Greater Yellowstone in Peril
The Threats of Climate Disruption

Lower Falls of Yellowstone River, Yellowstone NP

At stake are the resources and values that make the Greater Yellowstone Ecosystem a special place that Americans love.

the ROCKY MOUNTAIN CLIMATE Organization

GREATER YELLOWSTONE COALITION

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About RMCO

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.

About GYC

The Greater Yellowstone Coalition (GYC) is a member-based conservation organization that works to protect the lands, waters and wildlife of the Greater Yellowstone Ecosystem. Visit www.greateryellowstone.org to learn more.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

NPS/John Brandow

Hayden Valley, Yellowstone NP

Human disruption of the climate is the top threat to the Greater Yellowstone Ecosystem. This special place includes Yellowstone and Grand Teton national parks, parts of six national forests, and three national wildlife refuges, is one of the last largely intact temperate ecosystems on Earth, and has some of the planet's most spectacular natural wonders.

The threats of climate disruption to Greater Yellowstone are also threats to the region's economy. (See pages 4-6.) In 2010, 6.3 million people visited Yellowstone National Park (NP) and Grand Teton NP; the year before, visitors to the parks spent nearly $700 million, responsible for over 10,000 local jobs. The six national forests in 2009 drew 8.7 million visitors, who spent more than $515 million. These and other economic benefits could be at risk, though, as a changing climate threatens the special resources that draw both vacationers and residents to the region.

Human activities have led to large increases in the atmospheric concentration of heat-trapping gases, which already is changing the climate, around the world and in Greater Yellowstone. (See pages 7-13.) Globally, the last decade, 2001-2010, was 1.0°F above the 20th century average. In Greater Yellowstone, according to new analysis for this report, the last decade was 1.4°F above the region's 20th century average. Summer temperatures in Greater Yellowstone have gotten hotter by an even larger margin, with the summers of the past decade 2.3°F above the average for 20th century summers. (For more on the evidence that projected changes are already underway in Greater Yellowstone, see page iv of this Executive Summary.)

New "downscaled" climate projections obtained for this report show how much hotter year-round (or annual) average temperatures across Yellowstone and Grand Teton national parks could become as a

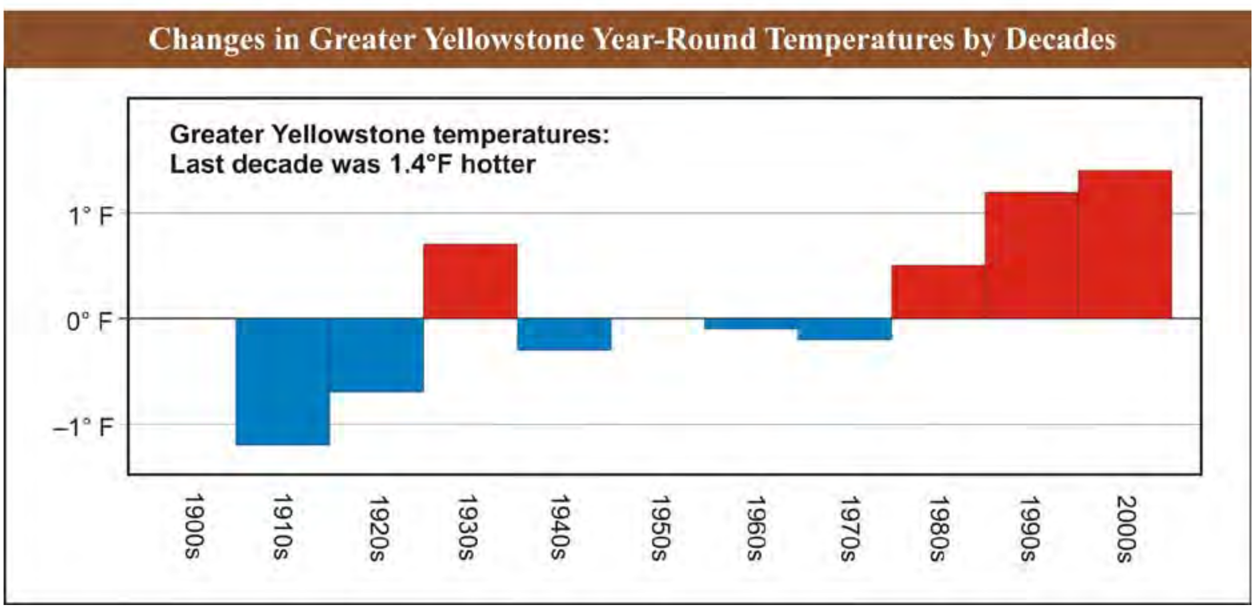

Figure ES-1. Average year-round (or annual) temperatures 1901 through 2010, by decade (e.g., 1901-1910), compared to corresponding 1901-2000 averages, for high-quality weather stations near the identified national parks. Data from the U.S. Historical Climatology Network. Analysis by the Rocky Mountain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

result of continued human emissions of heat-trapping gases. With a scenario of lower future emissions, temperatures in Yellowstone NP could become 2.9°F hotter by 2030-2059 and 4.6°F hotter by 2070-2099. With medium-high future emissions, the park could become 3.5° and 7.5°F hotter by these time periods. (These values are the averages of projections from 16 different climate models; individual projections vary.) Projections for Grand Teton NP are similar. These projections illustrate that how much the climate changes depends in large part on whether or not future emissions are limited.

RMCO also obtained projections of future temperature increases across Yellowstone NP in summer, when visitation is highest and when future temperature increases are generally projected to be highest. The results are in the table below. With medium-high future emissions, summers in Yellowstone NP could become as hot late in the century as recent summers in Culver City, California, in the Los Angeles metropolitan area.

Greater Yellowstone may well also get drier in summer. (See pages 14-17.) Across the Central Rocky Mountains region, higher temperatures have already led to reduced snowpack, earlier spring snowmelt and peak flows, and, in some cases, lower summer flows for major basins. In Greater Yellowstone in recent decades, snowpacks have been smaller than in previous centuries and glaciers have melted. These changes in combination with higher summer temperatures have made Greater Yellowstone summers drier in recent years. Summers are expected to continue getting drier, as climate models do not project the kinds of increases in precipitation that would be needed to offset these changes in hydrology and an increase in evaporation from higher temperatures.

Every ecosystem in Greater Yellowstone faces effects from a hotter climate and drier summers. (See pages 18-23.) The region's forests already are being disrupted in ways that will leave them fundamentally different.

Whitebark pines, the dominant trees of Greater Yellowstone's highest-elevation forests, are under assault in several different ways and in July 2011 were determined by the U.S. Fish and Wildlife Service to qualify for protection under the Endangered Species Act. Destruction of the whitebark pines is being caused by an introduced disease; an unprecedented epidemic of tree-killing mountain pine beetles, aided and abetted by an altered climate; and other climate change-related threats. According to aerial surveys in 2009, 46% of the whitebark stands in Greater Yellowstone had suffered substantial mortality, and 36% had medium mortality. Nearly 5,000 individual live whitebark pines were surveyed in Greater Yellowstone in 2004-2007; in the next three years, more than half of the resurveyed larger trees had already died. A majority of the country's whitebark pines are located within Greater Yellowstone, where they play such key ecosystem roles as sustaining late-season water flows and

Hotter Future Summers in Yellowstone National Park

	Lower Future Emissions	Medium-High Future Emissions
2030-2059		
Average projection	+ 3.6° (to 64.7°)	+ 4.7° (to 65.8°)
Effect of average projection	As hot as recent Green River, WY (64.7°)	As hot as recent Idaho Falls, ID (65.7°)
Range of projections	+ 1.1° to + 5.3°	+ 2.3° to + 7.4°
2070-2099		
Average projection	+ 5.6° (to 66.7°)	+ 9.7° (to 70.8°)
Effect of average projection	As hot as recent Logan, UT (66.6°)	As hot as recent Los Angeles metropolitan area, CA (70.2°)
Range of projections	+ 2.2° to + 8.2°	+ 5.2° to + 15.0°

Table ES-1. Projected June-July-August temperature increases in Yellowstone NP, compared to 1970-1999. Possible future temperatures (such as 70.8°F in 2070-2099 with medium-high future emissions) are the projected increases beyond measured temperatures at the Yellowstone NP-Mammoth weather station. Comparisons to other cities are to their 1971-2000 average summer temperatures.

providing food for grizzly bears as well as a host of other species.

The infestation of whitebark pines by mountain pine beetles is but one part of several simultaneous, unprecedented infestations by tree-killing insects across Greater Yellowstone and western North America, with climate change believed to be a driving factor.

Aspens, iconic trees of western mountains, are so ill-suited for hotter and drier conditions that they are in danger of near complete elimination from most areas in the American West where they now are found—including across much of Greater Yellowstone, particularly in Grand Teton NP and southward. In a study, two models project that with medium-high future emissions aspens would substantially disappear from Greater Yellowstone by midcentury and be almost totally eliminated by late in the century; a third model suggests some, but a far less drastic, decline.

With recently hotter, drier conditions, wildfires in Greater Yellowstone have increased and are projected to continue increasing. The region's massive fires of 1988 burned the most land in any year since 1972, but the next six highest years all occurred in the 2000-2008 period. One study projected that seasons with fires as extensive as in 1988 will become more common, with one model projecting five such years in the next four decades.

Among Greater Yellowstone's wildlife species that could be particularly affected by climate change are grizzly bears, wolverines, and lynx. (See pages 24-28.) For the region's grizzly bears, the seeds of whitebark pines are a crucial pre-hibernation food, and the decline in the whitebarks is a principal reason that a court has kept Endangered Species Act protections in place for the bears. Wolverines and lynx, other species threatened with extinction, are snow-dependent species, and projected declines in snow are among the threats to them.

A reduced snowpack and hotter, drier summers pose major threats to the native coldwater trout of Greater Yellowstone. One study projects that with summers hotter by 5.4°F and other climate changes, just 53% of the Yellowstone cutthroat trout populations in the Yellowstone River basin would persist in the future.

Other wildife in the region, including birds dependent on wetlands, are also vulnerable to the effects of an altered climate.

Climate change may interfere in several ways with the enjoyment people derive from outdoor recreation in Greater Yellowstone. (See pages 29-31.) Increases in wildfires can disrupt vacations and other visits to Greater Yellowstone. The region's prized fishing is likely to suffer. Less snow will mean less opportunity to enjoy the special wonderland of Yellowstone NP in winter. Already, the National Park Service has sometimes had to delay in recent winters the normal start of the winter season, when most of Yellowstone NP is open only to vehicles that can travel over snow (snowcoaches and snowmobiles.) More downpours and flooding also can disrupt public uses of the area.

As the risks of a changed climate dwarf all previous threats to special places such as Greater Yellowstone, so too must new actions to face these new risks be on an unprecedented scale. (See pages 32-33.) National parks, national forests, and other special areas 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.

The Greater Yellowstone Coalition is doing its part to keep the ecosystem healthy in the face of these new threats. (See pages 33-34.) GYC's goal is to give the habitats and wildlife of Greater Yellowstone the best chance possible to adapt as the climate continues to change.

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Grand Teton NP

Projected Changes Are Already Underway

Already underway in Greater Yellowstone are many changes consistent with human-caused climate change.

- The years 2001-2010 are the **hottest decade on record for Greater Yellowstone**, having averaged 1.4°F above its 20th century average. This is more than the 1.0°F by which the planet as a whole was hotter than its 20th-century average. (See Pages 8–9.)

- In Greater Yellowstone, **summers have become even hotter**—2.3°F hotter in the last decade than 20th century summers. (Page 9.)

- Increasing winter and spring temperatures have resulted in **reduced snowpack, earlier spring snowmelt and peak flows**, and, in some cases, **lower summer flows** for major basins. (Page 14.)

- Regional **snowpack levels in recent decades have been the lowest since the mid-13th century**, according to tree-ring data. (Page 14.)

- The watershed containing Grand Teton NP's two largest glaciers **lost 45% of its glacier surface area between 1994 and 2007**, and a watershed with smaller glaciers lost 97%. Four glaciers in the Absaroka-Beartooth mountains have had "dramatic ice loss" in recent decades. (Page 15.)

- Two studies indicate that recent years in Greater Yellowstone have been **the driest stretch of years since 1895**. (Pages 15–16.)

- Hotter temperatures have enabled **an epidemic of tree-killing mountain pine beetles in high-elevations that previously were too cold** for such widespread infestations. (Pages 18–20.)

- The epidemic is causing unprecedented mortality among ecologically key trees—whitebark pines—and contributing to a threat of extinction facing the trees. **Nearly half of the whitebark pine stands in Greater Yellowstone have already suffered widespread mortality**, and only 5% have no mortality. (Page 20.)

- Since 1972, the largest wildfires in Greater Yellowstone were the huge fires of 1988, prompted by extreme dry conditions. **The next six largest wildfire seasons were all in 2000 through 2008**. (Page 22.)

- According to NPS, in Yellowstone NP **small lakes and ponds "are already drying up."** (Page 23)

- In recent years, **meadow grasslands have given way** to more bare ground, herbaceous plants, and shrubs, including sagebrush. (Page 23.)

- In years with low production of whitebark pine seeds, a key pre-hibernation food for Greater Yellowstone's grizzly bears, the **bears have more conflicts with humans** as they search for other foods, resulting in more bear deaths. Years with few whitebark seeds also lead to **lower bear birth rates**. (Page 25.)

- A migratory herd of **elk has had lower birth rates in recent years**, which appears linked to climate-related changes in the timing and availability of the vegetation on which the migrating elk feed. (Pages 26–27.)

- In Yellowstone NP, low flows and high water temperatures have led to **fishing restrictions in 2002, 2003, and 2007**. In July and August of 2007, the park closed 232 miles of 17 prime fishing rivers and streams after 2:00 p.m., when high stream temperatures most stressed trout. (Page 29.)

- Perhaps as a result of the closures, in YNP in 2008 **the number of fishing permits dropped** by nearly 30% below 2000 levels. (Page 30.)

- Low snow in some recent years has forced **delayed openings of Yellowstone NP's winter over-snow season** for snowcoaches and snowmobiles, usually in mid-November, until the middle of December or even, in the winter of 2004-2005, until January. (Page 30.)

- The Yellowstone River had **back-to-back "100-year floods"** in 1996 and 1997. (Page 31.)

INTRODUCTION

Aspens in fall, Grand Teton NP

Human disruption of the climate is the greatest threat to America's national parks and to many of our nation's other special places.[1] For the Greater Yellowstone Ecosystem, human-caused climate change is also its top threat. This report details the particular risks that a changed climate poses to Greater Yellowstone, which includes Yellowstone and Grand Teton national parks and surrounding lands, is one of the last largely intact temperate ecosystems on Earth, and is the home of some of the planet's most spectacular natural wonders.

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 Service[2]

Yellowstone and Grand Teton national parks, six national forests, and other special places in Greater Yellowstone face their greatest threats ever as humans continue changing the climate.

At stake are some of our greatest natural treasures, which have been set aside for the enjoyment of present and future generations of Americans.

The planet and our entire nation face the consequences of how humans are disrupting the climate and its natural cycles. But Greater Yellowstone, or the Greater Yellowstone Ecosystem (GYE), deserves particular attention. What could happen here 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.

Greater Yellowstone is a unique and wild region. In addition to its two national parks, it includes parts of six national forests, three wildlife refuges, and state and private lands, which together make up one of the world's last largely intact temperate ecosystems It also is vast, with about 20 million acres, an area larger than 10 of the states in the United States.

The heart of GYE is, of course, Yellowstone National Park (Yellowstone NP or YNP), famously the world's first national park. Its 300 geysers are two-thirds of those found on Earth, its 10,000 other hydrothermal features half of the planet's total. These geologic wonders inspired the establishment of the park in 1872, and still dazzle today. Because of the protections that date back to the park's designation, its ecosystem and wildlife have been actively protected longer than those anywhere else. The park's displays of wildlife are unmatched, with visitors readily able to observe grizzly bears, wolves, the last remaining wild bison herd, and much more. The park's roads, eight visitor centers and museums, lodging, campgrounds, and restaurants make these natural wonders accessible to all, but even a short hike brings a visitor into some of the largest, most untrammeled wilderness in the contiguous United States.

Grand Teton National Park (Grand Teton NP or GTNP), just a few miles south of Yellowstone, is highlighted by the Teton Range, which features the highest rise above the immediately surrounding land of any mountains in the contiguous United States, making these among the most scenic of any mountains in the world. The park also contains nearly all of the wildlife diversity of Yellowstone, with even greater chances of seeing some species, such as moose.

The Gallatin, Custer, Shoshone, Bridger-Teton, Caribou-Targhee, and Beaverhead-Deerlodge national forests further add to the scope, integrity, and wonder of Great Yellowstone. Encircling Yellowstone and Grand Teton, these national forests provide opportunities for recreation in less visited, developed, and regulated areas. The region's three national wildlife refuges protect other key wildlife areas.

Greater Yellowstone has many advantages that will make it more resilient than most areas to human-caused climate change. GYE's sheer size offers more opportunity for plants and animals to migrate into new areas where they can survive changed conditions. The range of elevations and variety of habitats will increase their chances. The length of the protective management here—in Yellowstone NP, literally the longest such stretch in the world—and the relative lack of disruptive development have left the ecosystem less stressed and more resilient. The relatively cool climate means that even as Greater Yellowstone gets hotter it will remain cooler and still

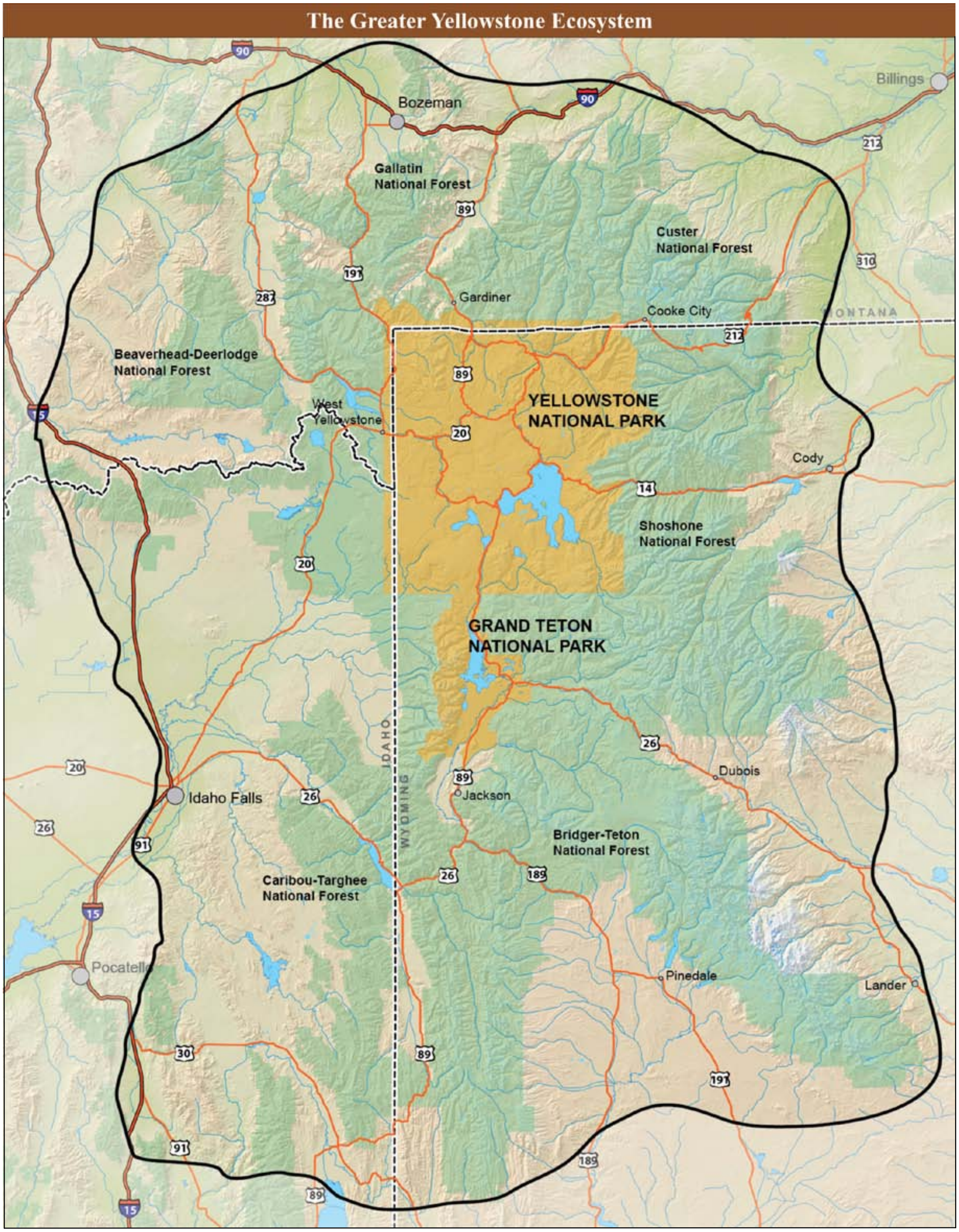

Figure 1. Greater Yellowstone, showing an approximate border of the overall ecosystem.

attractive compared to other areas that also will experience their own temperature increases.

But Greater Yellowstone is still threatened by continuing alteration of the climate. Yellowstone NP 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.[3] The entire GYE faces substantially similar risks. Summers, now generally mild and pleasant, could become as hot as those of cities in southern California or New Mexico. Ecosystems could be disrupted. Whitebark pines already could be on their way to extinction in the region, and aspens are expected to suffer major declines. Wildfires could become more frequent and widespread. Wildlife from grizzly bears, wolverines, and lynx to swans and trout face new threats, and some could disappear from the region.

The consequences of climate disruption on Greater Yellowstone could be not just ecological but economic. Yellowstone NP drew 3.6 million people in 2010 and Grand Teton NP 2.7 million, making them the fourth and seventh most-visited national parks. That visitation is a foundation of the region's economy. If the experience of visiting the GYE were to become less attractive to people, the businesses and workers who support that visitation and the entire regional economy could suffer, too.

This report summarizes what is known about the possible impacts on this ecosystem, now and in the future, from human emissions of heat-trapping pollutants. The report contains new analyses of how much hotter the ecosystem has become in recent years and new local projections from climate models of how temperatures may change in Greater Yellowstone 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' consultations with scientists and other professionals of the National Park Service (NPS), U.S. Forest Service (USFS), U.S. Geological Survey (USGS), universities, and others who work in the Greater Yellowstone Ecosystem. No truly complete accounting is yet possible, though, of the full range of impacts that could unfold in Greater Yellowstone; too little is known about exactly how a hotter climate will manifest itself across ecosystems and about which resources and values of these national parks and forests may be most affected. We are in the early stages both of changing the climate and of understanding the consequences of what we are doing.

Even before more information becomes available on all of the risks climate change poses to Greater Yellowstone, two important truths are already clear. First, a common thread throughout much of this report is that how much the special places featured here will be affected depends on future levels of heat-trapping pollutants. Second, there are actions we can take now to give fish and wildlife a better chance to adapt to change, such as protecting their ability to move and migrate and restoring degraded habitats to increase resiliency. (See pages 33-34.) As new information about climate change and its impacts comes forward, these themes come into ever-sharper focus. At the end of the day, if we continue to release high levels of heat-trapping emissions, the consequences on the ecosystem will be drastic. If we reduce emissions, the worst of these potential impacts can be avoided. And the sooner we curtail that pollution, the better—for these special places and our enjoyment of them, as well as for the planet as a whole.

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Yellowstone NP

Greater Yellowstone Economy at Risk

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Visitors at Yellowstone NP

The threats of climate disruption to Greater Yellowstone are also threats to the region's economy. The same spectacular resources that are at risk as the climate changes are the foundation of the regional economy, responsible for drawing businesses and residents to locate there and people from afar to visit.

Most tourism to and recreational use of the GYE involves the two national parks at the center of the region, Yellowstone and Grand Teton, which together drew about 6.3 million visitors to the region in 2010.

Yellowstone National Park is, of course, the region's headliner. In Wyoming, the park is the most popular overall tourist destination, and four of the state's top five individual tourist attractions are there—Old Faithful, Yellowstone Lake area, Grand Canyon of the Yellowstone, and Mammoth Hot Springs.[4] In Montana, two-thirds of all spring and summer visitors visit Yellowstone.[5] One quarter of summer travelers and one third of spring travelers cite the park as the primary reason for their visit to the state.[6]

The combined effects of Yellowstone and Grand Teton national parks are even greater. Of all income in Wyoming derived from travel and tourism, 40% is in the two local counties, Park and Teton, and 34% of all jobs related to travel and tourism are there.[7]

According to an analysis done annually by a Michigan State University researcher on the local economic contributions of all national parks, visitation to these two parks alone generated nearly $700 million in non-resident spending and supported nearly 10,300 jobs in 2009, as shown in Table 1.[8] (Economic data for 2010 are not yet available, but presumably since visitation increased last year, visitor spending and other economic benefits likewise increased).

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 Greater Yellowstone parks become less attractive to visitors, that would threaten nearly $700 million in spending and about 10,000 jobs in the region.

Spending and Jobs from Visitors to Greater Yellowstone National Parks in 2009

	(Visitors In 2010)	Visitors In 2009	Total Visitor Spending	Total Jobs Supported
Yellowstone NP	(3,640,185)	3,295,187	$296,989,000	4,369
Grand Teton NP	(2,669,374)	2,580,081	$397,322,000	5,928
Totals	(6,309,559)	5,875,268	$694,311,000	10,297

Table 1. Source: Stynes (2010).[9] The report makes adjustments in spending estimates to avoid double-counting for those who visit both parks.

The national forests of Greater Yellowstone also contribute to the region's economy, combining to attract in 2009 an estimated 8.7 million visitors. Their spending that year added more than $515 million to local businesses.[10]

Among those who recreate in Greater Yellowstone and contribute to the regional economy are hunters and anglers. Non-resident hunters and anglers spent an estimated $18.5 million in Greater Yellowstone in 2001.[11] The four southwestern Montana counties drew 1.1 million angler days in 2003, and Yellowstone NP drew 264,444 angler days in 2008.[12] The natural wonders of Greater Yellowstone also make the region attractive to residents and businesses choosing to locate there instead of elsewhere.

"The 20-county Greater Yellowstone region is one of the country's wildest places. In no small measure because of its core of wildlands, it also has one of the country's healthiest economies, keeping up with, and even outperforming, other well-recognized and successful regions around the country."

National Parks Conservation Association[13]

All these economic benefits could be at risk as a changing climate threatens the special resources that draw both vacationers and residents to the region.

How climate change may affect tourism patterns has not yet been thoroughly studied. It is possible an altered climate could lead to increased visitation in Greater Yellowstone. Warmer springs and falls could be expected to extend the tourism season. Although the ecosystem would be hotter in summer, it likely would remain cooler than areas farther to the south, where most visitors come from, so it could still offer relative escapes from summer heat.

But two separate studies based on visitor surveys in two other mountain parks in western North America—Rocky Mountain National Park in Colorado and Waterton Lakes National Park in Canada—suggest that climate change could adversely affect how visitors experience those parks, in ways that could be substantial enough to reduce visitation.

The study in Rocky Mountain NP showed that although visitation to the park has generally gone up with warmer temperatures, visitation declined by 7.5% during one summer of very high temperatures (with 60 days over 80°F).[14] Similarly, projections of future visitation levels to Rocky Mountain based on surveys of current visitors showed that in a hotter 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.

In the Waterton Lakes study, 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.[15] Examples of such changes included altered plant communities, changes to animal populations, warmer lakes, more wildfire, and loss of fishing—all of which are among the impacts projected for the Yellowstone ecosystem. The survey results, presented in Table 2 on the next page, suggest that climate-change effects could cause visitation to the Canadian park 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.

NPS/Ed Austin and Herb Jones

Mt. Washburn Trail, Yellowstone NP

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).[16]

3

More Heat and Other Climate Changes

Yellowstone NP

Human activities, principally the burning of fossil fuels, have led to large increases in atmospheric levels of heat-trapping gases over the last century. As a result, the climate is already changing, around the world and in Greater Yellowstone. Future increases in temperatures are likely to be even greater than those that have occurred already, with the ultimate extent depending on whether and how much we limit future emissions of heat-trapping pollutants.

Perhaps the clearest statement yet of the current scientific understanding of human-caused climate change is a 2009 national impacts assessment report of the U.S. government's interagency Global Change Research Program (USGCRP).[17] That report, *Global Climate Change Impacts in the United States*, begins:

> "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."[18]

This statement supports the central conclusions reached two years earlier by the United Nations-led Intergovernmental Panel on Climate Change (IPCC), which declared that there is more than a 90% likelihood that human emissions have caused most of the temperature increases over the last 50 years.[19] The U.S. National Academy of Sciences similarly states, "Climate change is occurring, is caused largely by human activities, and poses significant risks for—and in many cases is already affecting—a broad range of human and natural systems."[20]

Comparable statements have been made by, among many others, the American Association for the Advancement of Science, the World Meteorological Organization, and other scientific bodies.[21]

According to both the USGCRP and the IPCC, without the effects of heat-trapping pollution, the factors causing natural climate variability likely would have made the world cooler since 1950, instead of markedly hotter.[22]

"[N]atural factors cannot explain the warming of recent decades; in fact, their net effect on climate has probably been a slight cooling influence over this period."

U.S. Global Change Research Program[23]

The last decade in Greater Yellowstone was the hottest on record.

The average projection from many climate models is for Yellowstone NP to be 4.6°F hotter by late in the century if future emissions are low, or 7.5°F if they are medium-high.

Summers would be hotter—with medium-high emissions, Yellowstone NP summers could become as hot as those in the Los Angeles metro area have been.

Recent Temperature Increases

Figure 2 shows the worldwide trend in temperatures by decade for the last hundred years. The last decade, 2001–2010, was 1.0°F above the 20th century average.[24] Last year tied with 2005 as the hottest year on record, nine of the 10 hottest years have been since 2001, and 34 straight years have been above the 20th century average.[25]

Compared to an earlier, cooler baseline of the late 19th century, a time with little industrialization, the last decade represents an even larger temperature change, 1.4°F rather than 1.0°F.[26] That change to the global climate is already causing major impacts on natural, social, and economic systems, as detailed in this and many other reports.[27] 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.[28] The parties to that agreement reaffirmed last year that avoiding dangerous climate

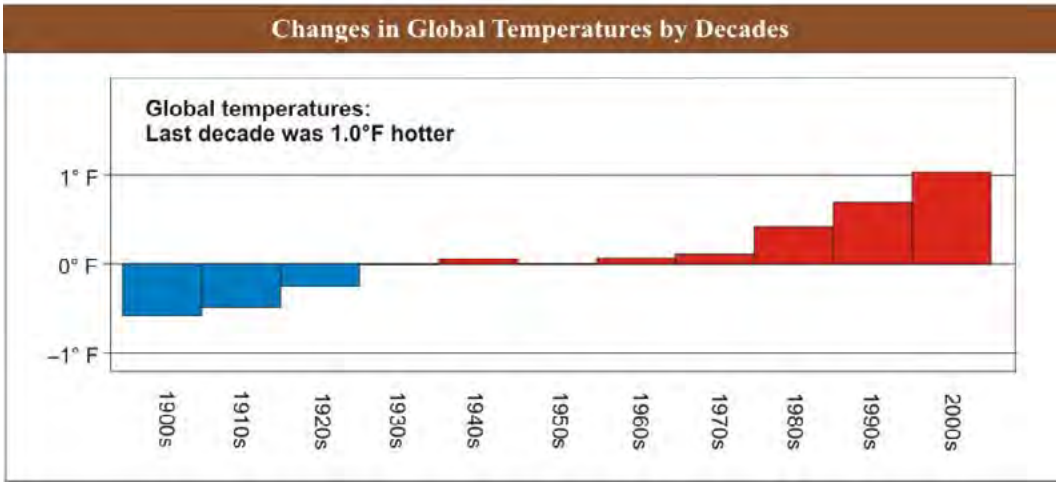

Figure 2. Average global surface temperature by decade (for example, 2001–2010) compared to corresponding 1901–2000 averages. Data from the National Climatic Data Center (NCDC), U.S. National Oceanic and Atmospheric Administration.[29] Decadal analysis by the Rocky Mountain Climate Organization. See the Appendix for an explanation of source and methodology.

interference requires meeting a goal of holding global average temperatures to no more than 3.6°F (2.0°C) above pre-industrial temperatures; they also agreed to reexamine that goal in the light of the current best available scientific evidence, which they acknowledged now suggests that the goal perhaps should be revised to be as low as 2.7°F (1.5°C) above pre-industrial levels.[30] 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 United States has gotten hotter as a whole, too, and the West even more. According to the 2009 national assessment by the U.S. government mentioned above, the country has become 1° to 2°F hotter overall compared to the 1960s and the 1970s.[31] Temperatures in the West have increased at a higher rate than for the contiguous United States as a whole.[32] The higher western temperatures have been "confidently" attributed by scientists to the effects of heat-trapping pollutants, not natural causes.[33]

For this report, the Rocky Mountain Climate Organization (RMCO) prepared a parallel analysis to the global temperature trend shown in Figure 2, using five weather stations in the U.S. Historical Climatology Network (USHCN) in Greater Yellowstone that have extensive data records for the past 100 years. The USHCN is a collection of weather stations with long-term data records that have been reviewed for reliability in detecting long-term climate trends.

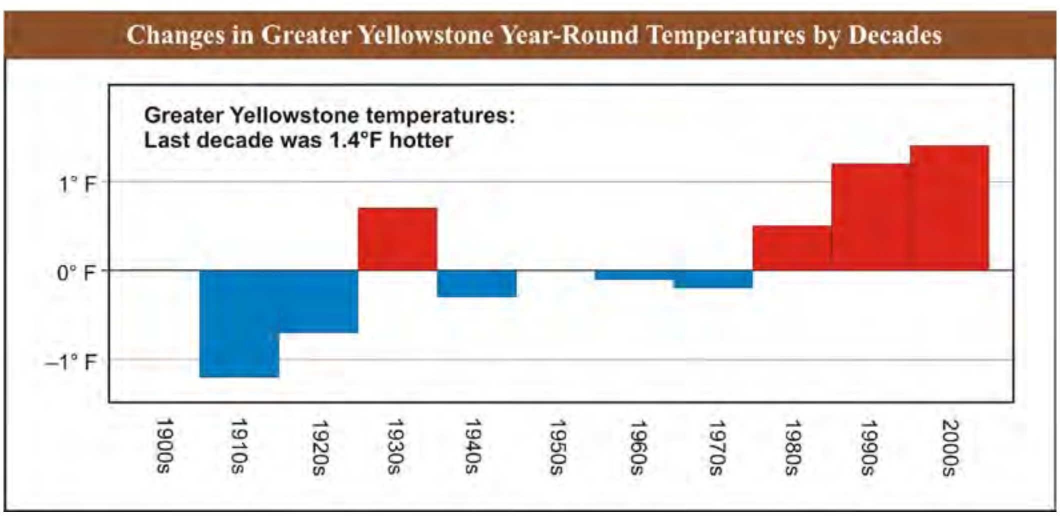

Figure 3. Year-round (or annual) average temperatures for five high quality, long-term U.S. Historical Climatology Network weather stations in Greater Yellowstone by decade (for example, 2001–2010) compared to corresponding year-round (or annual) averages for the 20th century (1901–2000). Data from NCDC, U.S. National Oceanic and Atmospheric Administration.[34] Decadal analysis by the Rocky Mountain Climate Organization. See the Appendix for an explanation of source and methodology.

(See the Appendix for details of the USHCN, these weather stations, and the methodology used for this analysis.) As shown in Figure 3, annual temperatures have become markedly hotter than they used to be. The last decade (2001–2010) is the hottest on record for Greater Yellowstone, with these five weather stations together having averaged 1.4°F above their 20th-century average. This is more than the 1.0°F by which the planet as a whole was hotter than its 20th-century average (as shown in Figure 2.)

RMCO also analyzed the pattern of Greater Yellowstone summer (June-July-August) temperatures, using the same five high-quality USHCN stations as used for the analysis of annual average temperatures. Summers warrant particular attention for two reasons. First, more visitors, by far, come to Greater Yellowstone's national parks and forests in summer than in any other season. For example, over two-thirds of the year's visitors to Yellowstone National Park come in June, July, and August.[35] So temperature increases during summer months would affect more visitors and their experiences in the GYE. Second, current climate models project greater future temperature increases in summer than in other seasons (see below), and it is an interesting question whether this projected trend has begun to appear.

As Figure 4 shows, compared to the corresponding averages for the 20th century, summer temperatures in Greater Yellowstone in the last decade were hotter by an even larger margin than was true for year-round (or annual) temperatures—2.3°F compared to 1.4°. The summers of the last decade in Greater Yellowstone are the hottest on record, with much more of a temperature increase than other seasons. (Summers in the 1930s were also hot, although they were not as hot as the most recent decade; this also was true for much of the nation, especially in the areas where the unusual heat of the 1930s was a major cause of the Dust Bowl.)

Whether and to what extent there will be a continuing trend of larger increases in summer temperatures is yet to be seen. Prior to the past decade, higher temperature increases had occurred in the region during the winter, rather than summer.[36] As stated above, however, current climate models generally project that in Greater Yellowstone summer will be the season with the greatest future temperature increase.

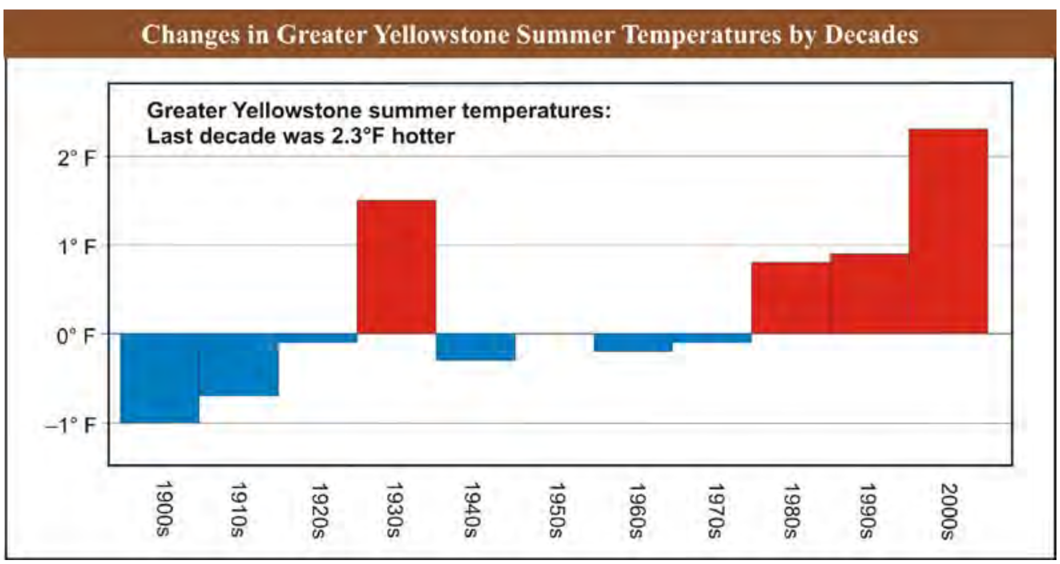

Figure 4. Average summer (June-July-August) temperatures for five high quality, long-term U.S. Historical Climatology Network weather stations in Greater Yellowstone by decade (for example, 2001–2010) compared to the corresponding annual averages for the 20th century (1901–2000). Data from NCDC, U.S. National Oceanic and Atmospheric Administration.[37] Decadal analysis by the Rocky Mountain Climate Organization.

"The choices we make now may help to avoid catastrophic impacts in the future."

National Park Service[38]

PROJECTIONS OF FUTURE TEMPERATURES

Some further global temperature increases in the next few decades are nearly certain because of the continuing atmospheric effects of past and present emissions of heat-trapping gases, which can persist in the atmosphere for a century or longer.[39] How much temperatures actually go up will be determined in large part by future emissions levels – by whether we humans take actions to reduce emissions or continue emitting heat-trapping pollutants at high rates.[40]

Annual Average Temperatures

The Rocky Mountain Climate Organization obtained for this report new "downscaled" climate projections of how much hotter year-round (or annual) average temperatures across Yellowstone and Grand Teton national parks could become as a result of human emissions of heat-trapping gases. The projections are of average temperatures across all of Yellowstone NP and across most of Grand Teton NP other than the high mountains. (For details on the sources and methodology for these projections, see the Appendix, pages 35–37.) 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. Very importantly, the two scenarios used in the RMCO projections do not span the full range of possible future emissions. The database available to RMCO for making these projections does not offer a scenario with higher future emissions. As a result, these projections understate what could happen in terms of future climate change if future emissions are not controlled. Just as importantly, none of the currently available scenarios assume new global policies deliberately designed to reduce emissions of heat-trapping gases. As a result, these projections also overstate what could happen if future emissions are deliberately and aggressively controlled. (See page 13 for more detailed information on these different emissions 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 averages and ranges of the results from all models are shown.

The projections in Table 3 illustrate that how much the climate changes depends in large part on whether 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 Yellowstone, the average result from the 16 models is for the park to get 4.6°F hotter late in the century with lower emissions, but 7.5° hotter with medium-high future emissions.

Other conclusions are also evident from the information in Table 3. First, the wide ranges of the projections from the 16 models illustrate why these (or any) projections of future temperature changes should be taken as suggestions of the direction and possible range of future changes, not definitive

Hotter Future Year-Round Temperatures in Yellowstone and Grand Teton

	Lower Future Emissions		Medium-High Future Emissions	
	2030-2059	2070-2099	2030-2059	2070-2099
Yellowstone NP				
Average of projections	+2.9°	+4.6°	+3.5°	+7.5°
Range of projections	+1.1° to +4.6°	+2.7° to +7.1°	+2.0° to +5.2°	+4.8° to +10.9°
Grand Teton NP				
Average of projections	+2.9°	+4.7°	+3.6°	+7.7°
Range of projections	+1.2° to +4.7°	+2.8° to +7.2°	+2.1° to +5.3°	+4.9° to +11.2°

Table 3. Projected future year-round (or annual) temperatures compared to 1971–2000 temperatures, in degrees Fahrenheit. Data from the World Climate Research Program's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset.[41] Analysis by the Rocky Mountain Climate Organization. See the Appendix for details on sources and methodology.

predictions. Scientists simply do not yet know how sensitive the climate will be to different levels of heat-trapping pollutants. Also, current models are less reliable in estimating future local conditions than in estimating future global averages.[42]

Second, every model shows further increases in temperature (beyond those that have already occurred—see pages 7–9)—for both parks, 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.[43]

These new RMCO projections are generally consistent with other projections of future climate change (see the Appendix, pages 36–37).

"Choices made now will influence the amount of future warming. Lower levels of heat-trapping emissions will yield less future warming, while higher levels will result in more warming, and more severe impacts on society and the natural world."

U.S. Global Change Research Program[44]

Hotter Summers

For this report, RMCO also obtained projections of future summer temperatures across Yellowstone National Park. Summer deserves particular attention because, as mentioned previously (see page 9), visitation to Greater Yellowstone is much higher in summer than in other seasons. Also, current climate models project that temperatures across this region will go up more in summer than in other seasons.[45]

As Table 4 shows, the average of the projections assuming medium-high future emissions is for summers in Yellowstone to get 9.7°F hotter by late in this century (2070–2099). It is difficult to grasp how much difference such an increase in summer temperatures could make to the park. One illustration of the magnitude of the changes that would be involved comes from the comparisons to other cities shown in Table 4. The average of the projections by late in the century with medium-high future emissions is for summers in Yellowstone NP (at the Yellowstone/Mammoth weather station, as an illustration) to become slightly hotter than summers in the Los Angeles metropolitan area (at Culver City, to be precise) were in 1971–2000. That is the average result from the 16 different models, none of which has yet been shown to be more reliable than the others. The full range of results from the models ranges from a low projection of "only" a 5.2°F increase, which would make

Hotter Future Summers in Yellowstone National Park

	Lower Future Emissions	Medium-High Future Emissions
2030-2059		
Average projection	+ 3.6° (to 64.7°)	+ 4.7° (to 65.8°)
Effect of average projection	As hot as recent Green River, WY (64.7°)	As hot as recent Idaho Falls, ID (65.7°)
Range of projections	+ 1.1° to + 5.3°	+ 2.3° to + 7.4°
2070-2099		
Average projection	+ 5.6° (to 66.7°)	+ 9.7° (to 70.8°)
Effect of average projection	As hot as recent Logan, UT (66.6°)	As hot as recent Los Angeles metropolitan area, CA (70.2°)
Range of projections	+ 2.2° to + 8.2°	+ 5.2° to + 15.0°

Table 4. Projected June-July-August temperature increases in Yellowstone NP, compared to 1970–1999, from WCRP's CMIP3 multi-model dataset.[46] Possible future temperatures (such as 70.8°F in 2070–2099 with medium-high future emissions) are the projected increases beyond measured temperatures at the Yellowstone NP-Mammoth weather station. Comparisons to other cities are to their 1971–2000 average summer temperatures, from NCDC.[47] See the Appendix for details on sources and methodology.

Mammoth summers as hot as those of Spokane, to a staggering 15.0°F increase, which would make Mammoth summers nearly as hot as those in Albuquerque recently have been.[48]

Another way to make sense of the projected future temperatures is to compare them to the park's recent summer temperatures. For the five USHCN stations in Greater Yellowstone used in the analysis shown in Figure 4, the summers of the past decade averaged 1.3°F above their average summer temperatures for 1970–1999. (Note that in Figure 4, a different baseline period—1900–1999—is used, to maintain consistency with figures 2 and 3, yielding a slightly different change than when compared to 1970–1999.) The average projected increase in summer temperatures by 2070-2099 with lower future emissions is 3.6 times the last decade's increase. With medium-high emissions, the average projected increase woudl be 7.5 times the last decade's increase. And the last decade has been hot enough to already affect park resources and values (see, for example, the effects on whitebark pines, pages 18–20, and wildfire, pages 21–22). These early impacts may barely begin to suggest what could happen with continued climate change.

Obviously, if humans were to cause Yellowstone NP to get as hot as the upper end of these projections, this national gem would be profoundly, irrevocably, and tragically altered.

The RMCO projections of changes in average summer temperatures in Yellowstone NP are also generally consistent with other projections for summer temperatures in the region (see the Appendix, page 37).

"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 Program[49]

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Yellowstone NP

Future Emissions of Heat-Trapping Pollution

The climate projections obtained for this report by the Rocky Mountain Climate Organization and other projections cited here depend on both emissions scenarios, which provide assumptions about levels of future emissions of heat-trapping pollutants, and climate models, which project how the climate may respond to atmospheric levels of those pollutants. (For more on the climate models used by RMCO, see the Appendix.)

The emission scenarios now in widest use were developed in the 1990s and used in 2007 reports by the Intergovernmental Panel on Climate Change (IPCC) on the state of scientific understanding of climate change and its worldwide affects. Differences among the scenarios are due to different assumptions about changes in population, rate of adoption of new technologies, economic growth, and other factors. Importantly, none of them assume new policies explicitly designed to reduce heat-trapping gases.[50]

In this report, the IPCC scenarios are identified in these ways:

- "Medium-high" future emissions: scenario A2, producing atmospheric concentrations of carbon dioxide by 2100 of about 2-1/2 times today's concentrations.[51]
- "Lower" emissions: B1, producing 2100 levels about 40% above today's.[52]

Figure 5 depicts these and four other IPCC scenarios.

In the RMCO projections of future temperature change in Greater Yellowstone, the lower and medium-high scenarios were used, to illustrate how different levels of emissions will impact the amount of future change.[53] But these two emissions scenarios alone do not represent a full, realistic range of possible future emissions. No projections using an emissions scenario at the higher end of the current range are now available on a publicly available database used to obtain the RMCO projections. Until this changes, significant financial and computational resources are needed to obtain projections representing a full range of possible futures. As a result, the range of projections used in the RMCO projections is skewed toward the low end of possible future emissions.

Actual future emissions also could be well above the levels in any of these current scenarios, even the high scenario. These scenarios were developed in the 1990s, when global emissions of heat-trapping gases were growing at a rate of about 1.1% per year. Since then, emissions have been much higher, in some years – such as the stretch from 2000 to 2004 – rising faster than assumed in any current scenarios.[54]

The good news, on the other hand, is that future emissions could be well below any of the current scenarios, none of which assume new policies to ward off climate change. The U.S. government's 2009 national assessment report, for example, pointed to a "stabilization" scenario that has the potential to hold further global temperature increases below an additional 2°F and avoid dangerous climate change.[55] Downscaled climate projections are not now available for that scenario. But the key point is that 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.

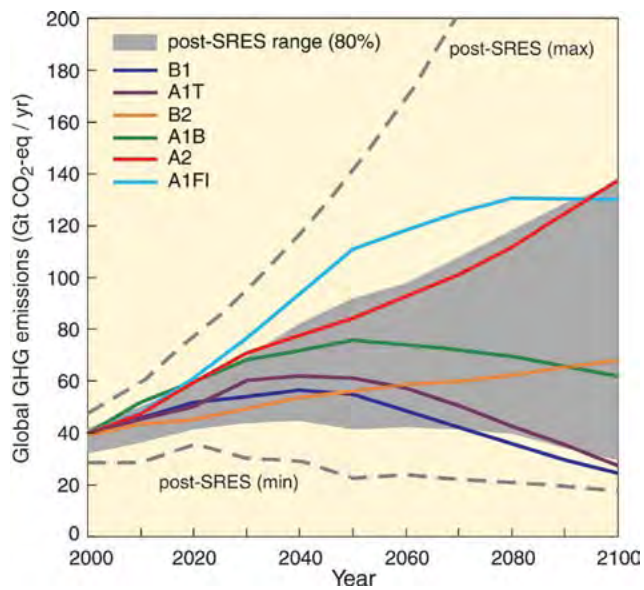

Figure 5. Selected current emissions scenarios, including those cited in this report. Those used in the new RMCO projections are A2 ("medium-high") and B1 ("lower"). Dashes indicate the range of new ("post-SRES") scenarios being developed, with the gray area representing the middle 80th percentile of 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.[56]

4

Less Snow, Drier Summers

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Grand Teton NP

Greater Yellowstone seems nearly certain to continue getting significantly hotter, as detailed in the previous section. It also may well get drier, especially in summers.

OBSERVED LOSSES OF SNOW AND ICE

Scientists have already documented that across the West less winter precipitation is falling as snow and more as rain, spring snowmelt is occurring earlier, and spring snowpack levels are lower.[57] Three recent studies attribute up to about 60% of these observed West-wide changes to the effects of human emissions of heat-trapping pollutants.[58] The observed reduction in western snowpack has been cited by the Intergovernmental Panel on Climate Change as one of seven key indicators that climate change is underway in North America.[59] In areas where snowpack is the major source of water—as in Greater Yellowstone—the combined effect of these changes is to reduce the water available in the summer, especially late in the summer, when it is most needed by plants and animals.

Most of these types of changes have been detected specifically in Greater Yellowstone as well as across the West.[60] In the Central Rocky Mountains/Greater Yellowstone area, according to a recent NPS scientific summary prepared by David B. McWethy and six other scientists, "Increasing winter and spring temperatures have resulted in reduced snowpack, earlier spring snowmelt and peak flows, and, in some cases, lower summer flows for major basins."[61] Sometimes the GYE trends are not as strong as in areas of lower elevations or latitudes—and therefore warmer temperatures. For instance, according to McWethy and colleagues, "A greater proportion of precipitation is likely falling as rain rather than snow in this region but the impacts are less pronounced than in other parts of the western United States."[62] Having less change occurring in Greater Yellowstone is to be expected; in an area with such deep cold an increase of winter temperatures by a few degrees (so far) would less often represent the difference between above-freezing and below-freezing temperatures.

But the changes that have already occurred in the GYE are still significant and perhaps unprecedented.

> *Snowpack levels in Greater Yellowstone have been particularly low in the last few decades, compared to levels over several centuries.*
>
> *Glaciers in the region are shrinking.*
>
> *Snow is melting earlier in the spring, leading to lower streamflows late in the season.*
>
> *The region's summers are expected to become not just hotter but also drier.*

A new study by Greg Pederson of the U.S. Geological Survey's Northern Rocky Mountain Science Center in Montana and other scientists offers an analysis of snowpack trends in Greater Yellowstone over several centuries.[63] Their analysis, part of a study looking at trends across the western United States, uses both actual measurements of snowpack levels from recent decades and estimates based on tree-ring data for previous centuries. The tree-ring data reveals climate variations from before the time of human measurements, demonstrated by the annual growth rings in tree trunks being wider in wet years (following high snowpack) and narrower in dry ones. In the case of the GYE, the researchers traced trends back to the mid-13th century, as shown in Figure 6. Their analysis shows that regional snowpack levels over the last 100 years or so have been below the centuries-long average, and that recent levels have been particularly low. Even more of an indication that recent years have been different is their finding that West-wide snowpack levels of the late 20th century were "almost unprecedented" in two ways: for the extent to which they were below the long-term average and for occurring simultaneously in both the northern and southern Rocky Mountains. Previously, patterns of ocean temperatures and atmospheric circulation consistently led to a north-south alternation of snowpack levels, meaning that when they have been high in the north they have been low in the south, and vice versa.

Data from particular localities in Yellowstone NP also show a loss of snow in recent decades, consistent with the region-wide trend shown in Figure 6. An analysis by two scientists shows that, at the Yellowstone National Park-Mammoth and Tower Falls weather stations over the period 1948–2003, snow depth has declined, with statistically significant declines in late-winter months; mid-winter snowfall has declined; the date of the last snow cover has moved earlier in the year; and the number of winter days above freezing has increased.[64]

"Winters in Yellowstone are getting shorter."

Christopher C. Wilmers and Wayne M. Getz[65]

Glaciers, too, are in decline. The Intergovernmental Panel on Climate Change reported in 2007 that glaciers are melting worldwide and expressed "confidence that the glacier wastage in the late 20th century is essentially a response to post-1970 global warming."[66] Glaciers are melting across the western United States, especially in our national parks, a handful of which contain most of the glaciers in the contiguous United States.[67]

Lisa Bauer/shutterstock.com

Absaroka Mountains

Glaciers are present in some areas of Greater Yellowstone, including in Grand Teton NP, which has 12 named glaciers. They also are present in the Absaroka-Beartooth mountains just north of Yellowstone NP and in the Wind River Range of western Wyoming. In Grand Teton NP, research funded by the state of Wyoming shows that the watershed containing the park's two largest glaciers, Teton and Middle Teton glaciers, lost 45% of its glacier surface area between 1994 and 2007 and that a watershed containing smaller glaciers had lost 97% of its glacier surface area.[68] Four glaciers in the Absaroka-Beartooth mountains have also had "dramatic ice loss" in recent decades.[69]

Scientists have recently found indications of drier conditions in Greater Yellowstone. Two teams

Snowpack Trends In Greater Yellowstone

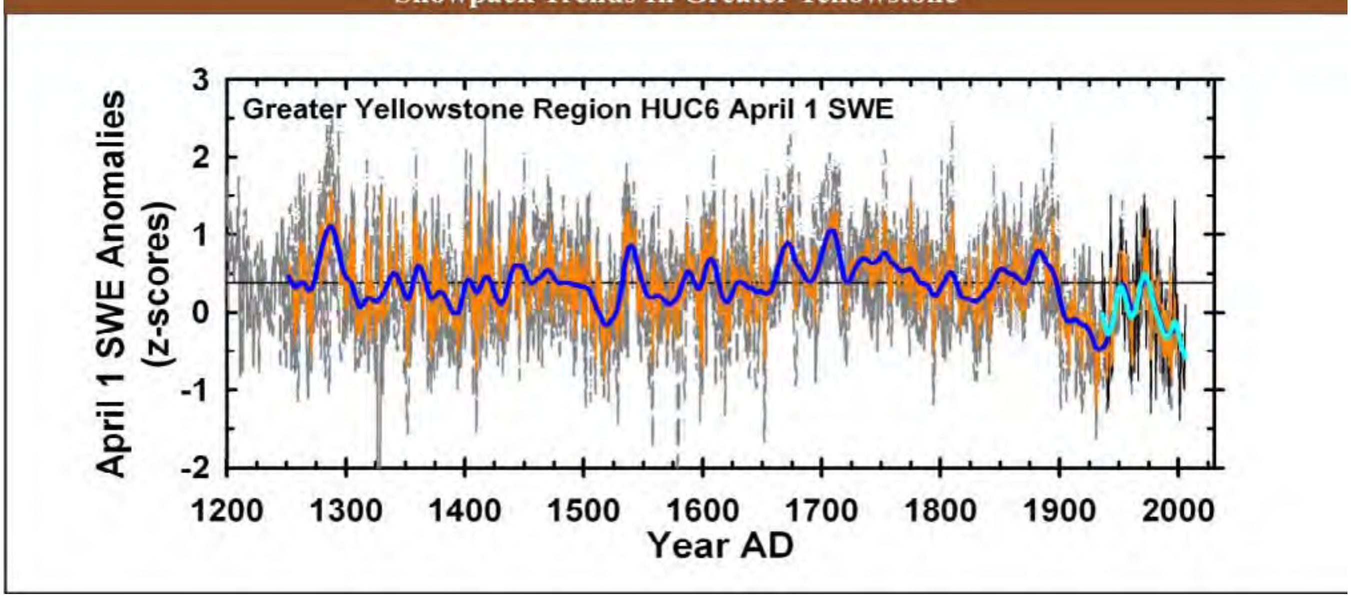

Figure 6. Changes in spring snowpack levels for Greater Yellowstone, in snow-water equivalent (SWE) of snowpacks as of April 1, compared to the 1400–1950 average, including estimates based on tree-ring data. Gray lines show values for individual watersheds and darker lines (medium blue for reconstructions, light blue for measured values) show regional averages. Source: G. Pederson, from Pederson and others (2011).[70]


Julie Lubick/shutterstock.com

Firehole River, Yellowstone NP

of scientists have independently reported that in different parts of the GYE recent years have been the driest since the beginning of the period of reported weather measurements in 1895. One team, looking at climate-change effects on Greater Yellowstone meadows (see page 23) calculated that the stretch of 2000 through 2003 was the driest consecutive four years (through the study's end in 2007) in the period of weather measurements.[71] Another team, studying the hydrology and amphibian populations in YNP's Lamar Valley, calculated that the summer flows of the Lamar River declined significantly between 1924–1966 and 1989–2007, that the Yellowstone River drainage in the park has experienced a century-long trend toward drought, and that the years 2001 through 2007 (the last year they studied) was the region's driest stretch in the period of weather measurements.[72]

PROJECTED FUTURE CHANGES

Scientists consistently project a continued future loss of snow and ice in the mountainous West as the climate keeps getting hotter. A recent, relevant example is a study by Celine Boisvenue, then at the University of Montana and now at the Canadian Forest Service, and Steven W. Running, of the University of Montana.[73] They assessed possible future climate-change impacts on forests in the northern Rocky Mountains in a medium-emissions future (see page 13), using six representative sites, including one in the GYE, at Tower Falls in Yellowstone NP. Their results suggest major changes in snowpacks and snow cover at the other sites but not at Tower Falls, the coldest site in their study. As an example of the changes they project elsewhere in the region, at a site on the southern edge of Glacier National Park the projected peak snowpack level near the end of the century would occur on average about February 25 each year, compared to about April 8 in 1950. In other words, snowpacks would stop accumulating and begin melting 41 days earlier. Another projection for this site is that snow would cover the ground for about 70 fewer days, on average, near the end of the century. As measured by this key condition, the length of Glacier's winters could be shortened by more than two months. The Boisvenue and Running projections suggest that across most of the Northern Rockies, and presumably much of the GYE, although not in its coldest areas such as in the interior of Yellowstone NP, winter snow cover could be substantially reduced in this century.

In the GYE, as elsewhere, a reduction in snowpack is not occurring in isolation but instead in tandem with other changes that threaten to fundamentally alter the region's overall hydrology, including when water is available in ecosystems. The U.S. government's 2009 national assessment report states, "Future projections for most snowmelt-dominated basins in the West consistently indicate earlier spring runoff, in some cases up to 60 days earlier."[74] According to an article in the NPS journal *Park Science*, "These shifts in water timing will probably have large impacts on regional ecosystems, resulting in rapid, threshold-type responses."[75]

> *"Increasing temperatures will likely bring a suite of consequences for rivers in Wyoming, including earlier and faster spring runoffs, and diminished late-season flows."*
>
> University of Wyoming[76]

To offset these changes in snowpacks and glaciers and the timing of their annual melting, there would have to be future increases in precipitation, particularly in summer. To offset the effects of increased evaporation from hotter summers would require additional precipitation increases; one estimate is that in the central Rocky Mountains only sustained future precipitation at the highest levels of


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Yellowstone NP

the past 800 years would counterbalance the drying effects of higher temperature.[77]

An increase in precipitation is a possibility, but not something now generally being projected. Instead, most climate projections suggest that summer precipitation levels could decline, compounding summer dryness. Projections for the Northwest region by the Climate Impacts Group at the University of Washington (see the Appendix, pages 36–37) are "equivocal"—they do not show a clear trend for future precipitation levels for the larger region, nor for Greater Yellowstone.[78] The average result of many different climate models is for no change in overall regional precipitation levels, although some individual models project as much as a 10% decrease and some as much as a 20% increase by the 2080s.[79] For seasonal precipitation levels, most models project some increases in winter by the 2080s, but most also project larger decreases in summer by then.[80] These kinds of regional projections about future precipitation, though, are more uncertain than those about temperature.[81] In the GYE, precipitation projections are especially difficult because of the large influence of Pacific Ocean-atmospheric circulation interactions.[82]

The study by Boisvenue and Running (see page 16) also included projections of much drier summer conditions in the northern Rocky Mountains.[83] The climate models and scenarios they used projected that late-summer dry periods would become six to eight weeks longer than normal, resulting from the effects of higher temperatures on snow levels and snowmelt.

> *"Over the course of this century … Spring snowmelt [in the Northern Rocky Mountains] will occur four to six weeks earlier, and the summer drought period will be six to eight weeks longer. The growing season will shift one to two months earlier in the spring. Late summer drought will be extended by six to eight weeks."*
>
> Stephen Running[84]

Among the effects of hotter and drier summers in Greater Yellowstone would be harm to the area's plant communities (see pages 18–23), increased wildfire (see pages 21–22), impacts on wildlife (pages 24–28), and reduced opportunities for fishing (pages 29–30).

Another consequence could be that snow-covered mountains would not last as long into the summer, when most visitors come to the GYE. If this were to happen at the Teton Range, in particular, future summer visitors would be robbed of a key element of some of the world's greatest mountain scenery.

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Mount Moran from Oxbow Bend, Grand Teton NP

5

DISRUPTION OF ECOSYSTEMS

Yellowstone NP

Every ecosystem in Greater Yellowstone faces effects from a climate made hotter year-round and drier in summer.

Whitebark pine, the keystone tree species of the region's highest forests, face a threat of extinction because of climate change and other risks.

High future heat-trapping gas emissions could eliminate aspens from most of the region.

Large fires like those of 1988 could become normal in the future.

Streams, wetlands,and wildflowers could all suffer from hotter, drier conditions.

FORESTS

The most obvious, widespread impacts to already appear in Greater Yellowstone are in its forests, which cover much of the region and already are being disrupted in ways that will leave them fundamentally different.

Loss of Whitebark Pines

A changing climate is a major driving force behind the ongoing, widespread destruction and possible extinction of the whitebark pines, the dominant trees of Greater Yellowstone's highest-elevation forests. Whitebark pines play such key ecosystem roles as sustaining late-season water flows and providing food for grizzly bears and a host of other wildlife. The whitebark pines are under assault in several different ways, including an unprecedented epidemic of tree-killing mountain pine beetles, aided and abetted by an altered climate. This is an illustration of how a natural force, the beetles, can be so unnaturally magnified by a hotter climate that ecosystem disruption occurs.

Whitebark pines, which sometimes live more than a 1,000 years, tolerate poor soils, steep slopes, windy exposures, and arid conditions where other trees generally cannot grow, and so enable forests to exist near mountaintops and in other harsh environments which otherwise would not be forested.[85] In Greater Yellowstone, home to half the country's whitebark pines, they are widespread in stands approaching timberline and also common in mixed forests down to 8,500 feet in elevation. Where other trees cannot grow, they play a unique role in controlling erosion and also holding snow drifts and producing shade, which slows springtime snowmelt and yields higher streamflows later in the season when ecosystem needs are greater. Their nutritious, nutty seeds, unique in North America, are valuable food for both birds and mammals. The whitebark seeds, in fact, are such an important food for Greater Yellowstone's grizzly bears that the decline in whitebark pine is a principal reason for a court decision leaving the bears with protections under the Endangered Species Act (see pages 24–25).

Whitebark pines, though, are in "substantial and pervasive decline" across the West and in Greater Yellowstone, in the words of a July 2011 decision by the U.S. Fish and Wildlife Service (FWS) that the species qualify for protection under the Endangered Species Act.[86] (The actual listing decision will be made later because of a backlog of uncompleted listing decisions for other species.) The threats to the whitebarks come from the effects of a non-native disease, white pine blister rust; mountain pine beetles; disruption of the West's natural fire regime, which used to give whitebarks a competitive advantage over other tree species; and a projected range decline as a hotter climate makes places where they now live unsuitable for them. See the text box on the next page for statements taken from the FWS decision, which is a recent, very good summary of the threats to whitebark pines.

As the excerpts from the FWS decision indicate, epidemic outbreaks of mountain pine beetles (MPBs)

U.S. Fish and Wildlife Service Identifies Climate-Change Threats to Whitebark Pines

In July 2011, the U.S. Fish and Wildlife Service found that whitebark pines are at risk of extinction for the following reasons, in the agency's words.[87]

Whitebark pines are undergoing a substantial and pervasive decline throughout almost the entire range of the species. The primary threat to whitebarks is an introduced, nonnative disease, white pine blister rust, and its interaction with other threats. That disease, which now infects whitebarks throughout essentially their entire range, kills an overwhelming majority of infected trees. Seedlings are killed rapidly; some mature trees may persist for decades, but their cone-bearing branches typically die earlier, eliminating seeds.

The second major threat to whitebarks from mountain pine beetle (MPB), a native insect that kills most trees that it infests. When conditions are favorable, MPB populations can erupt to epidemic levels and create stand-replacing events that kill 80 to 95% of suitable host trees, subsiding only when suitable host trees are exhausted or temperatures are sufficiently low to kill beetle larvae and adults. MPB epidemics affecting whitebark pine have occurred throughout recorded history. However, the high-elevation sites occupied by whitebarks typically have been climatically inhospitable to mountain pine beetle. At the low temperatures typical of high-elevation sites, MPBs mostly have a 2-year life cycle, which is not favorable to epidemic outbreaks.

The warmer temperatures and drier conditions brought on by climate change have provided the favorable conditions necessary for the current, unprecedented MPB epidemic in high-elevation communities across the western United States and Canada. Warmer temperatures promote a 1-year life cycle, which facilitates synchronized mass attacks that overcome host tree defenses. Winter temperatures are now warm enough for winter survival for all MPB life stages and for maintenance of the 1-year life cycle that promotes epidemic MPB levels. Along with warmer winter conditions, summers have been drier, with droughts occurring through much of the range of whitebark pines. MPBs frequently target drought-stressed trees, which are more vulnerable to attack as they are less able to mount an effective defense against even less dense mass attacks by MPBs.

Whitebark pines have been killed on millions of acres from the late 1990s through 2011. In that time, warming temperatures have facilitated large mountain pine beetle outbreaks even in areas of whitebark pine habitat previously thought climatically immune to beetle epidemics. Unlike previous epidemics, the current outbreak is having an increasingly significant impact on whitebark pines, with the highest recorded MPB mortality ever reported for whitebarks. Warming trends have resulted in not only intensified MPB activity in high-elevation whitebark pine forests but also in MPB range expansion into more northern latitudes and higher elevations. The ongoing and predicted environmental effects from climate change are expected to create more favorable conditions for MPB outbreaks to persist in whitebark pine habitats into the foreseeable future.

The third threat is that whitebark pines, adapted to cool, high-elevation habitats, are anticipated to have direct habitat loss from climate change, with current habitats becoming unsuitable as temperatures increase and soil moisture decreases. Habitat loss is expected because of temperatures too warm for whitebarks to tolerate or warmer temperatures favoring other conifer species of conifer that currently cannot compete with whitebarks in cold high-elevation habitats. Adaptation to a rapidly warming climate also seems unlikely for whitebark pines, which have an estimated generation time of 60 years. Although there are many limitations to modeling techniques, models predict that suitable habitat for whitebarks will decline precipitously, by about 70% by the 2030s and 97% within the next 100 years.[2]

The fourth threat is that human suppression of wildfires has disrupted a natural fire regime that previously gave whitebark pines a competitive advantage. When fire is present, whitebark pine have an advantage over competitor trees, as it can better withstand low-intensity fires and regenerate better after fire. Fire suppression, which is likely to continue, has enabled areas of whitebark pines to undergo succession to other conifers. Climate change is expected to result in increased fire severity and habitat loss, as whitebark pines cannot withstand high intensity fires.

These threats interact. For example, as a result of white pine blister rust and mountain pine beetles, whitebark seed sources are expected to be reduced or effectively eliminated on a landscape scale, making regeneration following fire unlikely in many cases.

Based on these threats, the whitebark pine is in danger of extinction, or likely to become so in the foreseeable future.

have occurred among whitebark pines in the past, but the cold temperatures of high-elevation sites occupied by whitebarks limited those outbreaks. Additional light on this is shed by a recent study in which Barbara Bentz of the U.S. Forest Service and other scientists estimated the temperatures for every hour over eight decades for a site in Greater Yellowstone of an earlier MPB outbreak among whitebark pines.[88] Only in the few years of the late 1920s and early 1930s when the earlier outbreak occurred were local temperatures warm enough to produce a high proportion of MPBs completing their life cycle not over two years but in a single year, which is needed to produce explosive population growth for epidemic-level outbreaks. The 1930s was an atypically warm decade in Greater Yellowstone (see Figure 3 on page 8). The high temperatures seen then are now commonly exceeded. (See pages 7–9.)


Wally Macfarlane

Dead and dying whitebark pines, indicated by the red color of the trees, Gros Ventre Range, Greater Yellowstone

Efforts are underway to monitor the extent of whitebark pine mortality from all causes in Greater Yellowstone.[89] According to aerial surveys in 2009, 46% of the whitebark stands in Greater Yellowstone had suffered substantial mortality, 36% had medium mortality, 13% low mortality, and only 5% no mortality.[90] In a federal interagency monitoring program, nearly 5,000 individual live whitebark pines were surveyed in Greater Yellowstone in 2004-2007; in the next three years, more than half of the resurveyed larger trees had already died, although most of the smaller ones were still alive.[91]

The risk to GYE's whitebark pines is so substantial that both USFS and NPS are intervening in the ecosystem in attempts to preserve and restore the tree species.[92]

> *"Whitebark pine is a species whose loss would reverberate through the entire Rocky Mountain ecosystem, resulting in impacts that far outweigh its physical presence on the landscape."*
>
> W. W. Macfarlane, J. A. Logan, and W. R. Kern[93]

Other Mountain Pine Beetle Effects

The destruction of whitebark pines by mountain pine beetles is but one part of several simultaneous, unprecedented infestations by tree-killing insects across the entire West, from the piñon-juniper forests of the Southwest to the boreal forests of Alaska and Canada.[94] Across Greater Yellowstone, especially in the southern portions of the region, the same mountain pine beetles that are laying waste to high-elevation whitebark pine forests are also killing huge numbers of lodgepole pines, the region's most abundant tree. The latest report, for instance, is that almost half of the Shoshone National Forest—1.1 million acres out of 2.4 million acres—has so far been affected by beetles.[95] In Yellowstone National Park, four types of bark beetles and the spruce budworm had simultaneous outbreaks in the past decade—a development never seen before, as outbreaks by different insects have previously occurred in different cycles.[96] Reports by both the U.S. government and the Intergovernmental Panel on Climate Change point to hotter conditions, and often drier ones, as driving these outbreaks.[97] A recent symposium on bark beetle outbreaks in western North America called the combination of climate change and bark beetles "the perfect storm."[98]

Loss of Aspen

Aspens, iconic trees of western mountains, are so ill-suited for hotter and drier conditions that they are in danger of near complete elimination from most areas in the American West where they now are found—including across much of Greater Yellowstone, particularly in Grand Teton NP and southward. Even in Yellowstone NP, where aspen stands are only about 2% of the park's tree cover, they are ecologically significant as essentially the only deciduous trees in the park.

For the past century, aspens across Greater Yellowstone have been in steady decline, with existing stands gradually thinning and deteriorating and not being replaced, for reasons that are not yet

Projected West-Wide Reductions in Areas Suitable for Aspens U.S. Forest Service Projections			
	2026-2035	2056-2065	2086-2095
Medium-High Future Emissions (average of three climate models)	25%	60%	85%
Lower Future Emissions (average of two climate models)	25%	41%	48%

Table 5. Projected declines in the future suitability of areas now climatically suitable for aspens. Source: Rehfeldt, Ferguson, and Crookston (2009).[99]

fully understood.[100] On top of that has come the new threat of a changed climate, as researchers have projected that the areas now climatically suitable for aspens will decline greatly by the end of the century, in Greater Yellowstone and across the West.[101] Table 5 shows that, as with most climate-change impacts, the effects are projected to become greater if emissions levels are higher. For the Greater Yellowstone region, two of the models based on medium-high future emissions project that aspens will substantially disappear from the region by midcentury and be almost totally eliminated by late in the century. The third model suggests some, but a far less drastic, decline.

A new, still-unpublished study focused on Greater Yellowstone suggests another climate change threat to the region's aspens—declines in snowpack (see pages 14–16)—may be playing a previously unconsidered role in the region's aspen decline.[102] Deep snowpack reduces the ability of elk to browse on young aspen shoots, letting more young trees survive. With fewer instances of deep snow in recent years, elk may now be consuming more aspens.

Substantial loss of aspen from Greater Yellowstone would alter the region's ecology. Aspen stands support important types of understory plants, birds, and mammals, including elk and deer. And there could be no replacement for the spectacular color that aspens add to the Greater Yellowstone landscape in the fall.

More Wildfires

Wildfires, like tree-killing beetles, are naturally occurring agents of disturbance in the region's forests. As the National Park Service says, "wildfire has had a role in the dynamics of Yellowstone's ecosystems for thousands of years."[103] Wildfire maintains a natural balance and mix of plants and trees, reduces build-up of deadfall and organic material, creates a natural succession of plant growth, and makes forests more resistant to drought, insects, and invasion by non-native plants. But, as with beetles, climate change—hotter and drier conditions and longer fire seasons—is already expanding the natural force of wildfire in Greater Yellowstone.

In this region, wildfire evokes for many people memories of Greater Yellowstone's extreme fires of 1988, which were prompted by the driest summer recorded for the region, with Yellowstone NP receiving only 32% of the normal seasonal precipitation.[104] Across the region, 248 fires burned; 50 were in Yellowstone NP and burned across about 36% of the park.[105] (For the effects on visitors, see page 29).

Recent scientific studies have put the Yellowstone fires of 1988 in context: Wildfires in general are now

NPS/Jim Peaco

Yellowstone NP

more numerous, larger, and more destructive than they used to be. A landmark study published in 2006 by Anthony Westerling and others reported that spring and summer temperatures in the West in the 17 years after 1987 were 1.5°F higher than in the 17 years before then—and that those recent higher temperatures were linked to:

- a 78-day increase in the length of the fire season;
- a fourfold increase in the number of fires;
- a fivefold increase in the time needed to put out the average wildfire; and
- 6.7 times as much area being burned.[106]

A new study by Westerling and others, published in 2011, focused on wildfire in Greater Yellowstone.[107] It shows that although the fires of 1988 burned the most land in any year since 1972, the next six highest years all occurred in the 2000-2008 period, with high fire activity strongly correlating with hot and dry conditions.

Their study projects that:

- Seasons with massive fires as in 1988 are projected to become more common, with one model projecting five such years between 2011 and 2050.
- Years with no large fires, historically the norm in the region, are projected to become very uncommon, with such seasons after 2050 projected by only three out of 1,000 different model simulations.
- By 2075, the annual area burned by wildfire in Greater Yellowstone is projected to regularly exceed the signature 1988 event, often by a large margin.

"Large fires, such as those in 1988, may represent the 'norm' rather than the exception under future climate scenarios."

Erica Smithwick, Anthony Westerling, and others[108]

Changes in Forest Types

Forest tree species also are expected to shift their ranges northward and upslope in response to climate change, resulting in major changes in the character of forests in the United States and the types of forests that will be most prevalent in different regions.[109] As a result, some tree species may be eliminated in Greater Yellowstone—in addition to whitebark pines and aspens, threatened in ways described above. One study that modeled changes in suitable conditions for several tree species in Greater Yellowstone projected that whitebark pine could have the greatest range reduction of the studied trees, with Douglas-fir and Engleman spruce also losing much of their current distributions.[110] One reason that Douglas-firs, found throughout much of Greater Yellowstone, could be quite affected by a hotter world is that when young they must be exposed to deep winter cold to achieve maximum growth.[111] Another threat to cold-environment trees and plants struggling to hang on in a hotter climate would be new competition for water, nutrients, and growing space from others better suited to the new environment.[112] The modeling effort mentioned above projected that Gamble oak, western larch, ponderosa pine, and western red cedar could spread into Greater Yellowstone.[113]

General Forest Decline

Two scientists, Celine Boisvenue and Stephen Running, recently projected that earlier snowmelt and less spring snow cover will create new water stresses leading to declining forest health in the northern Rocky Mountains, including Greater Yellowstone.[114] (See pages 16–17 for more on this study.) They projected that periods of late-summer dryness would last six to eight weeks longer toward the end of this century. The coniferous forests at the Yellowstone NP site in their study, they suggested, would face above-average stress (by previous norms) from water shortages in about 80% of the years in this century (2006 through 2089). Other forests across the northern Rockies would face similarly increased stress from water shortages. As the availability of adequate moisture is one of the primary determinants of forest health in this region, the scientists concluded that there would be a substantial decline in the health of forests across the region.


NPS

Forest near Bechler Meadows, Yellowstone NP

OTHER ECOSYSTEM THREATS

Streams and Lakes

Hotter and drier conditions could lead to lower late-season water levels (see page 16). One study projects that with likely future precipitation levels average regional streamflows could fall 15% by midcentury, compared to the 20th century average.[115]

Stream temperatures are also already increasing, and this trend is expected to continue.[116] In a central Idaho river basin near the GYE, summer stream temperatures rose an average of 0.68°F from 1993 to 2006.[117] (For the effects of hotter waters on fish, see page 28.)

Wetlands

Wetlands, although not common across much of Greater Yellowstone, still are key ecosystems. In Yellowstone NP, for example, where wetlands are "few and far between," they support about 38% of the park's plant species, including 11% that grow only in wetlands, and provide essential habitat for mammals, birds, reptiles, amphibians, and insects.[118] According to a park publication, Yellowstone NP's small lakes and kettle ponds "are already drying up" and it is unknown how much water they would need to recover.[119] "However, precipitation and snowpack will likely continue to decrease, which will continue to decrease surface and ground water—and thus the lakes and ponds may not recover," NPS warns. "As wetlands diminish, sedges, rushes, and other mesic (water-loving) plants will lose habitat. In turn, amphibians and some birds will also lose habitat."[120]

Meadows

Hotter and drier conditions are expected to alter the distributions of all types of plant communities, not just forests.[121] As one example of such changes that already appear to be underway, scientists have already detected that mountain meadows are being encroached upon in some other mountain areas around the West.[122]

In Greater Yellowstone, scientists studied changes between 1997 and 2007 in the plant life in mountain meadows in two areas, in southwestern Montana and around Jackson, looking particularly at the effects of drought in those years.[123] They found that grasslands had decreased, that bare ground increased, and that shrubs including sagebrush and forbs (plants other than trees, woody shrubs, and grasses) had increased.

©istockphoto.com/Greg Ritchie

Grand Teton NP

Wildflowers

The Yellowstone region is justly famous for its mountain wildflowers, but there is evidence from the southern Rockies that suggests that wildflowers across the mountainous West could be diminished in a hotter climate. Researchers at the Rocky Mountain Biological Laboratory in Colorado have documented that higher temperatures suppress the growth of mountain wildflowers. Using electric heaters to artificially raise summer temperatures of test plots by 4°F for more than a decade, they have observed a loss of wildflowers in these conditions and an increase in sagebrush, normally found in lower, drier areas.[124] Another study shows that, paradoxically, earlier snowmelt actually leads to wildflowers blooming too soon, doubling losses of flowers to mid-spring frosts.[125] Yet another study has linked higher mid-summer temperatures with a decrease in flowers, to a degree that could threaten future populations of pollinators—without which the remaining flowers could not reproduce.[126]

> *"Fewer wildflowers are projected to grace the slopes of the Rocky Mountains as global warming causes earlier spring snowmelt."*
>
> U.S. Global Change Research Program (2009)[127]

Impacts to Wildlife

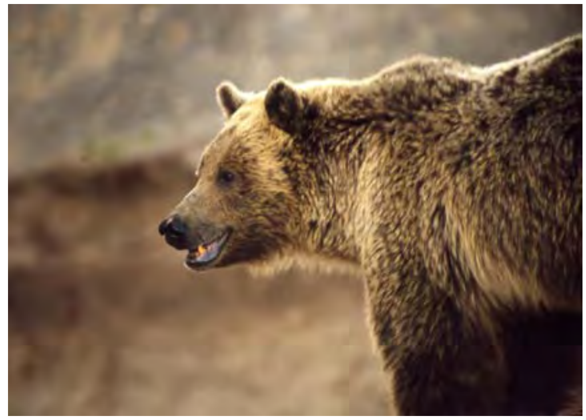
For many visitors to Greater Yellowstone, the highlight of their trip can be seeing some of the wildlife unmatched anywhere else in the United States for its diversity and sheer numbers. But a changed climate could mean a loss of some wildlife species now found in the GYE, as well as changes in its natural suite of wildlife. The Intergovernmental Panel on Climate Change warns that just 4°F 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."[128]

Even if species do not become extinct everywhere, local populations of species in a particular area, such as a national park, may be lost.[129] As temperature drives changes in habitat conditions, species searching out suitable habitats as their home ecosystems change are likely to migrate into new geographies. The new immigrants will compete with existing species for habitat and food, potentially driving further changes in wildlife populations. Similarly, changes in the timing of seasonal events can drive changes in summer and winter ranges and local abundance of wildlife.

One important point to recognize is that climate change threats to wildlife will come atop other existing threats and stresses—primarily a loss of habitat from human development.[130] Greater Yellowstone is unique in the contiguous United States for having such a large, protected land base, which has sustained the variety and abundance of its wildlife. The vastness and high quality of the ecosystem will be an advantage to species facing the new threat of an altered climate, especially by creating opportunities for animals (as well as plants) to migrate into new areas that may better support them in the future. Still, climate change poses threats that can fundamentally alter the natural composition of wildlife that has long persisted in Greater Yellowstone.

MAMMALS

NPS has stated about how an altered climate may affect mammals in Yellowstone NP, "Climate-change effects on large mammals are hard to determine and predictions are not easy to find. In general, scientists seem to think ungulates depending on grasslands will be able to find suitable habitat. Other species might not be so fortunate."[131] Among the species that could be particularly affected are grizzly bears, wolverines, lynx, pikas—and perhaps also some grazing animals (or ungulates), including elk.



NPS/ryan Harry

Grizzly Bear, Yellowstone NP

A threat to Greater Yellowstone's grizzly bears is the effects of climate change and other risks on whitebark pines and their seeds, a key food for the bears.

Wolverines, lynx, and other snow-dependent species are at greater risk as a hotter climate reduces the snow cover they require.

Greater Yellowstone's native cutthroat trout are cold-water fish that are likely to experience severe declines due to hotter streams.

Grizzly Bears

The grizzly bear, a living symbol of Greater Yellowstone's wildness, is among the creatures at risk to a changing climate. In fact, it is one of the few species so far to have its protected status under the Endangered Species Act rest on the threats posed by climate change. In 2009, a U.S. district court, in a lawsuit brought by the Greater Yellowstone Coalition and others, reversed a decision by the U.S. Fish and Wildlife Service to remove Yellowstone-area grizzly bears from the endangered species list, in large part because climate change threatens to eliminate the region's whitebark pines and their nuts, which are a crucial food for the bears (see page 18).[132] The court found that "there is a connection between whitebark pine and grizzly survival" and that "[t]he identifiable best available science indicates that whitebark pines are expected to decline due to a variety of causes, including climate change, increased forest fires, the mountain pine beetle epidemic, and infection by white pine blister rust."[133] Accordingly, the court determined that the region's grizzly bears remained threatened with extinction and restored Endangered Species Act protections.

Whitebark pine nuts have long been one of the most important food sources for grizzly bears in the GYE. These nutritious nuts are available in the fall and are a key source of the late-season fat needed to sustain bears through hibernation.[134] Grizzly bear mortality rates are higher during years of low whitebark pine nut production as bears are forced to search for alternative foods at lower elevations and consequently come into increased conflict with humans.[135] Conversely, years of abundant whitebark nuts lead to increases in the bear populations and grizzly birth rates.[136] The importance of whitebark pine nuts as a food source for the bears is reflected in the strategy of the NPS and USFS for managing whitebark pine forests: The forest areas prioritized for protection and restoration are based partly on whether they are located within the primary conservation area designated for grizzly bears.[137]

Other grizzly bear food sources, such as large animal carcasses, are affected by climate change, too. Following milder winters—likely to become more common—fewer grizzly bear cubs survive, at least in part because fewer carcasses, especially those of elk, are available as food than following traditionally harsh winters.[138] (Black bears, gray wolves, foxes, coyotes, and bald and golden eagles—scavengers all—are similarly affected.)

Finally, grizzly bears have long congregated each June to feed on spawning Yellowstone cutthroat trout in streams flowing into Yellowstone Lake. This once reliable food source, however, has become increasingly scarce in recent years because of predation by introduced, non-native lake trout.[139] Hotter and drier conditions are expected to further diminish the cutthroat trout (see page 28)—and lake trout are not a replacement food source as they do not spawn in the streams and cannot be caught by the grizzly bears.

Grizzly bears are opportunistic omnivores and may survive these challenges. But a changing climate adds to the threats they face.

Wolverines

Wolverines, famously tough and fierce, embody the wildlands they inhabit—remote high-mountain expanses large enough to offer them the vast amount of room they need to roam. In Greater Yellowstone, these largest members of the weasel family are found in low numbers throughout the region, principally in the high elevations of the Bridger-Teton, Caribou-Targhee, and Gallatin national forests.

Wolverines, unfortunately, also illustrate how wildlife with precise climate-related habitat requirements are vulnerable to climate change. Wolverines seem to require mid-spring snow cover,

NPS

Wolverine, Yellowstone NP

which has been present at 98% of all documented wolverine dens and is the only studied habitat condition that fully corresponds with known denning sites, according to research by U.S. Forest Service scientists.[140] Females give birth in dens they have dug in persistent, stable snow more than five feet deep, which both insulates their young from cold and protects them from predators.[141] Consistent with this, scientists have documented that wolverine populations in Canada ebb and flow as snow cover increases and decreases.[142]

Wolverines are also vulnerable in a second way, which again illustrates how climate change can threaten other forms of wildlife. As adequate spring snow becomes restricted to only higher elevations, wolverines could become isolated in smaller areas, making it more difficult for young wolverines to range widely into new territory when they leave their parents—reducing the chances for genetic exchanges among different populations.[143] This could take away an asset any species needs to be able to adapt to profoundly different conditions: enough genetic variation in its population to give some individual animals different traits that may enable them to survive and carry on the species. Other species with small populations are also at increased risk from climate change for the same reason.[144]

Based on these threats to wolverines, the U.S. Fish and Wildlife Service determined in 2010 that they are a candidate for protection under the Endangered Species Act in the contiguous 48 states.[145] The agency found that "climate changes are likely to result in permanent loss of a significant portion of essential wolverine habitat within the foreseeable future."[146] FWS is now moving to the next step, doing a full review to determine whether to officially add wolverines to the list of species protected under the law.[147]

"The impacts of climate change constitute a threat to the contiguous [population] of the wolverine, and will likely be irreversible within the foreseeable future. Due to the magnitude and extent of the effects of climate change… the North American wolverine is likely to become in danger of extinction in the foreseeable future due to destruction, modification, and curtailment of its habitat and range by climate change."

U.S. Fish and Wildlife Service[148]

Lynx

Greater Yellowstone is one of the few places where Canada lynx, a threatened species in the contiguous United States under the Endangered Species Act, can still be found. Lynx are superbly adapted to snow cover, with huge, snowshoe-like feet for traveling on top of snow and catching prey in winter. Some scientists, in fact, have suggested that snow cover is an absolute habitat requirement for lynx.[149] Having determined that most areas where lynx now occur have four months of snow cover and average January temperatures under 17°F, these scientists have estimated that 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—including Bridger-Teton National Forest and Yellowstone and Grand Teton national parks. As the NPS states about climate-change effects on lynx in Yellowstone NP, "Canada lynx will have less habitat and food as snow cover decreases in amount and duration."[150]

"Snow-dependent species such as wolverine, lynx, and snowshoe hare are considered particularly vulnerable to climate change."

National Park Service[151]

Pikas

American pikas, climate-sensitive residents of cool, rocky, high-elevation areas, have disappeared from some sites in the West (outside of Greater Yellowstone) where they were previously documented. In some places where pikas persist, they can no longer be found in previously occupied lower-elevation portions of their ranges.[152] Many people consider pikas an indicator species of climate change effects, one that could run out of higher ground to escape a changing climate. As the U.S.

NPS

Pika, Grand Teton NP

government's 2009 national assessment of climate change impacts put it, "as species move up the mountains, those near the top simply run out of habitat."[153] After an Endangered Species Act review, the U.S. Fish and Wildlife Service recently concluded that climate change may eliminate more lower and mid-elevation portions of some populations by mid-century, with a greater risk if future emissions of heat-trapping gases are higher, but that based on current climate projections for mid-century neither the species as a whole nor any of the five recognized subspecies now qualifies as threatened or endangered.[154]

The NPS, however, concerned about what an altered climate may do to pikas in western national parks, has launched a "Pikas in Peril" study to monitor and assess the vulnerability of pika populations in eight national parks, including Yellowstone and Grand Teton, in the face of continued climate change.[155] It is too early for the detection of any trends in population levels or occupied areas in Greater Yellowstone.[156]

Elk

One GYE elk herd, the migratory Clarks Fork elk herd, which annually moves between the headwaters of the Lamar Valley in Yellowstone NP in summer and the Cody area in winter, is in recent decline, which could

Sascha Bukard/shutterstock.com

Bull elk, Yellowstone NP

be the result of changed climatic conditions. The herd has had pregnancy rates drop sharply in recent years, which scientists suspect could be resulting from the health effects of two climate-change related effects on their food.[157] First, warmer springs have led to earlier and more rapid green-up of vegetation on the summer range the herd migrates to, shortening the time in which the elk can take advantage of the highly nutritious early growth. Second, hotter, drier, and longer summers have led to more dried-out, less nutritious food late in the year.

A resident (non-migratory) elk herd in the same area has not experienced a similar decline in pregnancy rates. The decline of the Clarks Fork herd could be an illustration of how climate change can adversely affect migratory wildlife by causing a mismatch between the timing of their movements and the availability of climate-influenced food sources. These mismatches are becoming more common as interdependent species respond in different ways to changing climatic conditions, with evidence of effects on many species around the world.[158]

Other migratory wildlife in Greater Yellowstone could also be at risk, including the region's pronghorns. For thousands of years pronghorns have migrated for hundreds of miles between Grand Teton National Park and the Upper Green River Basin, in the longest remaining mammal migration in the contiguous United States.[159] The corridor used by the pronghorns is narrow and already heavily affected by land-use changes in the area, making any vegetation shifts caused by climate change even more threatening.

"Large-scale shifts have occurred in the ranges of species and the timing of the seasons and animal migration, and are very likely to continue."

U.S. Global Change Research Program[160]

BIRDS

With its large range of habitats, Greater Yellowstone is home to a rich variety of birdlife. In Yellowstone NP, for example, 330 different species have been documented.[161] Many bird species in the GYE could be affected by an altered climate, which could cause range shifts, and changes in migratory patterns and timing.[162]

The NPS concedes that "relatively few studies" have been conducted for climate-change impacts on birds in Greater Yellowstone and the surrounding larger region, but more efforts are now getting underway.[163] As one example, the Service intends to expand monitoring of the migration timing of birds in YNP.[164] Across the country and the planet, birds have already begun shifting the timing of their migrations and their breeding ranges in response to a changing climate, which can lead to major changes in which birds are present in particular areas.[165]

The birdlife of Greater Yellowstone may be less affected by climate change than in most other places, in large part because of the range of elevations present, which provide an opportunity for species to respond to changes in their current habitats by shifting to new suitable habitats.[166] Still, the current suite of birdlife is expected to change, as, for example, birds now found at lower-elevation surrounding areas shift into higher-elevation areas of the GYE.[167]

"Approximately 30 percent of bird species that breed in the park depend on wetlands. Scientists are concerned about these species because wetlands are expected to diminish as temperatures increase."

Yellowstone NP, NPS[168]

NPS

Trumpeter swans, Yellowstone NP

Some types of habitats in Greater Yellowstone and the bird species that inhabit them are more vulnerable than others. Alpine and wetland habitats are expected to diminish in the GYE, putting at risk the birds that depend on them, including the 30% of Yellowstone NP breeding bird species that depend on park wetlands.[169] According to the 2009 annual report of Yellowstone NP Bird Program, "The trumpeter swan and common loon are two wetland-dependant species that [in Yellowstone NP] have experienced declines in population (swans) and reproduction in recent decades that may be attributed to climate change."[170]

Trumpeter swans are North America's largest waterfowl and are among YNP's most magnificent birds. The park's resident trumpeter swans, which recently numbered only 14, also are among the most imperiled birds in the park, although the larger migratory population across Greater Yellowstone is stable. The recent decline in YNP's resident population appears to result from a variety of factors, including fewer swans taking up residence in the park, competition with migratory birds, and predation.[171] Addressing another possible reason, the park's 2009 annual bird report states, "It is speculated that a warmer, drier climate has reduced the quality and quantity of suitable wetlands in the region but the extent of these changes has not been quantified."[172] A focused study on the park's swans and their wetlands has been undertaken but not yet completed. A separate recent study identified "with strong support in the data" that YNP's resident trumpeter swan population fluctuates depending on annual weather conditions.[173] The strongest association between population changes and several weather conditions was that swan population increases followed cool summers, presumably because they lead to less drying of the wetlands used by the swans. This suggests that hotter future summers (see pages 11–12) could adversely affect Yellowstone NP's resident trumpeter swans.

The Yellowstone 2009 bird report similarly states with respect to loons, "Factors responsible for declines in nest attempts and fledglings is unknown; however, [they] may be the result of warmer, drier temperatures observed in the region which could reduce the availability of suitable nest sites."[174] The park's loons, too, are important components of Yellowstone's birdlife, representing one of the most southerly breeding populations in North America and one of the only populations breeding in Wyoming.

FISH

Hotter, drier summers and a reduced snowpack(see pages 11–12 and 16–17) pose major threats to the native coldwater trout of Greater Yellowstone. Cutthroat trout are found throughout the region, but have become increasingly rare due to habitat degradation and fragmentation and the introduction of non-native trout species. These fish require cool water temperatures at every stage of their lives, and a hotter climate is a threat to their survival.[175] In general, trout mortality is high in waters above 68°F and can be complete above 73°, especially if exposure lasts for an extended period.[176] Low flows are a substantial additional risk that compounds the problems caused by warmer waters.[177]

A recent USGS study examined the influence on western native trout and grayling species of a changed climate—of summers hotter by 5.4°F (roughly consistent with an average projection for 2070-2099 with lower emissions of heat trapping gases or sooner with medium-high emissions; see pages 11–12), more winter flooding, more wildfire, and more drought.[178] Included in the study were five species occurring in Greater Yellowstone: westslope, Yellowstone, Bonneville, and Colorado River cutthroat trout, and Montana Arctic grayling. All of the species were found to have a high risk in some portion of their range from one or more of the factors analyzed, most often from drought. The GYE fish populations were generally at a lower risk than populations in other basins, but the projected declines were still major. For example, only 34% of the populations of Colorado River cutthroat in the Upper Green basin, and just 53% of the Yellowstone cutthroat populations in the Yellowstone River basin were projected to persist in the future, changed conditions.

Another recently published study using 10 climate models and a scenario of medium future emissions of heat-trapping gases (scenario "A1B"—see page 13) projects a 28% decline in native cutthroat trout in the central and northern Rocky Mountains by the 2040s, and a 58% decline by the 2080s.[179]

For the effects on fishing in Greater Yellowstone, see pages 29–30.

"Large declines in trout populations are also projected to occur around the United States. Losses of western trout populations may exceed 60 percent in certain regions."

U.S. Global Change Research Program[180]

Loss of Visitor Enjoyment


NPS/Bob Greenburg

Yellowstone NP

The effects of a changing climate may interfere in several ways with the enjoyment people derive from Greater Yellowstone.

Increases in wildfires can disrupt vacations and other visits to Greater Yellowstone.

The region's prized fishing is likely to suffer.

Less snow will mean less opportunity to enjoy the special wonderland of Yellowstone NP in winter.

More downpours and flooding can disrupt public uses of the region.

Disruption from Wildfires

Projected increases in wildfire (see pages 21–22) could lead to more disruption of family vacations and other trips to the GYE. Some consequences from the huge fires in Yellowstone NP in 1988 illustrate how visitors can be affected.[181] On two separate occasions, about 4,000 people had to be evacuated from Grant Village, and other evacuations were required from various locations. Additionally, all lodging in the park, typically open until late September or mid-October, closed for the season on September 8, and two days later was the first day in YNP's history that the entire park was closed. The number of park visitors in August and September of 1988, was 371,000 below 1987 levels.[182]

NPS

Old Faithful park facilities, Yellowstone NP

Loss of Fishing

Greater Yellowstone is justly famous for its fishing, having long attracted anglers from around the world. The projected decline of trout populations in the region (see page 28) is a significant threat to fishing opportunities in the future. Even before populations begin to disappear from some of the region's streams, fishing closures are likely to be imposed to protect fish. Trout can die in waters that are too warm (see page 28); short of that point, warm waters can stress trout enough that being caught and released is more likely to kill them.[183] To avoid that, streams can be closed to fishing.

The effects of the hotter, drier conditions of 2000-2007 are telling. The summer of 2007's record-setting temperatures was the worst. By August, high water temperatures and low flows triggered fishing bans and restrictions on 29 stretches of Montana's world-renowned fishing streams and rivers.[184] Based on outfitters' reports, business was down 10% in 2007 on three prime fishing rivers—the Yellowstone and its Clarks Fork in the GYE region, and the Bitterroot.[185] The president of the Fishing Outfitters Association of Montana pegged outfitters' one-year income losses for just these three rivers at nearly $323,000.[186]

In Yellowstone NP, low flows and high water temperatures have led to fishing restrictions in 2002, 2003, and 2007.[187] From July into August, 2007, the NPS closed 232 miles of 17 prime fishing rivers and streams after 2:00 p.m. each day, when stream temperatures were highest.[188]

Perhaps as a result of the closures, in 2008 the number of annual fishing permits issued to YNP visitors dropped by nearly 30% below 2000 levels, from 67,700 to 48,300, even as total park visitation increased.[189] At stake is economic activity as well as visitor enjoyment; anglers in Yellowstone NP normally spend more than $4 million annually on their sport.[190]

"Given predictions of a warming climate, drought conditions in Yellowstone may persist long term, and actions to protect trout may become routine."

National Park Service[191]

akva/shutterstock.com

Yellowstone NP

LOSS OF WINTER RECREATION

Warmer winters very likely will decrease opportunities for snow-dependent outdoor winter recreation in the GYE. Yellowstone NP is an astonishing wonderland in winter, and the only park in the lower 48 states where most interior roads are closed in winter to conventional motor vehicles and instead groomed for travel by over-snow vehicles (OSVs)—snowcoaches and snowmobiles. The park, as it has several times in recent years, is currently considering what rules should apply to future OSV use. However, regardless of what type or mixture of OSVs are allowed in Yellowstone, the ability of visitors to experience the park by OSVs depends on adequate snow cover on the roads that are groomed for their use. According to the latest draft environmental impact statement prepared by the NPS, about 15 to 18 inches of cumulative snowfall is necessary to open the roads between Old Faithful to West Yellowstone to OSV use; mid-winter melt can be a problem for maintaining sufficient snow on roadways for OSVs; and spring melting of snow can end the OSV season.[192]

Already, snow levels in the park have declined, mid-winter snowfall is down, and winters are getting shorter as snow cover is now disappearing earlier (see pages 14–16). In several recent years, the NPS has had to delay the opening of the winter over-snow season, which used to be in mid-November, until the middle of December or even in the winter of 2004-2005 until January.[193] If winters continue to warm, the Yellowstone winter use season can be expected to continue to contract in the coming years.

NPS/Jim Peaco

Yellowstone NP

"As remarkable as Yellowstone National Park is during the rest of the year, the park in winter is a magical place. Steam and boiling water erupt from natural cauldrons in the park's ice-covered surface… snow-dusted bison exhale vaporous breaths as they lumber through drifts of white…foxes and coyotes paw and pounce in their search for prey in the deep snow…gray wolves bay beneath the frozen moon… No wonder the park is so popular in this magical, vulnerable season with those who have enjoyed its charms."

National Park Service[194]

HEAVY DOWNPOURS AND FLOODING

Because warmer air can hold more moisture, a hotter climate leads to larger downpours, which in turn leads to more flooding. Already, the amount of rain falling in the heaviest storms across the nation increased by 20% over the past century.[195] The U.S. government's 2009 national assessment of climate-change impacts says there is at least a 90% likelihood that heavy downpours will become even more frequent and intense.[196] An increase in these types of downpours likely leads to increased flooding as well.[197]

Greater Yellowstone has experienced its share of extreme weather consistent with increases in downpours and flooding. For example, in June 1996, Park County, Montana, experienced a record flood on the Yellowstone River, a 100-year event. The river's flow was very high for more than a week, caused massive bank erosion, and flooded a number of homes.[198] Just a year later, in June 1997, another 100-year flood hit the same spot, causing damage and flooding homes yet again.[199]

Downpours and flooding in other national parks suggest the problems that can be caused. In November 2006 at Glacier National Park, 12 inches of precipitation (mostly rain) fell in just six days—including 6 inches of rain in a 24-hour period, setting a record for Montana.[200] The damage forced road closures, required expensive emergency repairs, and kept visitors out of parts of the park.[201] The same storm in Mount Rainier National Park dumped 18 inches of rain in 36 hours, washing out roads, destroying trails, severing power, telephone and sewer systems, damaging campgrounds, and, in the National Park Service's words, "changing the landscape of the park forever."[202] Nearly the entire park was closed until the following May, with only 8% the normal number of park visitors until then.[203]

NPS/Jim Peaco

Camper caught in mudslide, Gibbon Canyon, Yellowstone NP

8

TACKLING CLIMATE DISRUPTION

Yellowstone NP employee pumps bio-diesel into truck

Protecting Greater Yellowstone will take actions to reduce heat-trapping pollution and to protect resources.

Federal agencies, Congress, and all of us have to do our share.

The Greater Yellowstone Coalition is doing its part to keep the ecosystem healthy in the face of these new threats.

As the risks of a changed climate dwarf all previous threats to special places such as Greater Yellowstone, so too must new actions to face these new risks be on an unprecedented scale. National parks, national forests, and other special areas 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 by the National Park Service will be especially important in Greater Yellowstone—not only to protect the resources and values of Yellowstone and Grand Teton national parks but also to take advantage of the 6.3 million visits a year to these parks. NPS can inform visitors of how climate change is threatening the parks they are visiting, show them what can be to reduce emissions of heat-trapping gases, and inspire them to take and support emission-reduction efforts when they return home.

In September 2010, NPS adopted a Climate Change Response Strategy that provides an excellent roadmap for National Park Service actions.[204] It includes many of the steps that are needed and are within the Service's control. NPS reinforced this in 2011 with its strategy for the Service's upcoming second century, stating as its first resource-protection goal, "To preserve America's special places in the next century, the NPS must manage the natural and cultural resources of the National Park System to increase resilience in the face of climate change and other stressors."[205] Now, NPS actions are needed to implement its strategies, and Congress and others need to take additional actions that are within their areas of responsibility. Examples include:

- 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 areas and about what is being done to address climate change and those impacts. NPS should require concessionaires to do so, too.
- The Congress and the Administration should adequately fund NPS actions to address a changing climate. A previous recommendation by the Rocky Mountain Climate Organization and the Natural Resources Defense Council is that NPS and other land-management agencies should be allowed to use funds from entrance and recreation fees to address climate change and its impacts, by both reducing emissions and protecting resources.[206] 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.
- The Congress and the Administration should restore and enhance the internal scientific and research capacity NPS had prior to 1993.

> *"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 Service[207]

Similar actions are needed by other federal agencies, individually and together. Both the U.S. Forest Service and the U.S. Fish and Wildlife Service also have new strategic plans for addressing the effects of climate change.[208] Federal agencies and other conservation partners are working together in a Great Northern Landscape Conservation Cooperative to address climate change impacts in the central and northern Rocky Mountains.[209] Fully carrying out these strategies and plans will be important in Greater Yellowstone, as elsewhere.

Ultimately, to protect the resources and values of Greater Yellowstone as well as the rest of the planet, we humans will need to reduce the extent to which we are polluting the atmosphere with heat-trapping gases. That will take action on many fronts by federal, state, and local governments, by the private sector, and by families and individuals. And the sooner we begin taking those actions, the better, in terms of reducing the extent to which we disrupt the planet's climate.

ADDRESSING CLIMATE CHANGE IN THE GREATER YELLOWSTONE ECOSYSTEM

Contributed by Scott Christensen, Greater Yellowstone Coalition

The Greater Yellowstone Ecosystem has a long and rich history of individuals, agencies, and organizations taking action to protect the iconic species and habitats found within the region. The threats posed by rapid climate change present new, more complex challenges that will require increased conservation efforts, along with new strategies and approaches to ensure the world's first national park and the lands that surround it continue to support this diverse and vital ecosystem. The Greater Yellowstone Coalition's goal is to give the habitats and wildlife of Greater Yellowstone the best chance possible to adapt to change as temperatures warm.

The Ecological Society of America has stated, "Ecosystems are naturally dynamic and diverse—they are the products of change and adaptation. But human activity has impaired the ability of many systems to respond. Preserving natural function is central to maintaining resilience and safeguarding ecosystem services in the face of climate change."[210] Preserving natural function in the Greater Yellowstone Ecosystem translates to an immediate need for increased conservation measures for vulnerable species and habitats, as well as targeted restoration efforts that seek to enhance ecological resilience to change.

Not only is there a need for increased conservation and restoration efforts, but this work must also be well coordinated and broadly distributed. Greater Yellowstone is a large, diverse, and complex landscape, with many different landowners and boundaries. Species such as deer, elk, pronghorn, and others rely on summer range within Yellowstone and Grand Teton national parks. They also rely on critical winter range found on lower-elevation public and private lands outside the protected confines of the parks system. Collaboration among public-land managers and private landowners will become increasingly important as habitats shift and wildlife species struggle to adapt.

The Greater Yellowstone Coalition relies on several key principles in pursuing climate- change adaptation strategies, and these should serve as recommendations for managing and conserving Greater Yellowstone in the face of climate change. Based on these principles, there are many site- and issue- specific actions that GYC is taking in order to reduce the impacts of climate change and enhance the adaptive capacity of this ecosystem.

- Reduce existing stressors to species and habitats:
  - Ensuring rivers and streams are protected from pollution associated with open pit phosphate mining and overseeing the cleanup of the 17 phosphate mine Superfund sites in located in eastern Idaho;
  - Phasing out the artificial winter feeding on the National Elk Refuge and state feedgrounds in western Wyoming to eliminate impacts from unnaturally dense concentrations of big game on habitat and the potential for devastating disease outbreaks; and
  - Restoring the world famous Yellowstone Lake population of Yellowstone cutthroat trout by removing non-native, illegally introduced lake trout.

- Protect and enhance water quality and quantity:
  - Enhancing habitat conditions for the four native cutthroat trout subspecies of Greater Yellowstone in places where they are likely to persist in a warmer climate;
  - Preventing new, proposed dams on East and West Rosebud Creeks and on the Bear

- River, as well as proposed hydropower developments on the Madison River at Quake Lake and the Snake River in Idaho; and
  - Continuing efforts to improve aquatic habitat and enhance Bonneville cutthroat trout populations in the Bear River Watershed.

- Protect and enable natural movement and migration of wildlife;
  - Protecting critical winter range and migration corridors in the Green River Basin and along the Absaroka-Beartooth Front in western Wyoming;
  - Securing protections for key public and private lands west of Yellowstone National Park in the Henry's Fork and Madison Watersheds, and in the Centennial and Snowcrest Mountains, so that wildlife can move and migrate between Yellowstone and other large protected ecosystems in central Idaho and northwest Montana;
  - Designating the Hyalite-Porcupine-Buffalo Horn Wilderness Study Area within the Gallatin Range as Wilderness;
  - Ensuring grizzly bears are adequately protected and able to access new habitats and food sources as climate change impacts whitebark pine and cutthroat trout;
  - Protecting the northern portion of the Bridger-Teton National Forest from the fragmenting effects of oil and gas development; and
  - Restoring and maintaining wildlife permeability across highways by advocating for wildlife crossing structures that increase safety and promote connectivity.
- Improve our capacity to predict future changes and extreme events:
  - Increasing funding for climate change research in Greater Yellowstone; and
  - Creating partnerships with the scientific and academic community to initiate research and develop climate-change projections and impacts analyses that inform conservation actions.

- Manage collaboratively at the ecosystem level:
  - Leading and facilitating the Greater Yellowstone Ecosystem Climate Change Working Group; and
  - Creating new collaborations to manage across boundaries in key areas of Greater Yellowstone, such as the Madison and Centennial valleys, Henry's Fork Watershed, Gallatin Range, and Absaroka-Beartooth Front.

- Employ careful, well-informed interventions or treatments:
  - Implementing scientifically rigorous and well monitored habitat-restoration projects that improve habitat resilience;
  - Designing and testing small-scale pilot projects focused on improving resilience and maintaining natural processes, such as fire, floods and wildlife migrations; and
  - Managing high-elevation lands to protect healthy whitebark pine stands.


NPS/Jim Peaco

Solar panels at Buffalo Ranch in Lamar Valley, Yellowstone NP

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.

Figures 3 and 4: Past Temperature Trends

For the analysis presented in figures 3 and 4, the weather stations are the Hebgen Dam, MT, U.S. Cooperative Observing Network (COOP) station 244038; the Yellowstone Park/Mammoth, WY, weather station, COOP station 489905; the Cody, WY, station, COOP station 481840; the Moran 5 WNW, WY, COOP station 486440; and the Grace, Idaho, station, COOP station 103732. These stations are part of the U.S. Historical Climatology Network (USHCN). Other USHCN stations within Greater Yellowstone were considered for inclusion in this analysis, including the Norris Madison PH, Red Lodge, and West Yellowstone in Montana and the Lake Yellowstone and Alta stations in Wyoming, but they do not have as complete records of actual observations (as opposed to estimated values) as the five stations included in the analysis.

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.[211] 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. The stations in the USHCN 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.

The data for figures 3 and 4 are from the USHCN, meaning that the data have been reviewed and adjusted as necessary for reliable long-term analysis—such as by adjusting data to compensate for movements of weather stations over time so that the data can be reliably compared; by including estimated values, based on measurements elsewhere from surrounding areas, to fill in gaps when actual measurements are missing; and by excluding daily data that fail data-quality tests. As stated above, the analysis in this report is based on those USHCN stations with few estimated, missing, or excluded values.

Using averages of USHCN stations with particularly complete data records as estimates of region-wide temperatures is a method commonly used by scientists, even though this is using a relatively few points within the region.[212] Another method is to use data from all available weather stations, which are aggregated for this purpose by NOAA into climate divisions, sub-regions of states that in the western United States typically are based on river basins. There are weaknesses with this method: The climate divisions rarely correspond exactly with the region of interest (in this case, Greater Yellowstone); the number of stations changes dramatically over time; most stations have not been in existence for the full period of review, as some have been added and some discontinued; most weather stations in existence for long periods of time have moved to different locations; many data are missing; and the data have not been subject to quality reviews or adjustments. Nevertheless, as another point of comparison with the analysis of the USHCN data presented in Figure 3, RMCO performed a parallel analysis of the 1901-2010 temperatures trends for the two NOAA climate divisions entirely located within Greater Yellowstone, Wyoming climate divisions 1 (the Yellowstone River drainage) and 2 (the Snake River drainage). An area-weighted average of the data from those two climate divisions also suggests that the latest decade (2001-2010) was the hottest in the period 1901-2010 and that that decade averaged 1.4°F above the 1900-1901 average temperature, the same value shown for that decade in Figure 3.[213]

Table 3: Projected increases in annual average temperatures

The data for Table 3 were obtained by the Rocky Mountain Climate Organization 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).[214] 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 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 Yellowstone NP 56 grids and for Grand Teton NP three grids, each 1/8 of a degree of longitude by 1/8 of a degree of latitude, with overall boundaries as shown in the following table.

National Park	Latitude	Longitude
Yellowstone NP	44.125° to 45.0°	-110.0° to -111.0°
Grand Teton NP	43.625° to 44.0°	-110.625° to 110.75°

Table App-1. Grids used for climate projections for the Greater Yellowstone national parks.

The grids described above cover most of Yellowstone NP and most of the lower-elevation portion of Grand Teton NP east of the Teton Range.

Projections of surface temperature were obtained from the first listed model run for each of the 16 climate models in the CMIP3 dataset (the models are listed below), 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 individual models used for this analysis are:

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. Global Climate Models used for projection scenarios.

For each combination of emissions scenario and climate model, the projections for a future period (2030-2059 or 2070-2099) was compared to the modeled results using that scenario and climate model for the baseline period of 1971-2000, yielding a projected increase in the average temperature for the future period compared to the baseline period.

Climate projections using these scenarios and climate models yield precise-appearing numbers, but they should be taken as indications of how the future could unfold, not as predictions of what is most likely to happen. The current state of scientific knowledge is probably best reflected not by any one scenario or modeled projection, but by paying attention to the average of results from multiple scenarios and models, the range of those results, and the degree of agreement or disagreement among them.

The new RMCO projections of future annual (or, more accurately, year-round) temperatures are generally consistent with other projections of national and regional temperature changes, including those in U.S. government's 2009 national assessment. It includes projections that by the end of the century the country would average about 4 to 6.5°F hotter with lower future emissions or about 7 to 11°F hotter with medium-high future emissions.

Regional climate projections by the Climate Impacts Group (CIG) at the University of Washington for the multi-state Northwest region are presented in Table App-3. These projections are for a much larger area than the GYE, which only partially overlaps the GYE: the area between -124° and -111° west longitude and 41.5° to 49.5° north latitude—the states of Washington, Oregon, and Idaho; western Montana; and a small slice of adjacent states and British Columbia. For these projections, a slightly different set of climate models and model runs were used than for the RMCO projections—19 models with lower future emissions and 17 with medium-high future emissions (A2).[215] (The CIG projections also include models using a medium future emissions scenario, the A1B scenario, not shown in Table App-3.

As these CIG regional projections were obtained from sources and with a methodology very similar to the more locally-focused RMCO projections, they are believed by RMCO to be the best regional projections for a general comparison with the RMCO projections and for confirming that how much future temperatures increase will depend on future levels of emissions. In fact, we chose to use in our projections the same future periods of 2030-2059 and 2070-2099 as in the CIG projections to enable comparisons between the two projections.

Projected Regional Annual Temperature Changes, Pacific-Northwest Region		
	Lower Future Emissions	**Medium-High Future Emissions**
2030–2059	+1.6 to 4.8° F	+2.1 to 5.4°F
2070–2099	+3.7 to 7.1°F	+3.8 to 11.2°F

Table App-3. Projected changes in annual (or year-round) temperatures in the Northwest region, compared to a 1970–1999 baseline, with emission scenarios as identified on page 13. Source: Mote and Salathé.

Table 4: Projected Yellowstone National Park Summer Temperatures

Projected differences in June-July-August temperatures were obtained from the CMIP3 dataset referred to above, using the same models and model runs identified above, for 2030-2059 and 2070-2099, both compared to modeled 1971-2000 levels, but in this case using only the medium-high emissions scenario (A2). The projected differences were added to the measured 1971-2000 June-July-August average mean temperature for the Yellowstone National Park/Mammoth, Wyoming, station, chosen to represent Yellowstone NP for the reasons stated above, using monthly data from the U.S. Historical Climatology Network. That average 1971-2000 summer temperature at the Yellowstone/Mammoth station was 54.7°F.

The 1971-2000 June-July-August temperatures for the comparison locations are from the the National Climatic Data Center's 1971-2000 normal monthly temperatures, obtained from the Southern Regional Climate Center.

The RMCO projections of changes in average summer temperatures in Yellowstone NP are generally consistent with other projections for summer temperatures in the region. The University of Washington Climate Impact Group's regional projections for the Pacific Northwest described above also include projections of temperature changes in future summers—which also are projected to be greater than those of other seasons. Those projections are shown in the table on the next page.

Projected Regional Summer Temperature Changes Pacific-Northwest Region				
	Lower Future Emissions		Medium-High Future Emissions	
	2030-2059	2070-2099	2030-2059	2070-2099
Average Projection	+3.2°F	+5.0°F	+4.5°F	+7.9°F
Range of Projections	+1.4 to 5.6°F	+2.5 to 8.6°F	+2.0 to 8.0°F	+3.2 to 12.4°F

Table App-4. Projected changes in June-July-August temperatures in the Northwest region, as in Table App-3. Source: Mote and Salathé.

NOTES

For general information on climate change and its overall impacts, readers are referred to a report by the U.S. government's Global Change Research Program, *Global Climate Impacts in the United States*, released in 2009, which is cited in many of the following notes, beginning with number 17. This national assessment is both comprehensive and, and unlike most scientific publications, easily readable. For any reader interested in digging deeper, it also lists several hundred sources on particular points.

1. S. Saunders and T. Easley, *Losing Ground: Western National Parks Endangered by Climate Disruption*, report of the Rocky Mountain Climate Organization [RMCO] and Natural Resources Defense Council [NRDC] (New York, NY: NRDC, 2006), http://www.rockymountainclimate.org/website%20pictures/Losing%20Ground.pdf; S. Saunders, T. Easley, and S. Farver, *National Parks in Peril: The Threats of Climate Disruption*, report of RMCO and NRDC (Denver, CO: RMCO, 2009), http://www.rockymountainclimate.org/programs_6.htm; National Park Service [NPS], *National Park Service Climate Change Response Strategy* (Fort Collins, CO: Climate Change Response Program, NPS, 2010), http://www.nature.nps.gov/climatechange/docs/NPS_CCRS.pdf.

2. NPS, *Climate Change Response Strategy* (see note 1).

3. Saunders, Easley, and Farver, *National Parks in Peril* (see note 1).

4. National Parks Conservation Association [NPCA], *Gateways to Yellowstone: Protecting the Wild Heart of Our Region's Thriving Economy* (Helena, MT: NPCA, 2006), p. 19, www.npca.org/northernrockies/gateway.

5. C. Oschell and N. Nickerson, "Niche news: 2010 3rd quarter nonresident visitor characteristics," (Missoula, MT: Institute for Tourism & Recreation Research [ITRR], University of Montana, 2010), http://www.itrr.umt.edu/nonresNNQNR.htm; C. Oschell, "Niche news: 2010 2nd quarter nonresident visitor characteristics (Missoula, MT: ITRR, University of Montana, 2010), http://www.itrr.umt.edu/nonresNNQNR.htm.

6. Oschell and Nickerson, "Niche news: 2010 3rd quarter" (see note 5).

7. NPCA, *Gateways to Yellowstone* (see note 4), p. 19.

8. NPS, "Economic benefits to local communities from national park visitation and payroll, 2009," D. Stynes, author (Fort Collins, CO: Natural Resource Program Center [NRPC], NPS, 2010), http://www.nature.nps.gov/socialscience/docs/NPSSystemEstimates2009.pdf.

9. NPS, "Economic benefits to local communities" (see note 8).

10. U.S. Forest Service [USFS], National Visitor Use Monitoring, Natural Resource Manager, Natural Resource Information System, http://apps.fs.usda.gov/nrm/nvum/results/Forest.aspx.

11. S. M. Miller, *Wildlife's Contribution to the Greater Yellowstone Regional Economy* (Lolo, MT: Dunrovin Research, 2006), p. 7, Table 2A, http://www.npca.org/northernrockies/gateways_yellowstone/Dunrovin-GYE-Wildlife-Feb-2006.pdf.

12. NPCA, *Gateways to Yellowstone* (see note 4), p. 22; Yellowstone NP, NPS, *Yellowstone Fisheries & Aquatic Sciences Annual Report 2008*, p. 29, http://www.nps.gov/yell/planyourvisit/upload/2008_fisheries_ar_final.pdf.

13. NPCA, *Gateways to Yellowstone* (see note 4), p. 8.

14. R. B. Richardson and J. B. Loomis, "The effects of global warming on mountain tourism: A contingent behavior methodology," prepared for N. Hobbs and others, *Future Impacts of Global Climate on Rocky Mountain National Park: Its Ecosystems, Visitors, and the Economy of Its Gateway Community – Estes Park*, (2003), pp. 16–17; J. B. Loomis and R. B. Richardson, "An external validity test of intended behavior: Comparing revealed preference and intended visitation in response to climate change," *Journal of Environmental Planning and Management*, vol. 49 (2006), 621–630; see also F. G. Sussman and others, "Effects of Global Change on Human Welfare," in U.S. Climate Change Science Program [USCCSP], *Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems*, J. L. Gamble, editor (Washington, D.C.: U.S. Environmental Protection Agency [EPA], 2008), pp. 111–168, p. 148, http://www.globalchange.gov/publications/reports/scientificassessments/saps/308.

15. D. Scott and B. Jones, *Climate Change & Nature-Based Tourism: Implications for Park Visitation in Canada* (Waterloo, Ontario: University of Waterloo, 2006), http://www.fes.uwaterloo.ca/u/dj2scott.

16. Scott and Jones, "Climate change" (see note 15); D. Scott, B. Jones, and J. Konopek, "Implications of climate and environmental change for nature-based tourism in the Canadian Rocky Mountains: A case study of Waterton Lakes National Park," *Tourism Management*, vol. 28 (2007), pp. 570–579.

17. U.S. Global Change Research Program [USGCRP], *Global Climate Change Impacts in the United States*, T. R. Karl, J. M. Melillo, and T. C. Peterson, editors (New York, NY: Cambridge University Press, 2009), pp. 22–23, available at: http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/download-the-report.

18. USGCRP, *Climate Change Impacts* (see note 17).

19. Intergovernmental Panel on Climate Change [IPCC], "Summary for policymakers," S. Solomon and others, authors, in IPCC, *Climate Change 2007: The Physical Science Basis*, S. Solomon and others, editors (New York, NY: Cambridge University Press, 2007), pp. 3, 8, http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf.

20. National Research Council of the National Academies, *Advancing the Science of Climate Change* (Washington, DC: National Academies Press, 2010), p. 3, available at http://www.nap.edu/catalog.php?record_id=12781.

21. American Association for the Advancement of Science, "AAAS board statement on climate change" (2006), http://www.aaas.org/news/press_room/climate_change/mtg_200702/aaas_climate_statement.pdf; American Geophysical Union, "AGU position statement: Human impacts on climate" (2007), http://www.agu.org/sci_pol/positions/climate_change2008.shtml; American Chemical Society, "Climate change" (2010), http://portal.acs.org/portal/PublicWebSite/policy/publicpolicies/promote/globalclimatechange/WPCP_011538.

22. USGCRP, *Climate Change Impacts* (see note 17), pp. 16, 19–20; IPCC, "Technical Summary," in IPCC, *The Physical Science Basis* (see note 19), p. 60.

23. USGCRP, *Climate Change Impacts* (see note 17), p. 16.

24. National Climatic Data Center [NCDC], National Oceanic and Atmospheric Administration [NOAA], "The annual global (land and ocean combined) anomalies (degrees C)," ftp://ftp.ncdc.noaa.gov/pub/data/anomalies/monthly.land_ocean.90S.90N.df_1901-2000mean.dat; see also NCDC, NOAA, "Global surface temperature anomalies," http://www.ncdc.noaa.gov/cmb-faq/anomalies.html. Decadal average and comparison calculated by RMCO.

25. NCDC, "Annual global anomalies" (see note 24).

26. IPCC, "Summary for policymakers" (see note 19), 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 24, so the IPCC comparison also holds true for the entire decade of 2001-2010.

27. See, e.g., USGCRP, *Climate Change Impacts* (see note 17).

28. United Nations Framework Convention on Climate Change [UNFCCC], http://unfccc.int/resource/docs/convkp/conveng.pdf.

29. Data from NCDC, NOAA, "Annual global anomalies" (see note 24); see also NCDC, NOAA, "Global surface temperature anomalies" (see note 24). Decadal averages and comparisons calculated by RMCO.

30. UNFCCC, "Conference of the Parties: The Cancun Agreements" (2010), http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf#page=2.

31. USGCRP, *Climate Change Impacts* (see note 17), p. 28.

32. S. Saunders, C. Montgomery, and T. Easley, *Hotter and Drier: The West's Changed Climate*, report of RMCO and NRDC (New York, NY: NRDC, 2008), http://www.rockymountainclimate.org/website%20pictures/Hotter%20and%20Drier.pdf.

33. C. Bonfils and others, "Detection and attribution of temperature changes in the mountainous western United States," *Journal of Climate*, vol. 21 (2008), pp. 6404-6424.

34. Data from NCDC, NOAA, "Annual global anomalies" (see note 24); see also NCDC, NOAA, "Global surface temperature anomalies" (see note 24). Decadal averages and comparisons calculated by RMCO.

35. NPS, "Yellowstone NP reports: Visitation by month/year," available at NPS, NPS Stats, http://www.nature.nps.gov/stats/park.cfm.

36. D. B. McWethy and others, *Climate and Terrestrial Ecosystem Change in the U.S. Rocky Mountains and Upper Columbia Basin: Historical and Future Perspectives for Natural Resource Management* (Fort Collins: Natural Resource Program Center, NPS, 2010), p. 31, https://irma.nps.gov/gueststs/users/issue.aspx?wa=wsignin1.0&wtrealm=https%3a%2f%2firma.nps.gov%2fapp%2f&wctx=rm%3d0%26id%3dpassive%26ru%3d%252fApp%252fReference%252fDownloadDigitalFile%253fcode%253d419538%2526file%253dMcWethy_et_al_2010_NPS_NRR260_Climate_Terrestrial_Change_RockyMtns_UprColBasin.pdf&wct=2011-09-11T23%3a21%3a23Z.

37. Data from NCDC, NOAA, "Annual global anomalies" (see note 24); see also NCDC, NOAA, "Global surface temperature anomalies" (see note 24). Decadal averages and comparisons calculated by RMCO.

38. NPS, "Key climate change messages," http://www.nature.nps.gov/climatechange/docs/NPSKeyClimateChangeMessages.pdf.

39. USGCRP, *Climate Change Impacts* (see note 17), p. 22.

40. USGCRP, *Climate Change Impacts* (see note 17), p. 22.

41. The data in this table are bias-corrected and spatially downscaled climate projections derived from the World Climate Research Program's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset; provided by Lawrence Livermore National Laboratory, U.S. Bureau of Reclamation, Santa Clara University, and Climate Central and served at: http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/; and described by E. P. Maurer and others, "Fine-resolution climate projections enhance regional climate change impact studies," *Eos, Transactions, American Geophysical Union*,

vol. 88 (2007), p. 504. We acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modeling (WGCM) for their roles in making available the WCRP CMIP3 multi-model dataset. Support of this dataset is provided by the Office of Science, U.S. Department of Energy. For an explanation of the methodology used for this report, see the Appendix (pages 35-38).

42. "Added value of regional climate model simulations," in USCCSP, "*Climate Models: An Assessment of Strengths and Limitations*, D. C. Bader and others, authors (Washington, DC: U.S. Department of Energy, 2009), http://www.globalchange.gov/publications/reports/scientific-assessments/saps/298.

43. USGCRP, *Climate Change Impacts* (see note 17), p. 22.

44. USGCRP, *Climate Change Impacts* (see note 17), p. 22.

45. P. W. Mote and E. P. Salathé, Jr., "Future Climate in the Pacific Northwest," in Climate Impacts Group [CIP], University of Washington, *The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate*, J.S. Littell and others, editors (Seattle, WA: CIP, University of Washington, 2009), pp. 21-43, p. 34; McWethy and others, *Ecosystem Change in the U.S. Rocky Mountains* (see note 36), figure 34, p. 47; A. J. Ray and others, "Rapid-response climate assessment to support the FWS status review of the American Pika," 2010, figure 22, p. 27, http://www.esrl.noaa.gov/psd/news/2010/pdf/pika_report_final.pdf; but see C. Boisvenue and S. W. Running, "Simulations show decreasing carbon stocks and potential for carbon emissions for Rocky Mountain forests over next century," *Ecological Applications*, vol. 20 (2010), pp. 1302–1319, which reports that three climate models using a scenario of medium future emissions project that winter temperatures in the Northern Rocky Mountains may increase more than in other seasons.

46. See note 41.

47. City data for comparison purposes from NCDC, NOAA, available at Southern Regional Climate Center, "1971-2000 NCDC Monthly Normals," http://www.srcc.lsu.edu/climateNormals/.

48. With a 5.2°F increase beyond its 1971-2000 average mean temperature in June, July, and August, using U.S. Historical Climatology Network data (see note 212), the Mammoth Yellowstone weather station would average 66.3°F in summer, and with a 15.0°F increase would average 76.0°F. The 1971-2000 average mean June-July-August temperature for the Spokane, Washington, weather station (COOP station number 457938) was 66.3°F and that for the Albuquerque International Airport weather station (station number 290234) was 76.5°F, according to the NCDC 1971-2000 climate normals (see note 47).

49. 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, (Washington, DC: EPA, 2008), p. 4-4, http://downloads.climatescience.gov/sap/sap4-4/sap4-4-final-report-all.pdf.

50. USGCRP, *Climate Change Impacts* (see note 17), pp. 22–23.

51. The A2 scenario yields atmospheric concentrations of carbon dioxide of about 970 parts per million by 2100, Hayhoe and others, "Past and future changes in climate and hydrological indicators in the U.S. Northeast, *Climate Dynamics* (2006), p. 3, http://www.northeastclimateimpacts.org/pdf/tech/hayhoe_et_al_climate_dynamics_2006.pdf. The mean monthly atmospheric concentration of carbon dioxide in May 2011 was 392 parts per million, Earth System Research Laboratory, NOAA, "Trends in atmospheric carbon dioxide: global," http://www.esrl.noaa.gov/gmd/ccgg/trends/global.html#global_data.

52. The B1 scenario yields atmospheric concentrations of carbon dioxide of about 550 parts per million by 2100, Hayhoe and others, "Changes in the Northeast" (see note 51), p. 3. Compare NOAA, "Trends in atmospheric carbon dioxide (see note 51).

53. Scenario B1 is referred to here as a "lower" emissions scenario, as it often in other reports and studies. Scenario A2, is referred to here as a "medium-high" scenario, similar to its characterization in a 2010 Great Lakes climate-change study by Katharine Hayhoe and others (in which it is called it a "mid-high" scenario) and in reports by the California Climate Change Center (where it is called "medium-high," as it is here). Hayhoe, "Regional climate change projections" (see note 51), pp. 7–21 and S. Moser and others, "The future is now: An update on climate change science impacts and response options for California," California Climate Change Center (2009), p. 40, http://www.energy.ca.gov/2008publications/CEC-500-2008-071/CEC-500-2008-071.PDF. The U.S. government's 2009 national climate-change assessment report also used these same two emissions scenarios. USGCRP, *Climate Change Impacts* (see note 17), for example, note 93, p. 169, and note 109, p. 170.

54. M.R. Raupach and others, "Global and regional drivers of accelerating CO_2 emissions," *Proceedings of the National Academy of Sciences*, vol. 104 (2007), pp. 10288–10293. In the last few years, emissions have grown at a somewhat slower rate than in the 2000-2004 period, with an actual slight decline between 2008 and 2009 in emissions from fossil-fuel consumption because of the worldwide recession. Still, in the nine years from 2000 to 2009, emissions from fossil-fuel burning grew by 28%, compared to 11% over the previous nine years, the time during which the current emissions scenarios were developed. (U.S. Energy Information Administration (USEIA), "Total carbon dioxide emissions from the consumption of energy," spreadsheet available

at USEIA, "International energy statistics," http://tonto.eia.doe.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=90&pid=44&aid=8). As a result of the higher-than-expected growth in emissions, in the next round of IPCC reports, scenarios at the higher end of the current range (including A2, the "medium-high" scenario used in this report, as well as those assuming emissions above its level), will be considered intermediate ones and new scenarios with even higher emissions assumptions will be developed. (S. Moser and others, "The future is now" (see note 53), p. 40; R. Moss and others, *Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies,* IPCC, Geneva, Switzerland (2009), http://www.ipcc.ch/pdf/supporting-material/expert-meeting-report-scenarios.pdf).

55. USGCRP, *Climate Change Impacts* (see note 17), p. 24.

56. Figure obtained from IPCC, "Figures and tables," figure 3-1, http://www.ipcc.ch/publications_and_data/publications_and_data_figures_and_tables_IPCC_AR4_synthesis_report_SYR.htm.

57. Snowfall versus rainfall: N. Knowles, M. Dettinger, and D. Cayan, "Trends in snowfall versus rainfall for the western United States, 1949–2004," *Journal of Climate*, vol. 19 (2006), pp. 4545–4559. Snowpack: P. Mote and others, "Declining mountain snowpack in western North America," *Bulletin of the American Meteorological Society*, vol. 86 (2005), pp. 39–49; S. Regonda and B. Rajagopalan, "Seasonal climate shifts in hydroclimatology over the western United States," *Journal of Climate*, vol. 18 (2005), p. 377; Snowmelt: I. Stewart, D. Cayan, and M. Dettinger, "Changes in snowmelt runoff timing in western North America under a 'business as usual' climate change scenario," *Climatic Change*, vol. 62 (2004), pp. 217–232.

58. D. W. Pierce and others, "Attribution of declining western U.S. snowpack to human effects," *Journal of Climate*, vol. 21 (2008), pp. 6425–6444; T. Barnett and others, "Human-induced changes in the hydrology of the western United States," *Science*, vol. 319 (2008), pp. 1080–1083; P. Mote, "Climate-driven variability and trends in mountain snowpack in western North America," *Journal of Climate*, vol. 19 (2006), pp. 6209-6220.

59. IPCC, "North America," C. B. Field and others, authors, in IPCC, *Climate Change 2007: Impacts, Adaptation and Vulnerability*, M.L. Parry and others, eds. (Cambridge, UK: Cambridge University Press, 2007), p. 621.

60. McWethy and others, *Ecosystem Change in the U.S. Rocky Mountains* (see note 36), p. 38.

61. McWethy and others, *Ecosystem Change in the U.S. Rocky Mountains* (see note 36), p. 38.

62. McWethy and others, *Ecosystem Change in the U.S. Rocky Mountains* (see note 36), p. 38, citing Knowles, Dettinger, and Cayan (see note 57).

63. G. T. Pederson and others, "The unusual nature of recent snowpack declines in the North American cordillera," *Science*, vol. 333 (2011), pp. 332–335, published online in *Science Express*, June 9, 2011, http://www.sciencemag.org/content/early/2011/06/08/science.1201570.

64. C. C. Wilmers and W. M. Getz, "Gray wolves as climate change buffers in Yellowstone," *PLoS Biology*, vol. 3 (2005), pp. 0571-0576, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1064850/pdf/pbio.0030092.pdf.

65. Wilmers and Getz, "Wolves as climate change buffers" (see note 64), p. 0572.

66. IPCC, "Observations: Changes in snow, ice, and frozen ground," P. Lemke and others, authors, in IPCC, *The Physical Science Basis* (see note 19), pp. 5, 10.

67. Saunders, Easley, and Farver, *National Parks in Peril* (see note 1), pp. 7-9.

68. J. Edmonds and G. Tootle, "Glacial surface area change in Grand Teton National Park," 2008, http://www.cfc.umt.edu/cesu/NEWCESU/Assets/Individual%20Project%20Reports/NPS%20Projects/Wyoming/2008/08Tootle%20_GRTE_glacier%20variability_irpt.pdf.

69. D. Seifert and others, "Monitoring alpine climate change in the Beartooth Mountains of the Custer National Forest," abstract, in *Agenda and Abstracts, Questioning Greater Yellowstone's Future: Climate, Land Use, and Invasive Species*, p. 28, from 10th Biennial Scientific Conference on the Greater Yellowstone Ecosystem, Oct. 11-13, 2010, Yellowstone NP, available at http://www.greateryellowstonescience.org/gyesciconf2010.

70. Figure supplied by and courtesy of G. T. Pederson, Northern Rocky Mountain Science Center, USGS, from Pederson and others, "Unusual nature of recent snowpack declines" (see note 63).

71. D. M. Debinski and others, "Montane meadow change during drought varies with background hydrologic regime and plant functional group," *Ecology*, vol. 91 (2010), pp. 1672–1681, http://www.fedgycc.org/documents/10Debinski_GYE_CCandmeadows_Ecology.pdf.

72. S. K. McMenamin, E. A. Hadly, and C. K. Wright, "Climatic change and wetland desiccation cause amphibian decline in Yellowstone National Park," *Proceedings of the National Academy of Sciences,* vol. 105 (2008), pp. 16988–16993.

73. Boisvenue and Running, "Emissions for Rocky Mountain forests" (see note 45).

74. USGCRP, *Climate Change Impacts* (see note 17), pp. 45-46.

75. J. Lundquist and J. Roche, "Climate change and water supply in western national parks," *Park Science*, vol. 26, (2009), http://www.nature.nps.gov/parkscience/index.cfm?ArticleID=285.

76. S. Gray and C. Anderson, *Assessing the Future of Wyoming's Water Resources: Adding Climate Change to the Equation*, (Laramie, WY: William D. Ruckelshaus Institute of Environment and Natural Resources, University of Wyoming, 2009), p. 8, http://www.uwyo.edu/enr/_files/docs/UofW-Water_Climate_final_comp.pdf#Water and Climate Report.

77. S. T. Gray and G. J. McCabe, "A combined water balance and tree ring approach to understanding the potential hydrologic effects of climate change in the central Rocky Mountain region," *Water Resources Research*, vol. 46 (2010), pp. W05513 (1–13).

78. Mote and Salathé, Jr., "Future climate in the Pacific Northwest" (see note 45), p. 31.

79. Mote and Salathé, Jr., "Future climate in the Pacific Northwest" (see note 45), p. 31.

80. Mote and Salathé, Jr., "Future climate in the Pacific Northwest" (see note 45), figure 10, p. 35.

81. USGCRP, *Climate Change Impacts* (see note 17), p. 30.

82. McWethy and others, *Ecosystem Change in the U.S. Rocky Mountains* (see note 36), p. 39.

83. Boisvenue and Running, "Emissions for Rocky Mountain forests" (see note 45).

84. S. Running, *Impacts of Climate Change on Forests of the Northern Rocky Mountains* (Missoula, MT: University of Montana, 2009), p. 4, http://www.bipartisanpolicy.org/sites/default/files/RockyClimate-pages-Proof150.pdf.

85. For information on whitebark pines and their ecological roles as outlined in this paragraph, see FWS, "Endangered and threatened wildlife and plants; 12-month finding on a petition to list *Pinus albicaulis* as endangered or threatened with critical habitat," *Federal Register*, July 19, 2011, pp. 42631-42654; Rocky Mountain Research Station (RMRS), USFS, *The Future of High-Elevation, Five-Needle White Pines in Western North America: Proceedings of the High Five Symposium, 28-30 June 2010, Missoula, Montana*, R. E. Keane and others, editors, (Fort Collins, CO: RMRS, USFS, 2011), http://www.fs.fed.us/rm/pubs/rmrs_p063.html; D. F. Tomback, S. F. Arno, and R. E. Keane, editors, *Whitebark Pine Communities: Ecology and Restoration* (Washington, DC: Island Press, 2001); Greater Yellowstone Science Learning Center, "Whitebark pine," http://www.greateryellowstonescience.org/topics/biological/vegetation/whitebark-pine; and D. Gonzalez and N. Bockino, "Whitebark Pine of the GYE – An Overview," TreeFight, http://www.treefight.org/whitebark-pine-of-the-gye/.

86. FWS, "Finding on Pinus albicaulis (see note 85), p. 42635.

87. FWS, "Finding on Pinus albicaulis (see note 85), p. 42638.

88. B. Bentz and others, "Mountain Pine Beetle in High-Elevation Five-Needle White Pine Ecosystems," in RMRS, *Five-Needle Pine Symposium* (see note 85), pp. 78-84, pp. 80-81.

89. USFS, "Wyoming forest heath highlights 2008," 2008, pp. 1–3, p. 2, http://www.fs.fed.us/foresthealth/fhm/fhh/fhh_08/wy_fhh_08.pdf.

90. W. Macfarlane, J. Logan, and W. Kern, "Using the landscape assessment system (LAS) to assess mountain pine beetle-caused mortality of whitebark pine, Greater Yellowstone Ecosystem, 2009: Project report," prepared for the Greater Yellowstone Coordinating Committee, Whitebark Pine Subcommittee (Jackson, WY: Geo/Graphics, Inc., 2010), pp. 1–69.

91. Greater Yellowstone Whitebark Pine Monitoring Working Group. 2011, "Monitoring whitebark pine in the Greater Yellowstone Ecosystem: 2010 annual report," in U.S. Geological Survey [USGS], *Yellowstone Grizzly Bear Investigations: Annual Report of the Interagency Grizzly Bear Study Team, 2010*, C.C. Schwartz, M.A. Haroldson, and K. West, editors, (Bozeman, MT: USGS, 2011), pp 56–65.

92. Whitebark Pine Subcommittee, Greater Yellowstone Coordinating Committee, *Whitebark Pine Strategy*, 2011, pp. 1-45, http://fedgycc.org/documents/WBPStrategyFINAL5.31.11.pdf. See also R. E. Keane, "Strategies, tools, and challenges for sustaining and restoring high elevation five-needle white pine forests in western North America," in RMRS, *Five-Needle Pine Symposium* (see note 85), pp. 276-294.

93. Macfarlane, Logan, and Kern, "Mortality of whitebark pine" (see note 90), p. 7.

94. *Bark beetle outbreaks in western North America: Causes and consequences*, B. Bentz, editor, report of Bark Beetle Symposium, Snowbird, Utah, Nov. 15-18, 2005 (Salt Lake City, UT: University of Utah Press, 2005).

95. USFS, Shoshone National Forest, "Bark Beetles," http://www.fs.usda.gov/wps/portal/fsinternet/!ut/p/c4/04_SB8K8xLLM9MSSzPy8xBz9CP0os3gjAwhwtD-Dw9_AI8zPyhQoY6BdkOyoCAGixyPg!/?ss=110214&navtype=BROWSEBYSUBJECT&cid=stelprdb5192930&navid=091000000000000&pnavid=null&position=Not%20Yet%20Determined.Html&ttype=detail&pname=Shoshone%20National%20Forest-%20Home.

96. Yellowstone National Park [NP], NPS, "Chapter 8, Park Issues," in NPS, *Yellowstone Resources and Issues 2011,* 2011, p. 177, http://www.nps.gov/yell/planyourvisit/resourceandissues.htm.

97. USGCRP, *Climate Change Impacts* (see note 17), p.82; IPCC, "North America" (see note 59), pp. 624, 631.

98. *Bark beetle outbreaks* (see note 94), p 24.

99. G. E. Rehfeldt, D. E. Ferguson, and N. L. Crookston, "Aspen, climate, and sudden decline in western USA", *Forest Ecology and Management*, vol. 258 (2009), pp. 2353-2364, p. 2363, http://www.fs.fed.us/rm/pubs_other/rmrs_2009_rehfeldt_g001.pdf.

100. C. Kay, "Long-Term aspen exclosures in the Yel-

lowstone ecosystem," *USDA Forest Service Proceedings* (2001), pp. 225-241, p. 225; W. H. Romme and others, "Aspen, elk, and fire in northern Yellowstone Park," *Ecology*, vol. 76 (1995), pp. 2097–2106, p. 2097; W. J. Ripple and E. J. Larsen, "Historic aspen recruitment, elk, and wolves in northern Yellowstone National Park, USA," *Biological Conservation*, vol. 95 (2000), pp. 361–370, p. 366, fig. 5;

101. Rehfeldt, Ferguson, and Crookston, "Sudden decline in western USA" (see note 99).

102. J. Brodie and others, "Climate change intensification of herbivore impacts on tree recruitment," *Proceedings of the Royal Society* (forthcoming).

103. Yellowstone NP, NPS, "Fire ecology," http://www.nps.gov/yell/parkmgmt/fireecology.htm.

104. Yellowstone NP, NPS, "Fire ecology" (see note 103); R. A. Renkin and D. G. Despain. "Fuel moisture, forest type, and lightning-caused fires in Yellowstone National Park." *Canadian Forestry of Forest Research*, vol. 22 (1992), pp.37–45, http://www.greateryellowstonescience.org/files/pdf/Renkin_Despain_1992.pdf.

105. Yellowstone NP, NPS, "Fire ecology" (see note 103).

106. A. Westerling and others, "Western U.S. forest wildfire activity," *Science*, vol. 313 (2006), pp. 940–943.

107. A. Westerling and others, "Continued warming could transform Greater Yellowstone fire regimes by mid-21st century," *Proceedings of the National Academy of Sciences*, vol. 32 (2011), pp. 13165–13170, p. 13167, "Supporting information," p. 5, Figure S-5.

108. E. Smithwick and others, "Vulnerability of landscape C fluxes to future climate and fire in the Greater Yellowstone Ecosystem," abstract, in *Questioning Greater Yellowstone's Future* (see note 69), pp. 20-21, p. 20. The five authors of this abstract are the same as the authors of Westerling and others, "Greater Yellowstone fire regimes" (see note 107); Westerling and others, "Greater Yellowstone fire regimes" (see note 107), p. 13166.

109. USGCRP, *Climate Change Impacts* (see note 17), p. 81.

110. P. J. Bartlein, C. Whitlock, and S. L. Shafer, "Future climate in the Yellowstone National Park region and its potential impact on vegetation," *Conservation Biology*, vol. 11 (1997), pp. 782-792.

111. Yellowstone NP, NPS, "Chapter 8, Park Issues," in *Yellowstone Resources and Issues 2010*, p. 174, http://www.nps.gov/yell/planyourvisit/resourceandissues.htm.

112. USGCRP, *Climate Change Impacts* (see note 17), p. 81; Natural Resource Program Center [NRPC], NPS, *Observed and Projected Ecological Response to Climate Change in the Rocky Mountains and Upper Columbia Basin: A synthesis of current scientific literature*, E. Ashton, author, (Fort Collins, CO: NRPC, NPS, 2010), NRPC, NPS, *Ecological Response to Climate Change*, p. 19.

113. Bartlein, Whitlock, and Shafer, "Impact on Yellowstone vegetation" (see note 110).

114. Boisvenue and Running, "Emissions for Rocky Mountain forests" (see note 45), pp. 1302–1319.

115. Gray and McCabe, "Potential hydrologic effects of climate change" (see note 77).

116. A. Haak and others, "The potential influence of changing climate on the persistence of salmonids of the inland West," USGS, 2010, pp. 2–3, http://pubs.usgs.gov/of/2010/1236/pdf/OF10-1236.pdf.

117. D. Isaak and others, "Effects of climate change and wildfire on stream temperatures and salmonid thermal habitat in a mountain river network," *Ecological Applications*, vol. 20 (2010), pp. 1350–1371, p. 1350.

118. Yellowstone NP, NPS, *Yellowstone Resources and Issues 2011* (see note 96), pp 82, 177.

119. Yellowstone NP, NPS, *Yellowstone Resources and Issues 2011* (see note 96), p. 177.

120. Yellowstone NP, NPS, "*Yellowstone Resources and Issues 2011* (see note 96), p. 177.

121. M. H. P. Hall and D. B. Fagre, "Modeled climate-induced glacier change in Glacier National Park, 1850–2100," *Bioscience*, vol. 53 (2003), pp. 131-140.

122. D. B. Fagre and D. L. Peterson, "Ecosystem dynamics and disturbance in mountain wildernesses: Assessing vulnerability of natural resources to change," in *Proceedings of Wilderness Science in a Time of Change, vol. 3, May 23-27, Missoula MT* (Ogden, UT: RMRS, USFS, 2000, pp. 74-81, http://www.nrmsc.usgs.gov/files/norock/products/GCC/WildernessConf_Fagre_00.pdf; C. Millar and others, "Response of subalpine conifers in the Sierra Nevada, California, U.S.A., to 20th-century warming and decadal climate variability," *Arctic, Antarctic and Alpine Research* 36 (2004), pp. 181-200; Yosemite National Park, NPS, "Tuolumne Meadows Lodgepole Pine removal," 2006, http://www.nps.gov/archive/yose/planning/projects/tmtrees.pdf.

123. D. M. Debinski and others, "Montane meadow change during drought varies with background hydrologic regime and plant functional group," *Ecology*, vol. 91 (2010), pp. 1672–1681, http://www.fedgycc.org/documents/10Debinski_GYE_CCandmeadows_Ecology.pdf.

124. T. J. Perfors, J. Harte, and S. Alter, "Enhanced growth of sagebrush (Artemisia tridentate) in response to manipulated ecosystem warming," *Global Change Biology*, vol. 9 (2003), pp. 736–742. See also F. Saavedra, and others, "Changes in flowering and abundance of Delphinium nuttalianum (Ranunculaceae) in response to a subalpine climate warming experiment," *Global Change Biology*, vol. 9 (2003), pp. 885–894.

125. D. W. Inouye, "Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers," *Ecology*, vol. 89 (2008), pp. 353-362.

126. G. Aldrdige and others, "Emergence of a mid-season period of low floral resources in a montane meadow ecosystem associated with climate change," *Journal of Ecology*, vol. 99 (2011), pp. 905–913.

127. USGCRP, *Climate Change Impacts* (see note 17), p. 86.

128. IPCC, "Ecosystems, their properties, goods, and services" in IPCC, *Impacts, Adaptation and Vulnerability* (see note 59), p. 213.

129. C. E. Burns, K. M. Johnson, and O. J. Schmitz, "Global change and mammalian species diversity in U.S. national parks," *Proceedings of the National Academy of Sciences*, vol. 100 (2003), pp. 11474-11477.

130. USGCRP, *Climate Change Impacts* (see note 17), p. 82.

131. Yellowstone NP, NPS, *Yellowstone Resources and Issues 2011* (see note 96), p. 177.

132. *Greater Yellowstone Coalition v. Servheen et al*, U.S. District Court, District of Montana, (Sep. 21, 2009), case citation: 07-CV-134-DWM, http://www.greateryellowstonescience.org/sites/default/files/references/MSJ_Order_9_21_09.pdf.

133. *Greater Yellowstone Coalition v. Servheen et al* (see note 132), p. 26.

134. J. A. Logan, "Yellowstone case study of wildlife effects: Global warming, bark beetles, whitebark pine, and grizzly bears in Yellowstone," in Saunders, Easley, and Farver, *National Parks in Peril* (see note 1), p. 28.

135. NRPC, NPS, *Ecological Response to Climate Change* (see note 112), p. 49 (citing D. Mattson and D. Reinhart, "Excavation of red squirrel middens by grizzly bears in the whitebark pine zone," *Journal of Applied Ecology*, vol. 34 (1997), pp. 926–940).

136. C. Schwartz and others, "Temporal, spatial, and environmental Influences on the demographics of grizzly bears in the Greater Yellowstone Ecosystem," *Wildlife Monographs*, vol. 161 (2006), pp. 1–68, pp. 1–2.

137. Whitebark Pine Subcommittee, *Whitebark Pine Strategy* (see note 92), pp. 13-19.

138. Schwartz and others, "Demographics of grizzly bears in the Greater Yellowstone Ecosystem" (see note 136), p. 24.

139. M. Haroldson and others, "Changing numbers of spawning cutthroat trout in tributary streams of Yellowstone Lake and estimates of grizzly bears visiting streams from DNA," *Ursus,* vol. 16 (2005), pp. 167-180.

140. K. B. Aubry, K. S. McKelvey, and J. P. Copeland, "Distribution and broadscale habitat relations of the wolverine in the contiguous United States," *Journal of Wildlife Management*, vol. 71 (2007), pp. 2147–2158, p. 2151.

141. FWS, "Endangered and threatened wildlife and plants; 12-month finding on a petition to list the North American wolverine as endangered or threatened," *Federal Register* Notice, December 13, 2010, 50 CFR Part 17, vol. 75, no. 239, pp. 78030–78061, p. 78031.

142. J. F. Brodie and E. Post, "Nonlinear responses of wolverine populations to declining winter snowpack," *Population Ecology*, vol. 50 (2010), pp. 279–287.

143. R. M. Inman and others, *Greater Yellowstone Wolverine Program: Progress Report – November 2008* (Ennis, MT: Wildlife Conservation Society, 2008), http://wolverinefoundation.org/research/WCS%20WP%20Update%20Nov%202008.pdf; K. Murphy and others, *Wolverine Conservation in Yellowstone National Park: Final Report* (Yellowstone NP, WY: Yellowstone NP, NPS, 2011), p. 42, www.greateryellowstonescience.org/download_product/3198/0.

144. L. G. Pearlstine and others, South Florida Natural Resources Center, NPS, *Potential Ecological Consequences of Climate Change in South Florida and the Everglades: 2008 Literature Synthesis* (Homestead, FL: Everglades National Park, NPS, 2009), p. 11, http://www.nps.gov/ever/naturescience/featuredpublication.htm.

145. FWS, "Finding on North American wolverine" (see note 141).

146. FWS, "Finding on North American wolverine" (see note 141), p. 78046.

147. *Center for Biological Diversity v. Salazar*, 10-cv-0230 (D.D.C), Listing Work Plan Supplementary Settlement Agreement with Center for Biological Diversity, p. 5, http://www.fws.gov/endangered/improving_ESA/218963-v1-hhy_071211_exh_1_re_CBD.PDF.

148. FWS, "Finding on North American wolverine" (see note 141), pp. 78049–50.

149. P. Gonzalez and others, *Potential Impacts of Climate Change on Habitat and Conservation Priority Areas for Lynx Canadensis (Canada Lynx)* (Arlington, VA: The Nature Conservancy, 2007), report to the USFS, http://conserveonline.org/workspaces/climate.change/climate.change.vegetation.shifts/climate_change_Lynx.pdf; NRPC, NPS, *Understanding the Science of Climate Change—Talking Points: Impacts to Western Mountains and Forests*, R. Loehman, author (Fort Collins, CO: NRPC, NPS, 2009), p. 10.

150. Yellowstone NP, NPS, *Yellowstone Resources and Issues 2011* (see note 96), p. 177.

151. NRPC, NPS, *Ecological Response to Climate Change* (see note 112).

152. FWS, "Endangered and threatened wildlife and plants; 12-month finding on a petition to

list the American Pika as threatened or endangered," Federal Register, Feb. 5, 2010, http://www.fws.gov/mountain-prairie/species/mammals/americanpika/02052010FRTemp.pdf; newer information: E. A. Beever and others, "Contemporary climate change alters the pace and drivers of extinction," *Global Change Biology*, vol. 17 (2011), pp. 2054–2070; E. A. Beever and others, "Testing alternative models of climate-mediated extirpations," *Ecological Applications*, vol. 20 (2010), pp. 164–178; L. P. Erb, C. Ray, and R. Guralnick, "On the generality of a climate-mediated shift in the distribution of the American pika (Ochotona princeps)," *Ecology*, vol. 92 (2011), pp. 1730–1735.

153. USGCRP, *Climate Change Impacts* (see note 17), p. 86.

154. FWS, "Finding on American pika" (see note 152).

155. Upper Columbia Basin Network, Inventory and Monitoring Program, NPS, "Pikas in Peril," http://science.nature.nps.gov/im/units/ucbn/monitor/pika/pika_peril/index.cfm.

156. K. Gunther, Bear Management Office, Yellowstone NP, NPS, personal communication (email to S. Saunders), Sep. 12, 2011.

157. Absaroka Elk Ecology Project, Wyoming Cooperative Fish and Wildlife Research Unit, Kauffman Group, 2010, http://www.wyocoopunit.org/index.php/search/absaroka-elk-ecology-project/; Absaroka Elk Ecology Project, "2010 progress update," 2010, http://www.wyocoopunit.org/index.php/download_file/view/294/85/.

158. USGCRP, *Climate Change Impacts* (see note 17), p. 80; NRPC, NPS, *Ecological Response to Climate Change* (see note 112), p. 10.

159. J. Berger, "The last mile: How to sustain long-distance migration in mammals," *Conservation Biology*, vol. 18 (2004), pp. 320–331, p. 320; NRPC, NPS, *Ecological Response to Climate Change* (see note 112), p. 10.

160. USGCRP, *Climate Change Impacts* (see note 17), p. 80.

161. Yellowstone NP, NPS, "Yellowstone National Park Checklist of Birds," http://www.nps.gov/yell/naturescience/upload/birdlist_2011.pdf.

162. North American Bird Conservation Initiative [NABCI] and others, *The State of the Birds 2010: Report on Climate Change* (Washington, DC: U.S. Department of the Interior, 2010); GYSLC, NPS, "Monitoring Ecological Responses to Climate Change," 2010, http://www.stateofthebirds.org/2010/pdf_files/State%20of%20the%20Birds_FINAL.pdf.

163. NRPC, NPS, *Ecological Response to Climate Change* (see note 112), p. 47.

164. L. Baril, L. Henry, and D. Smith, *Yellowstone Bird Program 2009 Annual Report* (Yellowstone NP, WY: YCR, NPS, 2010), p. 6, http://www.nps.gov/yell/naturescience/upload/2009_Bird_AR.pdf.

165. D. P. MacMynowski and T. L. Root, "Climate change and the timing of Songbird migration in California: Focus on coastal central and northern regions," Public Interest Energy Research Program, California Energy Commission, 2007; A. P. Møller, D. Rubolini, and E. Lehikoinen, "Populations of migratory bird species that did not show a phenological response to climate change are declining," *Proceedings of the National Academy of Sciences*, vol. 105 (2008), pp. 16195–16200; NABCI and others, *State of the Birds 2010* (see note 162), p. 29; J. Price and P. Glick, *The Birdwatcher's Guide to Global Warming*, report of American Bird Conservancy [ABC] and National Wildlife Federation [NWF], 2004, http://www.abcbirds.org/newsandreports/special_reports/birdwatchersguide.pdf.

166. ABC and NWF, "Global warming & songbirds: Wyoming," http://www.abcbirds.org/newsandreports/special_reports/globalwarming/Wyoming.pdf.

167. ABC and NWF, "Global warming & songbirds: Wyoming" (see note 166).

168. Yellowstone NP, NPS, *Yellowstone Resources and Issues 2011* (see note 96), p. 135.

169. Baril, Henry, and Smith, *Yellowstone Bird Program 2009* (see note 164), p. 5.

170. Baril, Henry, and Smith,*Yellowstone Bird Program 2009* (see note 164), p. 5.

171. Yellowstone NP, NPS, *Yellowstone Resources and Issues 2011* (see note 96), p. 140; Yellowstone NP, NPS, "Trumpeter swan facts," http://www.nps.gov/yell/naturescience/trumpeterswan.htm; Yellowstone NP, NPS, *Yellowstone National Park Draft Winter Use Plan/ Environmental Impact Statement*, (Yellowstone NP, WY: Yellowstone NP, NPS, 2011), pp. 109–110.

172. Baril, Henry, and Smith,*Yellowstone Bird Program 2009* (see note 164), p. 12.

173. K. M. Proffitt and others, "Trumpeter swan abundance and growth rates in Yellowstone National Park," *Journal of Wildlife Management*, vol. 75 (2010), pp. 728-736, p. 735.

174. Baril, Henry, and Smith, *Yellowstone Bird Program 2009* (see note 164), p. 13.

175. J. G. Eaton and R. M. Scheller. "Effects of climate warming on fish thermal habitat in streams of the United States," *Limnology and Oceanography*, vol. 41 (1996), pp. 1109-1115; Defenders of Wildlife and Natural Resources Defense Council, *Effects of Global Warming on Trout and Salmon in U.S. Streams*, K. O'Neal, author (Washington, DC: Defenders of Wildlife, 2002), p. 17, table 2, http://www.defenders.org/resources/publications/programs_and_policy/science_and_economics/global_warming/effects_of_global_warming_on_trout_and_salmon.pdf.

176. Haak and others, "Salmonids of the inland West" (see note 116), p. 7.

177. S. J. Wenger and others, "Flow regime, temperature, and biotic interactions drive differential declines of trout species under climate change," *Proceedings of the National Academy of Sciences,* published online ahead of print August 15, 2011, pp. 1–3, http://www.pnas.org/content/early/2011/08/09/1103097108.full.pdf+html?sid=9e25412c-fc18-4eaf-a306-d9f170be0128.

178. Haak and others, "Salmonids of the inland West" (see note 116), p. 2.

179. Wenger and others, "Flow regime, temperature, and biotic interactions," (see note 177), pp. 1–3.

180. USGCRP, *Climate Change Impacts* (see note 17), p. 87.

181. M. Franke, "Chapter 3: The human aftermath" in *Yellowstone in the Afterglow: Lessons from the Fires* (Mammoth Hot Springs, MT: Yellowstone Center for Resources [YCR], NPS, 2000), p. 40.

182. NPS, NPS Stats, http://www.nature.nps.gov/stats/index.cfm; Franke, "The human aftermath" (see note 181), pp. 40-41.

183. Yellowstone NP, NPS, *Yellowstone Fisheries & Aquatic Sciences: Annual Report, 2007,* T. M. Koel and others, authors (Mammoth Hot Springs, MT: YCR, NPS, 2008), pp. 38-39.

184. State of Montana, *Restrictions and Closures* (Missoula, MT: Department of Fish, Wildlife and Parks, accessed July 16, 2007), http://fwp.mt.gov/fishing/guide/waterclosure.aspx; S. Cooke, Associated Press, "Dramatic spike in temps raises fire danger, kills fish in Montana," *Missoulian* (Montana), July 19, 2007, http://www.missoulian.com/articles/2007/07/20/bnews/br60.txt.

185. R. Cunningham, president of Fishing Outfitters Association of Montana, personal communication (email to T. Easley), Aug. 13, 2007.

186. Cunningham, personal communication (see note 185).

187. Yellowstone NP, *Yellowstone Fisheries & Aquatic Sciences: Annual Report, 2007* (see note 183), p. 38.

188. Yellowstone NP, NPS, "Yellowstone to implement mandatory fishing restrictions," news release, July 20, 2007, http://www.nps.gov/yell/parknews/0739.htm.

189. Yellowstone NP, NPS, *Yellowstone Fish Reports*, 2000 to 2008, http://www.nps.gov/yell/planyourvisit/fishreports.htm; NPS, NPS Stats, http://www.nature.nps.gov/stats/.

190. Yellowstone NP, NPS, "Chapter 7, Wildlife" in NPS, *Yellowstone Resources and Issues 2011* (see note 96), p. 144.

191. NPS, *Aquatic Ecology*, p. 38, http://www.nps.gov/yell/planyourvisit/upload/fishar32-54.pdf.

192. Yellowstone NP, NPS, *Draft Winter Use Plan/Environmental Impact Statement* (see note 171), p. 143.

193. Yellowstone NP, NPS, "Archive," http://www.nps.gov/yell/parknews/newsarchive.htm.

194. Yellowstone NP, NPS, "A place of winter magic … and vulnerability," http://www.nps.gov/yell/parkmgmt/winter_magic.htm.

195. USGCRP, *Climate Change Impacts* (see note 17), p. 32.

196. T. R. Karl and others, editors, *Weather and Climate Extremes in a Changing Climate: Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands*, report of USCCSP (Washington, DC: NCDC, NOAA, 2008), p. 5.

197. Karl and others, *Weather and Climate Extremes* (see note 196), p. 104.

198. USGS, *Sediment-Transport Investigations of the Upper Yellowstone River, Montana, 1999 through 2001: Data Collection, Analysis, and Simulation of Sediment Transport*, S. R. Holnbeck, author, 2005, p. 6, http://pubs.usgs.gov/sir/2005/5234/pdf/sir2005-5234.pdf.

199. USGS, *Investigations of the Upper Yellowstone River* (see note 198), p. 6; Federal Emergency Management Agency, U.S. Department of Homeland Security, "Mitigation project in Yellowstone: Floods in 1996 and 1997 were severe," http://www.fema.gov/mitigationbp/briefPdfReport.do?mitssId=1525.

200. D. Bernhart, "Glacier National Park flooding November 2006," National Weather Service, Helena, MT, http://www.wrh.noaa.gov/wrh/talite0823.pdf.

201. Bernhart, "Glacier flooding" (see note 200), p. 9.

202. Mount Rainier NP, NPS, "Mount Rainier National Park: A year after the flood," news release, Nov. 2, 2008, http://www.nps.gov/mora/parknews/upload/Flood%20Anniversary%20Release%20Nov%2007.pdf.

203. NPS, "Glacier NP reports: Visitation by month/year," available at NPS, NPS Stats, http://www.nature.nps.gov/stats/park.cfm.

204. NPS, *Climate Change Response Strategy* (see note 1).

205. NPS, *A Call to Action: Preparing for a Second Century of Stewardship and Engagement*, 2011, p. 17, http://www.nps.gov/calltoaction/PDF/Directors_Call_to_Action_Report.pdf.

206. Saunders, Easley, and Farver, *National Parks in Peril* (see note 1), p. 42.

207. J. Jarvis, director, NPS, testimony, Subcommittee on National Parks, Committee on Energy and Natural Resources, U.S. Senate, Oct. 28, 2009, http://energy.senate.gov/public/index.cfm?FuseAction=Hearings.Testimony&Hearing_ID=5a2ad7e2-0fd3-4ea2-1028-

d22bfb502e87&Witness_ID=1a7d865e-8bf0-4dae-a6e2-4a4023c2383f.

208. USFS, *National Roadmap for Responding to Climate Change*, 2010, http://www.fs.fed.us/climatechange/pdf/roadmap.pdf; FWS, *Rising to the Urgent Challenge: Strategic Plan for Responding to Accelerating Climate Change*, 2010, http://www.fws.gov/home/climatechange/pdf/CCStrategicPlan.pdf.

209. Northern Rocky Mountain Science Center, USGS, "Great Northern Landscape Conservation Cooperative," http://www.nrmsc.usgs.gov/gnlcc.

210. Ecological Society of America, "ESA position statement: Ecosystem management in a changing climate," 2010, http://www.esa.org/pao/policyStatements/pdfDocuments/Ecosystem%20Management%20in%20a%20Changing%20Climate.pdf.

211. NCDC, NOAA, "The USHCN Version 2 Serial Monthly Dataset," http://www.ncdc.noaa.gov/oa/climate/research/ushcn/.

212. An example is G. Pederson and others," A century of climate and ecosystem change in Western Montana: what do temperature trends portend?," *Climatic Change*, vol. 98 (2010), pp. 133-154.

213. Data from Western Regional Climate Center, http://www.wrcc.dri.edu/cgi-bin/divplot1.pl.

214. The World Climate Research Program's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset (see note 41).

215. Mote and Salathé, Jr., "Future Climate in the Pacific Northwest" (see note 45).