THE CHALLENGES OF CLIMATE CHANGE

Losing Ground: Western National Parks Endangered by Climate Disruption

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Part 1: Climate disruption poses an unprecedented risk to western national parks

THE NATIONAL PARKS IN THE AMERICAN WEST include some of the country's most treasured places: the geysers of Yellowstone, the nation's first national park; the gorges of Grand Canyon; Yosemite's dramatic rock domes; and Mesa Verde's cliff dwellings. To preserve these national treasures for all time, Congress directed the National Park Service (NPS) to manage them "in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."[1]

Congress believed that NPS could preserve the national parks unimpaired by managing properly the resources and uses within the parks. Now, however, the continued ability of the national parks to bring enjoyment to the American people is at risk because of an unprecedented, external threat: climate change. A climate disrupted by human activities poses such sweeping threats to the scenery, natural and cultural resources, and wildlife of the national parks and to our enjoyment of the parks that it dwarfs all previous risks to these American treasures.

Climate disruption and its causes

Although local temperatures fluctuate naturally, over the past 50 years the average global temperature has increased at the fastest rate in recorded history—primarily, scientists agree, as the result of human activities that spew heat-trapping gases into the atmosphere.[2] These pollutants, particularly carbon dioxide from the burning of fossil fuels, collect in the atmosphere like a thickening blanket and trap the sun's heat, causing the planet to warm up.

The consequences of climate-changing pollution are sweeping, and its full-scale impacts are hard to predict far in advance. But each year, scientists learn more about how climate change already is affecting the planet and what consequences are likely to occur if current trends continue, including:

- Changing temperatures will reduce snowfall and snowpacks, change water supplies, and lead to more severe droughts.
- Rising sea levels will lead to coastal flooding.
- Warmer seas will fuel more intense hurricanes.
- People will face more mosquito-borne and other diseases.
- Key habitats, from coral reefs to mountain meadows, will be disrupted and many plant and animal species driven to extinction.

Climate disruption particularly affects the West

Many scientists think the American West will experience the effects of climate change sooner and more intensely than most other regions.[3] To begin with, the West already is warming faster than the East.[4] Over the past 100 years, warming west of the 100th meridian (the traditional beginning of the West) has been twice as great as east of that boundary.[5] Warming is also greater in mountainous areas, putting the spectacular mountain ranges of the American West (home to many national parks) at more risk than lowlands.[6] These changes are already profoundly affecting the scarce snow and water resources of the West: more winter precipitation is falling as rain rather than snow.[7] Snowpacks have declined at most sites measured by the government.[8] Snow is melting earlier in the spring, and peak flows of streams and rivers have moved earlier in the year, leaving summers drier.[9] And recent widespread, severe droughts in the West are consistent with scientific projections that climate change will make the world's wet areas wetter and dry areas drier.[10]

Scientists predict that these changes in the West will likely continue. Projections of future warming by the end of the century range from, on the low end, 3 to 7 degrees Fahrenheit for the entire West to, on the high end, as much as a 14-degree (Fahrenheit) warming in the Southwest.[11] With this warming, more winter precipitation will fall as rain instead of snow, less snow will accumulate atop mountains through the winter, and the snowpacks will melt earlier in the year.[12] And a scientific workshop concluded that in areas like the American West, a combination of hotter summers and earlier snowmelt "is a recipe for increased intensity, frequency and duration of drought."[13]

In the arid and semi-arid West, changes of these magnitudes would fundamentally disrupt the region's ecosystems. The region's national parks, representing the best examples of the West's spectacular resources, will be among the places where the changes in the natural environment will be most evident. As a result, a disrupted climate is the single greatest threat to ever face western national parks.

Part 2: Climate disruption threatens natural resources and wildlife

The rising temperatures and changing precipitation patterns of a disrupted climate could drastically reshape entire ecosystems across the West, including in the region's national parks. If we allow climate change to continue unchecked, everything from the glaciers, snowfields, and meadows to the plants and animals living in parks could be fundamentally altered. And these changes could occur in our lifetime, not in some distant future.

Glacier loss from rising temperatures

Scientists predict that a quarter of the ice in the world's mountain glaciers could melt away by 2050 as a result of climate change.[14] Western national parks, home to most of the glaciers in the lower 48 states, share this vulnerability. National parks known, in part, for their spectacular glaciers are Glacier, Mount Rainier, North Cascades, Olympic, and Yosemite.

Glacier National Park in Montana, despite its name, is in great danger of losing all its glaciers. U.S. Geological Survey scientists now count only 26 ice bodies that still qualify as glaciers, down from 38 glaciers in 1968, and project that by 2030 all glaciers in the park could be gone, as shown in Table 1 and Figure 1.[15]

Glacier is not the only western national park losing glaciers and icefields. Washington's North Cascades National Park has 318 glaciers, representing 60% of the land covered by glaciers in the United States south of Alaska (Figure 2). But since 1958, the total mass of the park's glaciers has shrunk by 80%.[16] Here, as in other national parks, the loss of glaciers affects more than just the scenery. NPS estimates that as much as 50% of the park's late summer stream flow is fed by its glaciers. In the Thunder Creek watershed, shrinking glaciers have already reduced summer flows by 31%. If all the glaciers were lost, flows in the streams would decrease by perhaps another 25%.[17] Among the consequences would be additional stress on endangered and threatened salmon species that spawn in the park and downstream.[18]

Other national parks are feeling the heat. At Mount Rainier National Park in Washington, 25 major glaciers form the largest collection of permanent ice on a single U.S. peak south of Alaska (Figure 3). Those glaciers lost 21% of their area between 1913 and 1994, and a series of ice caves that used to draw visitors to Paradise Glacier melted away by 1991.[19] In Olympic National Park in Washington, glaciers nearly one mile thick gouged out Puget Sound and other waterways, isolating the Olympic peninsula from the mainland and leading to the evolution of species found nowhere else on Earth. Studies here document that Blue Glacier and others in the park are in retreat.[20] In Yosemite National Park in California, six glaciers decreased between 31 and 78% during the last century, with the largest, Lyell Glacier, having lost 35% of its west lobe and 70% of its east lobe, mostly since 1944.[21]

Table 1. Projected melting of glaciers in Glacier National Park, Montana. Source: U.S. Geological Survey.

Year	Average July–August temperature	Remaining glacier area
1990	62.4°F	1.95 square miles
2000	62.7°F	1.50 square miles
2010	63.1°F	0.94 square miles
2020	63.6°F	0.24 square miles
2030	64.3°F	none

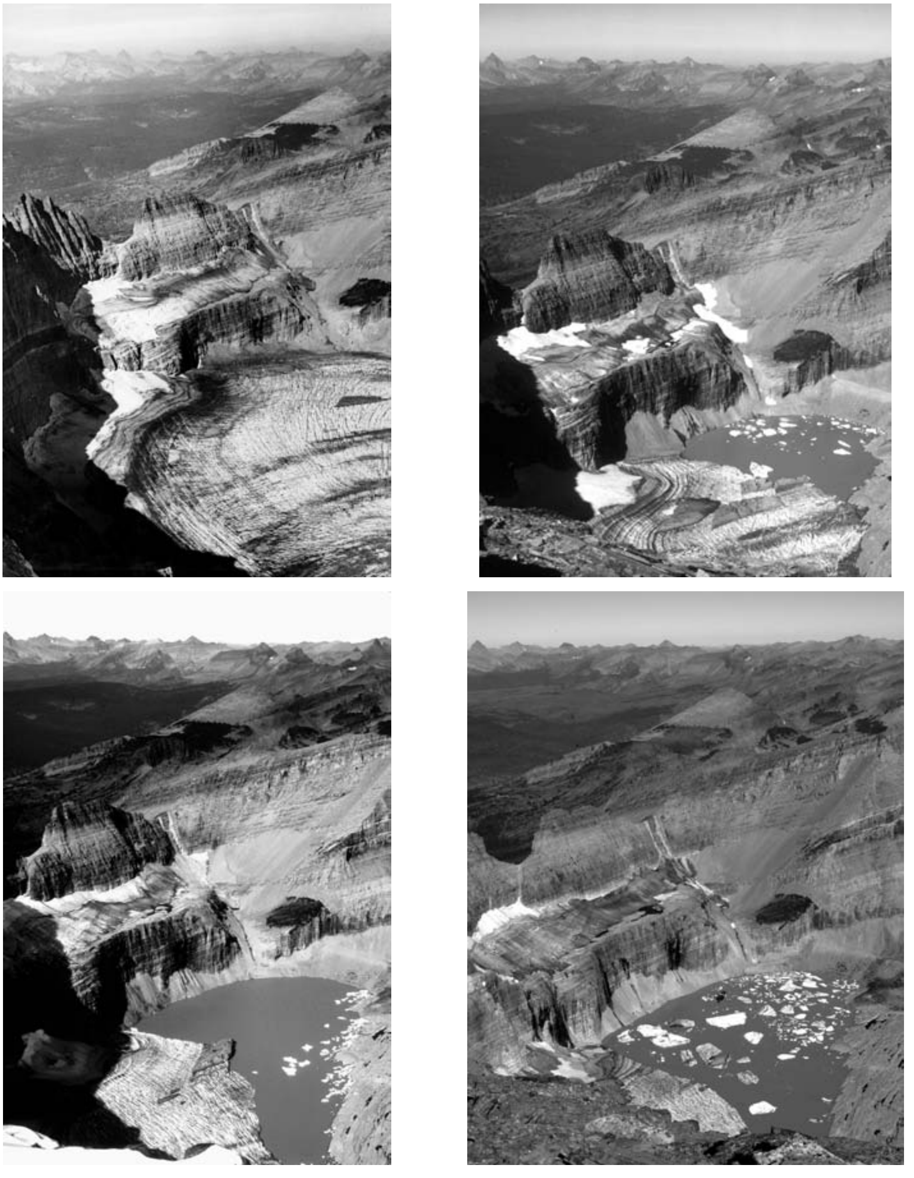

Figure 1. These photographs of Grinnell Glacier in Glacier National Park, taken from the same point over the course of nearly seven decades, demonstrate the retreat of the glacier. Upper left: 1938 (photo by T.J. Hileman, Glacier National Park). Upper right: 1981 (photo by C. Key, USGS). Lower left: 1998 (photo by D.B. Fagre, USGS). Lower right: 2005 (photo by B. Reardon, USGS). For analysis, see M.H.P. Hall and D.B. Fagre, "Modeled Climate-Induced Glacier Change in Glacier National Park, 1850-2100," *BioScience* 53 (2003), 131–140.

Figure 2. Washington's North Cascades National Park has 318 glaciers, representing 60% of the land covered by glaciers in the United States outside of Alaska. Since 1958, the total mass of the park's glaciers has diminished by four-fifths. Photo courtesy of National Park Service.

Figure 3. U-shaped valley looking upstream from the bridge over Nisqually Creek (draining from the toe of Nisqually Glacier on the south flank of Mount Rainier). Mount Rainier National Park could experience losses of glaciers and snowcover and changes in vegetation cover as a result of global warming. Photo courtesy of U.S. Geological Survey.

No snow-covered mountains in summer

Glaciers are in just a few western national parks; snow-covered mountains are in many, and provide some of the West's most dramatic scenery. But less snowfall, less snow build-up, and earlier snowmelt would lead to less snow coverage of the region's mountains. Most importantly for visitors who come to the parks in the summer, the mountains would not be snow-capped then, when visitation is greatest. Different teams of scientists have projected that climate change could diminish future snowpacks on April 1, the traditional day used to measure a season's snowpack before melting begins in most places, by shocking amounts: in California by 29 to 89%, in the Columbia River basin by nearly half, in the Cascade Mountains as much as much as 72%, and in the water-short Colorado River basin by 30%.[22] After April 1, when more visitors are present and when higher temperatures have been in place longer, the reductions in snow coverage should be even greater. So summertime visitors to Glacier, Grand Teton (in Wyoming; Figure 4), Rocky Mountain (in Colorado), Mount Rainier, North Cascades, Yosemite, and other mountain parks will still see mountains, but they will be much less likely to see snow-capped mountains.

Vegetation changes from shifting temperatures

Loss of alpine tundra. Alpine tundra is found on mountaintops where it is too cold for trees to grow. This distinctive habitat supports plant and animal species uniquely adapted to the harsh high-altitude environment, include plants such as tussock grasses, dwarf trees, small-leafed shrubs, and heaths, and animals such as pikas, marmots, mountain goats, bighorn sheep, elk, and ptarmigan. Because areas of alpine tundra are especially vulnerable

Figure 4. If global warming increases as projected, summertime visitors to Grand Teton National Park will likely see fewer scenes like this—mountains whose peaks are covered in snow year-round. Photo courtesy of U.S. Geological Survey.

to warming and could shrink or disappear, the animals and plant species that are adapted to the short growing season and extreme cold and wind of these areas are particularly at risk of having shrinking populations or disappearing.

Shrinking tundra could squeeze hundreds of species. For example, more than 40% of about 300 total plant species that grow in alpine tundra in the southern Rocky Mountains occur only above the treeline.

In places where tundra plants and animals have no higher elevation to climb to, they could disappear altogether. At risk are many animals popular with park visitors, including ptarmigan, pikas, and marmots. The scenery of national parks could be much different, too. Without alpine tundra, park visitors would see more uniformly forest-covered mountains, instead of forested mountain sides and open mountaintops.

Rocky Mountain National Park would be most affected. Each summer as many as two million visitors drive up Trail Ridge Road, the highest paved through road in the country, to enjoy the largest expanse of alpine tundra in the lower 48 states. Visitors to the park, according to a 2002 survey done as part of a study of climate change effects there, would consider the loss of tundra one of the most troubling possible consequences of climate change in the park (Figure 5).[23] The study's scientific researchers projected that for every degree of warming, the treeline in the park could encroach onto the tundra by nearly 250 feet. A 5.4-degree (Fahrenheit) rise in temperature could eliminate half the park's tundra, separating what remains into small patches and making it more difficult for alpine species of plants and animals to survive and re-colonize neighboring patches. And temperature increases between 9 and 11 degrees Fahrenheit could eliminate all alpine tundra from the park.[24]

Figure 5. Visitors to Rocky Mountain National Park consider the tundra landscapes alongside Trail Ridge Road to be among the most valuable in the park. Photo courtesy of National Park Service.

In Glacier National Park, scientists have used repeat photography near the popular Logan Pass Visitor Center to document changes at treeline. Pine trees at treeline (called "krummholz") that have adapted to extreme cold and weather by growing branches primarily on their downwind side, out of the prevailing harsh winds, have begun to grow more upright and to fill in forest edges at treeline.[25]

Loss of forests. Higher temperatures can eliminate an entire plant species from an area. Researchers from the U.S. Geological Survey and universities have documented substantial mortality of Joshua trees in California's high desert and project that because of climate warming the trees "will be unable to persist much longer within Joshua Tree National Park."[26] Joshua trees need the relatively cooler temperatures now found in the higher Mojave desert, compared to those of nearby Colorado or Sonoran deserts, in part because they require winter freezes to flower and set seeds (Figure 6).[27]

Figure 6. The life cycle of Joshua trees in the eponymous national park is threatened by warmer winter temperatures. Photo courtesy of National Park Service.

Entire forests, not just individual tree species, are also at risk. Forests can be lost suddenly through climate-driven mortality of entire stands, not just gradually in response to changes in tree growth and reproduction. Sudden, widespread, climate-driven loss of forests is now occurring in the American Southwest, where semiarid conditions make even the hardy trees that can survive there susceptible to drought. National parks most at risk of losing forests are Bandelier National Monument in New Mexico, Mesa Verde National Park in Colorado, and others of the 23 parks on the Colorado Plateau, a region encompassing much of Utah, Colorado, New Mexico, and Arizona that is full of many of the country's greatest natural and cultural wonders.

In Bandelier National Monument, five years of extreme drought in the 1950s killed off ponderosa pine forests in parts of the park, leading to the most rapid change in forest boundaries ever documented. The immediate cause of death for most trees was infestation by bark beetles, but as the beetles are more likely to be fatal to drought-stressed trees, researchers attributed the mortality to the drought. The loss of the ponderosa forests has persisted, as ponderosas have failed to re-grow in the decades since, even when precipitation levels have been normal. The loss of the ponderosas has been accompanied by a loss of other plant cover and increased soil erosion.[28]

The ongoing multi-year drought in the Southwest has brought about a replay, although this time with piñon pines the victims instead of ponderosas, and this time with an even greater loss of forests. In just the two years of 2002 and 2003, drought led to the loss of piñon trees across more than 60,000 square miles in the Southwest—a more extensive forest loss than from the 1950s drought. The recent drought was accompanied by higher heat than the earlier one, magnifying its effect and increasing greater stresses on trees. As a result, piñon pine trees died across a wider geographic area and at higher (and normally cooler) elevations. Piñons of all ages died, with mortality reaching as high as 90% in Bandelier National Monument and parts of Mesa Verde National Park. Just as a half-century ago, the immediate cause of many tree deaths was infestation by bark beetles, which again were often fatal because of stress from drought and heat. Also as in the 1950s, the death of the dominant trees has been accompanied by rapid and substantial disruption of the ecosystem, including significant mortality of other types of trees and of shrubs, grasses, and other plants in the woodlands and a significant increase in soil erosion. And the substantial disappearance of piñon nuts means reduced populations of the piñon jays and small mammals that feed on them.[29] Because piñons are the dominant tree species in the piñon–juniper forests that cover much of the West, these forest losses in the Four Corners area could foretell greater losses across the entire region.

Mesa Verde National Park's forests are especially vulnerable to forest loss because the park itself is relatively small, surrounded by lands altered by human use, and atop a mesa. Tree species in the park stressed by a warmer climate have no adjacent grounds—in particular, no higher, cooler grounds—into which they can spread. Drought in the 1950s and recent years have nearly eliminated the park's Douglas firs and ponderosa pines and fragmented its piñon–juniper woodlands, creating more space for opportunistic invasive plant species that will stress the woodlands even more (see below).[30]

Losses of mountain meadows and wildflowers. Mountain meadows exist where the combination of heavy snow cover in the winter and a short growing season in the summer make it impossible for tree seedlings to survive. Climate change is likely to both reduce snow cover and extend the growing season, so mountain meadows likely will disappear in many places.[31] Scientists are already detecting a loss of mountain meadows. At Olympic National Park, a reduction in meadows has been measured on both the wetter west and dryer east sides of the park's mountains.[32] Repeat photography over the years in Glacier National Park has documented subalpine fir forests taking over meadows.[33]

At risk are some of the West's largest meadows: Paradise Valley in Mount Rainier National Park, the most visited spot in the park; Yosemite National Park's Tuolumne Meadows, which draws thousands of people every summer to view wildflowers; and the open expanse of Hayden Valley in Yellowstone National Park (Wyoming, Montana, Idaho), one of the best places to view the full range of that park's unparalleled wildlife, including grizzly bears and the world's largest remaining unfenced bison herd (Figure 7). Also vulnerable are countless small mountain meadows in every mountain national park across the West.

Scientists have also documented how higher temperatures suppress the growth of mountain wildflowers. For 14 years, researchers have used overhead heaters to warm Rocky Mountain meadows by 4 degrees Fahrenheit to mimic global warming. With the resulting

Figure 7. The Yellowstone River flows through Hayden Valley in Yellowstone National Park. The valley is one of a number of large high-elevation meadows in western parks that might see encroachment by forests in a warmer climate. J. Schmidt photo courtesy of Yellowstone National Park.

longer snow-free growing seasons and hotter and drier soil conditions, wildflowers become much less common and are replaced by sagebrush.[34]

Shifts in plant cover. A team of scientists from The Nature Conservancy, Oregon State University, and the U.S. Forest Service have projected how climate change would shift plant cover across North America. Their findings indicate that one-third of the land area of the 11 western states could experience a change in an area's dominant type of vegetation by 2100. The greatest changes in the West, measured as a percentage of an area that will undergo a change in dominant plant cover, are projected to be in mountain areas as lower-elevation species of trees and plants move uphill and subalpine and alpine species are reduced or eliminated. Their projections for areas including western national parks include:

- Subalpine forests could be replaced by temperate evergreen forests in North Cascades National Park.
- Boreal forests could be replaced by mixtures of temperate evergreen forests, shrub steppes, and savanna woodlands in Grand Teton, Rocky Mountain, and Yellowstone national parks.
- Shrub steppes could largely be replaced by savanna woodlands and grasslands across the many national parks of the Colorado Plateau, including Arches, Bryce Canyon, Canyonlands, and Capitol Reef national parks in Utah and Grand Canyon National Park in Arizona (Figure 8).[35]

Figure 8. Shurb steppes in Colorado Plateau parks such as Great Basin could be displaced by other vegetation types. Photo courtesy of U.S. Geological Survey.

A vivid illustration of the changes that could be in store for mountain parks is from a U.S. Geological Survey model of possible changes in one area of Glacier National Park. The USGS model projects that the loss of glaciers is just the beginning: decade by decade, forests move upslope to cover what is now bare rock, and grasslands move into lowlands to replace the forests.[36]

More invasive plants. Invasive plants, non-native plants that cause environmental or economic harm, cause an estimated $20 billion a year in economic damage in the United States and already infest some 2.6 million acres in the national parks. Examples are Russian olive trees, which destroy plant and animal habitat in New Mexico and Arizona national parks (Figure 9); tamarisks, which deplete water and overrun riparian corridors in national parks on the Colorado Plateau; knotweeds and knapweeds which take over stream corridors and degrade salmon spawning habitat in national parks of the Northwest; and exotic grasses that thrive in wet periods and then burn native cacti in desert national parks.

Figure 9. Russian olive trees are invading a number of parks, including Petrified Forest. Photo courtesy Petrified Forest National Park.

As climate changes disrupt natural ecosystems, the spread of invasive plants likely will accelerate because they are especially adaptable, reproduce quickly, and thrive in disturbed areas. They can also be more successful than native plants in responding to increases in temperature, changes in precipitation patterns, or elevated atmospheric carbon dioxide levels. Once established in an area, invasive plants can displace native plants, diminishing food and shelter for animals that evolved with an area's native plants; deplete surface and ground water levels; alter runoff patterns; increase soil erosion; and change fire patterns and intensities.[37]

Loss of plant species to increased wildfires. Wildfire is a natural part of western ecosystems and essential to their health. But climate changes have already unnaturally increased wildfires in the West, and are likely to do so even more in the future. Particularly at risk from an unnatural increase in wildfires are plant and animal species with narrow habitat requirements, little mobility, or restricted distributions, and those in parks that are relatively small, surrounded by developed areas, or otherwise ecologically isolated. These species have little opportunity to spread into neighboring areas when their original habitat is disturbed by fire.[38]

Figure 10. If the frequency and intensity of wildfires increase because of climate change, the signature species of Saguaro National Park outside of Tucson could be at risk. Photo courtesy of National Park Service.

The saguaros of Saguaro National Park in Arizona illustrate how even the dominant plant species of a national park can be highly vulnerable to increased wildfires, particularly when fire-prone invasive plants have moved into the area (Figure 10). A symbol of the American Southwest and North America's largest cactus, the saguaro has such an imposing stature and regal presence that it has been nicknamed the "desert monarch." But these majestic cacti have a high mortality rate when there is fire in the deserts, and fires are now occurring more often because of the spread of invasive grasses and the higher temperatures and precipitation changes of a disrupted climate. The invasive grasses proliferating in the Upper Sonoran desert, where the national park is, almost always outcompete native plants for limited supplies of water and nutrients. When the invasive grasses dry out after wet spells, they become ready fuel for wildfires, which used to be rare in this ecosystem. This is creating a new, serious risk to the long-term survival of saguaros, not only in the national park but also across the entire Southwest.[39]

Mesa Verde National Park's forests also illustrate how park resources are at risk from unnatural increases in wildfire. The national park's forests are inherently vulnerable and already suffering from climate-driven changes, as explained earlier. National Park Service modeling suggests that invasive weeds are likely to increase fire risks so much that future fires may irreversibly eliminate the park's woodlands.[40]

Wildlife extinction and other threats from shifting temperatures

The chance to see wildlife in its native habitat is one of the main reasons people visit national parks. But a disrupted climate is likely to lead to widespread extinctions of wildlife species, in national parks as well as elsewhere. In "the largest scientific collaboration ever to apply itself to this problem," a team of 18 scientists studied the likely effects of climate change on more than 1,000 species in areas representing one-fifth of the world's land. They predicted that by 2050, 15 to 37% of the studied species are likely to be irreversibly on the road to extinction because of climate change. Extrapolating their conclusions to all species in the world, the researchers suggested that one million species could become extinct by 2050.[41]

The threat of wildlife extinction from climate change stems from several factors: changes in ecosystems, the spread of invasive species that out-compete native species, the spread of diseases, changes in the timing of seasons so they no longer match migration and hibernation schedules, and temperature changes that push a species out of the temperature range in which it can survive. Some species may be able to migrate to adjust to warming temperatures, but isolated wildlife populations and alpine species with no higher elevations to climb to are in particular danger of extinction.[42]

Climate change is already affecting wildlife. More than 80% of species showing changes in their ranges are changing in directions consistent with a response to climate change.[43] Some mammals are ending hibernation earlier and some birds are migrating earlier in the spring.[44] There are only a few studies of the vulnerability of species in particular western national parks, but they suggest the local extinctions that could take place there.

White-tailed ptarmigan numbers in Rocky Mountain National Park have been cut in half in just two decades, and researchers predict they will be extinct in the park by mid-century if temperatures rise as predicted. Ptarmigan's primary habitat is the tundra that is itself endangered by warming, and they depend on deep snow to survive the alpine winter, using the natural insulation of snow caves to keep warm and using snowpack like a ladder to reach willow shrub branches for food.[45]

Desert bighorn sheep are in danger of extinction across their range, including in California's Death Valley and Joshua Tree national parks and Mojave National Preserve, Utah's Canyonlands and Zion national parks, Arizona's Grand Canyon National Park, and Nevada's Great Basin National Park (Figure 11). Thirty of the 80 separate populations of desert bighorn sheep that once lived in California are already extinct; scientists point to climate change as a major contributor to the local extinctions. Further local extinctions are most likely for herds in lower elevations where temperatures are hotter and precipitation lower, reducing forage.[46]

Pika populations in the West, especially in the lower elevation portions of the range, are in danger. As warming temperatures enable forests to move upslope and cover alpine rockfields, the pikas' habitat could recede right off the mountaintops. Warming is also deadly to the animals, as they cannot survive even modest temperature increases. In the Great Basin, eight of 25 pika populations are already extinct. The remaining populations live at or above

Case study of climate change's effects on wildlife: Global warming, bark beetles, whitebark pines, and grizzly bears in Yellowstone

Contributed by Jesse A. Logan

WHEN I CONSIDER THE LARGE-SCALE BARK BEETLE MORTALITY occurring in lodgepole pine forests across the western United States, I think it is interesting and unusual, although I have no doubt that lodgepole forests will remain on the landscape for future generations. My response to the current mortality in whitebark pines is much different: It breaks my heart.

We are witnessing the catastrophic collapse of high-mountain ecosystems as a result of how people are changing the climate, and grizzly bears could end up paying the price. The grizzly bear is perhaps the most emblematic symbol of America's remaining wildlands. Unfortunately, in one of its last strongholds, the greater Yellowstone area, its very existence is in peril. The threats to the great bear there are multifaceted; among the most challenging is a loss of critical food resources. Grizzly diet consists of four major foods. In spring, carrion from winter-killed elk and bison are readily available. Early summer finds the bear feeding on spawning cutthroat trout. As the summer progresses, bears move to the high country to eat nuctuid moths feeding on the nectar of alpine flowers. In fall, the large and nutrient-rich seeds of whitebark pine provide the majority of the diet. Of all these, the availability of whitebark pine seeds is most critical; that is what they depend on in the time before hibernation. Nutritionally stressed bears have a lowered over-winter survival rate, and, more importantly, embryos will be reabsorbed if pregnant females lack sufficient fat resources entering hibernation. Without enough whitebark pine nuts, grizzly bears are also more likely to become involved in human conflicts as they search for other foods.

Grizzly bear in Yellowstone. B. Harry photo courtesy of Yellowstone National Park.

In recent years, a new threat has erupted to this critical element in the grizzly diet: the expansion into high-elevation forests of a small, native bark beetle in response to a warming climate. The mountain pine beetle is a native insect that has co-evolved with some pine forests. Without disturbances like mountain pine beetles and fire that open up the forests, some types of trees, like lodgepole pine, would be replaced by shade-tolerant spruce and fir. But whitebark pines are different from lodgepoles. Whitebarks live for centuries, not decades, and are adapted to life at high elevations (with one of their adaptations being the large, highly nutritious seeds that are so important to grizzly bears). Whitebark pines do not depend on catastrophic forest disturbance to survive; instead, they are threatened by it. One of the hypothesized reasons for the restriction of whitebark pines to high elevations is that they are poorly defended against the insect pests and pathogens prevalent in more benign lower-elevation forests. Mountain pine beetles have not been a major threat to whitebark pine survival; the high-elevation climate has been their defense, as it historically has been too cold for long-term survival of outbreak beetle populations.

Unfortunately, things have dramatically changed in response to climate warming that began in the mid 1970s. Computer simulations had predicted mountain pine beetle outbreaks in high-elevation systems in response to this warming, but even the modelers were surprised by how quickly and how far beetles have now spread into whitebark pines. Significant mortality is occurring across the entire American distribution of whitebark pine, with no sign of it diminishing. When added to another stress—from an introduced pathogen, white pine blister rust—the spread of bark beetles into higher elevations makes the continued existence of these ecosystems an open question. Mountain pine beetle mortality in whitebark pines has occurred in the past, in relatively short-lived warm periods. In contrast, the current warming is a trend that began in the western United States over 30 years ago.

Given the likelihood of continued warming, what, if anything can be done to protect whitebark pines and the grizzlies that depend on them? First, we need to better understand the basic ecology of mountain pine beetle in whitebark pine. Most of our knowledge regarding host–insect interactions comes from lodgepole or other pine species. By understanding the unique aspects of mountain pine beetle in whitebark pines, we may come to better understand how we might tip the scale to favor the host. Second, we need better tools to evaluate the extent of mortality. Whitebark pine habitats are in the most remote and wild places (often designated wilderness areas) in the Rocky Mountains. Mortality there goes almost completely unrecorded. Without knowing the extent of the problem it is not possible to formulate effective responses. Advanced technology, such as satellite imagery combined with traditional aerial photography and ground surveying, is needed. Third, management tools (e.g., pheromone strategies) need to be fine-tuned for high-elevation environments and whitebark pine ecosystems. All of these approaches need to be integrated across large, remote, and inhospitable landscapes.

Logan retired in June 2006 from the U.S. Forest Service. He is a world authority on the relationship between climate and bark beetles.

Figure 11. Local populations of desert bighorn sheep are in danger of extinction throughout the West because their forage is being reduced by hotter temperatures. This male was photographed by a remote camera set up at a spring in Mojave National Preserve. Photo courtesy of Mojave National Preserve.

8,310 feet, while the extinct populations used to occur as low as 5,750 feet.[47] In Yosemite National Park, where pikas were recorded living as low as 7,500 feet in the early twentieth century, researchers now cannot find pikas below 9,500 feet.[48] These studies indicate that pika populations across the West, including in Great Basin and Yosemite national parks and Craters of the Moon (Idaho) and Lava Beds (California) national monuments, are at risk.

Worldwide, amphibians appear to be the first large-scale wildlife victims of climate change. Since 1980, more than 120 species have become extinct, with researchers certain that climate change was the key factor, as it made possible the rapid spread of a fungal disease to which the amphibians had no defense.[49] Evidence of amphibian decline is now showing up in western national parks. Mountain yellow-legged frog populations in lakes and streams of the Sierra Nevada, including in Yosemite and Sequoia/Kings Canyon (in California) national parks declined 10%. Most lakes in the parks now host only one to five individual frogs and about 85% of them are infected with the same fungal disease responsible for amphibian extinctions elsewhere. Researchers also link shrinking snowpacks to the decline because smaller snowpacks dry up smaller ponds, limiting the frogs to larger permanent ponds where introduced non-native trout can prey on them.[50]

More invasive animal species. Climate change accelerates the spread of non-native invasive animal species that pose threats to native wildlife. Of a sample of 10% of harmful non-indigenous species in the United States, 48% are considered likely to expand their ranges as a result of climate change, while only 4% will contract their ranges.[51] A study on how climate change would affect wildlife in several national parks, including Glacier, Yellowstone, Yosemite, and Zion, concluded that there would be an influx of non-native species, increasing by 70% the number of species in the parks and creating competitive stresses on the native wildlife of the parks.[52]

Stresses on wildlife from changes in seasonal timing. Changes in the timing of seasons can cause wildlife's needs and actions to no longer align with the conditions in which they evolved. These mismatches may lead to declines of certain species or enable other, potentially destructive species to expand their ranges or their populations. In Rocky Mountain National Park, presumably as a result of earlier spring thaws, young white-tailed ptarmigans now hatch significantly earlier than they did in 1975. Researchers have suggested that this change in timing may have contributed to the sharp decline in the ptarmigan population, as the timing of plant growth has not changed in the same way and chicks now hatch when there is less food available for them.[53]

Part 3: Climate disruption threatens cultural resources

By preserving some of the best of our cultural resources—buildings, landscapes, archeological sites, and artifacts—America's national parks provide information about the past and provide important links to the present. Many of the cultural resources of western national parks are at risk from the possible effects of a climate disrupted by human activities.

Resources at risk from increased flooding and erosion

With a changed climate, severe storms are likely to become more frequent and powerful.[54] Earlier and more sudden springtime melting of mountain snowpacks may increase peak flows of rivers and streams in the West.[55] As a result, western national parks are likely to experience an increase in flooding and erosion, which even at normal historical levels pose one of the largest threats to the cultural resources in the West. In the arid West, although there is not much precipitation, a relatively high percentage comes in downpours that flood the dry land, leading to significant erosion. Also, as explained earlier, a climate-driven loss of forest cover in the Southwest has already led to increased erosion. Further, an increase in wildfire, projected to occur with climate change, is likely to increase erosion even more.[56]

At particular risk are the irreplaceable pueblos, cliff dwellings, churches, and forts already identified in the National Park Service's "Vanishing Treasures" program as "rapidly disappearing from the arid West," often because they are "in immediate, imminent danger from natural erosive factors," with inadequate NPS funding to protect them.[57] The national parks containing the inventoried Vanishing Treasures include:

- Sixteen national parks in Arizona, with the largest inventoried risks at Canyon de Chelly National Monument.
- Nine in New Mexico, including Bandelier and Fort Union national monuments and Chaco Culture National Historical Park (Figure 12).
- Nine in Utah, including Canyonlands and Zion national parks and Glen Canyon National Recreation Area.
- Four in Colorado, including Colorado, Dinosaur, and Hovenweep national monuments; three in California, including Mojave National Preserve; Fort Laramie National Historic Site in Wyoming, and five in Texas, including Big Bend National Park.[58]

Resources endangered by increased wildfire

Global warming is already leading to more frequent and more severe wildfires in the

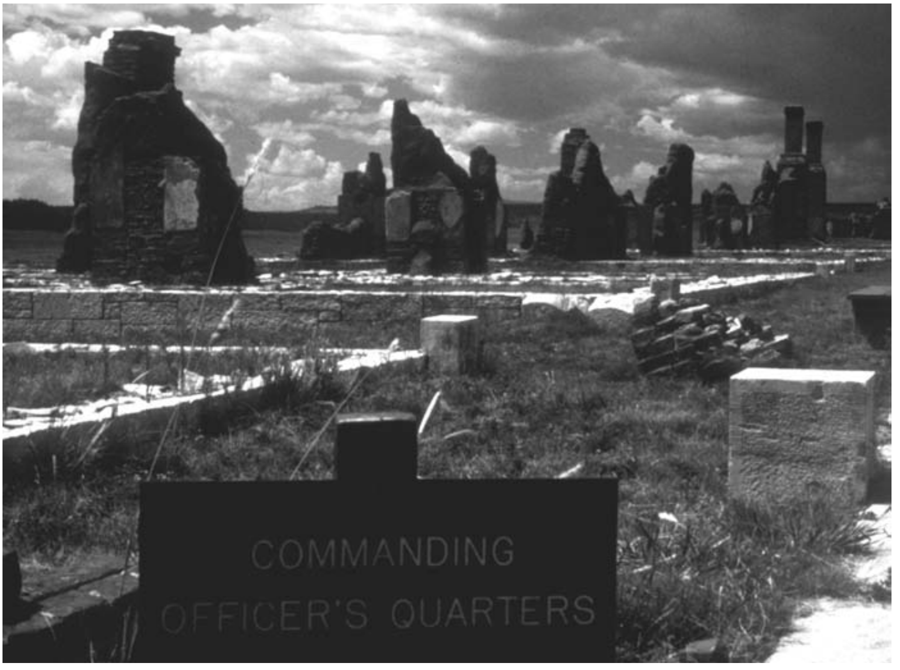

Figure 12. Many archeological and historic sites in western national parks are already naturally vulnerable to erosion damage. The ruins of Fort Union in New Mexico are no exception, and their vulnerability will be greater as the severity of storms increases. Photo courtesy of Fort Union National Monument.

West, with even greater increases likely in the future. This increase in wildfires threatens cultural resources in western national parks, as fires can burn historic structures, destroy archeological sites and artifacts, and alter cultural landscapes. Efforts to fight fires can also be destructive to cultural resources, since such fire suppression efforts as fire line construction, establishment of firefighting bases and camps, and the use of firefighting chemicals also may damage cultural resources.[59]

Studies in Bandelier National Monument illustrate the vulnerability of cultural resources to fire. The first obvious effect is that flammable structures or artifacts can be lost to fire. For example, an extensive fire in the park in 2000 burned nearly all homestead archeological sites on the Pajarito Plateau in the park, since most were constructed of wood.[60] Second, fire can damage the stone used in buildings in archeological sites and stone, ceramic, and bone artifacts.[61] Third, and potentially most significantly, wildfires may increase the erosion that, as in much of the Southwest, is already causing impacts to cultural sites by removing artifacts from their original location and destroying architectural features including buildings, houses, hearths, storage bins, and other constructed items (Figure 13). In the Bandelier area, surveys have already identified that approximately 80% of the archeological sites have been impacted by erosion.[62] The park's archeologist has expressed concern that greater erosion from increased wildfires and from possible climate-driven loss of vegetation may have great adverse impacts on the integrity of the park's archeological sites.[63]

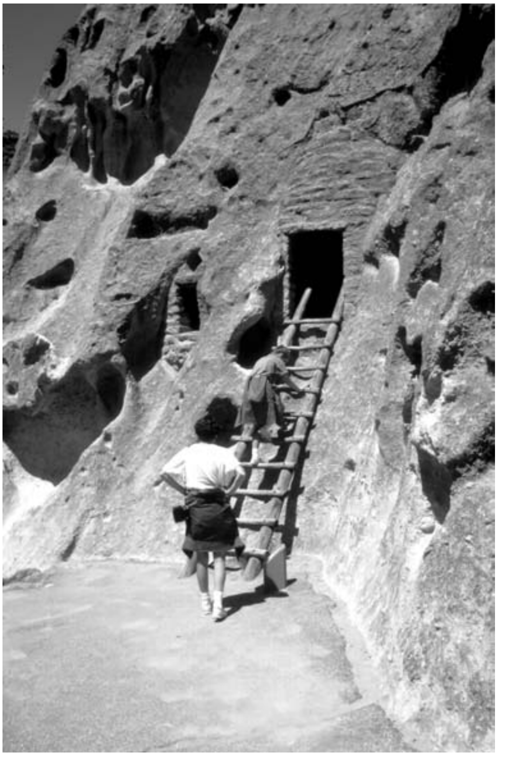

Figure 13. Erosion is probably the biggest climate-change-induced threat to archeological resources in Bandelier National Monument. Photo courtesy of National Park Service.

In the large fires of 1988 in Yellowstone National Park, the historic building of Old Faithful Lodge narrowly escaped the flames, some undiscovered remnants of native American tribal sites may well have been destroyed, and a wickiup—the framework for a native American dwelling—was damaged. In Mesa Verde National Park, the heat of a 1996 fire irreparably damaged a 1,000-year-old Native American petroglyph (or rock art).

Particularly vulnerable are those western national parks that contain cultural resources in woodlands or rangelands subject to wildfires. These include Bandelier National Monument, with several thousand ancestral Pueblo dwellings; Little Bighorn Battlefield National Monument in Montana; Mesa Verde National Park, with its world-famous cliff dwellings and other notable and well-preserved sites (Figure 14); and Yellowstone National Park. All these parks have in recent years experienced significant fires that have endangered archeological resources. Other parks, including Nez Perce National Historical Park in Idaho, Montana, and Washington, Santa Monica Mountains National Recreation Area in California, and Zion National Park in Utah also have archeological and other cultural resources in environments at risk from wildfire.

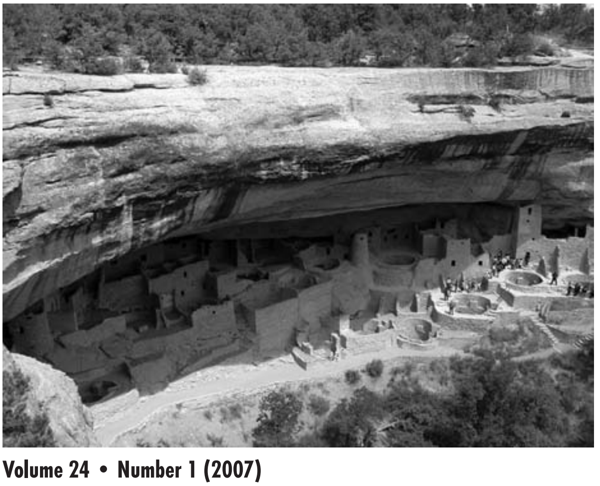

Figure 14. The wooded areas in close proximity to Cliff Palace at Mesa Verde National Park make it especially vulnerable to wildfires. Photo courtesy of U.S. Geological Survey.

Resources threatened by rising seas

With the level of the world's oceans predicted to rise as a result from climate change, cultural resources of the national parks along the Pacific coast could be at risk. Santa Rosa Island in Channel Islands National Park in California is renowned for its abundant archeological treasures dating back 11,000 years. Olympic National Park's petroglyphs carved into shoreline rocks and shell middens left behind by tribal occupants could be inundated by floodwaters. And in that park the National Park Service is already making plans to move Kalaloch Lodge and nearby historic cabins back from a bluff overlooking the ocean because of the threat of erosion and possible collapse of the bluff, a threat that is increased by the sea-level rise and increased wave action resulting from climate change.

Point Reyes National Seashore in California has more than 120 known sites that are evidence of the Coast Miwok Indians settlements going back 5,000 years. In Golden Gate National Recreation Area in California, historic Fort Mason and portions of the grounds of the Presidio of San Francisco, the oldest continuously used military post in the nation, are low enough to be vulnerable to rising waters.

Part 4: Climate disruption threatens public enjoyment

The western national parks provide millions of Americans with irreplaceable opportunities for enjoyment. These great parks enchant us with their beauty, and restore us with their peace. They are the destinations for generations of families who pack up the car in summer to see bison and wolves in Yellowstone National Park, marvel at the sunset over Grand Canyon, and hike through the cool woods of Yosemite. Just as climate change will disrupt the natural landscape of the West, so too will it interfere with the enjoyment we can derive from the national parks.

Closed parks from more wildfires

Climate disruption is likely to significantly and unnaturally increase wildfires in the West. Scientists have concluded that high temperatures are the climate factor most connected to severe wildfires.[64] With a hotter climate and greater summer dryness, summer fire seasons are likely to last longer, with more severe fires.[65]

And climate change is likely to increase the frequency and severity of storms and lightning, leading to more lightning ignitions of fires.[66] In Rocky Mountain National Park, for instance, scientists have predicted that the proportion of fires started by lightning could increase by 50% to 92%.[67] According to one study looking at the entire West, a modest 2.9-degree (Fahrenheit) increase in average temperatures could double the number of wildfires in western states by century's end and increase the amount of land burned by as much as 140%. According to this study, the western states most at risk for more wildfires are Montana, Wyoming, and New Mexico. In Montana, home of Glacier National Park, the researchers projected that wildfires could increase by as much as 500%.[68]

A more recent study even more emphatically linked the warming already underway in the West with an increase in wildfires. A team of scientists concluded that western wildfires have increased in recent years and that a changing climate, not previous fire-suppression efforts that let fuels accumulate or land-use changes, are the major cause. Comparing the most recent 17 years with the previous 17, they found that from 1987 on, spring and summer temperatures across the West have increased by 1.5 degrees Fahrenheit, leading to a two-month increase in the length of the wildfire season, a four-fold increase in the number of fires, a five-fold increase in the time needed to put out the average wildfire, and 6.5 times as much area being burned. The scientists found a very strong linkage between high spring and summer temperatures and early snowmelt in an area with severe wildfires there. With temperatures likely to continue getting hotter and snowmelt likely to continue getting earlier, the scientists predict further increases in wildfire frequency and severity. Consistent with the previous study that identified Montana and Wyoming as among the states most vulnerable to increased wildfires, this new study identified the northern Rocky Mountain region as having seen the largest increase in climate wildfires.[69]

Together, these two studies suggest that Glacier National Park, Yellowstone National Park, and Grand Teton National Park, all in the northern Rockies, are the national parks most at risk from increased wildfires (Figure 15). Other national parks in the West are also vulnerable. In Rocky Mountain National Park, researchers projected that changes in conditions resulting from climate change could increase the probability of any one fire spreading beyond 10 acres by 30 to 100%.[70]

Wildfires can disrupt summer vacations for park visitors. In the summer of 2002, when drought conditions and high temperatures combined to produce Colorado's worst fire season in memory, the number of July visitors to Rocky Mountain National Park dropped by

Figure 15. Among the many impacts of the 1988 Yellowstone fires was the disruption of tourism to the park. Here, a plume of smoke rises close to the gateway community of Silvergate, Montana. Jim Peaco photo courtesy of Yellowstone National Park.

nearly 100,000 from the previous year, even without any fires in the park itself.[71] Statewide, reservations at state campgrounds dropped 30% and the number of visitors to some areas declined by as much as 40%.[72]

In Mesa Verde National Park, in 2000, during the hottest, driest decade on record so far for the park, fires burned more than half of the park and led to closures to all visitors for nearly three weeks in July and August, cutting visitation in those months by almost half.[73] The projected increases in wildfire are also likely to reduce visibility in western national parks, one of their most valued qualities. The NPS underscores in its publications that "visitors to national parks expect clean, clear air."[74] Yet, according to the National Park Service, smoke from wildfires is a major contributor to the worst visibility days in many western parks.[75] So if climate change leads to more wildfire in the West, it also would lead to the scenery of the western national parks being obscured more often.

Beach loss because of rising sea levels

Global sea level has risen about seven inches during the past century, and five years ago the United Nations' Intergovernmental Panel on Climate Change, projected another three to 35 inches of increase by 2100.[76] More recent studies, including two this year, suggest that a similar or even greater sea-level rise is possible. The first, done for the state of California, gave a range of projections from a low of 4 inches to a high of 31 inches of sea-level rise.[77] The second found that future warming could be enough to melt polar ice caps, potentially leading to three feet of sea-level rise this century and as much as 20 feet over the next four or five centuries.[78]

The U.S. Geological Survey is working with the National Park Service to identify the possible effects of sea-level rise in several national parks, including in the West. Impacts could include coastal erosion, saltwater intrusion into groundwater aquifers, inundation of wetlands and estuaries, and threats to cultural and historic resources and park infrastructure, with low-lying beaches and estuaries at greatest risk. The USGS assessments identify these western national parks as particularly at risk.[79]

- **Golden Gate National Recreation Area.** All 59 miles of beaches in this national recreation area are judged high to very high in vulnerability because of their coastal slope, wave heights, and the range of local tides. The vulnerable beaches include heavily visited Ocean Beach, China Beach, and Baker Beach, all near San Francisco, and Muir Beach and Stinson Beach, along coastal bluffs north of San Francisco Bay. A sea-level rise of three feet or more would likely inundate most, if not all, of the sandy beaches. The beaches closest to San Francisco are among the most heavily used areas in the entire National Park System, attracting much of the 16 million visitor-days of use in Golden Gate National Recreation Area.
- **Point Reyes National Seashore.** All of the beaches on the west side of Point Reyes, where wave heights are highest and coastal slopes low, are rated high to very high in vulnerability (Figure 16). The estuaries of Abbotts Lagoon and Drakes Estero, adjacent to the coastline, are also at risk from sea-level rise. The seashore's beaches, including both the 10-mile-long natural and undeveloped Point Reyes Beach and Drakes Beach, right

below the visitor center, along with the estuaries, which are prime wildlife viewing areas, are central features of this park, just an hour's drive from the San Francisco Bay area.

- **Channel Islands National Park.** About one-half of the 250 miles of shoreline around the southern California islands making up this national park is rated high or very high in vulnerability to sea-level rise, based on coastal slopes and tidal ranges. The largest stretches of very high vulnerability are on the two westernmost islands, San Miguel and Santa Rosa. About a half million people a year visit this park, many to observe the 50,000 seals and sea lions, of six different species, that live and breed on the shore of San Miguel Island.
- **Olympic National Park.** More than half of the 65 miles of coastline in the park is rated high or very high in vulnerability, based on wave heights (especially during El Niño-driven storms) and a low coastal slope near the park's beaches. Especially vulnerable are Shi Shi Beach at the north end of the park, Rialto Beach in the middle section, and Ruby Beach at the south end (Figure 17). The park's intermittent sand or gravel pocket beaches against the coast's rocky cliffs are favorite destinations of many park visitors.

National parks intolerably hot

Some national parks may simply become too hot to be enjoyable for long stretches of the year. Death Valley National Park in California is one of the hottest places on Earth, already typically hotter than 100 degrees Fahrenheit from late May through September and with an average daily high of 115 in July (Figure 18). Not surprisingly, visitation here is lower in the summer than in the peak months in spring and fall. Other national parks in the California desert and

Figure 16 (top). Beaches on the west side of Point Reyes National Seashore have little relief, and so are particularly susceptible to sea-level rise. Photo courtesy of Point Reyes National Seashore.

Figure 17 (bottom). Sea stacks at Ruby Beach—one of Olympic National Park's most vulnerable. Photo courtesy of U.S. Geological Survey.

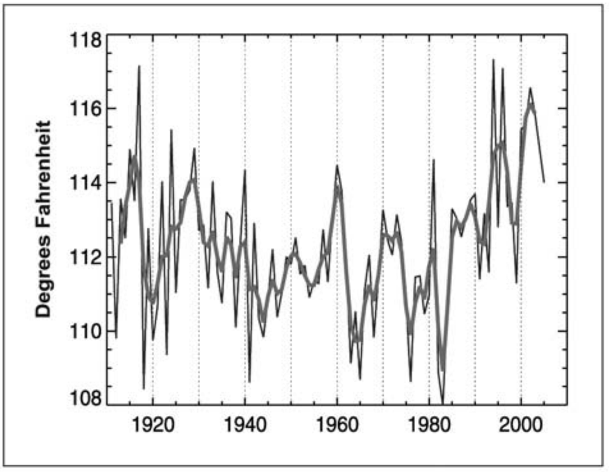

Figure 18. Average summer maximum temperatures in Death Valley National Park, 1905–2005. Average daily maximum temperatures are shown for the months of June, July, and August. Each year's average is shown by the black line, the running five-year average by the grey line. Data are from a Historical Climate Network weather station in the park. Analysis by J. A. Hicke, Department of Geography, University of Idaho.

many of the 23 parks on the Colorado Plateau are only slightly less hot. In Joshua Tree National Park, for example, average summer highs already are over 100, and in Zion National Park they typically range from 95 to 107.

According to some climate models, the Southwest may experience more warming than most parts of the country. One projection said average temperatures in the Southwest could increase by as much as 14 degrees Fahrenheit, or even more, by the late 21st century.[80] Another study of how global warming could increase heat waves also concluded that the western United States is likely to experience a greater increase in heat waves than the East.[81] All in all, it seems unfortunately likely that southwestern national parks that are already hot are at particular risk of becoming too hot to be tolerable for much of the year.

Overcrowded national parks

On the other hand, climate change may make relatively cooler mountain national parks and national seashores, increasingly attractive as places to escape the heat as well as enjoy the outdoors. In Rocky Mountain National Park, a survey of park visitors suggests that under the climate conditions projected by 2020 enough visitors would come more often and stay longer to increase the number of visitor-days each year by more than one million—nearly a one-third increase.[82] Similar results were obtained by researchers in a comprehensive study of Canadian national parks.[83]

Increased use of the western national parks is also likely as a result of growing population in the West; the region's total population is expected to grow from 48 million in 1999 to between 60 and 74 million in 2025, with California likely to experience the greatest increase in absolute terms (with about 10 million new people) and Arizona and Nevada the greatest in percentage terms. The greatest increases in visitation seem likeliest for national parks that both offer escapes from heat and are near the most rapidly growing populations. Yosemite National Park is the foremost example (Figure 19).

More congestion can make trips to national parks less enjoyable for visitors. Increased visitor numbers would also aggravate one of the most serious problems in the national park

Figure 19. Under a warmer climate regime, it is possible that more people than ever will go to high-elevation parks in the summer to beat the heat. Yosemite is a likely destination. Photo courtesy of National Park Service.

system: a shortage of funds to meet the needs of the parks and the visitors. Already, funding for park operations has not kept up with inflation and about one-third of park operating needs go unfunded each year.[84] As a result, park managers have to cut back important services: The numbers of commissioned park rangers dropped 16% from 1980 to 2001 and of seasonal rangers dropped 24%.[85] And the backlog of unmet maintenance needs is about $5 billion for the national park system, more than twice the National Park Service's annual operating budget.[86]

Boating and fishing loss because of less and warmer waters in summer

More winter precipitation falling as rain, rather than snow, in the West and earlier melting of mountain snowpacks have moved peak rivers flows sooner in the year, which also is before summer vacation schedules.[87] The seasonal shifts not only affect the timing of river flow, but also the amount of water in the rivers. On April 1, 2006, the Natural Resources Conservation Service (NRCS) of the U.S. Department of Agriculture forecast that the South Platte River would have 118% of its normal flow. A month and a half later, NRCS cut its projection in half, to 65% of the normal flow, because the month of April was so hot that much of the basin's snowpack simply evaporated instead of becoming runoff.[88]

With less runoff, water levels decline, jeopardizing summer recreational opportunities such as boating, rafting, and kayaking for many visitors to western national parks (Figure 20). Nearly 300,000 visitors each year go whitewater rafting and kayaking through some of the West's most dramatic landscapes in Black Canyon of the Gunnison (in Colorado), Grand

Figure 20. Summertime water levels could decline throughout the West, affecting popular river-based recreational activities, such as rafting in Dinosaur National Monument. Photo courtesy of National Park Service.

Canyon, and Grand Teton national parks, and in Dinosaur National Monument (in Colorado and Utah). Almost 10 million visitors a year go to Lake Mead National Recreation Area in Arizona and Nevada and to Glen Canyon National Recreation Area in Utah, which contains the Lake Powell reservoir created by Glen Canyon Dam, many to enjoy boating on the reservoirs.

Opinions on Glen Canyon Dam, in particular, remain sharply divided five decades after the dam was authorized. Environmentalists have long lamented how Glen Canyon Dam inundates natural and cultural resources, alters the natural cyclical flows of the Colorado River through the Grand Canyon, and threatens several fish species and the ecosystem as a whole. When drought dropped the water levels in Lake Powell from full in 1999 to 33% full in 2005—a larger and quicker decline than most river observers thought possible—many celebrated the natural and cultural resources that were revealed. But the lower water levels also affected boating. The number of visitors to Lake Powell also fell, by 800,000 or 30%, between 1999 and 2005. At Lake Mead the number of visitors fell by 1.2 million, or 13%. The National Park Service spent $20 million to extend boat ramps to the new, lower edge of the reservoir, a concessionaire spent $2 million to move a marina 12 miles, and at Boulder Beach people had to walk a half-mile to reach restrooms left behind by the receding waterline.

Climate studies suggest that the recent sharp drop in Lake Powell may not be an aberration. A recent study of possible climate change effects on the Colorado River project a 36% decline of water storage in Lake Powell and Lake Mead as early as 2010 to 2039, compared to historical conditions, and a 40% decline during the next 30 years.[89] Changes of this magnitude would have effects not just on the river's ecosystem and recreational boating, but also on the 30 million Americans from Denver to San Diego who now use Colorado River water.

Fishing is also popular in many western parks, with Black Canyon of the Gunnison, Glacier, North Cascades, Olympic, Rocky Mountain, and Yellowstone national parks particularly prized by many fly fishermen (Figure 21). But western trout and other coldwater fish species such as salmon are acutely vulnerable to increases in water temperature likely to result from climate change. In fact, in the Fraser River, downstream of Jasper National Park in Canada, salmon have suffered 50% mortality in several runs during years with warmer than normal water temperatures.[90]

Figure 21. Fly-fishing waters in several western parks could experience declines in prized species of trout and other colwater fish. Photo courtesy of Yellowstone National Park.

Studies show that most adult salmon, steelhead, and trout species can survive only where average highs on summer days are below 70 degrees Fahrenheit and that a 5.4-degree (Fahrenheit) increase in summer temperatures would make more than half of the trout streams in the Rocky Mountain region too hot for trout.[91] Another study, by Defenders of Wildlife and the Natural Resources Defense Council, predicts that overall habitat for some fish species could shrink as much as 17% by 2030, 34% by 2060, and 42% by 2090.[92]

Winter recreation loss caused by warmer winters

Climate scientists predict that as climate change continues, winter will start even later and end even sooner, with less wintertime snow on the ground, decreasing opportunities for snow-dependent outdoor winter recreation in western national parks and elsewhere.

Yellowstone is the most popular national park for snow-dependent recreation, with about 100,000 visitors during the winter season when roads are snow-covered and closed to conventional motor vehicles. The National Park Service has been engaged for several recent years in a controversial winter-use planning process to determine what types of uses to allow in the park. Whatever the outcome of that process, all sides to the controversy support a continuation of the longstanding policy of not plowing the park's interior roads after enough snow accumulates to allow over-snow recreation. But global warming is likely to continue making winters shorter and milder and diminish opportunities to enjoy a snow-covered Yellowstone. Already, the National Park Service has had to delay the opening day of Yellowstone's winter season, from mid-November 20 years ago to mid-December in most recent years, and all the way to January 1 in the winter of 2004–05. Figure 22 illustrates why. In the Yellowstone area, the temperature record since the beginning of the twentieth century shows that in the December-to-March winter-use season, while average daily maximum temperatures (top figure) have remained within the historical range, average daily minimum temperatures (middle figure) have shown a warming trend. Daily minimum temperatures can be more important for building up and maintaining sufficient snow to allow oversnow vehicles to operate. The bottom figure shows that over the past 10 years in the Yellowstone area, the months in the December-to-March winter-use season have experienced more warming than

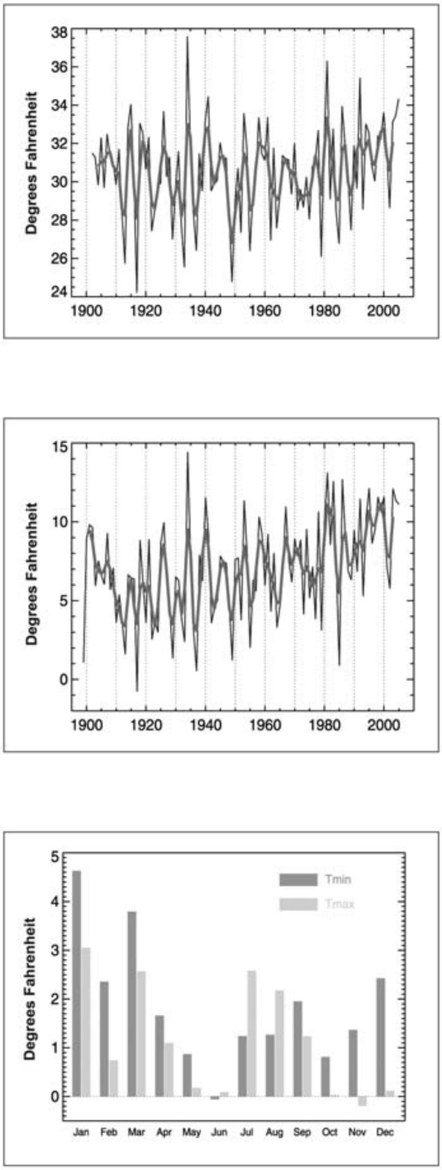

Figure 22. The top figure shows the average daily high temperatures and the middle figure the average daily low temperatures for the Yellowstone area in winter (December through March) for each year, from the beginnings of the temperature record through 2005. Each year's seasonal average is shown by the black line, a running 5-year average by the grey line. The bottom figure compares the average monthly low temperatures ("Tmin") and high temperatures ("Tmax") in the Yellowstone area for 1996–2005 to the historical monthly averages prior to 1991. Data are from four Historical Climate Network stations in and around Yellowstone National Park. Analysis by J. A. Hicke, Geography Department, University of Idaho.

other months of the year (with, again, a greater increase for average daily minimum temperatures than for daily maximum temperatures).

Opportunities for snow-dependent recreation will shrink not just in Yellowstone and nearby Grand Teton, but also in other mountain national parks. Rocky Mountain National Park, as one example, is a popular wintertime destination for thousands of cross-country skiers and snowshoers from among the 2.5 million people in Denver and other nearby Front Range cities. Researchers have projected that in the national park's Loch Vale basin, near popular ski and snowshoe trails, a 7-degree (Fahrenheit) increase in temperature could lead to a 50% reduction in the basin's snowpack.[93] The projected decreases in snowfall and snow accumulation everywhere in the West would similarly hurt cross-country skiing, snowshoeing, and other forms of winter recreation in national parks across the region.

National parks more polluted

Climate change may also increase levels of ozone, a form of smog. The pollutants that combine to form ozone can travel long distances, and national parks across the West are experiencing increasing levels of ozone (Figure 23). Joshua Tree, Sequoia/Kings Canyon, and Yosemite national parks all have ozone levels in violation of the Environmental Protection Agency's health-based standards, meaning that pollution levels in those parks can cause health problems for visitors. Many other western parks showed significant increases in ozone from 1990 to 1999.[94] Since high temperatures increase ozone production, climate change is likely to lead to higher ozone levels, in national parks and elsewhere.[95]

Part 5: Recommendations for reducing climate disruption

Protecting our treasured western national parks from climate disruption will take action to both reduce global warming pollutants and to prepare for the changes that may still occur.

Figure 23. Clear skies, such as those pictured below at Grand Canyon, are critical for the enjoyment of western parks. Rising ozone levels impair air quality, both in terms of human health and by damaging viewsheds. Photo courtesy of Grand Canyon National Park.

Fortunately, there are many commonsense actions that can be taken to change the odds. Encouragingly, more Americans are becoming aware of what is at stake, taking action themselves, and expecting action from their leaders.

Public officials in the West are particularly beginning to demonstrate leadership on this issue, perhaps motivated by a growing awareness of how the region's resources, quality of life, and economy are at risk. Senator John McCain of Arizona has long championed national legislation to reduce greenhouse gases. Senators Pete V. Domenici and Jeff Bingaman of New Mexico are working together to craft other strategies. At the state and local levels, too, some of the most significant steps to counteract climate change are being taken by public officials in the West. In the western United States and elsewhere, comprehensive action is needed—at all levels of government, by the private sector, and on the part of individuals—to secure the better future that is possible.

National Park Service climate action

When it comes to protection of the resources and values of our national parks, the National Park Service (NPS) has the first obligation. The Clean Air Act provides that NPS has "an affirmative responsibility to protect the air-quality related values" of national parks.[96] Park resources and values that are adversely affected by climate change certainly fall within this mandate, as climate change is caused by pollution of the atmosphere, which is defined as "the entire mass of air surrounding the earth."[97] The National Park Service's *Management Policies* also boldly declare that "the Service will use all available authorities to protect park resources and values from potentially harmful activities.... NPS managers must always seek ways to avoid, or minimize to the greatest degree possible, adverse impacts on park resources and values."[98] It is time for the National Park Service to exercise its authorities to address climate change, the greatest threat ever to national park resources and values. NPS should take the following actions.

Identify vulnerabilities in the national park system and determine the resources and values of individual parks most at risk from climate change. Much is already known about how climate change puts parks at risk, but a great deal is not yet known. The Park Service should greatly expand and accelerate the research, inventories, and analysis it has already conducted and permitted to better identify climate change's threat to the entire national park system and to individual parks.

Identify how NPS can take action to protect parks from climate change. Possible actions include revising management plans and taking measures to protect individual park resources and values. In some cases, park boundary changes and cooperative management with other landowners could be appropriate when current boundaries may no longer be adequate to protect a park in the face of the changed conditions accompanying climate disruption. Key plant and animal species may need to be able to use migration corridors and other habitat outside of a park to be able to maintain current populations within the park.

Cooperate with partners to mitigate climate change damage to parks. NPS should partner with other federal agencies; state, tribal, and local governments; other landowners; non-governmental organizations; and others to identify and promote actions to reduce both the extent of climate change and its impacts on park resources and values.

Speak out about the risks to parks. In communicating with individual NPS officials and employees in the preparation of this report, the authors were impressed by the extent of the knowledge and concern that many individuals in the Park Service have about climate change. The NPS leadership should gather and augment that information and disseminate it to the public at large and key decision-makers in Congress, other executive offices, and elsewhere. Such an approach is supported by the NPS *Management Policies,* which state that when park resources and values are at risk from external threats, "it is appropriate for superintendents to engage constructively with the broader community in the same way that any good neighbor would.... When engaged in these activities, superintendents should promote better understanding and communication by documenting the park's concerns and by sharing them with all who are interested."[99] In this case, when the external risk to parks comes not from other local or regional activities, but from human activities worldwide, the responsibility to speak out belongs not just to an individual superintendent addressing a local audience but also to the entire leadership of the National Park Service addressing a large audience.

National climate action[100]

The scientific community agrees that climate change is happening and that it is largely caused by consumption of fossil fuels, mainly in power plants and vehicles. Understanding of these truths among the general public has also increased greatly in the last two years. Unfortunately, policies to slow, stop, and reverse emissions of global warming have not yet been enacted where they are most needed—at the federal level.

The U.S. Senate did, however, take the important step in June 2005 of officially recognizing the problem, humankind's role in it, and the need for action. The majority of Senators (53) voted in favor of a nonbinding resolution stating: "It is the sense of the Senate that Congress should enact a comprehensive and effective national program of mandatory, market-based limits and incentives on emissions of greenhouse gases that slow, stop, and reverse the growth of such emissions...."

A recommended framework for action

The United States government must begin to significantly reduce our emissions within 10 years if we are to limit climate change to 3.6 degrees Fahrenheit and avoid the most dangerous impacts caused by rising temperatures. The window of opportunity is closing, and the time for action is now. The Senate and the House of Representatives have proposed legislation to address climate change. But to date, few if any of these proposals contain the policies necessary to cut back on emissions in time to stave off dangerous impacts.

The good news is that we can meet the emissions challenge through a combination of four approaches:

- **Energy efficiency.** By far the cheapest and fastest way to reduce emissions from power plants is to improve the efficiency of products and buildings that use electricity. This means developing technologies that allow us to get more power while using less energy—and releasing fewer emissions. We already know how to do it: we've achieved dramatic results by reducing the energy use of refrigerators, air conditioners, lighting systems, and buildings. It's time to set our sights on meeting our growing demand for energy with energy efficiency.

- **Cleaner power plants.** We have the technology to build power plants in a way that won't wreck the climate, and without turning to nuclear power. Through a combination of existing technologies—each in commercial operation today—we can convert coal into a cleaner-burning gas and siphon off the climate change pollutants before the gas-burning process. These pollutants, mainly carbon dioxide, can then be safely disposed deep underground. However, if we don't invest in this technology now, neither will China, India, or other countries with large coal supplies. It's up to the United States to lead the global response to climate change.
- **Cleaner vehicles.** Auto manufacturers know how to do it, and they already have the technology. Hybrid cars show us that dramatic improvements in emission reductions and fuel efficiency are possible. It's time to deploy hybrid and other fuel-efficient technologies throughout our vehicle fleets.
- **Clean, renewable power.** Biofuels and other renewable-energy technologies such as wind power are economically competitive today. Our cars are already equipped to run on ethanol that is blended with gasoline. And there are new methods for making ethanol from farm wastes and highly efficient crops that could compete with oil on a very large scale, generating more than 10 times the current ethanol production. This homegrown ethanol puts farmers in the business of growing fuel in addition to growing food.

Regional climate action

In the face of inaction to reduce climate change pollution at the federal level, states and cities are forming partnerships and moving forward on their own.

East Coast. In a historic agreement, eight states (Connecticut, Delaware, Maryland, Maine, New Hampshire, New Jersey, New York, and Vermont) have banded together to form the Regional Greenhouse Gas Initiative (RGGI), a market trading system covering carbon dioxide emissions from power plants. The RGGI agreement calls for states to stabilize emissions at roughly the current levels from 2009 through 2015, and for reductions to reach 10% by 2019.

West Coast. California, Oregon, and Washington are cooperating on a strategy to reduce emissions, known as the West Coast Governors' Climate Change Initiative. These states collaborated to produce a set of recommendations for cutting back on emissions that the states can pursue cooperatively and individually.

Southwest. In February 2006, Governors Janet Napolitano (Arizona) and Bill Richardson (New Mexico) signed the Southwest Climate Change Initiative, which establishes a framework for the two states to collaborate to reduce climate change pollution. Plans include developing measures for forecasting and reporting emissions; offering credits for emissions-reduction actions; promoting emissions mitigation, energy efficiency, and renewable energy sources that enhance economic growth; and advocating for regional and national climate policies.

Midwest. In early 2006, a bipartisan group of state legislators from Illinois, Iowa, Michigan, Minnesota, Ohio, and Wisconsin introduced legislation to limit carbon emissions, fund and/or mandate renewable energy development, and create standards and incentives for energy efficiency and efficient appliance purchases. Policy-makers are also working to encourage coal gasification and carbon sequestration, key issues for states that rely heavily on coal-fired generation.

State and local climate action

As of January 2006, 39 states had completed greenhouse gas emission inventories, 28 states had completed state climate action plans, and nine states had emission reduction targets. To date, 10 states have adopted California's landmark 2004 law requiring automakers for the first time to limit heat-trapping carbon dioxide emissions. The law calls for 30% reductions by 2016, beginning with the 2009 model year; Connecticut, Maine, Massachusetts, New Jersey, New York, Pennsylvania, Rhode Island, Oregon, Vermont, and Washington have adopted the standards. These 11 states account for about 5.7 million new vehicles, or about a third of the new U.S. passenger market.

Around the country, other states are making strides toward limiting their emissions:

- **Arizona.** In February 2005, Governor Janet Napolitano signed an executive order creating a Climate Change Advisory Group charged with recommending ways to reduce Arizona's greenhouse gas emissions. The group is expected to submit its report to the governor this summer.
- **California.** In June 2005, Governor Arnold Schwarzenegger called for a multiphase reduction of state greenhouse gas emissions that would bring emissions down to 2000 levels by 2010; 1990 levels by 2020; and 80% below 1990 levels by 2050. Also in 2005, the state established a greenhouse gas performance standard which requires that any new long-term power purchase contracts meet strict climate change pollution standards. This comes on the heels of a December 2004 requirement from the California Public Utilities Commission (CPUC) that power companies consider the financial risk associated with carbon emissions from power plants when comparing prices of fossil fuel and renewable generation, as well as demand-side management investments.
- **New Mexico.** In June 2005 Governor Bill Richardson established a climate change stakeholder panel charged with finding ways to reduce the state's emission to 2000 levels by 2012, 10% below 2000 levels by 2020, and 75% below 2000 emission levels by 2050.
- **North Carolina.** Governor Mike Easley signed a bill in September 2005 that established the Legislative Commission on Global Climate Change. The commission is charged with addressing the threats posed by climate change and determining the costs and benefits of the various mitigation strategies adopted by state and national governments. Findings and recommendations are due in November 2006.
- **Washington and Oregon.** These Northwest states have each created statutes requiring new power plants to offset anticipated carbon dioxide emissions by approximately 17 and 20%, respectively.

At the local level, the U.S. Conference of Mayors adopted a Climate Protection Agreement in June 2005 that replicates the Kyoto Protocol's goal of reducing greenhouse gas emissions to 7% below 1990 levels by 2012. In addition, 152 local governments in the United States participate in an ICLEI Cities for Climate Protection Campaign under which they inventory their greenhouse gas emissions, set targets for future reductions, develop local action plans to achieve those targets, and monitor their progress. Portland, Oregon, recently documented that it has reduced citywide emissions of greenhouse gases below 1990 levels—the first American city to do so.

As important and encouraging as these actions are, they are just first steps. Much more will be needed to preserve not just the national parks of the American West, but the quality of life worldwide. It is only prudent and responsible to move forward and meet this challenge.

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