Glacier National Park in Peril
The Threats of Climate Disruption

At stake is what makes Glacier National Park the special place that Americans love.

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About RMCO

The Rocky Mountain Climate Organization works to keep the interior American West special by reducing climate disruption and its impacts in the region. 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. Learn more at www.rockymountainclimate.org.

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Contents

D. FAGRE, US GEOLOGICAL SURVEY

Executive Summary

If we do not reduce heat-trapping pollutants and protect the resources of Glacier National Park, it will suffer from human-caused climate change.

Human disruption of the climate is the greatest threat ever to our national parks. Glacier National Park was identified in an October 2009 report, *National Parks in Peril: The Threats of Climate Disruption*, also by the Rocky Mountain Climate Organization (RMCO) and the Natural Resources Defense Council, as one of the 25 national parks most vulnerable to the effects of an altered climate. This profile details and documents the particular threats that a changed climate poses to Glacier.

Montana's economy is at stake as human-caused climate change affects Glacier National Park (GNP). (See section 2.) Drawn by the park's wonders, two million visitors a year come to Glacier, making it the eleventh most visited of our national parks. The spending by those visitors is a mainstay of Montana's economy. Nearly three-quarters of Glacier's visitors are from out of state, and almost one-third of all summer visitors to Montana are drawn primarily by the park. Spending by visitors to GNP may approach $1 billion, which supports more than 4,000 Montana jobs.

But a climate disrupted by human emissions of heat-trapping pollutants threatens both Glacier's special natural resources and the economic contributions from park visitors drawn by those resources. There is, as yet, no survey data on how visitors to Glacier might react to the effects there of climate change. But a suggestion of visitor effects comes a recent survey in Waterton Lakes National Park, the Canadian national park immediately adjacent to Glacier. When given a description of park conditions chosen to identify the most likely impacts of climate change near the end of the century, 19% of the respondents said they would not visit the park any more. An additional 38% said they would visit less often.

More heat and less cold are among the most obvious impacts of human-caused climate change in GNP. (See section 3.) These changes are already underway, and are likely to grow. At the one weather station in the park with relatively long-term records, a West Glacier station at park headquarters, the average temperature for the decade just completed (2000-2009) was 2.0°F hotter than the station's 1950-1979 average, according to a new analysis done for this report by RMCO, using government temperature data. This 2.0°F increase in average temperature is exactly double the 1.0°F increase in global average temperature in the past decade. For both Glacier and the planet as a whole, the last decade was the hottest in the period of recorded instrumental observations.

This new RMCO analysis is consistent with other regional temperature data. A study by U.S. Geological Survey scientists and others, updated by RMCO for this profile, shows that in 2000 through 2008, western Montana averaged eight days more per year of 90°F or higher and eight days fewer of 0°F or lower, compared to 1900 through 1979. Another study has identified that the greatest increases in temperatures in the region have been in late February and early March, a time when the additional heat has great effects on snowfall, snowpack accumulation, snowmelt, and the timing of streamflows.

The Northwest, including western Montana, near the end of this century could be about 4.1°F hotter in a future with lower emissions, or about 7.1°F hotter with higher emissions, compared to late 20^{th}-century averages. Western Montana is likely to heat up more than this regional average.

A **loss of ice and snow** in the park is likely. (See section 4.) Because of human-caused changes in our climate, Glacier could lose all or nearly all of its glaciers, which shaped the park and after which it is named – perhaps in the relatively near future. Seven years ago, scientists projected that even modestly hotter summers could eliminate by 2030 all glaciers in one basin in the park. Since this study was published, the glaciers in the basin have melted faster than projected. Now, one of the study's authors believes they might be gone in just 10 years. According to an April 2010 update by the U.S. Geological Survey, of the 37 named glaciers in the park, only 25 remain large enough to still be considered glaciers. Of the 12 that have melted away, 11 have done so since 1966.

A hotter climate is also expected to reduce snowfall and snowpack accumulation in the park. One recent study projects that near the end of this century, peak snowpack levels in the park may be reached 41 days earlier than in mid-20th century, and that snow could cover the ground for about 70 fewer days a winter. With mountains not snow-capped as much or as long into the summer, the scenery that draws most visitors to Glacier would be affected.

A **loss of water** in the park in summer may result from higher temperatures, earlier snowmelt, and a loss of summer meltwater from glaciers, with widespread ecosystem effects. (See section 5.)

A **loss of wildlife** in Glacier could result from human-caused climate change. (See section 6.) This could disrupt the unique mix of natural wildlife the park now supports, which offers Americans the best chance they have in the lower 48 states to see the full range of mammal predators present at the time of European settlement of the continent, including grizzly and black bears, wolves, lynx, wolverines, mountain lions, and more, as well as other large mammals including mountain goats, bighorn sheep, and elk. The park's staff is concerned that climate change could lead to “wholesale changes in species composition.” One study suggests that Glacier could experience the second largest influx of new mammal species of eight studied national parks, as ecosystem changes could lead to new, warmer-environment species moving into the park. Wolverines and lynx are at particular risk in the park, as for both spring snow cover apparently is an essential habitat requirement. Grizzly bears, bighorn sheep, mountain goats, pikas, ptarmigan, and trout could also be harmed by changes in the climate.

A **disruption of plant communities** in the park also could take place. (See section 7.) Some forests in the park could be replaced by grasslands. Other forests could decline because of hotter, drier conditions. The park's expanses of alpine tundra, meadows, and wildflowers, plus a rare cedar-hemlock ecosystem, could all be reduced. Infestations of insects such as mountain pine beetles could increase.

More wildfires are likely, leading to more campfire bans, closures of trails, and reduced visitation. (See section 8.) A **loss of fishing** can result if high water temperatures stress trout enough to lead to fishing closures or to elimination of trout from certain streams. (See section 9.) **More downpours and flooding** are likely to be caused by increases in extreme storms, which can result in closures of park areas and reduced visitation. (See section 10.)

Tackling climate disruption can help protect Glacier from these threats. (See section 11.) The National Park Service (NPS) should give priority to protecting park resources from climate-change impacts. With 275 million visits a year, our national parks can provide the public with information about climate change and its impacts. The NPS can demonstrate by its own operations how emissions can be avoided through money-saving actions.

Many of the threats to Glacier identified here assume continued, unchecked human changes to the climate. Sharply limiting emissions can reduce many impacts. Most important is comprehensive federal action to limit emissions of heat-trapping pollutants. Then we can ward off dangerous climate disruption, in Glacier and around the world.

1 INTRODUCTION

The effects of human-caused climate change may make Glacier National Park less attractive to people.

Human disruption of the climate is the greatest threat ever to our national parks. Glacier National Park was identified in an October 2009 report, *National Parks in Peril: The Threats of Climate Disruption*, by the Rocky Mountain Climate Organization and the Natural Resources Defense Council as one of the 25 national parks most vulnerable to the effects of an altered climate.[1] This profile details and documents the particular threats that a changed climate poses to Glacier (or "GNP").

Why single out a national park for attention, when a changed climate will affect the entire planet? Glacier and other national parks have been set aside to preserve, unimpaired, the very best of America's resources and to provide for their continued enjoyment by future generations. These spectacular, well-preserved places often are more at risk of degradation than are other places. And we Americans, appropriately, love our national parks. To ignore the enormous threats that climate disruption poses to them, just because other places may also be affected, would be to give up on our national parks.

Glacier is a particularly telling subject for a profile such as this one. Along with other high-elevation and northern parks, it is particularly vulnerable to a hotter climate. And more work may have been done to identify climate-change impacts on Glacier than on any other national park, in large part through research there by the U.S. Geological Survey's Northern Rocky Mountain Science Center.

Glacier also is, by any measure, a special place. In 2010, Americans are celebrating Glacier's 100th birthday as our ninth national park. It is well worth celebrating, with its jagged mountains – carved thousands of years ago by the glaciers after which the park is named – and ice fields, sweeping forests, and lakes of astonishing color.

In a nation blessed with great landscapes, Glacier has some of our most amazing scenery. The park also offers the best chance in the lower 48 states to see the full range of predators from the time of European settlement, including grizzly bears, wolves, mountain lions, lynx, and wolverines. Add in moose, elk, mountain goats, and bighorn sheep, and nearly every mammal here in pre-colonial days is still present; only bison and caribou are missing. As the National

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

U.S. Climate Change Science Program (2008)[2]

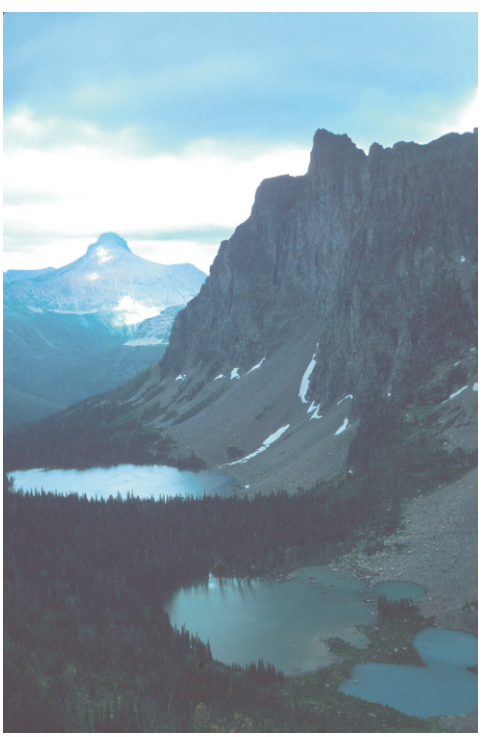
US GEOLOGICAL SURVEY

Park Service says of these mammals in Glacier, “they are all present in a spectacular mix that is unique in the continental U. S.”[3]

Drawn by these natural wonders, people come to Glacier in large enough numbers – two million visitors a year – to make it the eleventh most visited of our national parks, producing thousands of jobs and millions of dollars in spending that support Montana’s economy. (See section 2.)

But a climate disrupted by human activities – by our emissions of heat-trapping pollutants, principally carbon dioxide from burning fossil fuels – threatens both Glacier's special natural resources and the tourism based on them. Unless we change our ways, Glacier could become much hotter and, in summer, much drier. Its glaciers could be lost. Its mountains could be snow-capped less often. Some forests could be replaced by grasslands, and the remainder could be stressed by hot, dry summers. Some native wildlife could be lost, and non-native species could move in. The park could be closed more often by wildfires and flooding. Glacier, in short, could be fundamentally altered. (See sections 3-10.)

The most sobering news is that if we continue on our current course, human-driven climate change could damage Glacier even more than suggested in the studies described here, for two reasons. First, many of the impacts described in this profile would result from the lower- or midpoints of projected climate changes. More drastic changes are quite possible. For example, all glaciers are projected to melt in one of Glacier's basins by 2030 with just a 1.9°F increase in summer temperatures. (See section 4.) The latest estimates, though, are that the region could become 3.0°F hotter by then in a lower-emissions future and 4.1°F hotter in a higher-emissions future. (See section 3.) And an even hotter scenario is altogether plausible.[4]



US GEOLOGICAL SURVEY

Second, as a recent U.S. government report pointed out, in recent years emissions of heat-trapping pollutants have actually been going up even faster than assumed in the highest-emission scenario currently being used by scientists.[5]

The good news, though, is that even the lower-emissions scenario commonly used by scientists does not assume new policies to reduce heat-trapping pollutants. If we take action to sharply limit emissions, we can ward off the most severe of the impacts that scientists have projected.

Further good news is that Glacier, because it is both relatively pristine and connected to the much larger, intact ecosystem often called the Crown of the Continent – including Glacier and other protected lands in both the United States and Canada – offers one of our best chances to maintain a functioning, resilient ecosystem, with room for plants and animals to migrate and adapt to changed climate conditions.

Time is running short, but we can still ward off the worst possible effects of climate disruption, in Glacier and around the world.

“Choices made now will influence the amount of future warming. . . . Implementing sizable and sustained reductions in carbon dioxide emissions as soon as possible would significantly reduce the pace and the overall amount of climate change, and would be more effective than reductions of the same size initiated later.”

U.S. Global Change Research Program (2009)[6]

2

MONTANA'S ECONOMY AT STAKE

Glacier draws enough people to Montana to support thousands of jobs. But an altered climate threatens the special values of the park that bring those people to the state.

The two million people a year who come to Glacier make the park a mainstay of Montana's economy, producing millions of dollars in spending and thousands of jobs. But these economic benefits depend on the park's resources remaining compelling enough to continue drawing so many people to the park – even though it is more distant than most national parks from major population centers. Because climate disruption threatens the resources that make Glacier special, as detailed in this profile, it also threatens Montana's economy.

The most recent National Park Service (NPS) estimate of the local economic benefits of Glacier is that in 2002 park visitors contributed $160 million to Montana's economy and an additional $40 million to the economy of nearby areas in Canada.[7] This estimate is dated and could be low. In 2008, out-of-state travelers spent over $3 billion in Montana, and in 2009 29% of non-resident travelers cited Glacier as their primary attraction in coming to Montana, the highest-listed such attraction.[8] If 29% of all out-of-state traveler spending were attributed to Glacier, the spending from those travelers derived from GNP might now approach $1 billion.

For Montana, Glacier's drawing power is even greater than that of Yellowstone National Park, cited by 24% of tourists as the primary reason for their visit.[9] In Flathead County, fully 60% of visitors cited Glacier as their primary attraction.[10]

The NPS estimates that spending by visitors to Glacier in 2002 directly supported 3,200 jobs in Montana and indirectly another 850, plus 500 more total jobs in Canada.[11] (With a 5% increase in visitation in 2009 compared to 2002, it is reasonable to assume that more jobs now derive from visitation to Glacier than in 2002.)

Jobs Resulting from Visitation to Glacier National Park

Area	Direct Jobs	Secondary Jobs	Total Jobs
Flathead County	1,550	370	1,920
Glacier County	1,010	140	1,150
Lake County	640	130	770
Montana	3,200	850	4,050
Alberta	300	200	500
Total	3,500	1,050	4,550

Table 1. Jobs created by Glacier National Park visitation in 2002. Source: Glacier National Park (2003).[12]

As table 1 shows, most of the economic benefit of Glacier goes to immediately surrounding areas: Flathead County, which includes the western side of the park and gateway communities including Kalispell, Whitefish, Columbia Falls, and West Glacier; Glacier County, which includes the eastern side of the park and gateway communities including East Glacier and St. Mary; and Lake County, south of Flathead County, through which many park visitors travel.

"You can't measure the mark Glacier Park has made on this community. The whole economy is tied to the park."

Carol Edgard, Flathead Convention and Visitor Bureau (2003)[13]

The presence of Glacier and its attractions is also a central reason why nearby residents want to live in the region, so the park supports the economy of the region in broader ways than just attracting nonresident visitors.[14]

The economic benefits of Glacier's attractiveness, though, are statewide. Seventy-three percent of Glacier's visitors are from other states than Montana.[15] These out-of-state visitors to the park make up fully one-third of all summer visitors to the state.[16] And out-of-state visitors to Glacier typically spend four days in other parts of Montana.[17]

The goose that lays this golden egg is the special nature of Glacier, beginning with its spectacular scenery. In a recent survey, 63% of park visitors identified scenery as the primary reason for their visits.[18] Ninety-seven percent of park visitors report they go sightseeing in the park. The park's wildlife is a big draw, too; 87% of GNP visitors report viewing wildlife as one of their park activities.[19] But, as shown later in this profile, both Glacier's scenery – its glaciers, its snow-capped mountains, its sweeping forests – and its wildlife are vulnerable to human-caused changes in the climate. (See especially sections 5, 6, and 7.) On top of this, projected increases in wildfires and flooding can interfere with trips to Glacier. (See sections 8 and 10.)

Beyond that, the high level of visitation to Glacier depends in large part on people who have visited it before, know and love it, and return time and again. In 2000, the year of the most recent visitor survey on this point, over half of all park visitors – 56% of them – were people who had been to the park before. This was an increase over the 41% ten years earlier who were returning park loyalists.[20]

"[W]hen visitors come to Montana for the first time, they are more likely to visit both [Glacier and Yellowstone national] parks while they are here. If they are here as a repeat visitor, they go to Glacier."

Norma Nickerson
University of Montana (2003)[21]

There is, as yet, no survey data on how visitors to Glacier might react to the effects there of climate change. But there is this kind of information from Waterton Lakes National Park, the Canadian national park immediately adjacent to Glacier. The two parks are similar enough to each other and closely enough linked together that in 1932 they were designated as the Waterton-Glacier International Peace Park, the first such international park in the world. There is substantial overlap in visitation, too, with Americans making up 37% of visitors to Waterton Lakes.[22] So attitudes of visitors to Waterton Lakes may well suggest what visitors to Glacier would think. In fact, the National Park Service has used this survey as an indicator of how visitors may react to climate-driven changes in U.S. national parks across the West.[23]

In the Waterton Lakes survey, visitors to that park were given descriptions of three possible future sets of conditions there and asked what effect they would have on their willingness to return to the park.[24] The scenarios, chosen by the researchers to represent possible future conditions in the park resulting from climate change, are described in table 2. Under scenario 3, chosen to identify the most likely impacts of climate change near the end of the century, 19% of the respondents said they would not visit the park any more. An additional 38% said they would visit less often. (See table 2 on the next page.)

A nearly identical visitor survey in Canada's Banff National Park, farther to the north, suggested that 31% of current visitors would not return again at all and 36% would return less often if the most extreme of described future conditions were to occur.[25]

One caveat about these surveys is that by the time the conditions described in scenario 3 occur, people who then are potential park visitors may not have first-hand experience with the better park conditions of today. So their reactions to a changed park may be different from those of today's park-goers. Second, when a changed climate has worsened natural conditions everywhere, a national park, even in an altered state, may still be more attractive to many people than other places would be.

But the central question is: Do we want to continue changing the climate so much that our national parks – including Glacier – are not as special as they are now? The answer to that question is easier when we consider that the things we can do to stop changing the climate are not only realistic and achievable but also produce other benefits, including creating jobs and saving money. The steps we can take are outlined in section 11. First, though, we consider how a disrupted climate would affect Glacier and people's experiences of it, in the next eight sections.

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).[26]

3

More Heat and Less Cold

At West Glacier, the decade we just completed averaged 2.0°F hotter than the 1950-1979 average. That is twice the temperature increase of the overall planet.

In 2009, the U.S. government's multi-agency Global Change Research Program released a landmark report prepared by a team of expert scientists on how a changed climate will affect the United States. That report began, "Observations show that warming of the climate is unequivocal. The global warming observed over the past 50 years is due primarily to human-induced emissions of heat-trapping pollutants."[27] This reaffirms 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.[28] In fact, according to both the USGCRP and the IPCC, without the effects of that pollution, natural factors likely would have led to the world getting cooler instead of hotter since 1950.[29]

"Global warming is unequivocal and primarily human-induced."

U.S. Global Change Research Program (2009)[30]

Glacier National Park, too, is now hotter than it used to be. There is only one weather station in the park with relatively long-term records, a West Glacier station at the park headquarters just inside the park's southwestern boundary. There, the average temperature for the decade just completed (2000-2009) was 2.0°F hotter than the station's 1950-1979 average, according to a new analysis done for this report by the Rocky Mountain Climate Organization, using government temperature data. (See Figure 1 on the next page.)

For comparison, this is slightly more of a temperature increase than at Kalispell airport, which often is used by scientists to approximate temperature trends for Glacier. The Kalispell airport, about 13 miles southwest of the park, is the closest weather station to the park that is part of the National Oceanic and Atmospheric Administration's Historical Climatology Network. That system is comprised of the nation's best individual weather stations – those with long-term data which has been reviewed and adjusted to remove any biases such as from local urban heat-island effects. At Kalispell, the decade just completed was 1.6°F hotter than its 1950-1979 average. (See Figure 1.)

That West Glacier was 2.0°F hotter in the last decade represents twice as much of a temperature increase as the global average, as shown in Figure 1. For West Glacier, Kalispell, and the world as a whole, the last decade is the hottest in the period of recorded instrumental observations.[31]

The analysis of West Glacier and Kalispell temperatures by RMCO is consistent with the other available information about temperature changes in and around Glacier. As one major example, Greg Pederson, a U.S. Geological Survey (USGS) scientist at the Northern Rocky Mountain Science Center in Montana, and others recently analyzed temperature trends in western Montana, using eight Historical Climatology Network stations (including Kalispell).[32] Their study included an analysis not just of changes in average temperatures but also of changes in temperatures above or below particular significant thresholds. For this report, the Rocky Mountain Climate Organization updated through 2008 two analyses in this study: those of the number of days in western Montana with high temperatures of 90°F or higher and those with lows of 0°F or lower. (The original analysis by Pederson and others went through 2006 for highs and through 2005 for lows.)

With the update by RMCO, the study by Pederson and others shows that from 1900 through 1980 western Montana averaged 10.8 days a year reaching 90°F. Since 1980, there

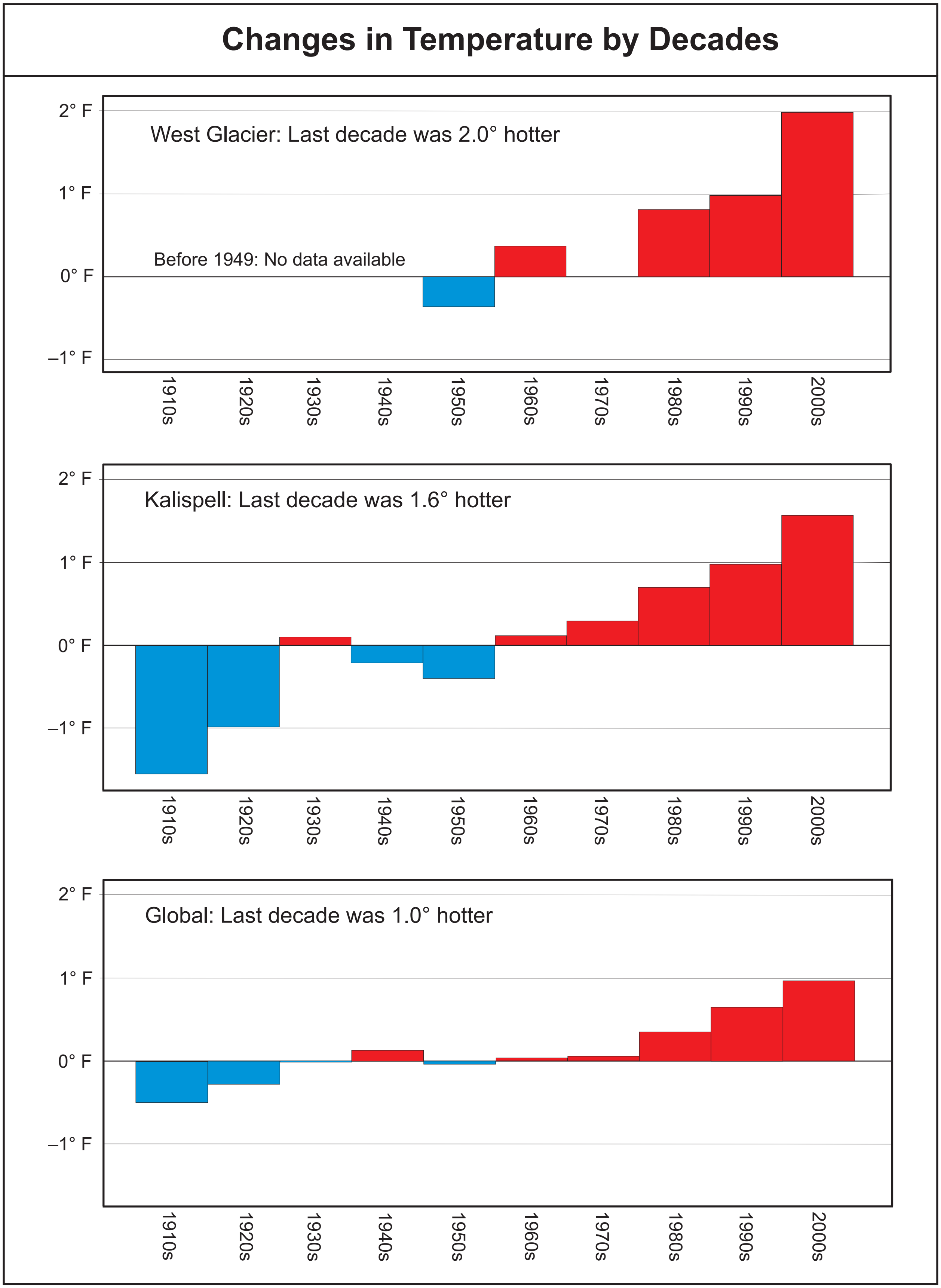


Figure 1. Average temperatures by decade, compared to respective average temperatures for 1950-1979. Data from the Western Regional Climate Center and National Oceanic and Atmospheric Administration.[33] Analysis by the Rocky Mountain Climate Organization.

have been 15.0 such extremely hot days a year – and in 2000 through 2008, an average of 18.6 a year. The most recent years, then, have more than one full week a year of extremely hot days.

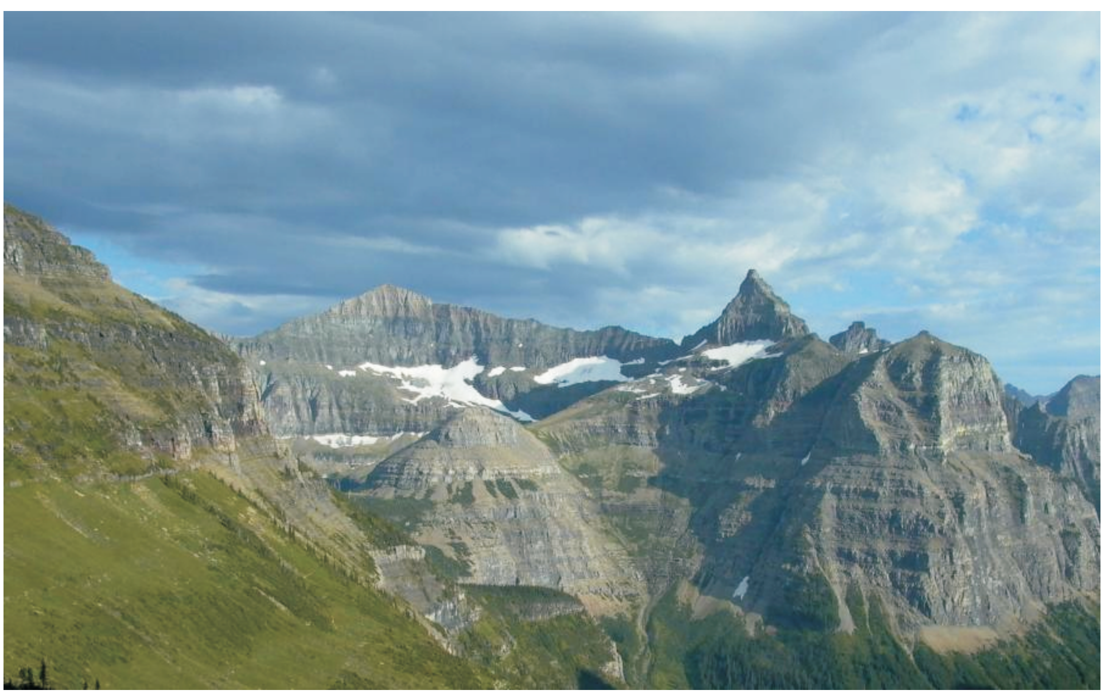
Since 1980, western Montana has averaged more than one full week a year of additional days of at least 90°F and more than one full week a year of fewer days of 0°F and below.

Along with more extreme heat, western Montana is getting less extreme cold. Days with lows of 0°F or lower occurred on average 19.8 times a year from 1900 through 1979. Since 1980, they have occurred 14.0 times a year – and in 2000 through 2008, only 12.1 times a year. The most recent years, again, have more than a full week fewer of extremely cold days.[34]

A third analysis done by Pederson and others, not updated here, shows that western Montana in 1900 through 1979 averaged 180.7 days a year with low temperatures at or below freezing. In 1980 through 2005, there was an average 152.0 such days – two and a half weeks less of frosts and freezes per year.

These three changes in extreme hot and cold temperatures, more than changes in annual averages, begin to suggest how changes of just a degree or two in average temperatures may involve changes in extreme temperatures that are ecologically or socially significant.

In another recent study, Joseph Caprio, who is a former Montana state climatologist, and two other scientists recently analyzed records of daily low temperatures (which usually are nighttime lows) in Bozeman and Coldstream, British Columbia.[35] As Caprio points out, the research is relevant to Glacier, which is between the two stations.[36] The researchers compared earlier 36-year base periods with more recent 18-year periods. (For Bozeman, the base period was 1947-1982 and the recent period was 1983-2000. For Coldstream, the base period was 1938-1973 and the recent period was 1974-1991.) Each decade, about 10% more daily lows have been in the extremely high end of the range of temperatures for daily lows. Each decade, about 10% fewer have been in extremely low end of the range. At both locations, there was more of a shift to hotter low temperatures from January through mid-April than in the rest of the year, and the greatest changes were in late February and early March. This means that the greatest increase in heat is concentrated in a time of the year when it has great effects on snowfall, snowpack accumulation, snowmelt, and the timing of streamflows; shifts in these key hydrological factors in turn have great effects on ecosystems. For example, an increase in west-



US GEOLOGICAL SURVEY

ern forest wildfires in the 17 years after 1987 compared to the 17 years before then has been closely linked to earlier streamflows and higher spring temperatures, along with higher early-summer temperatures. (See page 25.)

The greatest increase in western Montana temperatures has been in late February to late March, when the higher temperatures have pronounced effects on snowmelt,streamflows, and ecosystems.

The recent increase in temperatures that have been measured in the region containing Glacier National Park is expected to be followed by even greater increases as heat-trapping pollutants continue to accumulate in the atmosphere. Glacier, like other places, is projected to keep getting hotter.

The U.S. government, in its 2009 overview of likely climate-change impacts in the United States, reported that the Northwest, including western Montana, in the last three decades of this century could average 3° to 10°F hotter than in the last three decades of the 20th century.[37] That was based on (and represented an endorsement of) an analysis prepared by scientists at the University of Washington's Climate Impacts Group, a regional climate research center funded by the National Oceanic and Atmospheric Administration's Regional Integrated Sciences and Assessments program, summarized in Table 3.

Those regional projections probably understate how much hotter Glacier National Park will get. To begin with, in the Northwest as in most regions of the world, inland areas are likely to heat up more than coastal areas. Glacier therefore can be expected to get hotter by more than the average of the region, which includes the coastal areas of Washington and Oregon as well as inland areas.[38] Also, as is typical of most such projections, this one did not consider a plausible but even higher-emissions scenario that would have led to even higher temperature increases, nor did it reflect that in recent years actual emissions have exceeded the assumptions of that scenario. (See page 2.)

Most importantly, the projections in table 3 illustrate that there is a range of possible future temperature increases. How much hotter Glacier gets will depend in large part on what we people do – on how much heat-trapping pollutants we emit in the future. See section 11 for more information on what we can do to protect Glacier, along with the rest of the world.

Projected Future Temperature Increases in the Northwest

Time Period: 2030-2059	
Range of projected increases	+1.6 to 5.2°F
Lower-emissions future: Weighted average of models	+3.0°F
Higher-emissions future: Weighted average of models	+4.1°F
Time Period: 2070-2099	
Range of projected increases	+2.8 to 9.7°F
Lower-emissions future: Weighted average of models	+4.9°F
Higher-emissions future: Weighted average of models	+7.1°F

Table 3. Projected regional temperature changes for the Northwest (Washington, Oregon, Idaho, and western Montana) compared to the 1970-1999 average, from 20 climate models and a lower-emissions scenario and a higher-emissions one. Weighted averages reflect the accuracy of models in reconstructing actual regional temperatures for the baseline period. Source: Mote and others (2008).[39]

If we allow a higher-emissions future to occur, the median projection of regional climate models is that before the end of this century West Glacier will be hotter than Santa Fe, New Mexico, now is.[40]

4

Loss of Ice and Snow

Human-caused climate change is melting glaciers, which shaped Glacier National Park and after which it is named. A hotter climate also threatens the snow-capped mountains that add to Glacier's scenery.

As the climate gets hotter, Glacier National Park, along with other mountain areas around the world, is losing ice in glaciers and snow cover in the spring. These are among the most obvious effects of a changed climate.

LOSS OF GLACIERS

Because of human-caused changes in our climate, Glacier could lose all or nearly all of its glaciers – in the relatively near future, not generations from now.

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."[41] The World Glacier Monitoring Service has reported that glaciers around the world have melted in each of the last 18 years, with accelerated melting in recent years.[42] In the United States, glacier melting mostly is in our national parks, as a handful of parks contain the vast majority of the country's glaciers. America's best known example of glacier melting is in Glacier National Park, where many of the park's namesake features are headed for elimination, perhaps as soon as in 10 years.

Glacier was designated a national park in large part to showcase the effects of the colossal glaciers that sculpted the park's stunning landscape, beginning tens of thousands of years ago. At the end of what scientists call the Little Ice Age, which lasted from about 1550 to 1850, the area now included in the park had about 150 glaciers that continued to shape the park. As natural climate changes ended the Little Ice Age and warmed the area, the glaciers began melting. In the park's Mount Jackson-Gunsight Basin area, for example, scientists have estimated that the number of remaining glaciers went from 27 in 1850 to 10 in 1979, with the area they covered reduced by about two-thirds.[43]

By the 1980s, temperatures in the park, as around the globe, began increasing rapidly, with most of that increase resulting from human emissions of heat-trapping pollutants. (See section 3.) Across North America, measurements of the amount of ice in glaciers have shown "strong accelerating ice losses since the mid-1970s."[44]

In 2003, Myrna H. P. Hall of the State University of New York, Syracuse, and Daniel B. Fagre of USGS's Northern Rocky Mountain Science Center projected that human-caused climate change could lead to the elimination of all glaciers in the park's Blackfoot-Jackson basin.[45] That basin contains 5 of the park's 37 named glaciers. The glaciers in that basin had been the subject of earlier studies, providing a baseline of historic information to support projections of

Projected Melting of Glaciers In Blackfoot-Jackson Basin Glacier National Park

Years	Average July-August Temperature	Glacial Area Melting	Glacial Area Left
1990	61.9°F	1.16 km^2	5.05 km^2
2000	62.2°F	1.15 km^2	3.89 km^2
2010	62.6°F	1.45 km^2	2.44 km^2
2020	63.1°F	1.82 km^2	0.62 km^2
2030	63.8°F	2.29 km^2	0

Table 4. Each year represents the midpoint of an 11-year period, e.g., 2030 represents 2025-2035. Source: Hall and Fagre (2003)[46]

Glacial Melting in Glacier National Park

Figure 2. Photographs of Grinnell Glacier in Glacier National Park taken from the same point over seven decades demonstrate the melting of the glacier.

Loss of 12 of GNP's 37 Named Glaciers

Glacier	1966 Area	2005 Area	Change
Agassiz Glacier	1,589,174	1,039,077	-34.6%
Ahern Glacier	589,053	511,824	-13.1%
Baby Glacier[a]	117,111	77,510	-33.8%
Blackfoot Glacier	2,334,983	1,787,640	-23.4%
Boulder Glacier[a]	230,913	55,159	-76.1%
Carter Glacier	273,834	202,696	-26.0%
Chaney Glacier	535,604	379,688	-29.1%
Dixon Glacier[b]	452,211	241,940	-46.5%
Gem Glacier[a, b]	29,135	20,379	-30.1%
Grinnell Glacier	1,020,009	615,454	-39.7%
Harris Glacier[a, b]	152,694	34,526	-77.4%
Harrison Glacier	2,073,099	1,888,919	-8.9%
Herbst Glacier[a]	170,162	53,550	-68.5%
Hudson Glacier[a]	101,288	34,197	-66.2%
Ipasha Glacier	321,745	212,030	-34.1%
Jackson Glacier[b]	1,541,217	1,012,444	-34.3%
Kintla Glacier	1,728,828	1,136,551	-34.3%
Logan Glacier	503,298	302,146	-40.0%
Lupfer Glacier[a]	138,523	67,369	-51.4%
Miche Wabun Glacier[c]	296,139	131,298	-55.7%
N. Swiftcurrent Glacier[a]	116,651	79,117	-32.2%
Old Sun Glacier	421,254	370,257	-12.1%
Piegan Glacier	280,107	250,728	-10.5%
Pumpelly Glacier	1,489,137	1,257,211	-15.6%
Rainbow Glacier	1,284,070	1,164,060	-9.3%
Red Eagle Glacier[a, b]	206,576	97,149	-53.0%
Salamander Glacier	225,621	172,916	-23.4%
Sexton Glacier	400,444	276,780	-30.9%
Shepard Glacier[c]	250,609	110,254	-56.0%
Siyeh Glacier[a]	215,420	56,698	-73.7%
Sperry Glacier	1,339,244	874,229	-34.7%
Swiftcurrent Glacier	261,410	223,519	-14.5%
Thunderbird Glacier	358,284	238,331	-33.5%
Two Ocean Glacier	428,828	275,022	-35.9%
Vulture Glacier[b]	649,267	315,001	-51.5%
Weasel Collar Glacier	592,420	553,018	-6.7%
Whitecrow Glacier	373,439	196,228	-47.5%
TOTAL	19,890,542	16,314,914	-18.0%

future changes. Using then-current climate assumptions and models, Hall and Fagre projected that basin temperatures in July and August could be 1.9°F hotter by 2030, compared to 1990. Even that relatively modest temperature increase, they estimated, would overwhelm the effects of a projected slight increase in precipitation, leading by 2030 to the elimination of all remaining glaciers in the basin.

Since Hall and Fagre's 2003 projection, GNP's glaciers have melted faster than expected. In October 2007, based on the melting of Blackfoot Glacier, Fagre said, "[W]e're about eight and a half years ahead of schedule … Our initial projection has proved too conservative. They're going faster than we thought."[47] Fagre now says the glaciers in this basin could be gone "perhaps as early as 2020."[48]

In early April 2010, the USGS's Northern Rocky Mountain Science Center completed an update, as of 2005, of all 37 named glaciers (and remnants) in GNP.[49] That inventory, reproduced in Table 5, showed that by 2005 ten glaciers had melted away to the point that they were no longer large enough that USGS considers them to still be glaciers – using a threshold of 100,000 square meters (about 25 acres), below which the remaining ice generally is stagnant and does not move. Two other glaciers were estimated to be below this threshold as of 2010, based on their recent rate of melting. So only 25 of the park's 37 named glaciers remain.

"Observed and projected changes in glacial extent may have a negative effect on the number of visitors to Glacier National Park."

National Park Service (2009)[50]

Table 5. Area in square meters. [a]Too small to still be considered a glacier. [b]Area estimated. [c]Estimated to be too small as of 2010 to be considered a glacier. Source: Northern Rocky Mountain Science Center, USGS (2010).[51]

LOSS OF SNOW-CAPPED MOUNTAINS

Snow-covered mountains contribute to the Glacier's spectacular scenery that draws visitors. But more heat, less snowfall, and earlier snowmelt are already leading to less snow coverage of many western mountains.

University of Washington researchers have shown that April 1 snowpack levels at most of 824 government snowpack measurement sites across the West declined between 1950 and 2002 – including at all sites in western Montana.[52] The greatest declines were found in areas of relatively mild winters, where warming of a few degrees would more often mean that precipitation would be rain rather than snow, and more often lead to earlier snowmelt. For this and other reasons, the researchers concluded that the pattern of the snowpack declines points to the higher winter temperatures occurring in the West as the cause.

Other studies have found similar western snowpack declines, again especially at lower elevations; a decline in land covered by snow in winter and spring; a shift of winter precipitation from snow to rain; and earlier spring snowmelt.[53] Three recent studies attribute up to about 60% of these observed West-wide changes to the effects of human emissions of heat-trapping pollutants.[54] 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.[55]

An analysis of snowpack levels within the Crown of the Continent area (including Glacier National Park) through 2002 found a decline in most snowpack levels in the area, but no significant trend at the three measurement sites in Glacier itself, which have records going back to 1922.[56] The researchers concluded that winters in the high-elevation areas of the park have stayed cold enough so far, despite the warming that has occurred, to avoid a reduction in snowpacks at the three park sites. But they also found, though, that despite a 10% increase in annual levels of overall precipitation from 1922 to 2002, there has been no corresponding increase in snowpacks, suggesting a shift in GNP precipitation from snowfall to rainfall or earlier snowmelt, or both, over this period.

Scientists consistently project a future loss of snow in the region as the climate keeps getting hotter. A recent example is a new study by Celine Boisvenue, now at the Canadian Forest Service, and Steven W. Running, of the University of Montana.[57] They assessed possible future climate-change impacts on forests in the northern Rocky Mountains in a higher-emissions future, using six representative sites including the Summit weather station just outside Glacier's southern border. (For more, see section 7.) The results suggest major changes in snowpacks and snow cover in Glacier. By 2089, the peak snowpack level of a year at the Summit station would occur on average about February 25, compared to about April 8 in 1950. In other words, snowpacks would stop accumulating and begin melting 41 days earlier. Another projection from the study is that snow would cover the ground for about 70 fewer days, on average, by 2070-2089. As measured by this key condition, the length of Glacier's winters could be shortened by more than two months. (For more on the ecosystem effects, see the next section.)

One consequence would be that snow-covered mountains would not last as long into the summer, when most visitors come to Glacier. These snow-capped peaks are a major part of GNP's spectacular scenery, which is cited by 63% of park visitors as the primary reason they come to GNP. (See page 4.) Less spring snow would also mean a shorter season for cross-country skiing and snowshoeing in the park.

A loss of snow also makes the park drier in late summer, affecting ecosystems (see section 5), wildlife (section 6), plant communities (section 7), wildfires (section 8), and fishing (section 9).

NATIONAL PARK SERVICE

5

Loss of Water

Glacier's summers are likely to be drier, causing ecosystem water stresses.

In Glacier National Park, as across the interior West, changes in the climate are likely to reduce water availability in summer, when it is most needed by wildlife, plants, and entire ecosystems. This is already underway in Glacier and elsewhere in the West. The loss of summer water is expected to become more pronounced as human emissions of heat-trapping pollutants continue changing the climate.

Higher winter and spring temperatures have already moved peak spring streamflows from snowmelt to earlier in the year. According to the principal study on this point, by 2000 across western North America, peak streamflows were already occurring one to four weeks earlier in snowmelt-dominated streams.[58] In Montana, the peaks of streamflow were earlier on all measured streams, by periods ranging from about 5 days to over 20 days. Warmer winter and spring temperatures are primary drivers of the earlier streamflow, this study documents. This shift in the timing of streamflows does not mean that there is less overall streamflow, but it does mean that flows are higher earlier in the year and lower later in the year. As a result, ecosystems are drier in the summer, as well as hotter.

> *"Future projections for most snowmelt-dominated basins in the West consistently indicate earlier spring runoff, in some cases up to 60 days earlier."*
>
> U.S. Global Change Research Program (2009)[59]

In Glacier, a loss of glaciers is also making summers drier. Glacial ice melts in summer and the meltwater contributes to summer streamflows. In years when summer rainfall is low that meltwater is especially important to ecosystems. But as GNP's glaciers have melted away, there is less ice to produce more meltwater. Fewer watersheds in the park even contain glaciers; 23 used to, but only 14 still do.[60]

> *"We have several lakes that seem to be totally dependent on glaciers and snowmelt for fall flows. They're not doing well."*
>
> Wade Fredenberg
> U.S. Fish and Wildlife Service (2007)[61]

Most scientific projections are for late summers in this region to continue getting drier. A study by Celine Boisvenue and Steven W. Running (see section 7) included projections of much drier summer conditions in Glacier.[62] 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.

It also is possible that Glacier will get less rain in summer. Downscaled results from most current global climate models project, on average, a slight decrease in summer precipitation for this region.[63] However, global climate models are not yet judged reliable in projecting future regional precipitation trends, especially in an area like GNP, because they do not yet adequately represent the effects of mountain topography or oceanic influences on inland precipitation.[64]

The combination of hotter and drier conditions that is forecast for Glacier would harm the park's wildlife (see section 6), plant communities (section 7), and fishing (section 9), and also would increase wildfires (section 8.)

6

LOSS OF WILDLIFE

Glacier gives Americans their best chance of seeing the full range of this continent's large, native animals. But human-caused changes to the climate may disrupt the park's natural mix of species.

One of the glories of Glacier is the diversity of wildlife it harbors. The park offers Americans the best chance they have in the lower 48 states to see the full range of mammal predators present at the time of European settlement of the continent, including grizzly and black bears, wolves, lynx, wolverines, fishers, mountain lions, and more. Add in mountain goats, bighorn sheep, and elk, and it is little wonder that wildlife viewing is one of the greatest draws of the park.

But a changed climate could mean a loss of some of the species now in Glacier, as well as the park's natural mixture of wildlife. Here, as elsewhere, some species may go completely extinct. The Intergovernmental Panel on Climate Change warns that just 4° to 5°F of higher temperatures would leave 20 to 30% of plant and animal species that have been studied in climatic conditions far outside those of their current ranges, making them "likely to be at increasingly high risk of extinction."[65] One reason this percentage is so high is that stresses resulting from climate change would come atop others such as habitat loss.[66] And even if species do not become extinct everywhere, local populations of species in a particular area, such as a national park, may be eliminated.

Another change that can result from a disrupted climate is the movement into an area of new species not now able to live there, but which could as habitats and other conditions change. The presence of these species, by itself, would be a change in the naturally occurring ecosystems. The new immigrants also would create additional stresses for the natural residents, competing with them for habitat and food.

WHOLESALE SPECIES CHANGES

Glacier is at risk to these impacts. The park's staff has expressed concern to the authors of this report that as a result of the hotter and drier climate projected by scientists the park "potentially faces wholesale changes in species composition."[67]

The only study that has so far attempted to project future changes in the mammals present in Glacier was done by researchers from Yale University, who made such projections for eight national parks, including GNP.[68] Their work was based on a model projecting changes in plant communities resulting from a doubling of atmospheric levels of heat-trapping gases. (See section 7 for another projection of plant changes in Glacier.) The Yale scientists estimated that the future ecosystems present in GNP would no longer support the presence of two current mammal species (which were not identified) and so they would be eliminated from the park. The much more significant change they projected is that the park's new ecosystems would be suitable for an astonishing 45 new types of mammals, the second highest influx projected for the eight studied parks. (Yellowstone was projected to get 49 new mammals, Zion National Park 41, and five other parks from 8 to 29 new species.)

Two important caveats about this study, however, are in order. First, the projections rest on a model of how an altered climate can drive changes in the distribution of plants – and those changes are very difficult to project and modeled results cannot be taken as definitive. (See page 20.) Second, as the researchers acknowledged, they did not consider whether geographic or other barriers exist that would keep the new mammal species from moving into the parks.

Still, this study suggests that Glacier, more than most of eight studied national parks, could get new mammals moving in as a changed climate alters its ecosystems. New species would compete with native ones for habitat and food, so this could undercut one of Glacier's attractions to visitors – that it still hosts nearly the same mammals present there as at the time of European settlement.

According to a wildlife biologist on Glacier's staff, mammal species particularly vulnerable to habitat changes resulting from a changed climate are those at the southern end of their range. These include wolverines and lynx, among other species.[69]

WOLVERINES

Wolverines, famously tough and fierce, embody the wildlands they inhabit – remote high-mountain expanses large enough to offer them the large amount of room they need to roam. Although "roam" may be too tame a word for a wolverine. One radio-collared male in Glacier climbed to the top of Mount Cleveland, the park's highest peak, in the middle of winter – charging up the last 4,900 feet of elevation gain in 90 minutes.[70] Of all lower 48 states, Montana boasts the largest wolverine population, with 84% of all recent documented records.[71] And Glacier doubtless has the largest wolverine population of any national park in the lower 48 states.[72]

Wolverines provide a telling example of how wildlife can be vulnerable to a changing climate. To begin with, like many other species, they are linked to certain climate-related habitat requirements – in this case, areas with mid-spring snow cover, where 98% of all documented wolverine dens have been. This is the only studied habitat condition that fully corresponds with known denning sites, according to research by U.S. Forest Service scientists.[73] Other scientists agree that spring snow cover appears to be an absolute requirement for wolverine mothers and their babies.[74] Consistent with this, scientists in Canada have documented that wolverine populations there from 1970 through 2004 varied with the extent of snow cover; areas with the greatest declines in snow cover over that period also saw the greatest declines in wolverine populations.[75] As a hotter climate poses a threat to spring snow cover (see section 4), it also poses a threat to wolverines.

A second vulnerability of wolverines to a changed climate is that by reducing suitable habitat – such as by reducing spring snow cover, likely to happen most and first in lower-elevation

"Studies note that nearly one-third of the historical spring snowpack in existing wolverine habitat already has been lost as global temperatures continue to warm, and that that percentage could double by 2090.Without snow, these carnivores could quickly go extinct. Nowhere in the world has a female wolverine been documented to build her den anywhere else but in snow."

National Parks Conservation Association (2009)[76]

areas – it can reduce their needed room to roam. Not only do individual wolverines use large territories, but wolverine populations need large areas of connected habitats so young wolverines can disperse into new territory when they leave their parents and so adults from different areas can meet and provide an exchange of genes among different populations.[77] So Glacier's wolverines cannot persist in isolation; they need adjacent areas to remain suitable, too. If a hotter climate begins eliminating spring snow cover from nearby lower-elevation areas, restricting Glacier's wolverines to shrinking islands of suitable habitat, they could be in trouble.

LYNX

Canada lynx, a threatened species in the contiguous United States under the Endangered Species Act, also could be at risk in a hotter world. Lynx are equipped with large, almost snowshoe-like feet that enable them to travel on top of snow, helping them catch snowshoe hares, their primary winter food, and compete with other predators for hares. That advantage may be essential to the survival of lynx. One team of researchers has documented that most areas where lynx now occur have four months of snow cover and average January temperatures under 17°F.[78] If those identified habitat conditions identify areas that are suitable for lynx, just a 4° to 7°F increase in average annual temperatures could eliminate about half of the suitable habitat in the contiguous United States. This is not just a theoretical concern – a wildlife biologist on Glacier's staff has expressed concern to the authors of this report about the effects of declining snow cover on lynx in the park.[79]

"Boreal forest, snow, and showshoe hare – the primary food source for the lynx – may not shift synchronously. So climate change could produce habitat fragmentation and, at the least, disruption of the conditions that the Canada lynx require for survival."

Patrick Gonzalez
University of California, Berkeley[80]

GRIZZLY BEARS

Grizzly bears in Glacier have a relatively stable population and may not be as affected by climate change as those in the Yellowstone ecosystem. (In Yellowstone, the potential effects of an altered climate on a key food source – whitebark pine nuts, threatened by warming-promoted spread of tree-killing mountain pine beetles – were the basis of a federal judge blocking an effort by the U.S. Fish and Wildlife Service in the administration of President George W. Bush to remove Yellowstone bears from the protections of the Endangered Species Act.) In Glacier, whitebark pines have already been nearly eliminated, but other key local foods for grizzly bears could be affected by a changed climate. In particular, the park's staff has expressed to the authors of this report a concern that a changed climate could affect the availability of berry crops, an important food source for GNP-area grizzly bears.[81]

The federal Interagency Grizzly Bear Study Team has also detected that grizzly bears have begun hibernating at later dates over the period 1975 to 1999, coinciding with a rise in fall temperatures.[82] This could lead to more conflicts between bears and people, especially during fall hunting seasons. As conflicts with people are a major contributor to grizzly bear deaths, this could affect the regional grizzly bear population.

BIGHORN SHEEP, MOUNTAIN GOATS

At Rocky Mountain National Park, the NPS has expressed concern that the park's bighorn sheep population could decline over time due to loss of open alpine habitat as forests move upslope.[83] A USGS scientist at Glacier has expressed similar concern that the movement of plant communities in GNP in response to climate disruption (see section 7) could "dramatically alter mountain goat and bighorn sheep habitats" in the park.[84] Melting of the Blackfoot Glacier, which appears to limit movements between two genetically distinct bighorn populations in the park, could enable the spread to the southern group of diseases now found only in the northern population. The USGS staff is seeking funding to assess these types of potential impacts on mountain goats in the park.[85]

NATIONAL PARK SERVICE

NORTHERN BOG LEMMINGS

The northern bog lemming may not be what some people call "charismatic megafauna" – large animals with great popular appeal. Relatively few people know of this lemming or have seen it in Glacier. But it is part of the nearly unique, natural mix of mammal species in the park, and illustrates the vulnerability to climate change of species living in specialized habitat niches. Listed as a "species of concern" in Montana, it is present in GNP at the southern end of its range, in bog habitats in the North Fork of the Flathead River Valley and moist old-growth cedar-hemlock forests in the McDonald Valley. Both of these habitats could be highly vulnerable if an altered climate makes these areas drier or changes groundwater levels there. If the habitats are disrupted, the lemmings could be in trouble.[86]

PIKAS

Like northern bog lemmings, pikas do not qualify as charismatic megafauna; they are too small. But they have been called “the essence of cuteness” in a leading scientific journal.[87] These relatives of rabbits are year-round residents of mountaintop areas adapted to survival in extreme cold but not in heat – making them “early sentinels” to a changed climate, in the words of some scientists.[86] In warmer areas than Glacier, there already is evidence that pikas are being eliminated from some areas. Researchers recently surveyed 25 sites in the Great Basin (between the Rocky Mountains and the Sierra Nevada) where pikas are known to have previously lived. They were unable to find any pikas in nine of those 25 sites – primarily those at lower, hotter elevations.[89] This raises concerns for the future of the species as the climate continues getting hotter. The U.S. Fish and Wildlife Service in February 2010 decided not to now list pikas under the Endangered Species Act because of the threats of climate change, but said they warrant continued monitoring.

A University of Wisconsin-Madison researcher who has been studying pikas in Glacier for three years has found that their distribution in the park (as elsewhere) is affected by elevation, temperature, and vegetation cover – the latter two of which are likely to be affected by a changed climate. If climate-driven changes in plant communities reduce the alpine plants on which pikas depend and increase grasses instead, this may have adverse effects on pika persistence.

NATIONAL PARK SERVICE

Also according to the researcher, pikas in Glacier may be unable to move upslope to stay ahead of higher temperatures because of the steeper slopes and lack of persistent snowpack in the higher, wind-scoured areas.[90]

PTARMIGAN

D. BENSON

White-tailed ptarmigan, the only birds residing year-round on the tundra of Glacier, could be threatened by a hotter climate. In Rocky Mountain National Park, researchers have detected a decline of about 50% between 1975 and 1999 in ptarmigan numbers and projected that the birds could become locally extinct there in another 10 to 20 years as temperatures continue rising.[91] In Glacier, too, ptarmigan appear to be changing their distribution in the park, changing their habitat, and perhaps declining. In 2009, compared to 1996 and 1997, ptarmigan flocks are smaller and less numerous, and at Logan Pass have moved uphill about 1,000 feet.[92]

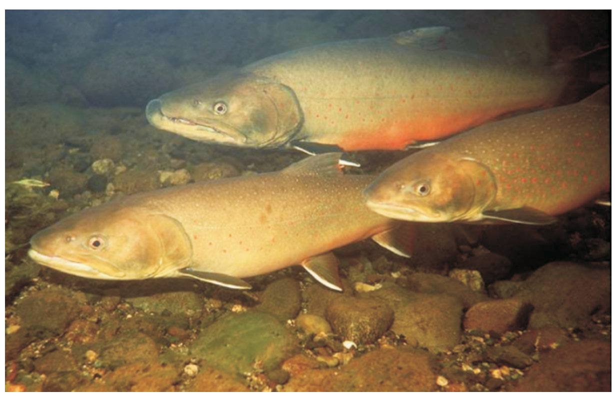
TROUT

An altered climate is likely to reduce inland populations of coldwater fish species, including trout and salmon. For trout in the interior West, a hotter climate is a real threat to their survival; when water temperatures reach the mid-70°s, trout can die.[93] In many streams and rivers in the West, trout are already living at the upper end of their natural thermal range. This means that a slight warming of stream temperatures could render those streams uninhabitable.

For example, in Yellowstone National Park's Firehole River in 2007, temperatures topped 80°F for several days and as many as a thousand trout died in the largest documented fish kill in the park's 135-year history.[94] Under a high-emissions future, Rocky Mountain streams could warm up enough to reduce trout habitat by 50% or more by the end of the century.[95] In Glacier, one contributor to warmer waters is a decline in glacier meltwater, which moderates stream temperatures.[96] In many cases, climate change will add to the stresses already threatening native fish populations, such as habitat fragmentation and competition from non-native species.[97]

According to U.S. Geological Survey researchers, bull trout and westslope cutthroat trout are "highly sensitive to elevated temperatures."[98] In particular, bull trout, present in Glacier and some of the West's other wildest places, have the lowest tolerance to hot waters of all North American fish in the family that includes both salmon and trout.[99] About 90% of bull trout are projected to be lost due to a changed, hotter climate.[100] Westslope cutthroat trout populations, which are native to Montana, Wyoming, Idaho, and Washington State, face threats similar to those of bull trout. Up to 65% of westslope cutthroat is regarded as at high risk from a combination of warming stream temperatures, changes in flood regimes, and wildfire disturbances.

In Glacier, an altered climate has the potential to impact habitat for bull trout in the park through a number of mechanisms including increasing water temperatures, altering precipitation patterns, changing hydrology (such as by increasing early winter rain-on-snow flood events), and reducing late summer contributions of cold water to spawning and rearing streams as perennial snow and ice-bodies are lost. Warmer water temperatures may also favor additional expansion of non-native species such as brook and rainbow trout into areas now occupied by bull trout and westslope cutthroat trout.[101] Parts of the Flathead River drainage in and near Glacier are regarded as being at particular risk.[102] A study is now underway examining the vulnerability of bull trout and westslope cutthroat populations in the upper Flathead River drainage (including in Glacier) to warming temperatures, flow alterations, wildfire, and invasive aquatic species under various climate-change scenarios.[103]



US GEOLOGICAL SURVEY

"Bull trout require the coldest water of all species native to the Rocky Mountains (summer temps less than 58 degrees F and spawning temps less than 48 degrees) . . . As late summer flows are affected by global warming, fewer rivers will be able to provide ample cold water for bull trout."

Endangered Species Coalition (2009)[104]

7

DISRUPTION OF PLANT COMMUNITIES

An altered climate threatens the natural plant communities of Glacier, from forests and alpine tundra to meadows and wildflowers – affecting the scenery that draws visitors to GNP.

An altered climate could lead to wholesale changes in Glacier's plant communities, and to changes in the mix of plant species in given areas, which may result in less biodiversity and altered ecosystems in the park.[105]

FORESTS REPLACED BY GRASSLANDS

Researchers Myrna Hall and Dan Fagre, besides projecting a changed climate's effects on glaciers in GNP (see section 4), also projected how the types and locations of plant communities in the Blackfoot-Jackson Basin in the park could be affected by changes in summer temperatures and soil moisture.[106] The results are shown in Figure 3 on the following page. Alpine tundra plants begin to inhabit areas now covered by glaciers, forests move upslope, and grasslands encroach into the basin. Overall, after the middle of the century, the total amount of area in forests of all types would decline. Grasslands, not now even present in the basin, would take over an increasing amount of the basin. There would be, in short, fundamental changes in the communities of plants in the basin, particularly a replacement of forests by grasslands.

Projecting the effects of climate changes on plant communities is difficult, and this type of projection needs to be taken as a suggestion of a plausible future, not a firm prediction.[107] The Hall-Fagre projection, however, is generally consistent with other modeling of how an altered climate may affect forests. For example, in Washington State, only 13% of the area now with Douglas-fir is projected to still be suitable for that species by the 2060s.[108]

So far, the evidence of forests moving upslope in GNP is limited to changes at treeline, summarized below. But elsewhere in the West there is wide-scale evidence of forests moving upslope in the same type of way projected for Glacier. In California, scientists have documented that the lower edge of the mixed conifer forests in the Sierra Nevada has moved upslope in the last 60 years, with ponderosa pines – the dominant lower-elevation tree of the forests – giving way to oak and chaparral.[109] The change in forest types has coincided with a change in temperature; areas that formerly but no longer have sub-freezing temperatures are where the conifers have given way to other plants. These changes have already reached the lowest elevations of Yosemite National Park.

DECLINE IN FOREST HEALTH

Two University of Montana scientists, Celine Boisvenue (now at the Canadian Forest Service) and Steven W. Running, recently projected that a changed climate will create new water stresses leading to declining forest health in the northern Rocky Mountains, including Glacier.[110] This is

Changes in Plant Communities in Glacier, 2000 Through 2080

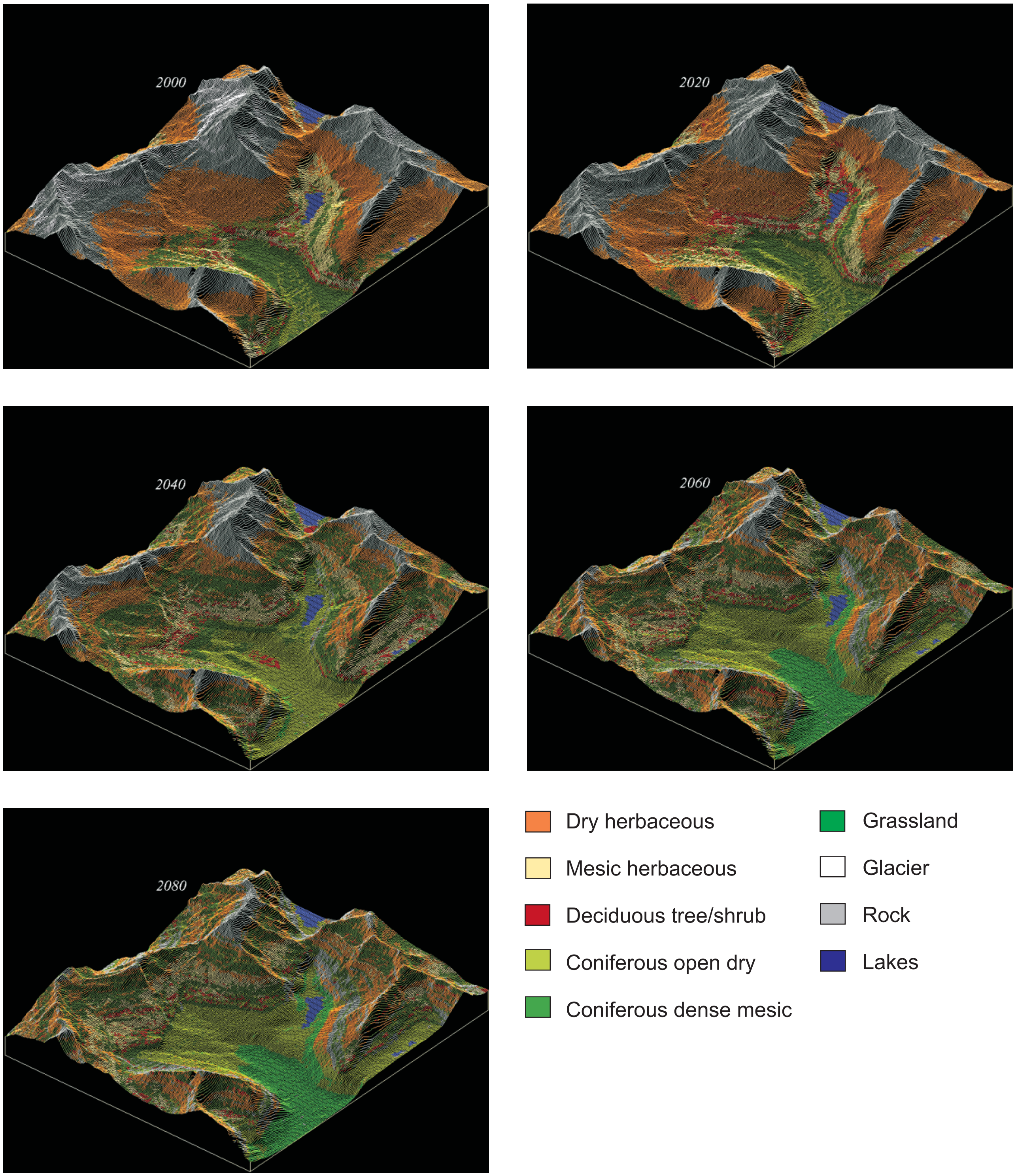


Figure 3. Projected changes in the plant communities of the Blackfoot-Jackson Basin, Glacier National Park. Source: Northern Rockies Science Center, U.S. Geological Survey, based on Hall and Fagre (2003).[111]

the same study that also projected early peak dates for snowpack accumulation and reductions in snow cover, described in section 4. Because of that earlier snowmelt and of hotter summers, they projected that periods of late-summer dryness would last six to eight weeks longer toward the end of this century. As a result, during this century (from 2006 through 2089), conifers at the Glacier site in this study would face above-average water stress (by previous norms) in about 85% of the years. As the availability of adequate moisture is the primary determinant of forest health in summers in this region, the effect could be a substantial decline in forest health.

Similarly, in Washington State, forests could face summer water deficits two to three times more often, because of reduced summer precipitation and hotter summer temperatures.[112]

> *"If existing trends in precipitation continue, forest productivity will likely decrease in the Interior West.*
>
> *"*U.S. Climate Change Science Program (2008)[113]

LOSS OF ALPINE TUNDRA

Alpine tundra – a mountain ecosystem that is treeless because conditions are too harsh for tree growth – may be especially vulnerable to a warming climate. Temperature increases appear to have been greater atop mountains than at lower elevations.[114] As mountaintop temperatures warm, plants adapted for survival there may not be able to tolerate the changed conditions and may have no nearby higher, cooler environments in which to disperse. At the same time, where soils permit, forests may move upslope and overtake the tundra as mountaintop conditions become less harsh and trees have a chance to survive there. This change is part of the projections for GNP's Blackfoot-Jackson Basin shown in figure 3 on the previous page. Similarly, In Rocky Mountain National Park, scientists have projected that a temperature increase of 5.6°F (consistent with a lower-emissions future by the end of the century) could cut that park's huge expanses of tundra in half and that an increase of 9 to 11°F (possible with a higher-emissions future) could virtually eliminate them.[115] Actual changes in the types of plants on mountain tops, however, will depend on a variety of variables, such as wind, topography, and soil, not just temperature.

Scientists in Glacier are monitoring for and finding evidence of the types of changes that have been projected. The park hosts the original North American site in a new worldwide network to track changes in the plant communities of the world's mountaintop tundra areas. The researchers are now finding evidence of changes in trees at GNP's treelines. In many sites in the park, tree seedlings are vigorously colonizing open areas; trees at treeline are growing

NATIONAL PARK SERVICE

Logan Pass, one of Glacier's most popular spots, where visitors can reach alpine tundra on the Going-to-the-Sun Road.

NATIONAL PARK SERVICE

faster and in upright form rather than in the stunted form typical of trees at treelines; and repeat photography has demonstrated changes in the elevation of treelines, although some of those shifts may result from changes in fire-management practices.[116] In monitoring seven types of typical tundra plants, scientists have found declines of 31% to 65% in four of them between 1989 through 2002, while none have increased.[117]

LOSS OF MOUNTAIN MEADOWS

Mountain meadows exist where the combination of heavy snow cover in the winter and a short growing season in the summer makes it impossible for tree seedlings to survive. A hotter climate is likely to both reduce snow cover and extend the growing season for trees, shrinking the alpine meadows that add to the scenery of Glacier. Scientists have already detected that trees are encroaching on mountain meadows in Glacier, as they are in other mountain areas around the West.[118]

"Repeat photography clearly shows that trees have invaded many subalpine meadows in GNP over the past century, which is likely the result of warming temperatures and reduced snowpack persistence."

Dan Fagre, U.S. Geological Survey (2007)[119]

LOSS OF CEDAR-HEMLOCK FOREST

Southwestern Glacier is home to the easternmost old-growth cedar-hemlock groves in the western United States, present here because of lake and Pacific Ocean influences on the local climate. This moist habitat is important to the biological diversity of Glacier because it hosts species found nowhere else in the park. Like mammal species that are at the edges of their ranges (see page 16), these cedar-hemlock groves are vulnerable to climate changes.[120] In this case, the ecosystem and the rare species in it are at particular risk if human-caused climate change continues making the area hotter and drier. As is often the case, the risk to the ecosystem is magnified because of other, existing stresses – in this case, because the cedar-hemlock groves are already fragmented by campgrounds, roads, and other human developments.

LOSS OF WILDFLOWERS

GNP is justly famous for its mountain wildflowers, but wildflowers across the West could be adversely affected by 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 raise summer temperatures of test plots by 4ºF for more than a decade, they have observed a loss of wildflowers and an increase in sagebrush, normally found in lower, drier areas.[121]

"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)[122]

Another study shows that, paradoxically, earlier snowmelt actually leads to more wildflowers being lost to frost.[123] The growing season starts earlier and flower buds open sooner, leaving them exposed to mid-spring frosts. From 1999 through 2006, the percentage of wildflower buds lost to frost doubled, compared to the previous seven years.

INSECT OUTBREAKS

Both a recent U.S. government report and the Intergovernmental Panel on Climate Change point to rising temperatures as being a significant cause of increased outbreaks of insects in forests.[124] One such outbreak, by mountain pine beetles, is widespread at epidemic levels in the West, and is killing trees across millions of acres. Much of Montana is experiencing the outbreak; while Glacier has so far been spared in this outbreak, the park staff anticipates a future increase in mountain pine beetle infestations in GNP.[125]

A key difference between the current mountain pine beetle outbreak and previous ones is that now, because of higher temperatures, beetle populations are no longer held back so much by extreme winter cold; the beetles are able to infest higher-elevation areas that used to be too cold for them; and the beetles have a longer active season and are able to complete their life cycles quicker.[126] Also, hotter and drier conditions have stressed trees, making them more susceptible to beetle attacks.[127] Even if Glacier escapes this epidemic, it does illustrate how unnatural conditions (in this case, a hotter climate) can unleash a natural force (bark beetles) that then disrupts an ecosystem.

INVASIVE PLANTS

In Glacier and elsewhere, an altered climate is likely to worsen the threats posed to natural plant communities by non-native invasive plants. Invasive plants generally appear to better tolerate a wider range of environmental conditions and may be more successful than native plants in migrating and establishing themselves in changing ecosystems. Invasive plants also are often very difficult to control once established in an area.[128] Twenty non-native invasive plants currently in Glacier threaten the diversity of the area's native plant communities, reduce wildlife habitat, and increase soil erosion. An example of an invasive plant that could more widely spread in GNP as a result of a changed climate is cheatgrass, currently present on about 20 acres in the park, which is considered by the park's staff to be a major potential threat to GNP's grasslands.[129] Cheatgrass is a non-native annual grass that is invasive in the intermountain West, where it typically invades perennial shrub lands and can displace native species by growing earlier in the spring season and using up available water resources.

8

More Wildfires

Hotter and drier conditions in Glacier are likely to lead to more wildfires, affecting visitors to the park.

Climate conditions are major factors influencing the frequency and extent of wildfires, and the hotter and drier conditions expected to result from an altered climate in Montana and the rest of the interior West are projected to lead to more wildfire activity than in the absence of human-caused climate change.[130]

Fire is a natural part of Glacier's environment – "as natural as a rain storm or a strong wind," according to the National Park Service.[131] Fire is essential for the health of Glacier's ecosystem, as it 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 wildfires also can disrupt summer vacations for park visitors. During the summer of 2003, unusually hot, dry, and windy conditions led to "what is known to many as the year of the fires in Glacier National Park."[132] Because of wildfires which burned about 10% of the park acreage, visitation in August, normally the second busiest month of the year, fell by 50%, with about 258,000 fewer visitors than in the three previous years.[133]

Even when fires are not present in a park, only nearby, visitation can be affected. In 2003, even though Canada's Waterton Lakes National Park – adjacent to Glacier – did not itself have any wildfires, park visitation declined 7% in July, 17% in August, and 15% in September, compared to the previous year, which officials in Parks Canada attributed to public awareness of that summer's wildfires and wildfire-driven restrictions in Glacier and in other Canadian mountain parks.[134] Similarly, in the summer of 2002, when hot and dry conditions led to large fires in Colorado, the number of July visitors to Rocky Mountain National Park dropped by nearly 100,000 from the previous year, even without any fires in the park itself.[135]

Clearly, unnatural increases in wildfire resulting from a human-caused change to a hotter, drier climate would reduce visitation to and enjoyment of Glacier.

NATIONAL PARK SERVICE

Smoke from the 2003 Trapper Fire in Glacier, seen from Logan Pass.

"Because of increases in fire season length and severity it is possible that visitors to mountain parks may experience more restrictions on their activities (e.g. campfire bans; trail and park closures)."

National Park Service (2009)[136]

9

LOSS OF FISHING

Hotter and drier conditions can lead to fishing restrictions to save fish populations.

Anglers have long enjoyed fishing amid the natural settings of Glacier – and fishing is an important and growing contributor to Montana's economy. Statewide, the number of fishing days increased from 2.6 million in 1996 to 4.1 million in 2001.[137] Anglers add nearly $300 million a year to Montana's economy.[138] But with a changed climate likely to reduce trout populations in GNP (see section 8), recreational fishing opportunities are likely to suffer, too.

In Glacier itself, the National Park Service has not yet had to impose fishing closures because of climate-related factors and their effects on trout. But what has recently happened in other parts of Montana suggests what could be in store in the park. In eight out of the last dozen years, drought and higher temperatures have led to fishing closures and restrictions in the state to sustain fish populations for the future. From 2001 through 2006, 119 segments of rivers were either entirely closed to fishing or subject to access restrictions for morning-only fishing or bag limits. The summer of 2007, with record-setting temperatures across the state, was even worse. By mid-August, 40 streams and lakes were closed, with 13 of those full 24-hour closures.[139] Farther to the south, the National Park Service closed 232 miles of streams in Yellowstone National Park to fishing.[140]

"The final ramification of [higher temperatures] is that our late summer stream flows in July and August are just dwindling to lower and lower stream flows, and that's really going to ultimately impact our trout populations and our fishing tourism."

Steven Running, University of Montana (2008)[141]

10

More Downpours and Flooding

More extreme precipitation is likely to lead to more downpours and flooding.

With a changed climate, more precipitation now comes in downpours. The amount of rain falling in heavy storms increased by 20% over the past century.[142] In a recent report, the U.S. Global Change Research Program says there is at least a 90% likelihood that heavy downpours will become even more frequent and intense.[143] With an increase in downpours, flooding also is likely to increase.[144]

Flooding at Many Glacier Lodge, Glacier National Park, 2006.

Glacier National Park, like virtually all national parks, is at risk to increased damage from more downpours and flooding. A recent example of how extreme weather can affect the park is from November 2006, when 12 inches of precipitation (mostly rain) fell at one weather station in the park in just six days. One 24-hour period saw 6 inches of rain, setting a new record for Montana and causing extreme flooding and damage in the park.[145] The flooding washed away all or parts of the Going-to-the-Sun highway at several points, necessitated $7 million in emergency repairs, and delayed the opening of the highway the following year until July. The 28-mile Inside North Fork Road on the park's west side was also closed from the flooding and did not fully reopen until July 2009, a full two and a half years later.

The same storm's effects in Mount Rainier National Park illustrates the even greater damage that greater downpours and flooding can cause. There, 18 inches of rain fell in the park 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.”[146] Nearly the entire park was closed until the following May, with the number of park visitors before then falling to only 8% of the normal level.

At Glacier, an earlier episode of flooding in 1995 also “resulted in diminished visitation, which continued through the remainder of the decade,” according to the NPS.[147] In the five years before the flooding, the annual number of visitors to the park averaged 2.1 million. In the five years afterward, visitation fell to an average of 1.7 million, a decline of 18%. It took a decade, until 2004, for visitation to again hit the two million mark.

11 TACKLING CLIMATE DISRUPTION

To keep Glacier National Park such a special place, local efforts are needed to protect park resources. Even more important is reducing heat-trapping pollution enough to avoid dangerous climate disruption.

As the risks of a changed climate dwarf all previous threats to our national parks, new actions to face these new risks must also be on an unprecedented scale. Needed are both actions specific to parks to preserve their resources and actions to curtail emissions of climate-changing pollutants enough to reduce the impacts in parks and elsewhere.

KEEPING GLACIER A LANDSCAPE OF INSPIRATION AND HOPE

Although the impacts of climate disruption that are already underway or are projected to occur in Glacier National Park are potentially severe, compared to other national parks Glacier is in a much better position to withstand those impacts – almost uniquely so in the lower 48 states. For other national parks, protection of other lands outside park boundaries, through acquisition of land from willing sellers or cooperative agreements for migration corridors, will be important to afford plants and animals and plants a chance to migrate and adapt. Glacier, though, is itself large – more than a million acres. More importantly, it is the heart of the much bigger, intact, vibrant Crown of the Continent ecosystem, which covers more than 10 million acres, mostly in public ownership. Taking care of this entire ecosystem is essential to reduce other stresses that can worsen the perils of climate change, to maintain functional plant and animal communities, and to help Glacier weather the storm of a disrupted climate.

Some recent, far-sighted actions serve as examples:

- Private conservation groups, the Montana state government, and the federal government (through the leadership of U.S. Senator Max Baucus) negotiated the purchase of more than 300,000 acres of private forestland from Plum Creek Timber Company, heading off residential and commercial development that would have affected wildlife habitat and increased wildfire risks and firefighting costs.

- Canada and the United States have jointly agreed to ban open-pit coal mining, mineral exploration, and oil and gas drilling in the North Fork of the Flathead River Valley, including the headwaters of Glacier National Park and Flathead Lake. This will help maintain Glacier's natural connection to adjoining habitat for its native fish and wildlife.

- Future oil and gas leasing has been banned on Montana's Rocky Mountain Front, again through Senator Baucus' leadership, and incentives have been provided to retire existing petroleum leases. This will help maintain Glacier's natural connection to adjoining habitat for its native fish and wildlife.

Continuing this kind of leadership in protecting the entire Crown of the Continent and Glacier will be even more important as future human-caused climate changes raise new risks. A full suite of other actions, by the National Park Service and others, also will be needed to protect Glacier's resources, as outlined in chapter 9 of *National Parks in Peril: The Threats of Climate Disruption*, the October 2009 report by RMCO and NRDC. Some examples:

- NPS should consider the combined effects of climate change and of other stresses on park resources and values, and work to reduce all the stresses that pose critical risks to parks.

- The NPS should develop park-specific and resource-specific plans to protect the

- particular resources most at risk in individual parks.

- NPS officials should speak out publicly about how climate change and its impacts threaten national parks and the broader ecosystems on which they depend.

- The NPS should use its environmental education programs to inform park visitors about a changed climate and its impacts in parks and about what is being done in parks to address climate change and its impacts. The NPS should require concessionaires to do so, too.

- The Congress and the Administration should adequately fund NPS actions to address a changing climate, through the energy and climate legislation now in Congress, through new NPS authority to use entrance fees to reduce emissions of heat-trapping pollutants and address impacts in parks, and through funding of the Land and Water Conservation Fund.

- The Congress and the Administration should rebuild and enhance the scientific and research capacity the NPS had prior to 1993.

- The National Park Service also has a role to play in reducing emissions; the NPS should adopt a nationwide goal of becoming climate-neutral in its own operations within parks, as has been adopted by its Pacific West Region, and work to reduce emissions from visitor activities. Those actions can inspire park visitors.

"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 (2009)[148]

AVOIDING DANGEROUS CLIMATE DISRUPTION

Contributed by Theo Spencer, NRDC

Ultimately, though, to protect our national parks for the enjoyment of this and future generations, it will take actions by all of us to reduce emissions of heat-trapping pollutants enough so that human disruption of the climate and its impacts do not overwhelm the parks. The federal government must lead the way, with broad, aggressive actions on three essential fronts:

- Enacting comprehensive mandatory limits on global warming pollution to reduce emissions by at least 20% below current levels by 2020 and 80% by 2050. This will deliver the reductions that scientists currently believe are the minimum necessary, and provide businesses the economic certainty needed to make capital investments to achieve those reductions.

- Overcoming barriers to investment in energy efficiency to lower emission reduction costs, starting now. To fully harness energy efficiency potential, many opportunities require additional federal, state, or local policies to unleash investments that are already cost-effective even without a price on greenhouse gas emissions. Policies include building, industry, and appliance efficiency (standard) upgrades, as well as incentives for "smart transportation," advanced vehicles, and smart growth.

- Accelerating the development and deployment of emerging clean energy technologies to lower long-term emission reduction costs. That means incentives and investments in renewable electricity, low-carbon fuels, and carbon capture and storage, including a federal renewable energy standard, as well as infrastructure upgrades to support transmission capacity for these renewable assets. Finally, regulations to require any new coal-fired power plant to capture and permanently geologically sequester at least 85 percent of its carbon dioxide emissions, along with state and federal regulatory frameworks for site selection, operation, and monitoring for carbon capture and geologic storage systems.

NOTES

For general matters of science with respect to climate change and its overall impacts, readers are referred principally to an excellent 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. It is a summary of the science of climate change and the impacts of climate change on the United States, now and in the future, in eminently readable form. For any reader interested in more detailed information on climate change and its effects across the United States, that report lists several hundred sources on particular points.

For matters of specific relevance to climate change and its impacts on Glacier National Park, this profile relies on 33 government sources, 55 scientific sources, and other sources listed here.

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