with higher temperatures. In the northeast part of the state, reduced fertility and survival rates from 2002 to 2008 also appear linked to higher daytime temperatures, especially in winter and spring. Unless fertility and survival rates rise again, “the moose populations in northeastern Minnesota will probably decline and ultimately the southern edge of moose distribution will shift northward and out of northern Minnesota,” according to scientists for the state agency.¹²¹

According to the superintendent of Grand Portage National Monument, located in northeast Minnesota where the outlook for the moose is bleak, the population decline is particularly alarming for the local Ojibwe population because of the important roles the animal plays in their culture, especially for members of the moose clan.¹²²

“Warming temperatures might already be related to the significant decline in moose populations in northern Minnesota and at Isle Royale National Park since the 1980s.”

National Park Service¹²³

According to the wolf/moose researchers on Isle Royale NP, higher temperatures cause another problem for moose—more ticks. Up to 80,000 ticks can infest a single moose. That is enough to cause a large enough loss of blood to weaken the moose and make it more vulnerable to the park’s wolves. In 2001-2007, a stretch with five of the six hottest years during the last half-century, tick numbers were especially high in winter and moose numbers declined.¹²⁴ Further increases in temperature could similarly lead to more ticks, threatening the moose population.

“Humans have made summers increasingly hot, which likely exacerbates moose ticks. Both the heat and the ticks are detrimental to moose. If wolves go extinct for a lack of moose, humans will be to blame. There are too few moose for the wolves to eat, and the reason there are too few moose is very likely that hot summers and ticks made them too easy for the wolves to kill.”

John Vucetich, Michigan Technological University¹²⁵

The wolves, moose, and other mammals on Isle Royale also face another particular vulnerability: 15 miles or more of water to the mainland. If a changed climate makes the island uninhabitable for them, moving to suitable conditions may not be possible.

Lynx

Canada lynx are a threatened species in the contiguous United States under the Endangered Species Act. Grand Portage National Monument is one of the very few national parks in those states where lynx can sometimes be found. Lynx are superbly adapted to snow cover, with huge feet that enable them to travel on top of snow and catch prey in winter. Researchers have determined that most areas where lynx now occur have four months of snow cover and average January temperatures under 17°F. If those conditions are essential for lynx, just a 4° to 7°F increase in average annual temperatures could eliminate about half of habitat suitable for them in the contiguous United States.¹²⁶

Martens

Martens, long absent from Pictured Rocks and Isle Royale, are now found in both parks again.¹²⁷ Small, tree-climbing members of the weasel family that do not hibernate, they need snow cover to retreat under for insulation in times of extreme cold. Snow cover also protects martens from predators and provides them with good hunting conditions. A recent study on martens in the northern Rockies concluded, “Deep persistent snowpack is a critical habitat element for American marten.”¹²⁸ Also, a 2011 report on climate change in Wisconsin, where the species is listed as threatened, said, “The marten’s low tolerance of snow-free conditions makes this species a good case study of climate change impacts.”¹²⁹ A further risk for martens is that they are habitat specialists not known to make rapid changes in the range they inhabit.¹³⁰ As explained earlier, these are precisely the kinds of wildlife that are most at risk as changes in the climate transform and disrupt ecosystems.



Erwin & Peggy Bauer/FWS

Marten

The NPS staff at Sleeping Bear Dunes has developed proposals for funding an effort to restore pine martens to the park. Now, though, the authors of this report have been told by the park staff that they are re-evaluating whether such an effort would be feasible, given the staff's concerns about how climate-change-driven changes in the park's ecosystems could make it less likely that martens could survive there.¹³¹

Changes in Mammal Distributions

Scientists project that habitat changes caused by an altered climate will lead to wholesale changes in the mammal species found in national parks across the country, with potentially dozens of new types of mammals moving into parks that now are not suitable for them, and some current mammal species facing local elimination.¹³²

“Due to vegetation shifts, and thus habitat shifts, parks may experience a shift in mammalian species greater than anything documented in the geologic record. . . National parks may not be able to meet their mandate of protecting current biodiversity within park boundaries for mammals.”

National Park Service¹³³

The projected changes appear to already be underway on Michigan's Upper Peninsula, where university scientists have recently documented that widespread changes have already occurred in the distribution and abundance of common forest mammals, with a changed climate apparently responsible.¹³⁴ Southern species such as opossums and southern flying squirrels are consistently increasing in numbers and are taking the place of northern species, which are consistently declining in numbers. Overall, the mammal population of the region has shifted from one dominated by northern species to one dominated by southern species.

BIRDS

The Great Lake parks are justly famous for their birdlife. The NPS calls Sleeping Bear Dunes, with its list of 240 recorded birds, “a veritable treasure chest for birders who want to add species to their lists.”¹³⁵ Indiana Dunes offers even more treasures, 352 by official count—the equal of Everglades National Park, probably the national park most famous for its birds.

But a hotter, disrupted climate threatens many of the birds of the Great Lakes national parks.

Botulism Outbreaks

A recent study by NPS and the U.S. Geological Survey has linked lower levels and hotter waters in the Great Lakes (see pages 15-18) with recent increased outbreaks among the region's birds of botulism, a disease which can paralyze and kill them.¹³⁶ The study documents that botulism outbreaks tend to occur when lake levels are low and lake water temperatures are high. According to the staff of Sleeping Bear Dunes, hundreds to thousands of dead birds have been found on park shorelines annually since 2006, with most that have been tested having been confirmed as being infected by botulism.

The ecological consequences could be severe. Among the victims of the botulism outbreak are piping plovers. This shorebird's Great Lakes population is listed as an endangered species under the federal Endangered Species Act, and 35 to 40% of all breeding pairs nest in Sleeping Bear Dunes.

The birds killed by botulism are numerous enough to disturb visitors to the lakeshore. The park has hired a seasonal employee and marshaled volunteers to monitor the beaches and clean up bird carcasses from June through November.¹³⁷

So many birds have been killed in Sleeping Bear Dunes from disease triggered by lower lake levels and hotter lake waters—conditions consistent with climate change—that the park has had to hire extra staff to clean up the carcasses.

Loons and Grouse

One measure of possible future disruptions in the region's birdlife has been suggested by a study by U.S. Forest Service (USFS) researchers who used two climate models to project changes in the habitat required by 150 species of eastern birds.¹³⁸ According to that study, wholesale changes are coming to the birds of the Great Lakes region – including two of its most iconic species, loons and grouse.

For many people, the haunting call of common loons is one of the most distinctive elements of the

Warblers and Other Migrants

Large-scale changes could also be in store for the migratory birds that breed in or pass through the Great Lakes national parks, some coming from as far away as Central and South America. The locations of Sleeping Bear Dunes, Pictured Rocks, and Apostle Islands on or just offshore of peninsulas make them particularly important as resting and feeding way stations for migrants seeking shorter over-water flights to cross the Great Lakes, and so all three parks are heavily used by migrants.

Among the migrants are warblers, “some of the most dazzling and colorful of all North America’s birds, making them one of the most popular groups of the region with birders and professional ornithologists alike,” according to a bird guide.¹⁴¹

The Great Lakes region abounds in warblers. At Indiana Dunes, 41 species of warblers have been recorded; on Michigan’s Upper Peninsula, 39 have.¹⁴² At least 20 species of warblers are known to breed in Isle Royale and 17 in Sleeping Bear Dunes.¹⁴³

“The upper Midwest is arguably North America’s finest location for finding migrant warblers. In this geographical region the three primary spring migration paths (the Caribbean-Florida, trans-Gulf, and Central American routes) converge. Accordingly, the diversity of migrant spring warblers near the Great Lakes is unparalleled elsewhere on the Continent.”

Kenneth J. Brock, *Birds of the Indiana Dunes*¹⁴⁴

According to the U.S. Forest Service study, at least nine types of warblers could be eliminated as breeders from the Great Lakes parks, and eight more face population declines in the region. That



Blackburnian warbler



Common loon

natural landscapes of the Great Lakes. Loons now nest in Sleeping Bear Dunes, Pictured Rocks, Apostle Islands—and especially in Isle Royale, home to a very high percentage of Michigan’s nesting loons.¹³⁹ The projections based on both climate models in the USFS study, though, indicate that common loons could be eliminated as breeding species across nearly the entire United States side of the Great Lakes. Only in extreme northeast Minnesota—and presumably Isle Royale, just offshore from there—does one of the models project that common loons may persist as breeders, although in reduced numbers. For many people, without the call of the loon the Great Lakes would not be the same.

Another species at risk is the ruffed grouse, a signature species of northern forests known for the drumming sound made by males in their spring displays. The grouse are year-round residents and breeders in Sleeping Bear Dunes, Pictured Rocks, and Apostle Islands. But projections in the USFS study using both climate models are that ruffed grouse will be eliminated from Sleeping Bear Dunes and the entirety of Michigan’s Lower Peninsula and from Pictured Rocks and its surrounding area of the Upper Peninsula (although in one model they would persist in some other areas of the U.P.). Again, should the drumming of the ruffed grouse disappear from the spring forests of these parks, a piece of their natural magic would be extinguished.

Pictured Rocks also is home to spruce grouse, which were not considered in the USFS study. These grouse are found nearly exclusively in coniferous forests, especially among the spruce after which they are named. As these types of forests migrate farther to the north (see pages 18-19), the spruce grouse can be expected to disappear with the forests. The spruce grouse is so vulnerable to the habitat changes believed likely with even moderate levels of further climate alteration that the Wisconsin Department of Natural Resources calls the species “an ideal candidate to provide early signs of climate change similar to the canary in the coal mine.”¹⁴⁰

Dennis Donohue/Shutterstock.com

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means that nearly all of the current breeding warblers of the region's parks face either potential elimination or population declines, based solely on projected ecosystem changes. Species that could be eliminated are golden-winged warbler, Nashville warbler, northern parula, black-throated blue warbler, yellow warbler, magnolia warbler, blackburnian warbler, northern waterthrush, and mourning warbler. Declines are expected for black and white warbler, yellow warbler, black-throated green warbler, pine warbler, ovenbird, common yellowthroat, Canada warbler, and American redstart.¹⁴⁵

The U.S. Forest Service study did not even assess climate-change threats beyond habitat changes—such as emerging mismatches between the timing of migrations and of the availability of food along migratory routes and on breeding grounds. In Europe, migrating birds that have not begun migrating earlier have had population declines, while earlier migrants have stable or increasing populations.¹⁴⁶ Adjusting migratory timing must be particularly difficult for long-distance migrants, whose wintering grounds offer no clues of the arrival of spring at distant breeding grounds. This could affect warblers that breed in the Great Lakes parks or migrate through them on their way to breed in Canada.

Shorebirds

Shoreline nesting birds also face a variety of threats in the parks—with low lake levels, increased erosion, more intense storms, and hotter temperatures each presenting distinct concerns.¹⁴⁷ Among the at-risk species is the endangered regional population of piping plovers. Lower lake levels could make beaches wider, potentially benefiting the plovers, which nest on open beaches. However, increased erosion and

accelerated encroachment of aggressive, non-native woody plants could reduce this breeding habitat; more frequent and intense storms could wash away more nests during the nesting season, and seasonal changes in temperatures might lead to mismatches between the hatching of young plovers and the availability of food for them, especially if the timing of insect hatches shift.¹⁴⁸ Also, according to NPS staff at Sleeping Bear Dunes, less winter ice cover (see pages 15-16) may already be reducing the scouring action of lake ice along shorelines, letting more vegetation grow there, cutting into the open beach habitat required for nesting by the park's endangered piping plovers.¹⁴⁹

Wintering Birds

Warmer winters in recent decades have already led birds to shift their winter ranges to the north. According to Christmas Bird Count data compiled annually by thousands of volunteer birders, over half of the 305 most widespread, regularly occurring winter species in the contiguous United States now winter farther to the north than before, moving their ranges by an average distance of 35 miles over 40 years.¹⁵⁰

In Indiana Dunes, one wintering species that already appears to be in local decline is the evening grosbeak, which used to regularly winter in the lakeshore or migrate through it to and from wintering grounds farther to the south. Local birding authority Kenneth J. Brock maintains records of all bird sightings in the lakeshore since 1975, which show a marked change in recent years. In the 23 years from 1975 through 1997, 11 years had 50 or more sightings of evening grosbeaks. In the 13 most recent years, there have not been any with 50 sightings, only two years with as many as 20 sightings, and in most years there have not been any sightings.¹⁵¹

Social and Economic Consequences

Loss of bird diversity in the national parks of the Great Lakes could not only affect the natural character of these parks and the enjoyment of visitors but also have economic consequences. Wildlife watching—principally bird watching—is a \$3.5-billion-per-year industry in northern Michigan, Minnesota, and Wisconsin.¹⁵²

“Changes in wildlife composition due to climate change will impact activities in the [Great Lakes] parks, such as fishing and bird watching.”

National Park Service¹⁵³



Bill Byrne/FWS

Piping plover on its open-beach nest

FISH

The aquatic ecosystems of the Great Lakes parks could undergo substantial changes driven by hotter air and water temperatures.

Higher water temperatures are expected to force fish to change their distributions within the lakes, with some warm-water fishes projected to move northward by as much as 400 miles into new waters. Some cold-water fishes may disappear from the Great Lakes altogether.¹⁵⁴

Many fish may also move into deeper waters to find tolerable temperatures.¹⁵⁵ Shallow waters should warm the most, particularly affecting the species that typically reside there, such as walleye.¹⁵⁶ Shallow waters help to protect fish from mid-lake predators, so species forced into deeper waters may be exposed to increased predation.¹⁵⁷

Some inland lakes in the Great Lakes national parks are large and deep enough to host coldwater fish species such as lake trout, cisco, and whitefish. With no opportunity to migrate, they could be eliminated from these lakes by higher water temperatures, according to park staff. Similarly, cool-water streams, such as Crystal River, Platte River, and Otter Creek at Sleeping Bear Dunes, may lose their ability to support both native fish and salmon, which help draw recreational visitors to the park.¹⁵⁸

Higher water temperatures also lead to lower oxygen levels, promoting release of contaminants such as phosphorous and mercury, which become more soluble when oxygen levels decrease. When fish absorb these contaminants, eating them can be health hazards for people.¹⁵⁹

Already, fish at Sleeping Bear Dunes and Pictured Rocks may be contaminated with chemicals in them that can be harmful to human health in certain amounts, prompting park officials to warn visitors to follow government warnings and eat the fish only in limited amounts or not at all.¹⁶⁰

Less ice cover on the Great Lakes (see pages 15-16) could harm some fish populations. For example, lake whitefish spawn in fall, spreading eggs over the lake bottom, where they remain until hatching in the spring.¹⁶¹ When there is inadequate surface ice, winter winds create currents and waves that can destroy the eggs. One study suggests that after an ice-free winter whitefish young numbered only about 30% as many as after a winter with ice cover.¹⁶² Other fish species that spawn in shallow regions could face similar risks.¹⁶³

Another effect on fish could come from changes in the onset and duration of lake stratification—the natural separation of the lake into different temperature gradients (see page 15). Stratification starting earlier and lasting longer can reduce both food produced by algae and the amount of oxygen available to bottom-dwelling bacteria, plants, and animals.¹⁶⁴ All of this could lead to a decline both in

population size and health of fish populations and other species dependent on mixing of lake waters.¹⁶⁵

“For all lakes except Lake Erie, the amount of food produced by algae and consumed by fish and other aquatic species will decrease in part due to nutrient limitation caused by the longer stratification period.”

National Wildlife Federation¹⁶⁶

Lower lake levels (see pages 16-18) threaten the loss of fish habitat, as seasonal coastal and inland wetlands may dry up and important transitional floodlands and marshes may be reduced.¹⁶⁷

Warmer waters may promote the replacement of native fish species by non-natives able to thrive in varied or disturbed environmental conditions.¹⁶⁸ Native species are instead often adapted to a narrower range of conditions, which can be disrupted by a changed climate. For example, Asian carp have moved up the Mississippi River and are threatening to establish a population in the Great Lakes.¹⁶⁹ If established, the prolific Asian carp could consume massive amounts of plankton, reducing the food available for native fish.¹⁷⁰

BUTTERFLIES AND OTHER INSECTS

Butterflies may be affected as other wildlife are. One estimate is that of 115 species of butterflies currently found around southern Lake Michigan, 20 species might be eliminated from the region, and 19 new species might appear.¹⁷¹

One special butterfly of the Great Lakes parks at particular risk to climate change is the Karner blue butterfly, a small, beautiful butterfly listed as an endangered species. Seeing this rare butterfly is such a treat that the National Park Service, on the home page of Indiana Dunes’s website, lists as



FWS

Karner blue butterfly

one of four featured sights for park visitors “Karner blue butterflies landing on wild lupines.”¹⁷² Lupines, indeed, are where Karner blues may be seen, as their caterpillars feed solely on this flowering plant. Lupines are found as far south as Florida, but Karner blues are found only where the lupines overlap with long-lasting winter snow cover.

In Indiana Dunes, the butterfly’s populations have declined in recent years of low snow cover, apparently because it is an insulating layer of snow that protects eggs laid in the fall on the ground or in leaf litter from freezing temperatures and dehydration.¹⁷³

For many visitors to the Great Lakes parks, a particularly troubling consequence of a hotter climate could be more mosquitoes and biting flies, as well as the spread into the region of ticks carrying Lyme disease (see page 31).

“As spring arrives earlier, mosquitoes and black flies could begin hatching earlier in the season and may take longer to die off as winters become shorter.”

National Park Service¹⁷⁴

LOSS OF VISITOR ENJOYMENT

Alteration of the climate may affect in several ways the enjoyment of the Great Lakes national parks by current and future generations. Pleasant conditions for outdoor recreation should exist earlier in the spring and later in the fall, extending the season for outdoor recreation in the parks. Most other changes, though, are likely to diminish visitor enjoyment, especially in the summer, the season of highest park visitation levels.

MORE HEAT

Summers in the Great Lakes national parks may simply get too hot for the parks to be as enjoyable for visitors as has been the case. With medium-high levels of future emissions of heat-trapping pollution, summers in Indiana Dunes could become as hot as those in Gainesville, Florida, have been. With higher levels, they could become as hot as those of Key West. (See pages 11-12). Either change would transform the experience of visiting the park in summer, and might be enough of a change to affect visitation levels (see page 5).

On top of the projected increases in average summer temperatures, increases also are expected in this region (as elsewhere) in the frequency, severity, and duration of heat waves—several days or more of abnormally hot weather. Since the 1980s, large heat waves have been more frequent in the Midwest than any time in the last century, other than the Dust Bowl years of the 1930s.¹⁷⁵ In the future, heat waves could become much more severe. A heat wave of the magnitude that Chicago suffered in 1995, which led to over 700 deaths, could occur in the region as frequently as every other year by the end of the century with lower future emissions, or happen as often as three times a year with medium-high emissions.¹⁷⁶

Visitors to national parks typically are outside, not in air-conditioned buildings, and often are engaged in physical activity, making them more susceptible to the unpleasant or dangerous effects of high temperatures. In particular, hotter summer days also could affect people enjoying one of the most popular activities in Sleeping Bear Dunes—climbing the park’s dunes, which rise as much as 450 feet above Lake Michigan. The staff at the park has expressed



Sleeping Bear Dunes NL

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Summers could get too hot for outdoor activities, ice fishing and other winter sports could be curtailed, and more air pollution could harm visitors.

Already, hotter conditions have allowed ticks carrying Lyme diseases to spread into the northern parks for the first time.

concern to this report’s authors that higher summer temperatures in the future could require management actions to protect the safety of people climbing the dunes, as well as for NPS staff working in the dune and shoreline environments.¹⁷⁷

“Increased temperatures could hinder physical activities in parks and refuges, resulting in increased heat exhaustion.”

National Park Service¹⁷⁸



Sleeping Bear Dunes

LOSS OF WINTER RECREATION

In the Great Lakes region, including its parks, a hotter climate could lead to much shorter seasons for winter sporting activities that require lake ice or inland snow cover, as a result of a later onset and an earlier end to freezing temperatures, more warm mid-winter days, and a higher percentage of winter precipitation falling as rain rather than snow. Ice fishing, cross-country skiing, and snowshoeing, popular in all the Great Lakes parks except Isle Royale (which is essentially closed in winter), could be affected. So could the iconic sledding on snow-covered dunes in Sleeping Bear Dunes. How much these winter park activities could be affected is suggested by possible effects on warmer winters on downhill skiing—an activity not offered in these national parks, but one which has been studied in this region (as elsewhere). One study suggests that a changed climate could shorten the downhill ski season at Mt. Brighton Ski Resort in Michigan by a full 65%.¹⁷⁹

Reductions in ice cover and quality also would mean greater safety risks for people who venture onto lake ice to recreate, which can include ice fishermen, skiers, and snowmobilers. These winter recreationists also stand to lose much of the solitude they now can enjoy in their pursuits, as shorter seasons and less safe ice will increase the crowds in the fewer suitable places and times remaining for their sports.¹⁸⁰

One unique winter park experience that could be affected is enjoyment of winter's beautiful ice formations at the mainland sea caves at Apostle Islands. Visiting the sea caves in winter requires a two-mile (round-trip) hike on the ice of Lake Superior. Because the walk is not safe when the lake ice is not thick and stable, the national lakeshore staff regularly checks ice conditions, monitors the weather, and maintains an Ice Line with reports of current conditions. With less ice, visits to the caves

would be unsafe more often, and visitors would not as often be able to experience the trek across the lake ice and the close-up views of the caves and their ice formations.

Another effect of less lake ice could be reduced availability of the over-ice road to Madeline Island available to Apostle Islands visitors.

EFFECTS ON PUBLIC HEALTH

Human-caused climate change is expected to lead to more air pollution, more insect-transmitted diseases, and longer seasons of exposure to airborne allergens, all affecting the health of visitors to the Great Lakes national parks.

Air and Water Pollution

Especially in Sleeping Bear Dunes and Indiana Dunes, which already are plagued by air pollution above federal health-protection levels, a hotter climate is likely to lead to more smog, which harms the health of visitors to those parks.

Hotter air temperatures lead to the creation of more ground-level ozone, a component of smog created when pollutants mix in sunlight. (In the upper atmosphere, ozone does not affect people's health and has the positive effect of filtering the sun's ultraviolet rays.) Ground-level ozone has been firmly established to harm people's health, exacerbating lung diseases such as asthma, causing breathing difficulties in healthy individuals, and even leading to premature deaths.¹⁸¹ The U.S. Environmental Protection Agency (EPA) has air quality standards that are supposed to prevent adverse health effects, and is considering strengthening them based on new evidence of the health problems ozone causes.

“Because ground-level ozone is related to temperature, air quality is projected to become worse with human-induced climate change.”

U.S. Global Change Research Program¹⁸²

Air quality measurements show that Sleeping Bear Dunes and Indiana Dunes have had recent ozone levels above the air quality standard as last revised by EPA in 2008.¹⁸³ As park visitors typically are outdoors, polluted air can be even more of a problem for them in the parks than when they are at home and work.¹⁸⁴ To offset the ozone-creation effects of higher air temperatures, additional local and regional actions will be needed to reduce the pollutants that form ozone, so that visitors to the parks can fully enjoy outdoors recreation in them without harming their health.



Apostle Islands NL

Increased water pollution also may result from climate changes. Projected increases in heavy rainfall events, warmer lake waters, and lower lake levels could all contribute to increased pollution of lake waters.¹⁸⁵ The effects on Indiana Dunes in 2008 of the remnants of Hurricane Ike illustrate what strong storms can do to the region's parks. Local rainfall amounts reached as much as 12 inches, causing flooding of untreated sewage into waterways and contamination of Lake Michigan waters with *E. coli* bacteria, and leading to closures of Indiana Dunes to swimming for weeks.¹⁸⁶

“Recreational beaches may face closure under climate change due to increased pollution and waterborne pathogens.”

National Park Service¹⁸⁷



Indiana Dunes NL

Lyme Disease and West Nile Virus

Hotter temperatures can promote the spread of infectious diseases carried by insects, by promoting their expansion into areas previously too cold for them and creating longer seasons in which ticks, mosquitoes, and other insects are active. As a result, more visitors to Great Lakes parks may be exposed to diseases such as Lyme disease and the West Nile virus.¹⁸⁸

For example, the ticks that carry Lyme disease cannot survive where average minimum monthly temperatures are below about 19°F.¹⁸⁹ In the Great Lakes region, the northern boundary of suitable habitat for these ticks previously has extended only to the southern shoreline of Lake Superior, sparing visitors to Isle Royale and Grand Portage National Monument the risk of Lyme disease that visitors face in Apostle Islands, Pictured Rocks, Sleeping Bear Dunes, and Indiana Dunes.¹⁹⁰

This past summer, however, a tick that carries Lyme disease was confirmed to have been found at Isle Royale for the first time. A park researcher found on his body one of the ticks; he had been on the island nearly a month, making it very unlikely that he had brought the tick with him from the mainland.¹⁹¹ This confirmed presence of the Lyme disease tick in the park apparently is being reported publicly for the first time in this report.

Also, at nearby Grand Portage National Monument, the superintendent is now persuaded by reliable anecdotal information that Lyme disease-bearing ticks have recently spread into that park, too.¹⁹²

This apparent spread northward of the Lyme disease tick is consistent with studies that show with warmer winters, suitable habitat could reach far into Canada—about another 125 miles farther north by 2020 and over 600 miles by the 2080s.¹⁹³

“There may be increased public health risk by the likely expansion [in the Great Lakes region] of the prevalence and range of Lyme disease and West Nile Virus.”

National Park Service¹⁹⁴

Just as air pollution is a particular problem for visitors to national parks because they are typically outdoors and more exposed to the pollution, so, too, can seasonal allergies particularly bother park visitors. Recent research has shown that in the United States and Canada the season for ragweed pollen, one of the worst offenders for many people with allergies, has gotten longer between 1995 and 2009, coinciding with a later occurrence over that time of the first frost of the year. The increase in the ragweed season has been greater in the north than in the south, and in the Great Lakes states of Wisconsin and Minnesota ragweed pollen has been in the air 12 to 16 more days per year by the end of the 1995-2009 period than at the beginning.¹⁹⁵

LOSS OF FISHING

A changed climate likely means major changes for the fishes that live in the Great Lakes themselves as well as in inland lakes and streams, which in turn threatens the recreational fishing popular in the Great Lakes national parks.¹⁹⁶ (Commercial fishing, a major industry in the Great Lakes, faces significant threats from climate change, but is beyond the scope of this report.) Many sites in the Great Lakes national parks (even before the parks were created) have been havens for fishing of many kinds—offshore, from shores and docks, and in inland lakes and streams. These fishing opportunities, in the attractive settings of the parks, attract both expert and novice fishermen—and continue to bring them back.

Trout and salmon are among the most common species fished recreationally at the Great Lakes national parks, with smallmouth bass, northern pike, walleye, yellow perch, whitefish, Menominee, and smelt also appearing in relative abundance.¹⁹⁷ Seasonal spawning of certain fish, such as steelhead (rainbow) trout throughout Lake Superior and rainbow smelt and salmon species in the Apostle Islands, are key to the visitor fishing experience.¹⁹⁸ Other draws for anglers in the Great Lakes national parks include the numerous inland lakes and streams at Pictured Rocks, Isle Royale, and Sleeping Bear Dunes; a fish-rich “sport fishing only” area between Madeline and Long Islands in the Apostle Islands; and various backcountry beaver ponds and shoreline waters.¹⁹⁹ The best fishing dates tend to vary from year-to-year, and in large part depend on water temperatures in lakes and streams as well as near and away from shore.²⁰⁰

As outlined in Section 5 (see page 27), a variety of consequences of warming temperatures could reduce the opportunities for fishing in the Great Lakes parks. Coldwater fish populations that are the mainstay of the lake fisheries will be pushed northward. Changes in lake stratification processes could interrupt food chains and even lead to dead zones in some places. The shallow, near-shore areas fished by park visitors as well as the lakes and inland streams are generally the fastest to warm, meaning the fish who reside there are particularly at risk.²⁰¹

As the climate warms, stream temperatures will also rise. Such changes would threaten the state fish of Michigan, the brook trout, which is native to lakeshore streams and requires clear, cool, shady habitats to thrive. Additionally, the possibility of more frequent and severe rain storms may stress trout populations in the streams, possibly putting this special fish in danger of being lost to the parks.²⁰² In part for these reasons, the brook trout is under consideration by Pictured Rocks National Lakeshore as a signature species to indicate the vulnerability of park resources to the expected effects of climate change.²⁰³

Additionally, lower lake levels could make existing docks and ports less accessible for anglers; impede navigation for both commercial and recreational boaters; and also reduce near-shore fishery habitat, requiring more expensive and extensive ventures offshore.²⁰⁴

Non-native species such as Asian carp, which now threaten to establish themselves in the Great Lakes, and already-present zebra mussels may out-compete the natives that are generally adapted to a narrower, specific, established range of conditions—the exact conditions threatened by a disrupted climate.²⁰⁵ Asian carp present their own peculiar challenges for anglers because they “breed like mosquitoes, eat like hogs and jump out of the water when disturbed by the sound of boat motors,” sometimes even right

into boats, injuring or frightening the occupants.²⁰⁶ In fact, experts on the fisheries of the Great Lakes cited the increased presence of invasive species as a whole (not specifically Asian carp) and a changing climate in projecting that sport-fishing participation and expenditures could fall by up to 13% by 2025.²⁰⁷ (Commercial fishing expenditures across all the Great Lakes are projected to drop even more, by as much as 25%.²⁰⁸)

Those coldwater fish populations that do manage to remain in warm waters or have the ability to shift northward within the Great Lakes—possibly including brook trout, lake trout, lake whitefish, round whitefish, and burbot—are expected to suffer declining populations. These changes would impact some of the iconic species of the Great Lakes: Brook trout, as already mentioned, is Michigan’s state fish, and whitefish account for half of the region’s commercial harvest.²⁰⁹ Cool-water fish such as muskie and warm water fish such as smallmouth bass, bluegill, carp, catfish, buffalo, and sunfish may migrate to fill the vacated areas, but they would not take the symbolic place of those special species.²¹⁰

LOSS OF BOATING

Climate change could adversely affect in several ways boaters enjoying access to and the resources of the Great Lakes national parks, especially Isle Royale and Apostle Islands, where boating is especially popular. Bob Krumenaker, the superintendent of Apostle Islands, enumerated some of his concerns to the authors of this report. According to him, as water temperatures warm and recreational boating seasons lengthen in the future, new boaters will likely be attracted to the parks who are less familiar with the dangers of Great Lakes boating and whose vessels may be less suited for large waves, fog, and other conditions which used to be common, especially on the upper lakes. Should stronger storms, which already occur on the lakes and are expected to increase in frequency with climate change (see page 14), arise unpredictably, park managers would very likely find themselves dealing with more capsizings, groundings, and rescues.²¹¹

“Warmer waters and longer open water (non-ice) seasons may ‘open’ boating to more people and different kinds of boats. Coupled with the increasing frequency and intensity of severe storms, however, this may lead to increasing issues of visitor safety (e.g., groundings, capsizings, etc.) and the need for more rescues by the managing agencies.”

National Park Service²¹²

Stronger storms also pose a threat to the infrastructure that supports boating in the parks. A November 1986 storm in Grand Portage Bay, estimated to be one typical of about a 20-year occurrence, generated wave heights of 8 to 12 feet on Lake Superior's open waters and wave heights of 4 to 6 feet within the bay, overtopping Grand Portage National Monument's dock, which is normally about 3-½ feet above water level. The end portion of the dock, which was only designed to withstand wave heights of 2 feet, was torn off completely.²¹³

Intense storms also present a concern for the parks with respect to large vessels, specifically cargo ships (often carrying corn, steel, or wind turbines) that pass through the international shipping lane at Isle Royale or that already seek shelter during storms in the Apostle Islands.²¹⁴ A catastrophe involving one of these ships, which carry massive amounts of fuel, could have severe and lasting effects on nearby parks.

MORE WILDFIRES

Much attention has been paid to how human-caused climate change has already contributed to increased wildfires in western North America, and scientists have projected that further increases could result from additional climate change.²¹⁵ In the Great Lakes region, too, scientists suggest that hotter and drier summers could increase wildfires in this region. The staff at Sleeping Bear Dunes has indicated that pine forest plantations and native conifer forests at that park could be at risk of increased wildfire.²¹⁶ The effects of increased wildfires would include disruption of more summer vacations for park visitors, through closures of trails, campgrounds, or other areas. Moreover, with fires historically having been

infrequent and of low intensity in the Great Lakes parks, the parks are not adequately staffed with expertise or response capability should wildfires there become more common.²¹⁷

“Rising temperatures and earlier springs are likely to increase forest fire hazards, lengthen the fire season, and create larger fires.”

National Park Service²¹⁸

DISRUPTIONS FROM STRONGER STORMS

Heavier downpours (see page 14) could lead to roads, campgrounds, facilities, and park areas in the Great Lakes parks being flooded or closed for safety reasons more often, causing more frequent disruption of visits to the parks.²¹⁹ The damage to Indiana Dunes from the remnants of Hurricane Ike (see page 31) illustrates the risks. The storm deposited on the park's beaches debris including more than a dozen wrecked boats, pieces of marina docks, fuel tanks, a barge, and a small crane, leading to beach closures and expensive cleanup.²²⁰

“Increasing frequency and intensity of severe storms and floods may pose threats to roads and trails, administrative facilities, and other park and refuge resources and infrastructure.”

National Park Service²²¹

LOSS OF CULTURAL RESOURCES

Human disruption of the climate can affect not only the natural resources of the Great Lakes national parks but also their invaluable cultural resources—the archaeological and historical resources that contribute to and help us understand our national heritage. A particular cultural resource—say, a historic building or a prehistoric site—may be affected by increased erosion or other effects of a disrupted climate. Also, as importantly, the natural or cultural contexts of particular resources may be disrupted. As a member of the NPS cultural resources program staff has pointed out to the authors of this report, cultural resources are more powerful in their historic locations and with their authentic historic links intact; if these contexts are transformed, our ability to experience, appreciate and learn from the resources can be diminished.²²²

A primary climate-change threat to many cultural resources of the Great Lakes parks is increased erosion from stronger storms and more winter waves on shorelines as lake ice diminishes. (See pages 14-16.) An example of cultural resources lost to the erosive power of storms is from 1905, when an entire point of what is now Grand Portage National Monument, called Premier's Point, was washed away. This point was very important to the historical stories told at the park, as the site where fur traders stored their 36-foot long canoes—their “Montreal canoes”—used to transport furs between Grand Portage and Montreal. The point also was the site of a scaffold



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Isle Royale NP

Increased erosion from stronger storms and waves threatens the historic lighthouses in the Great Lakes parks. Other historic resources are at similar risk.

Also vulnerable are traditional ways of life of the region's native people, who depend on natural resources that can be disrupted by a changed climate.

which held the remains of a famous Ojibwe chief.²²³

The historic lighthouses that abound in the Great Lakes national parks are the most obvious of the cultural resources at increased risk as a changed climate makes more likely a repeat of the 1905 storm at Grand Portage. Not only are the lighthouses located on shorelines, but they are old, dating back as far as the Civil War. Nearly all are listed on the National Register of Historic Places, our official national list of places most worthy of preservation.

Apostle Islands NL features the most extensive and well-preserved collection of lighthouses in the national park system—six lighthouse stations which have been recognized as the largest and finest group of historic lighthouses in the nation. Raspberry Island Light Station, the most visited, has already been subject to serious danger from shoreline erosion, as has the lighthouse at Outer Island. NPS has spent over \$2 million to stabilize shorelines at these sites.²²⁴ Facing similar dangers is Au Sable Light Station, the premier cultural attraction at Pictured Rocks NL, attracting 10,000 visitors annually. Isle Royale NP has four historic lighthouses, including Rock Harbor Lighthouse, built in 1855, and Rock of Ages Light House. Sleeping Bear Dunes NL also counts lighthouses among its various cultural attractions. The costs of preserving these and other



NPS

Grand Portage National Monument

cultural resources in the face of increased risks are of concern to park managers.²²⁵

The Great Lakes parks also contain numerous historical structures, old camp and mine sites, historical farms and homesteads, and other archaeological treasures—including those belonging to ancient indigenous occupiers of the region—that could be affected by heightened erosion or storm damage brought about by climate change. Isle Royale has 145 historical structures alone, spanning 4,500 years of human history. Many more areas, including expanses threatened by shoreline erosion, have yet to even be inventoried for archaeological resources. Apostle Islands features 158 historic structures of its own, including cabin sites, logging camps, quarries, shipwrecks, 1930s and 1940s fish camps, and resources related to American Indian heritage. Among the cultural resources at Pictured Rocks are historic structures, shipwrecks, and iron smelting furnace remains, making it one of the only remaining places where traces of the Great Lakes iron-smelting industry still exist. Sleeping Bear Dunes is home to 366 historic structures, including a National Historic Landmark, the only remaining lifesaving station from the 1850s. Increased erosion at that park could threaten that station, the historic Glen Haven Village and other historic town sites, as well as other properties listed on the National Register, such as South Manitou Island Lighthouse, Manitou Passage Maritime Landscape, and Sleeping Bear Point Life-Saving Station.²²⁶ Indiana Dunes also contains cultural resources from American Indians, European colonists, immigrant farmers, and the 1933 World's Fair, as well as 183 identified archaeological sites.

Submerged artifacts and structures in the Great Lakes parks and nearby areas, including shipwrecks and areas of prehistoric habitation, could also be affected by a variety of climate-change disruptions. For example, Pictured Rocks and the surrounding waters contain at least 22 shipwreck remains, representative of a wide range of vessels, which attract historians and sport divers due to their undisturbed and well-preserved nature.²²⁷ A disrupted climate could accelerate their deterioration in

several ways, such as from the impacts of hotter waters, exposure if lake levels drop far enough, or infestations by invasive species such as zebra mussels.²²⁸

Facilities for visitors such as museums and visitor centers, and the cultural resources in them, may also be at greater risk from stronger storms and increased flooding.²²⁹

“The one certainty is that climate change will produce challenges to the preservation of cultural resources that have not been faced previously.”

National Park Service²³⁰

Climate change also threatens traditional ways of life for the indigenous people and settlers of the region. For the Fond du Lac Band of the Chippewa and the Bad River Band of Lake Superior Ojibwe, who live near the shores of Lake Superior, their harvest of wild rice is important in their culture. The harvest, though, depends on certain weather and water conditions, and low water levels could make it impossible or unsafe to use canoes to hand-harvest rice.²³¹ Recent droughts and low water levels have forced the cancelation of some rice harvests.²³² The rice itself is very sensitive to hydrologic changes and is in danger of being replaced by other species.²³³ Adverse impacts to fish and wildlife could also seriously harm the abilities of tribes to engage in traditional subsistence activities, which in many cases are guaranteed by treaty.²³⁴

The staff at Apostle Islands also noted to the authors of this report that changes in spring temperatures, precipitation, and warmer nighttime temperatures are adversely affecting maple sugaring practices in the region, and pests and changes in habitat are affecting native tree species, such as birch and ash, used in traditional craft-making.²³⁵ Both of these historical uses of the Great Lakes parks are considered by the NPS as cultural resources of the parks.²³⁶

TACKLING CLIMATE DISRUPTION

As the risks of a changed climate dwarf all previous threats to our national parks, so too must new actions to face these new risks be on an unprecedented scale. Parks should be managed to preserve their resources at risk, to adapt to coming changes, and to provide visible leadership in addressing climate change. Ultimately, of course, we need to curtail emissions of climate-changing pollutants enough to reduce their impacts, in parks and everywhere else.

ACTIONS SPECIFIC TO PARKS

A full suite of actions by the National Park Service and others will be needed to protect the Great Lakes national parks and their imperiled resources. In September 2010, NPS adopted a Climate Change Response Strategy that provides an excellent roadmap for Service actions.²³⁷ It includes many of the steps that are needed and are within the Service's control. An even fuller set of actions to protect the resources of national parks, including actions by the larger Administration and Congress, were outlined in chapter 9 of *National Parks in Peril: The Threats of Climate Disruption*, an October 2009 report by RMCO and NRDC.²³⁸ Now, NPS actions are needed to implement its strategy, and Congress and others need to take additional actions that are within their areas of responsibility.

Examples include:

- The NPS should consider the combined effects of climate change and of other stresses on the resources and values of areas they manage, and work to reduce all the stresses that pose critical risks.
- NPS should develop area-specific and resource-specific plans to protect the particular resources and values most at risk from climate change and other stresses.
- Service officials and managers should speak out publicly about how climate change and its impacts threaten the areas for which they are responsible and the broader ecosystems on which they depend.
- NPS managers should use environmental education programs to inform visitors about a changed climate and its impacts in managed



Apostle Islands NL

NPS

Comprehensive actions by the National Park Service and others will be required to protect the Great Lakes national parks.

The parks must be managed to protect threatened resources.

Ultimately, heat-trapping pollution has to be limited to prevent unacceptable disruption of the climate, in the parks and everywhere else.

areas and about what is being done to address climate change and those impacts. The NPS should require concessionaires to do so, too.

- Congress and the Administration should adequately fund NPS actions to address a changing climate.
- The NPS should reduce emissions in their own operations, and provide information to visitors on those actions to inspire them to undertake their own emission reduction actions.
- Congress and the Administration should rebuild and enhance the scientific and research capacity the NPS had prior to 1993.

The Great Lakes national parks have already begun to take some important leadership steps in undertaking the types of actions called for in the NPS's Climate Change Response Strategy. The NPS Natural Resource Program Center, in partnership with the U.S. Forest Service's Rocky Mountain Research Station and the U.S. Fish and Wildlife Service, prepared in 2010 a 40-page document, "Understanding the Science of Climate Change: Talking Points—Impacts to the Great Lakes;" among other uses, it is very helpful in arming NPS staff in the Great Lakes parks with relevant information for discussing climate change with park visitors. Some

local parks have hired new staff members with a primary mission of addressing and communicating about climate change. Apostle Islands has displays for visitors illustrating impacts of climate change on lakeshore resources, visitor experiences, and is adding another on effects on the lifeways and traditions of the indigenous Ojibwe population.²³⁹ Pictured Rocks NL has entered into a cooperative agreement with a nonprofit organization to increase local awareness of climate change, its impacts, and actions to address it, perhaps the first such cooperative agreement by the NPS. These are the kinds of actions that the NPS should be taking to address this, the greatest threat ever to our national parks.

“The focus of the climate change discussion has largely shifted from the evidence that climate change is occurring to what we can do about it. As stewards of our nation’s natural and cultural heritage, we have an obligation to act now.”

Jon Jarvis, Director
National Park Service²⁴⁰

PREVENTING CLIMATE DISRUPTION

This section contributed by Theo Spencer, Natural Resources Defense Council

Ultimately, to protect the Great Lakes national parks for the enjoyment of this and future generations, it will take actions by all of us to reduce emissions of heat-trapping pollutants enough so that climate disruption does not overwhelm these parks, or any other special places.

The federal government must lead the way, with broad, aggressive actions on four essential fronts:

- Establishing comprehensive mandatory limits on carbon pollution to reduce emissions by at least 20% below current levels by 2020 and 80% by 2050. This will deliver the reductions that scientists currently believe are the minimum necessary, and provide businesses the economic certainty needed to make capital investments to achieve those reductions.
- Protecting the current Clean Air Act authority of the U.S. Environmental Protection Agency (EPA). This includes current authority under the Clean Air Act to set standards to curb carbon pollution from vehicles, power plants, and large industrial sources. EPA authority must also be

maintained to institute the tightest pollution controls necessary to protect public health and the environment. That includes standards for the pollution that causes smog and other dangerous and fatal respiratory ailments, pollution of hazardous materials like mercury and dioxin, and dangerous waste from power plants and other industrial facilities.

- Overcoming barriers to investment in energy efficiency to lower emission-reduction costs, starting now. To fully harness energy efficiency potential, many opportunities require additional federal, state, or local policies to unleash investments that are already cost-effective even without a price on greenhouse gas emissions. Policies include building, industry, and appliance efficiency (standard) upgrades, as well as incentives for “smart” transportation and growth and for advanced vehicles. Standards for more efficient lighting technologies, now under attack, should be enforced.
- Accelerating the development and deployment of emerging technologies to lower long-term emission reduction costs. That means incentives and investments in renewable electricity, low-carbon fuels, and carbon capture and storage; a federal renewable-energy standard; and infrastructure upgrades to support transmission capacity for these renewable assets.

With respect to natural gas use, updated, comprehensive regulation (from well-head to end use/site remediation), and proper transparency are essential to reducing public safety threats and environmental impacts. In addition, technologies to economically and effectively capture and store greenhouse gas emissions resulting from natural gas use will be needed if the full potential of this resource is to be delivered in an environmentally sound fashion

Finally, regulations are needed to require that, to the extent that any new coal-fired power plants are built, those plants capture and permanently geologically sequester at least 85% of their carbon dioxide emissions, along with state and federal regulatory frameworks for site selection, operation, monitoring, and liability for carbon capture and geologic storage systems. Any such new coal plants would also need to be held to stringent standards for controlling their other pollution emissions, source coal only from companies using less destructive mining techniques (which includes, but is not limited to, not relying on mountaintop removal), and ensure that their waste is disposed of safely.

APPENDIX: METHODOLOGY ON CLIMATE ANALYSIS AND PROJECTIONS

This appendix describes the methodology used by the Rocky Mountain Climate Organization (RMCO) in analyzing climate data and obtaining climate projections for this report.

Figure 3: Past Temperature Trends

For the analysis presented in Figure 3, the weather station near Indiana Dunes is Hobart 2 WNW, U.S. Cooperative Observing Network (COOP) station 124008, located about four miles inland of the western end of the lakeshore. The weather station near Pictured Rocks is Munising, Michigan, COOP station 205690, located in the town of Munising, about a mile and a half from the Munising Falls Interpretive Center at the southernmost end of Pictured Rocks NL. Both stations are part of the U.S. Historical Climatology Network (USHCN).

No other USHCN stations are close enough to Great Lakes national parks to be relevant. RMCO also examined all other weather stations to determine if any would be sufficient for showing long-term trends in or close to the Great Lakes national parks. That RMCO examination began with a review of a report prepared by the Western Regional Climate Center for the National Park Service (NPS) of weather stations in and near Great Lakes national parks.²⁴¹ Based on our review of that report and our own additional, supplementary examination, RMCO did not find any weather stations in or near the national parks, other than Hobart 2 WMW and Munising, that (1) have been in operation in one location, without any relocation, for a period of half a century or more—as needed to show a long-term trend; (2) are still in operation; and (3) have essentially complete temperature records. Accordingly, we have limited our presentation of local temperature records in Figure 3 to the two weather stations from the two USHCN Network sites that are close to two of the region's parks.

The USHCN is a high-quality data set of daily and monthly records of basic meteorological variables from 1218 observing stations across the 48 contiguous United States. Most of these stations are COOP stations located generally in rural locations, while some are National Weather Service first-order stations that are often located in more urbanized environments. The USHCN has been developed over the years at the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC) to assist in the detection of regional climate change. Furthermore, it has been widely used in analyzing U.S. climate. The period of record varies for each station. USHCN stations were chosen using a number of criteria including length of record, percent

of missing data, number of station moves and other station changes that may affect data homogeneity, and resulting network spatial coverage.²⁴²

Table 3: Projected increases in annual average temperatures

The data for Table 3 were obtained by RMCO from the World Climate Research Program's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset of climate models developed for the Intergovernmental Panel on Climate Change's Fourth Assessment Report (released in 2007). The WCRP's Working Group on Climate Modeling helped to coordinate these modeling efforts and enable their location in a single database archive, available online and hosted by the Lawrence Livermore National Laboratory's (LLNL) Program for Climate Model Diagnosis and Intercomparison. The conversion of all simulation results to a common data format has made probabilistic, multi-model projections and impacts assessments practical. To enable local projections from these models, the larger-scale outputs from the models have been combined with local historical climate observations to produce finer-scale projections. This particular approach, originally developed for hydrological analysis, has compared favorably to other downscaling techniques. Motivated by a common interest to establish data access for climate change impacts analysts, the U.S. Department of Interior's Bureau of Reclamation (Research and Development Office) and LLNL, through support from the U.S. Department of Energy's National Energy Technology Laboratory and the U.S. Army Corps of Engineers Institute for Water Resources, have teamed with Reclamation's Technical Service Center, Santa Clara University Civil Engineering Department, Climate Central, and the Institute for Research on Climate Change and its Societal Impacts to develop this public-access archive.

In using this database for the analysis, the Rocky Mountain Climate Organization selected for each studied national park a single-cell grid, 1/8 of a degree of longitude by 1/8 of a degree of latitude, centered on the coordinates in the table on the following page. The selection of the grids was made to match as well as possible with core areas of the relevant parks. Some grids well centered on parks contained too much lake surface to be in the database and no climate projections are available for them. When this was encountered, the closest grid with enough land surface for model results to be available was used. Most grids used in the analysis did contain significant lake surface; in these cases the

projections, which are average results for individual grids, may understate the surface temperatures over the land portions of the grids.

National Park	Latitude	Longitude
Indiana Dunes	41.5 to 41.625	-87.125 to -87.0
Sleeping Bear Dunes	44.75 to 44.875	-86.125 to -86.0
Pictured Rocks	46.75 to 46.875	-91.0 to -90.875
Apostle Islands	46.5 to 46.625	-86.5 to -86.375
Isle Royale	47.875 to 48.0	-89.125 to -89.0

Table App-1. Grids used for climate projections for the featured Great Lakes national parks.

Projections of surface temperature were obtained from the first listed model run for each of the 16 climate models in the CMIP3 dataset for each of the scenarios B1 ("lower-emissions") and A2 ("higher-emissions"). Each model's projection for a future period with a particular scenario was compared to that model's projection with the same scenario for the historical base period of 1971-2000.

The identities of the individual models used for the projections are listed in Table App-2 on the

following page. No current model is recognized as superior to others in all respects, and individual models have different strengths and weaknesses.²⁴³ A number of studies have shown that a multi-model average often out-performs any individual model in accurately replicating actual observations of climate variables.²⁴⁴ A common practice in recent scientific studies therefore has been to present averages of projections from multiple models. However, the current consensus of the experts is that it is problematic to consider an average of multiple projections as reflecting a more probable outcome and that consideration of the range of all model results remains important.²⁴⁵ Accordingly, for the new climate projections presented in this report (for changes in both annual and summer temperatures), the modeled results are presented to show both the averages of the projections from all 16 models and the ranges of those projections, and both the averages and the ranges should be considered as suggestions of what the future may hold.

Figure App-1 below provides an illustration of the range of projections the models generated, specifically highlighting the range of results for the change in annual average temperatures of Indiana Dunes NL under a medium-high future emissions scenario.

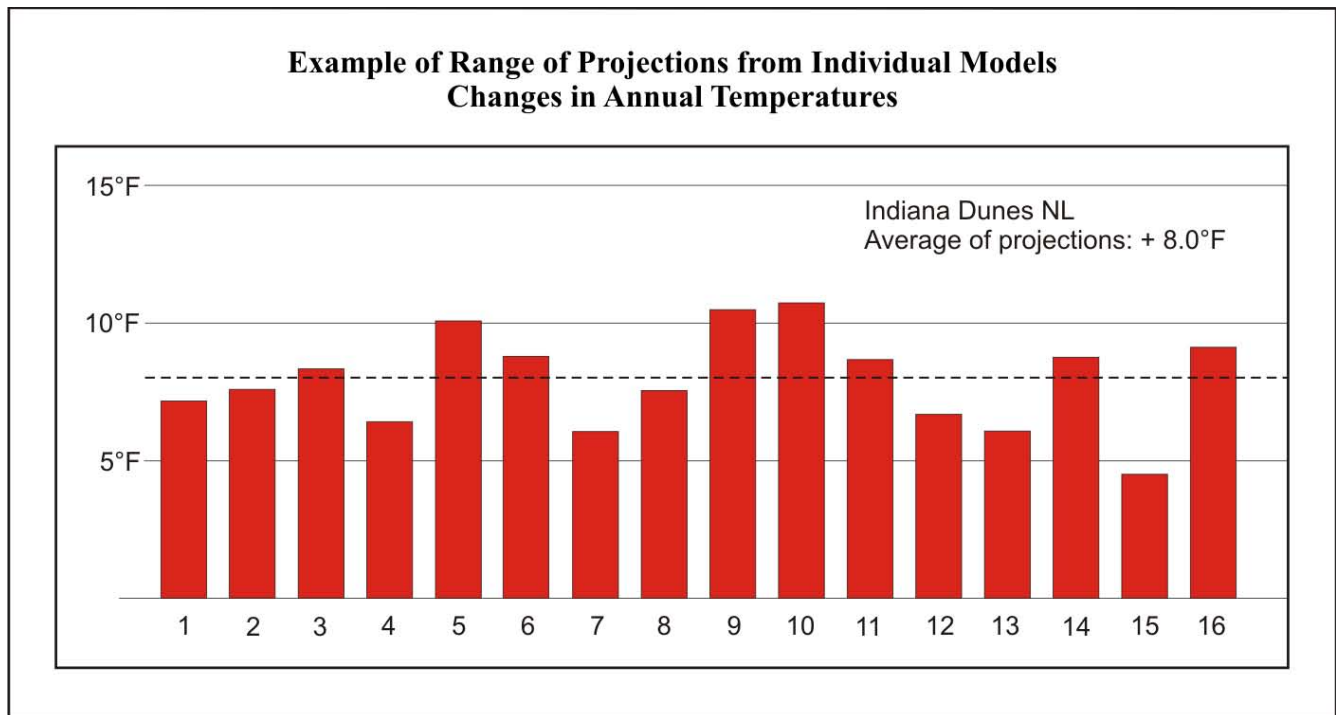


Figure App-1. Results for Indiana Dunes NL of 16 individual climate model projections of changes in average national park annual temperatures under a medium-high emissions scenario for 2070-2099 compared to modeled 1971-2000 averages. The dashed line shows the average of the 16 projections for that park. These are the 16 projections summarized in the top right cell of Table 3 on page 10 of the report. The ranges of all model results summarized in that Table would be similar to the range of the example shown in this Figure App-1. Data from the World Climate Research Program's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset.²⁴⁶ Analysis by the Rocky Mountain Climate Organization. For the identity of the models in this figure, see Table App-3, on the following page.

No.	Climate models used for projections
1	Bjerknes Centre for Climate Research
2	Canadian Centre for Climate Modeling & Analysis
3	Meteo-France / Centre National de Recherches Meteorologiques, France
4	CSIRO Atmospheric Research, Australia
5	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA (GFDL-CM2.0 model)
6	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA (GFDL-CM2.1 model)
7	NASA / Goddard Institute for Space Studies, USA
8	Institute for Numerical Mathematics, Russia
9	Institut Pierre Simon Laplace, France
10	Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan
11	Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA
12	Max Planck Institute for Meteorology, Germany
13	Meteorological Research Institute, Japan
14	National Center for Atmospheric Research, USA (CCSM3 model)
15	National Center for Atmospheric Research, USA (PCM model)
16	Hadley Centre for Climate Prediction and Research / Met Office, UK

Table App-2. Models from top to bottom in this table correspond (as numbered) to projections from left to right in figures App-1 and App-2.

Table 4 and page 13: Projected National Park Summer Temperatures

Table 4's indicated national park average summer (June-July-August) temperatures for 1971-2000 (or the period of record within those years) are from National Climatic Data Center (NCDC) data (available online from the Southern Regional Climate Center) for weather stations, identified in the following table, with sufficient periods of record and from within or as close as possible to the studied national parks.

National park	Weather station	Period of record
Indiana Dunes NL	Ogden Dunes	1971-1989
Sleeping Bear Dunes NL	Frankfort	1971-2000
Pictured Rocks NL	Munising	1971-2000
Apostle Islands NL	Madeline Island	1971-2000
Isle Royale NP	Grand Portage Ranger Station, MN	1971-2000

Table App-3. Weather stations used for projections of summer temperatures of featured Great Lakes national parks.

Projected differences in June-July-August temperatures were obtained from the CMIP3 dataset as explained above, for 2040-2069 compared to modeled 1971-2000 levels and for 2070-2099 compared to modeled 1971-2000 levels, using only emissions scenario A2. The projected differences were added to the measured 1971-2000 averages for the above weather stations to represent the actual levels of the projected future summer temperatures in the parks.

The 1971-2000 June-July-August temperatures for the comparison cities are also from NCDC data, also obtained from the Southern Regional Climate Center.

The projected summer temperatures for Indiana Dunes and Sleeping Bear Dunes with lower future emissions for 2070-2099, referred to in the text on page 13, were obtained exactly as above except with the use of scenario B1.

Different climate models currently produce more divergent results on seasonal projections than on projections of annual averages. Figure App-2 on the following page illustrates the range of the summer projections by showing for Indiana Dunes NL the projections from each of the 16 models for future summer temperatures with medium-high future emissions for late in the century. The ranges the four other parks are similar. Comparing Figure App-2 to Figure App-1 on the previous page helps to illustrate how the individual models produce more variation in their seasonal projections than they do for annual projections.

**Example of Range of Projections from Individual Models
Changes in Summer Temperatures**

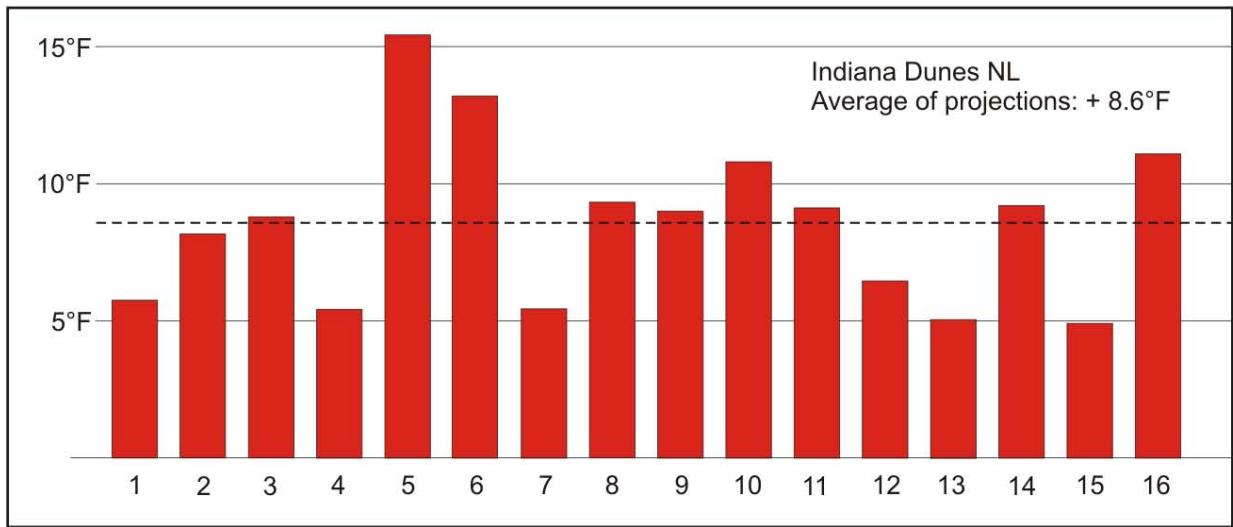


Figure App-2. Results for Indiana Dunes NL of 16 individual climate model projections of changes in average national park summer (June-July-August) temperatures under a medium-high emissions scenario for 2070-2099 compared to modeled 1971-2000 averages. The dashed line shows the average of the 16 projections for that park. These are the 16 projections summarized in the top right cell of Table 4 on page 12 of the report. The ranges of all model results summarized in that Table would be similar to the range of the example shown in this Figure App-2. Data from the World Climate Research Program’s (WCRP’s) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset.²⁴⁷ Analysis by the Rocky Mountain Climate Organization. For the identity of the models in this figure, see Table App-2, on the previous page.

Table 5: Summer Temperature Increases, Areas Immediately Bordering Great Lakes

The study by Hayhoe and others includes maps showing region-wide changes in summer temperatures, for the same periods as used in the RMCO projections, using two emissions scenarios (the lower scenario, B1, and also a higher one A1F1) that straddle the single, medium-high scenario used for the RMCO projections shown in Table 4 and

Figure 2. (For more on these emissions scenarios, see page 14.) The maps used to present the projections for increases in summer temperatures show that all areas immediately bordering the Great Lakes (which include all five national parks covered by the RMCO projections) have similar projected increases, according to an RMCO reading of the maps. The projections for those areas, based on the RMCO reading of the maps in the Hayhoe study, are presented in Table 5.

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21. NCDC, "Annual global anomalies" (see note 19). Decadal averages and comparisons calculated by the Rocky Mountain Climate Organization.
22. IPCC, "Summary for policymakers" (see note 17), p. 5 (comparing 2001-2005 global temperatures to 1850-1899 temperatures). Average global temperatures for 2001-2005 were virtually identical to those for 2001-2010, according to the NCDC database referred to in note 19, so the IPCC comparison also holds true for the entire decade of 2001-2010.
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33. USGCRP, *Climate Change Impacts* (see note 16), p. 22.
34. USGCRP, *Climate Change Impacts* (see note 16), p. 29.
35. Hayhoe, "Regional climate change projections" (see note 25), p. 11, figure 2(a). The projections by Hayhoe and others included only those grids comprised entirely of land, not those also comprised in part of lake surface. The projections for this report by RMCO for the Great Lakes national parks are based on grids for which downscaled projections could be obtained from the CMIP-3 database (see note 31) that most closely match the core areas of the parks, and so most grids used by RMCO were not included in the projections by Hayhoe and others. It appears from the map in the Hayhoe study that only the grid used by RMCO for the Indiana Dunes projections may be included in the Hayhoe projections. The use by RMCO of grids containing areas of lake surface may have had the effect of understating the

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37. J. S. Baron and others, “National parks,” in USCCSP, *Preliminary Review of Adaptation Options for Climate Sensitive Ecosystems and Resources*, S. H. Julius and J. M. West, editors, U.S. Environmental Protection Agency, Washington, DC, 2008, p. 4–4, <http://downloads.climate-science.gov/sap/sap4-4/sap4-4-final-report-all.pdf>.

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39. Hayhoe, “Regional climate change projections” (see note 25), p. 14, figure 5. For other projections of regional changes in seasonal temperatures from two climate models for lower, medium (scenario “A1B”), and medium-high future emissions, K. A. Cherkauer and T. Sinha, “Hydrologic impacts of projected future climate change in the Lake Michigan region,” *Journal of Great Lakes Research*, vol. 36, supplement 2 (2010), pp. 33–50.

40. The average 1971–2000 June–July–August temperature in Key West, Florida, was 84.1°F, according to NCDC data; see note 30. The projections by Hayhoe and others are of temperature increases in comparison to a 1961–1990 baseline. In the case of the Hobart, Indiana, weather station – the U.S. Historical Climatology Network station near Indiana Dunes (see note 30)—the difference between a 1961–1990 and a 1971–2000 baseline is 0.2°F; allowing for this difference, the projections by Hayhoe and others would be for about a 12.4°F increase over the 71.7°F 1971–2000 average measured temperatures at Hobart (see Table 4), or 84.1°F.

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43. Hayhoe, “Regional climate change projections” (see note 25), pp. 12, 16.

44. Hayhoe, “Regional climate change projections” (see note 25), p. 12; Cherkauer, “Hydrologic impacts in Lake Michigan region” (see note 39), p. 37; figure

3, p. 38; USGCRP, *Climate Change Impacts* (see note 16), pp. 31, 120; WICCI, *Wisconsin’s Changing Climate* (see note 29), pp. 30–31.

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46. Hayhoe, “Regional climate change projections” (see note 25), p. 16.

47. WICCI, *Wisconsin’s Changing Climate* (see note 29), pp. 30–31.

48. Hayhoe, “Regional climate change projections” (see note 25), pp. 12, 16.

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50. Hayhoe, “Regional climate change projections” (see note 25), p. 12.

51. USCCSP, *Weather and Climate Extremes in a Changing Climate: Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands*, T. R. Karl and others, editors, National Oceanic and Atmospheric Administration, Washington, DC, 2008, pp. 4–5; USGCRP, *Climate Change Impacts* (see note 16), p. 32.

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