Rocky Mountain Forests at Risk

Confronting Climate-driven Impacts from Insects, Wildfires, Heat, and Drought

Union of Concerned Scientists

the ROCKY MOUNTAIN CLIMATE Organization

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LEAD AUTHORS

Jason Funk

Stephen Saunders

CONTRIBUTORS

Todd Sanford

Tom Easley

Adam Markham

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Jason Funk is a senior climate scientist at the Union of Concerned Scientists. He is a former land-use and climate scientist at the Environmental Defense Fund, and is certified as an expert reviewer for land-use emissions inventories under the United Nations Framework Convention on Climate Change.

Stephen Saunders is president and founder of the Rocky Mountain Climate Organization. He served in the Clinton administration as deputy assistant secretary of the U.S. Department of the Interior over the National Park Service and the U.S. Fish and Wildlife Service.

Todd Sanford is an independent consultant and formerly a climate scientist with the Union of Concerned Scientists. His current work focuses on climate impacts in the western United States.

Tom Easley is director of programs at the Rocky Mountain Climate Organization. He is the former director of statewide programs for Colorado State Parks.

Adam Markham is the director of the Climate Impacts Initiative at the Union of Concerned Scientists. He has more than 20 years of experience working on conservation and climate change challenges in the United States and Europe.

The Union of Concerned Scientists puts rigorous, independent science to work to solve our planet's most pressing problems. Joining with citizens across the country, we combine technical analysis and effective advocacy to create innovative, practical solutions for a healthy, safe, and sustainable future.

The Rocky Mountain Climate Organization works to reduce climate disruption and its impacts, to help keep the interior West the special place that we cherish. 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.

More information about the Union of Concerned Scientists *(www.ucsusa.org)* and the Rocky Mountain Climate Organization *(www.rockymountainclimate.org)* can be found online.

This report is available online at *www.ucsusa.org/forestsatrisk* and *www.rockymountainclimate.org/reports_6.htm*.

Cover photo: © John Fielder

An unprecedented combination of tree-killing insects, wildfire, and heat and dryness is already severely affecting key trees across six states, jeopardizing the beauty and integrity of forests like this in Colorado's West Elk Wilderness.

[CONTENTS]

[FIGURES, TABLES, AND BOXES]

FIGURES

TABLES

BOXES

[ACKNOWLEDGMENTS]

This report is the outcome of an active collaboration between the Union of Concerned Scientists (UCS) and the Rocky Mountain Climate Organization (RMCO), with the generous support of a diverse range of experts. The report was made possible by the support of the Barr Foundation, the Clif Bar Family Foundation, the Energy Foundation, the Grantham Foundation for the Protection of the Environment, UCS members, and RMCO partner organizations.

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Americans revere the Rocky Mountains for their aesthetic, environmental, and economic value. The Rockies are home to some of the crown jewels of the national park system, including Yellowstone, Grand Teton, Glacier, and Rocky Mountain National Parks.

These parks alone receive 11 million visitors each year and generate more than $1 billion annually in visitor spending. Another 60 million people visit the region's 37 national forests each year.

Today, however, the forests of the Rocky Mountains are facing a triple assault: tree-killing insects, wildfires, and heat and drought. If allowed to continue unchecked, these stresses and their impacts could fundamentally alter these forests as we know them.

Human-caused global warming is driving these detrimental effects by bringing hotter and drier conditions, which not only cause their own effects but amplify those of other stresses. An exceptionally hot and dry stretch from 1999 to 2003 produced unusually severe impacts on the region's forests. If these trends continue, even hotter and drier conditions could become commonplace, leading to even greater effects on Rocky Mountain forests.

This report documents the latest evidence on how climate change is already disrupting the forests of the Rocky Mountain region and what scientists project for the decades ahead, and suggests how we can best meet these challenges.

Tree-Killing Insects

Native bark beetles have always been agents of change in western forests. In the early 2000s, however, bark beetle outbreaks across western North America, including the Rocky Mountain region, killed more trees, at a faster pace, for longer periods, and over more acreage than any other known infestations.

From 2000 to 2012, bark beetles killed trees on 46 million acres—an area just slightly smaller than Colorado. The U.S. Forest Service estimates that as many as 100,000 beetle-killed trees now fall to the ground every day in southern Wyoming and northern Colorado alone.

The changing climate played a key role in these outbreaks. Exceptionally hot, dry conditions stressed and weakened trees, reducing their ability to ward off the beetle attacks. Milder winters meant less extreme cold in winter—which had previously kept beetle populations in check. Higher temperatures also allowed more beetles to produce offspring in one year instead of two, leading to explosive population growth.

(Left:) The Rio Chama Wilderness Study Area in northern New Mexico is in the southernmost Rocky Mountains. Piñon woodlands cover the hills, and forests of ponderosa pine and Douglas fir cover the north-facing slopes. The diversity of habitat types provides for a variety of wildlife.

Bureau of Land Management/Bob Wick

More Wildfires

Wildfires have always been an important feature of the forest cycle. But in today's Rocky Mountain forests, the number of large wildfires has risen dramatically. One study documented a 73 percent increase in the annual number of large wildfires in the region from 1984 to 2011. Another study compared western wildfires in two time periods: 1970 to 1986 and 1986 to 2003. During the more recent period, nearly four times as many large wildfires occurred, they burned nearly seven times as much total area, and wildfire seasons lasted two and a half months longer.

A robust body of scientific research has linked these increases in wildfires to a changing climate. One important change is higher spring temperatures, which produce earlier spring snowmelt and peak streamflows, leaving forests drier and more flammable in summer. The recent increases in wildfires are also affecting people, especially because many more now live in and adjacent to forests and woodlands, where they and their property are vulnerable.

More Heat and Dryness

Besides increases in tree-killing insects and wildfires, scientists have found a rise in "background mortality"—the rate at which trees die from no obvious cause. For example, tree mortality in relatively undisturbed old-growth forests across the West has doubled in recent decades, with no compensating increase in the number of tree seedlings. And tree mortality has been highest in recent years. Scientists suggest that hotter and drier conditions across the West are driving these changes.

Impacts on Iconic Tree Species

These threats are already severely affecting three iconic tree species of the Rocky Mountains: whitebark pines, aspens, and piñon pines.

Whitebark pines (*Pinus albicaulis*)—a high-elevation species with unique ecological importance in the Northern Rockies—have faced both blister rust and epidemic-level infestations of mountain pine beetles, part of the recent West-wide outbreak. Earlier outbreaks of mountain pine beetles at high elevations were shorter and less severe, because winter temperatures were typically cold enough to kill the beetles. However, the sustained higher temperatures of recent winters have allowed the beetles to overwinter and thrive.

Today whitebark pines are in catastrophic decline throughout their range in western North America. Mortality in some areas has been 90 percent to 100 percent. This die-off has led the U.S. Fish and Wildlife Service to determine that they are in such risk of extinction that they qualify for listing under the Endangered Species Act.

Quaking aspens (*Populus tremuloides*), an emblematic species of the Rocky Mountains, have seen abrupt and extensive die-off across large areas of their range, in response to extreme heat and dryness at the beginning of this century. From 2000 to 2010, some 1.3 million acres in the Southern Rockies saw significant aspen decline, and regeneration of new aspens has been much lower than normal.

Piñon pines (*Pinus edulis*) are a foundation species of the forests that flank the Southern Rockies and many other areas in the Southwest. In 2002–2003, these areas suffered a mass die-off of piñon pines triggered by severe drought and exceptional heat. Sites in Mesa Verde National Park in Colorado, near Los Alamos in northern New Mexico, and near Flagstaff, AZ, lost some 90 percent of their piñon pines. One team of scientists described the mass piñon pine die-off as "one of the most extensively documented examples of a sudden ecosystem crash in response to climate change."

The Driver: Climate Change in the Rockies

The Rocky Mountain region has warmed more than the country as a whole since 1895, when modern record keeping began. Rising regional temperatures have led to reduced spring snowpacks, earlier snowmelt, and earlier peak streamflows. A growing number of studies conclude that these changes in western temperature and hydrology are outside the range of natural variability—driven largely by climate change.

An exceptionally hot and dry period occurred from 1999 to 2003, when the region recorded the second-hottest five-year interval since 1895, and the fourth-lowest five-year precipitation total. And 2002 was the driest year since 1895, with precipitation 22 percent below average. This exceptionally hot, dry period triggered many of the forest impacts documented in this report.

If climate change continues unchecked, scientists expect the region to become even hotter and drier—and the impacts on its forests even more severe. Depending on future levels of our heat-trapping emissions, the regional climate may be much hotter and perhaps drier later this century than even from 1999 to 2003. And if these emissions remain high, temperatures would be far hotter than they have been in several thousand years.

Our new analysis of information used in the 2014 National Climate Assessment shows that, given very low future carbon emissions, average temperatures in the six Rocky Mountain states could rise to about 3°F above 1971–2000 levels by mid-century and remain that high into the last decades of the century. However, if emissions continue unchecked, average temperatures could rise by about 6°F by mid-century—and by 10°F in the last decades of the century.

Robust science offers strong evidence of what likely lies ahead for Rocky Mountain forests. As the report explains in detail, scientists project the following effects:

- Further increases in bark beetle outbreaks, including expansion into new areas, are likely.
- Large, intense, and more frequent fires will occur in western forests. Even relatively modest temperature increases will likely mean large increases in acreage burned.
- In the Northern Rockies, earlier snowmelt and reduced spring snow cover, driven by higher temperatures, will create new water stresses and lead to a substantial decline in forest vitality.
- Although all such projections have inherent uncertainty, if climate change continues along today's trends, modeling projections suggest that the climate would become less suitable for widespread, characteristic conifer species such as lodgepole pine, Engelmann spruce, ponderosa pine, and Douglas fir, as well as iconic species including whitebark pine, aspen, and piñon pine. These species could be eliminated from much of their current ranges, potentially changing the fundamental makeup and extent of Rocky Mountain forests.

[***Human-caused global warming is bringing hotter and drier conditions, which not only cause their own effects but amplify those of other stresses.***]

A Call to Action

The dramatic impacts Rocky Mountain forests already face—coupled with scientific understanding of what is driving them—mean that unchecked heat-trapping emissions will bring more abrupt, damaging, and potentially irreversible effects.

The future of these forests depends on the speed and effectiveness of our efforts to limit global warming emissions, as well as to reduce other stresses.

We propose six sensible, practical steps to guide our efforts to protect these precious resources:

- **Assess risks.** More detailed scientific information will help policy makers choose the right priorities for managing these forests. The U.S. Forest Service has issued a new climate change response strategy calling for assessing risks as the first of three essential steps. Other agencies have also begun assessing the vulnerabilities to forested lands in the face of climate change, as well as gaps in our knowledge about those risks.
- **Engage stakeholders.** Because the effects of climate change on Rocky Mountain forests are so complex, engaging partners in seeking solutions is critical to managing these impacts. Indeed, the Forest Service posits engaging stakeholders as the second pillar of its climate change response strategy. Early examples of stakeholder engagement are already yielding lessons on which to build.
- **Manage for resilience.** In 2012, the U.S. Forest Service adopted "managing for resilience" as the third principle of its climate change response strategy. Managing for resilience begins with incorporating information on climate change into decisions on protecting important resources, and includes tackling other stresses that combine with climate change to produce cumulative effects on forests.
- **Increase the capacity of public agencies.** To combat the severe threats to Rocky Mountain forests and other national resources from climate change, public land managers must take an extraordinary suite of actions. Yet Congress has not even provided the relatively limited funds that federal agencies have requested for this essential work. Congress should provide the funds that the federal land-management agencies need to fulfill their responsibility to protect our nationally significant natural resources from climate change—in the Rocky Mountains and elsewhere.

- **Address the vulnerability of communities.** The impacts of climate change on forest resources will affect communities throughout the region and the nation. State and local governments, with federal agencies, need to assess existing impacts and consider those of future climate scenarios, and then work with others to combat them. Some effects, such as the growing risks of wildfire in the wildland-urban interface, will require federal, state, and local cooperation to reduce the exposure of people, property, and resources and to prepare for and respond to the remaining risks.
- **Reduce emissions.** The future of Rocky Mountain forests ultimately depends on how much and how quickly we can curb heat-trapping emissions. As individuals, we can help by taking action to reduce our personal carbon emissions. But to fully address the threat of global warming, we must demand action from our elected leaders to support and implement a comprehensive set of climate solutions.

  Reducing emissions can strengthen our economy. For example, the public health and climate benefits of the Clean Power Plan of the Environmental Protection Agency will be worth an estimated $55 billion to $93 billion per year in 2030—far outweighing the costs of $7.3 billion to $8.8 billion. State and local governments also have an essential role to play in reducing emissions, and many are taking action to curb emissions and climate change while promoting economic growth.

For the many Americans who cherish the forested landscapes and snowy peaks of the Rocky Mountains as iconic images of the American West, the choice is stark: unless we want to sit by and watch this majestic landscape and treasured resource degrade irrevocably, we must act now to preserve it.

[The forests of the Rockies are facing a triple assault: tree-killing insects, wildfires, and heat and drought. If allowed to continue unchecked, these stresses and their impacts could fundamentally alter these forests as we know them.]

[CHAPTER 1]

A Cherished Landscape at Risk

Americans cherish the forests of the Rocky Mountains. The forested landscapes and snowy peaks of the Rockies are iconic images of the American West. Their aesthetic, environmental, and economic values are important to both people who live in the region and those who visit it and treasure it from afar.

For many westerners, the scenery and the outdoor recreational opportunities it provides are an important part of their attachment to the region—in many cases, what drew them there. The forests also provide vital habitat for some of the most treasured species of the West: grizzly and black bears, elk, moose, golden eagles, and cutthroat trout. And the forests shelter mountain snowpacks and regulate streamflows, sustaining lower-elevation ecosystems, human populations, and agriculture.

In the Routt National Forest near Steamboat Springs, CO, aspen trees in a single colony with interconnected roots turn color at the same time.

© John Fielder

Prized for their aesthetic, environmental, and economic value, forests of the Rocky Mountains (as in Colorado's Dallas Divide, for example) are now at greater risk than ever before in U.S. history.

The forests of the Rockies are highly varied. Most are composed of conifers, including ponderosa, lodgepole, piñon, bristlecone, and whitebark pines; Douglas fir and subalpine fir; blue and Engelmann spruce; and several junipers. The most common deciduous trees are quaking aspens. Some forests are open woodlands with scattered trees. Others are dense stands of mixed or single species.

These forests are nationally significant resources. The federal government has retained ownership of 72 percent of forested land in the six Rocky Mountain states for the use and enjoyment of all Americans. Several of the crown jewels of America's national park system are in the Rockies, including Yellowstone, Grand Teton, Glacier, and Rocky Mountain National Parks, as well as Bandelier National Monument. These parks host 11 million visitors a year and generate more than $1 billion in visitor spending. Another 60 million people visit the region's 37 national forests each year. The White River National Forest in Colorado alone records more than 9 million visits a year, making it the nation's most visited national forest for recreation.

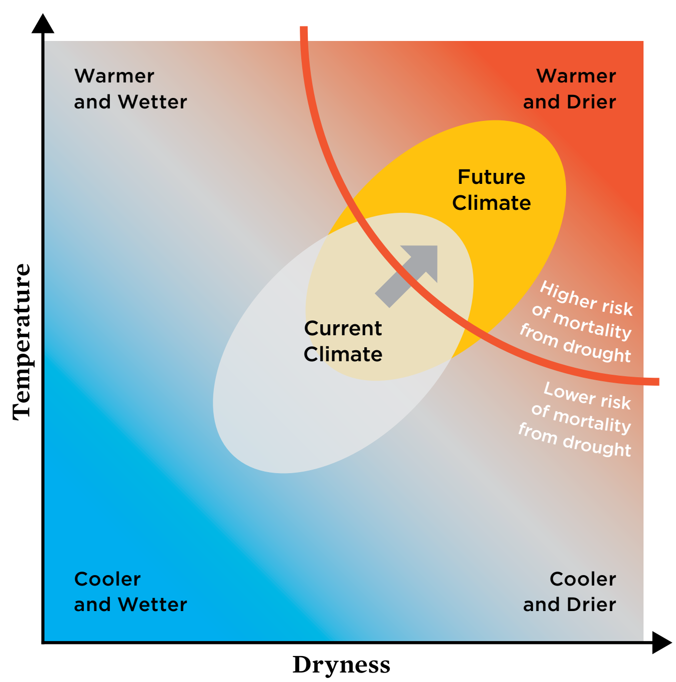
Yet the forests of the Rocky Mountains are now at greater risk than ever before in U.S. history. Average temperatures across the nation have risen 1.9°F since 1895—with 80 percent of that warming occurring since 1980 (Walsh et al. 2014). This warming has been even more pronounced in the Rocky Mountain region, which has seen an increase of 2.1°F since 1895. The resulting changes in the forests of the Rockies provide some of the clearest indications that the United States is already suffering the consequences of climate change.

An unprecedented combination of tree-killing insects, wildfires, and heat and dryness is disrupting the forests of the Rocky Mountains. These ecosystems have adapted over millennia to natural disturbances and stressors, persisting and thriving despite wildfires, droughts, insects, diseases, and extreme weather events. Now, though, climate change is bringing hotter and drier conditions, which create new stresses and amplify the effects of others.

Heat and dryness have accelerated the rate at which trees are dying across the West (Figure 1). Rising temperatures are driving warmer winters, reduced spring snowpacks, earlier snowmelts, and drier summers. Warmer conditions, droughts, and shorter winters have allowed bark beetles to kill forests that once covered an area the size of Colorado—far exceeding any known insect disturbances since Europeans arrived. Large wildfires have become more frequent and are destroying more homes and harming communities.

Other stresses—such as decades of forest management policy and encroaching human development—have helped set the stage for these transformational changes. However, climate change is the major driving force. If allowed to continue

FIGURE 1. Rising Risks of Tree Mortality in Forests as Climate Changes



Rising temperatures and more dryness stemming from climate change raise the risks that trees will die from numerous stresses, including water stress, wildfires, and insect outbreaks.

SOURCES: NATIONAL CLIMATE ASSESSMENT 2014; ALLEN ET AL. 2010.

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Several of the crown jewels of America's national park system, including Grand Teton, are in the Rocky Mountains.

unchecked, these and other impacts could fundamentally alter these forests as we know them.

Scientific projections consistently show that if heat-trapping emissions continue on their current trajectory, the effects will be more abrupt, damaging, and potentially irreversible. At least one key species, whitebark pines, could disappear entirely, and aspens and piñon pines could vanish from much of their existing habitat. In fact, climate models suggest that forests may disappear altogether from many parts of the region this century, replaced by shrublands or grasslands—fundamentally changing Rocky Mountain landscapes.

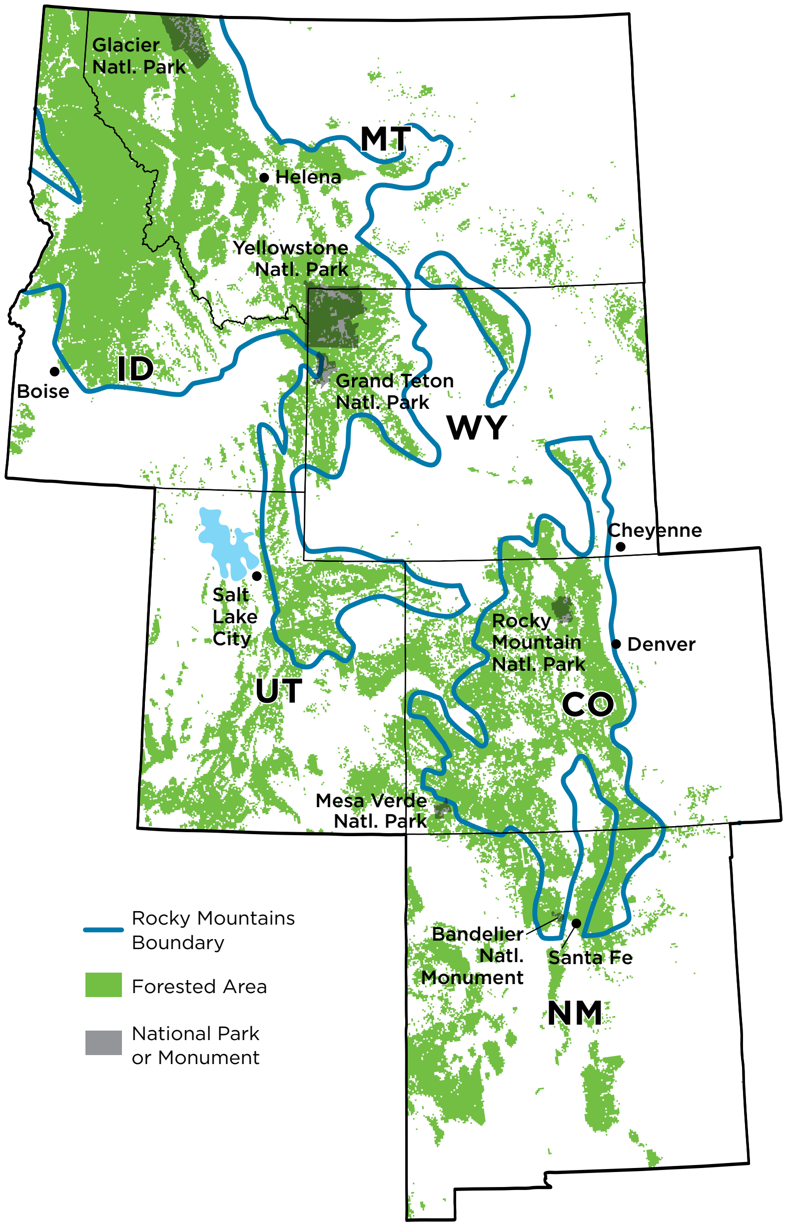
The future of these forests depends on the speed and effectiveness of our efforts to limit heat-trapping emissions while also curbing other stresses. The region also needs to prepare for continued climate change: many changes cannot be avoided entirely, but many could be managed. Forest planning and management must reflect a new understanding that tomorrow's forests may be very different, and that innovative adaptations are essential.

This report brings together the work of scientists who have documented changes occurring in the forests of the Rocky Mountains, which are found in Colorado, Idaho, Montana, New Mexico, Utah, and Wyoming (Figure 2, p. 8).[1] We focus not only on the forests of the Rockies themselves, but also on those of the surrounding foothills, including the piñon-juniper forests that flank the Southern Rockies, and forests on nearby lands such as Canyonlands and Mesa Verde National Parks.

The Union of Concerned Scientists (UCS) and the Rocky Mountain Climate Organization have partnered to produce this report because of our shared concern about the urgency and scale of the climate-related challenges facing these states. Our aim is to arm stakeholders and policy makers with the

1 *This report uses the following naming convention for different regions.* The West *refers to 11 states: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. The* interior West *refers to the eight states that do not border the Pacific Ocean. The* Rocky Mountain region *and* Rocky Mountain states *comprise the six states with portions of the Rocky Mountains: Colorado, Idaho, Montana, New Mexico, Utah, and Wyoming. The* Northern Rockies *refers to the Rockies in Montana and Idaho, and in Wyoming north of the southern border of Idaho (latitude 42° north). The* Southern Rockies *refers to southern Wyoming, Utah, Colorado, and New Mexico.*

FIGURE 2. Forest Cover in the Rocky Mountain Region



Forests are the predominant vegetation of Rocky Mountain landscapes, providing vital habitat for wildlife and important benefits for people, especially in our iconic national parks. The blue borders indicate the areas considered Rocky Mountain forests in this report, based on a widely used classification of ecosystems.

SOURCES: USFS N.D.C; MAP BASED ON USFS N.D. AND USFS MOSCOW LAB 2014.

information they need to respond to existing impacts and lessen future ones. At stake are some of the world's most spectacular mountain landscapes—made more inspiring and valuable by the forests that cover them.

The novelist and historian Wallace Stegner wrote, "One cannot be pessimistic about the West. It is the native home of hope." Westerners have long proven themselves adaptive, creative, and resourceful. Our hope is that by bringing the scale of the threats to these treasured landscapes to the attention of people in the West and across the nation, we can spark new efforts to safeguard them.

[CHAPTER 2]

Increases in Tree-Killing Insects

- Since 2000, epidemic-level populations of bark beetles have killed trees in western forests across an area the size of Colorado. These infestations have caused more widespread tree mortality than any other infestation in the twentieth century.
- Hot and dry conditions have driven these beetle outbreaks—stressing trees and reducing their defenses while allowing the beetles to reproduce more quickly.

The sight of mountainside after mountainside covered by dead and dying conifers with reddish-brown needles, or bare, gray snags with no remaining needles, startles residents and visitors alike in the Rocky Mountain region. Recent outbreaks of tree-killing bark beetles—more severe than any in the last century—have altered these landscapes, set in motion by unusually hot, dry conditions.

Mountain pine beetles are responsible for most insect-caused tree deaths in the West.

From 2000 to 2012, bark beetle outbreaks killed billions of trees in the West, covering an area almost the size of Colorado (U.S. Forest Service 2013a; Meddens, Hicke, and Ferguson 2012). According to the U.S. Forest Service, outbreaks of tree-killing bark beetles "are occurring more rapidly and dramatically than imagined a decade ago" (Ryan and Vose 2012). Mortality from insects is now seen as one of the two most significant and visible ways—the other is wildfire—that climate change is affecting forests across the West (Ryan and Vose 2012).

What Has Already Happened

Native insects have always been agents of change in western forests, where they regularly kill as many or more trees than wildfires (Hicke et al. 2013; Edburg et al. 2012; Meddens, Hicke, and Ferguson 2012; Bentz et al. 2009). Mountain pine beetles—responsible for most insect-caused tree deaths in the West—kill their host tree, typically a pine, when they burrow under its bark in large enough numbers. By midsummer the following year, an infested tree has died and its needles have turned the telltale reddish brown now seen across the West. By then, a new generation of beetles has flown on to infest new host trees. In another year or two, the needles fall from the tree, which then stands as a gray skeleton until it, too, falls, usually in 5 to 10 years.

Spruce beetles, the second most disruptive insect to Rocky Mountain forests, use similar strategies to attack spruce trees. Still other bark beetles specialize in other host trees. Piñon ips beetles, for example, primarily infest piñon pines (see Chapter 5) (Bentz et al. 2009).

Recent outbreaks of mountain pine beetles (right) and other insects have left mountainsides like these in Colorado's Flat Tops Wilderness (above) colored reddish-brown by dead and dying conifers.

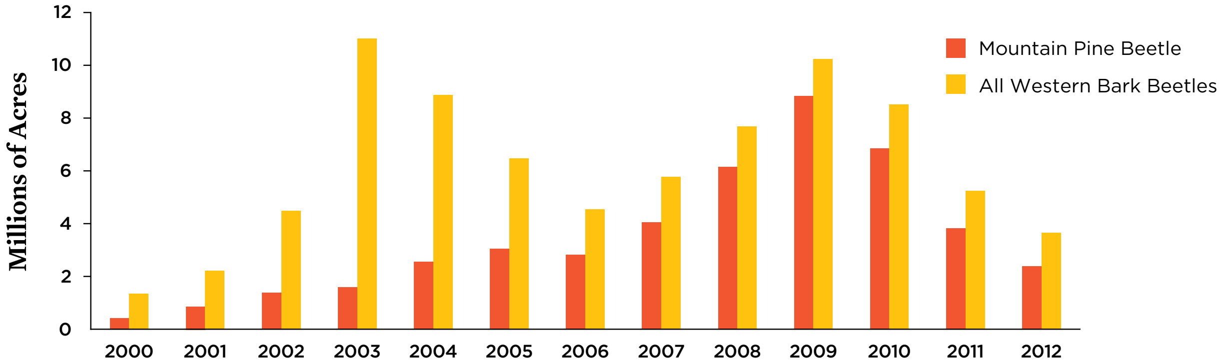
© John Fielder (mountains); USDA Forest Service Region 2/Rocky Mountain Region Archive, Bugwood.org (beetles)

Mountain pine beetles usually kill trees across relatively diffuse areas, with minor effects on individual forest stands. But when severe forest conditions and weather coincide, bark beetle populations can erupt, killing as much as 95 percent of mature trees of a favored type across an entire landscape (Bentz et al. 2009). Mountain pine beetle outbreaks typically subside when too few host trees remain to support the beetle population, winter temperatures fall below critical levels and kill the beetles, or summer temperatures are too cool to trigger enough new adults to emerge (Régnière and Bentz 2007; Logan and Bentz 1999).

Extensive, dense stands of mature trees of one or more species that a particular type of bark beetle will attack are most susceptible to such outbreaks (Bentz et al. 2009). Bark beetle outbreaks erupted near the turn of the twenty-first century across western North America, including the Rocky Mountains. These outbreaks differed from previous ones in several ways:

- **Severity and extent.** Recent bark beetle infestations have killed more trees at a faster pace, for longer periods, and across more of North America since record keeping began a little over a century ago (Bentz et al. 2009; Kaufmann et al. 2008; Raffa et al. 2008). The widespread and simultaneous onset of epidemic-level infestations suggests regional—not local—causes (Chapman et al. 2012).
- **Increased stress from heat and drought.** Exceptionally hot, dry conditions have stressed and weakened trees, reducing their defenses to beetle attacks, primarily the production of resin to flush out the insects (Bentz et al. 2009; Raffa et al. 2008). Previous droughts without such high temperatures did not produce comparable outbreaks (Creeden, Hicke, and Buotte 2014; Adams et al. 2009). According to leading scientists, "The West's changing climate—rising temperatures and decreasing precipitation—has created weather conditions that are ideal for bark beetle outbreaks" (Bentz et al. 2009).
- **More overwinter survival of beetles.** Beetles protect themselves from the deep cold of Rocky Mountain winters by producing an antifreeze-like compound. Even

FIGURE 3. Acres of Western Land with Trees Killed by Bark Beetles, 2000–2012



Bark beetles killed trees on 46 million acres in the western United States from 2000 to 2012—an area nearly as large as the 48-million-acre state of Colorado. Mountain pine beetles were responsible for tree deaths on half of that acreage. Piñon ips beetles were primarily responsible for a surge in mortality from other bark beetles in 2003–2005.

SOURCE: USFS 2013A.

then, sustained periods of extreme cold can kill enough beetles to sharply reduce their populations. However, recent Rocky Mountain winters have often been milder, allowing more beetles to overwinter (Creeden, Hicke, and Buotte 2014; Bentz et al. 2009; Raffa et al. 2008; Régnière and Bentz 2007).

- **Faster beetle reproduction.** Especially at high elevations, beetles typically took two years to produce a new generation. Higher temperatures mean that more beetles can produce offspring in one year. Faster reproduction means more explosive population growth, enabling more epidemic-level infestations (Bentz et al. 2014; Hansen and Bentz 2003).
- **Spread of beetles to new areas and host species.** Warmer winters and summers have allowed mountain pine beetles to erupt at elevations and latitudes where winters typically were cold enough to keep them in check. Sustained mountain pine beetle outbreaks are now occurring in limber pine, Rocky Mountain bristlecone pine, and whitebark pine—species that largely occupy high elevations (Bentz et al. 2009). In Canada, mountain pine beetles have spread farther north and to higher elevations, crossing the previously impenetrable Continental Divide into Alberta. The beetles are also infesting jack pine—a species not previously recorded as a host (de la Giroday, Carroll, and Aukema 2012; Cullingham et al. 2011).

California Department of Food and Agriculture/ M. O'Donnell and A. Cline, Bugwood.org

Spruce beetles are the second most disruptive insect in Rocky Mountain forests.

Because of these stressors, bark beetle outbreaks across the West are killing trees at a faster rate and on a larger scale than seen in 100 to 150 years of record keeping (Bentz et al. 2009). Bark beetles killed trees on 46 million acres in the western United States from 2000 to 2012—an area slightly smaller than the 48-million-acre state of Colorado—with mountain pine beetles responsible for half of that acreage (Figure 3) (USFS 2013a). After peaking in 2009, infestations of mountain pine beetles subsided in many areas because fewer host trees remained (CFSF 2013; USFS 2013b, 2012, 2010b). In other areas, though, ample trees remain to support further outbreaks (USFS 2013b). Spruce beetle outbreaks have not subsided in a similar way, and are expanding in Colorado (CFSF 2013).

Because trees shelter snowpacks from the sun and wind, the death of trees across entire landscapes can increase the risk of rapid snowmelt in the spring and alter the timing of streamflows (Bentz et al. 2009). Live trees also provide recreational opportunities and visitor enjoyment year-round, but

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When severe forest conditions and weather coincide, bark beetle populations can erupt, killing as much as 95 percent of the mature trees of a favored type across an entire landscape. This damage occurred in Colorado's Arapaho National Forest.

Bark beetles killed trees on 46 million acres in the western United States from 2000 to 2012—an area slightly smaller than the 48-million-acre state of Colorado.

beetle-killed trees can become a hazard (Bentz et al. 2009). In southern Wyoming and northern Colorado alone, up to 100,000 beetle-killed trees now fall to the ground every day, and both the National Park Service and the U.S. Forest Service have closed campgrounds to protect campers from falling trees (USFS 2011). In fact, some 14,000 miles of roads and trails, 1,400 recreation sites, and countless power lines and water supply reservoirs are at risk across the interior West.

What Scientists Project Will Happen

What will happen in forests where bark beetles have killed most mature host trees is not fully clear. Enough saplings and seedlings persist in Rocky Mountain National Park to reestablish forests—although they may not reach their previous density for about a century, and the composition of the forests may change (Kayes and Tinker 2012; Collins et al. 2011; Veblen et al. 1991). Aspens—which are quick to colonize disturbed areas—are already spreading in outbreak areas. Aspen populations are likely to expand beyond their pre-outbreak levels and then diminish as conifers largely replace them (Collins et al. 2011). And where standing dead lodgepole pines in Colorado provide some shade, more shade-tolerant young subalpine firs are growing faster than young lodgepoles. The firs could dominate these forests within a century (Collins et al. 2011).

Continued climate change may promote further outbreaks of mountain pine beetles and spruce beetles in some areas and limit them in others. One study projects that a medium-high level of heat-trapping emissions will increase the likelihood that mountain pine beetles survive the winter and emerge the next summer to infest new trees—both factors needed to support large beetle populations (Bentz et al. 2010).[2] That modeling suggests that these conditions will become more common with further climate change, with beetle populations growing most where beetle-caused tree mortality has been especially high (Bentz et al. 2010). The study also concluded that the likelihood that spruce beetles will produce a new generation in a single year would rise from low-moderate to high throughout most of the Rocky Mountains near the end of this century (Bentz et al. 2010).

However, this study examined the impact of climate change on beetle populations only, rather than considering factors such as the availability of host trees. Another study that considered both future populations of spruce beetles and the availability of spruce trees—and a medium-high level of heat-trapping emissions—projected that the beetles would spread to 9 percent more western forested land by 2050, and 16 percent more by 2080 (DeRose et al. 2013).[3]

High summer temperatures can also disrupt the development of bark beetles (Bentz et al. 2010; Safranyik et al. 2010). Higher summer temperatures could exclude mountain pine beetles from more than 40 percent of their existing range by mid-century, according to one projection, especially at lower latitudes and elevations. However, they could expand into areas that now account for only 11 percent to 15 percent of their range (Evangelista et al. 2011).

2 This level of future heat-trapping emissions is based on the A2 (medium-high) emissions scenario of the Intergovernmental Panel on Climate Change (IPCC).
3 This study also used the IPCC's A2 medium-high emissions scenario.

[CHAPTER 3]

Increases in Wildfires

- Although wildfires play an important ecological role in Rocky Mountain forests, growing population and development in and around them have set the stage for more costly and widespread impacts, including loss of life, worsening public health, and economic losses in communities.
- Hotter spring and summer temperatures and earlier snowmelt in the Rocky Mountains have led to more large wildfires and longer wildfire seasons.
- As the Rocky Mountains become hotter and drier, the risks to the region's forests from larger, more intense, and more frequent wildfires will grow, posing greater risks to communities.

Along with insect outbreaks, wildfires are perhaps the most significant and visible way that climate change is already affecting forests in the West (Ryan and Vose 2012). Large

National Park Service/Mike Lewelling

Large wildfires, such as the 2013 Alder fire in Yellowstone National Park, have become more frequent in Rocky Mountain forests, driven largely by a changing climate.

U.S. Forest Service/Brady Smith

Climate is the primary driving force behind the extent of wildfires (such as the 2010 Schultz fire that caused this damage in Arizona's Coconino National Forest), but human actions are also important.

wildfires have become more frequent in Rocky Mountain forests, driven largely by a changing climate. Scientists project that wildfires will become even more frequent, larger, and more intense, given continued climate change.

What Is Already Happening

In an analysis of nearly 7,000 large wildfires in the West from 1984 to 2011, scientists found a 73 percent increase in the average annual frequency of such fires in the Rocky Mountain region at the end of the period versus the beginning. This increase—an average of 18 more large fires each year—coincided with hotter temperatures and more-severe droughts (Dennison et al. 2014).

These findings amplify the results of a 2006 study that was the first to systematically document how wildfires in western forests have changed in the last few decades (Westerling et al. 2006). These scientists compared large wildfires on federal lands in the West during the periods 1970 to 1986 and 1987 to 2003. In analyzing a database of more than 1,000 fires, these researchers found that, compared with the earlier period, the latter period had:

- nearly four times as many large wildfires;
- 6.6 times as much total area burned;
- wildfire seasons that averaged 198 days rather than 120 days; and
- wildfires that burned for about five weeks rather than one.

The scientists linked these dramatic increases to higher spring temperatures and earlier snowmelt, which leave forests drier and more flammable in the summer. Some 72 percent of the area burned by wildfires occurred in years with early snowmelt, and only 4 percent in years with late snowmelt. And three-quarters of the early snowmelt years occurred in the second half of the period. Other factors—including historical efforts to suppress fire—had relatively little effect on the extent of wildfires (Westerling et al. 2006).

Other studies have also found recent increases in the frequency and extent of wildfires in the West, and that climate is the primary driver of the extent of wildfires (Climate Central

2012; Litschert, Brown, and Theobald et al. 2012; Littell et al. 2009; Heyerdahl, Morgan, and Riser 2008; Morgan, Heyerdahl, and Gibson 2008).

Climate largely determines the extent of wildfires in the West, but human actions are also important, although their roles vary in different ecosystems. For example, past fire suppression has led to changes in fire frequency and intensity in some southwestern ponderosa pine forests, but has had little impact in some other Rocky Mountain forests. And development has led to more wildfires in some areas and fewer in others (Dennison et al. 2014).

Scientists have linked human introduction of cheatgrass and other invasive grasses to increases in the frequency of fires and the amount of acreage burned in some areas in recent decades. Yet the introduction by Europeans of hundreds of thousands of cattle and sheep in grasslands and forests beginning late in the nineteenth century reduced the extent of grasses, an important fuel for many wildfires, so fire frequency declined sharply (Marlon et al. 2012).

These human influences helped reduce the extent of wildfires in the West from the mid-1930s to the mid-1980s, making them less extensive than during almost any other period in the past 3,000 years (Marlon et al. 2012; Littell et al. 2009). These reductions in western wildfires have left a legacy of accumulated fuel in western forests, creating what some scientists have called a fire deficit: the buildup of fuel in forests is making them more susceptible to fire (see Box 1, p. 16) (Marlon et al. 2012).

U.S. Forest Service/Ignacio Peralta

Residents of New Mexico's Taos Pueblo watch the 2003 Encebado fire. Vulnerability to wildfires can be high where wildlands and urban environments meet.

Both Positive and Negative Ecological Effects

Large, severe fires can have lasting harmful effects on both ecosystems and human communities. Colorado's largest recent fire, the Hayman fire of June 2002, occurred during an exceptionally dry period. The fire was intense enough to destroy all surface litter and the organic matter in the top layer of the soil (USFS 2003). Severely burned areas are subject to much more erosion, and storms have eroded enormous quantities of sediment into a reservoir used by Denver Water, Colorado's largest water supplier (Moriarty and Cheng 2012). Denver Water has spent $25 million to protect water supplies from this erosion (Miller and Yates 2006).

But even large wildfires can have positive effects. The extensive Yellowstone fires of 1988 are a memorable example. In that year—the driest on record for the region—multiple fires burned 1.2 million acres including 36 percent of the national park, destroying 67 buildings and disrupting thousands of vacations (Yellowstone National Park n.d.; Romme et al. 2011; Yellowstone National Park 2008). These were among the first large, severe western wildfires in recent years, so scientists were unsure what the ecosystem effects would be (Romme et al. 2011). Within 20 years, the mix of tree species in forests largely resembled the pre-fire mix (McWethy et al. 2013; Romme et al. 2011). However, instead of widespread conifers (mostly lodgepole pines) more than 150 years old, the park now has mixed-age stands of trees. These are more resilient in the face of disturbances such as bark beetle infestations and large wildfires (Schoennagel, Smithwick, and Turner 2008). Scientists now see the Yellowstone fire as evidence that, in the right context, large, severe fires are not ecological catastrophes but powerful natural shapers of ecosystems (Romme et al. 2011).

As the Rocky Mountains become hotter and drier, the risks to the region's forests from larger, more intense, and more frequent wildfires will grow, posing greater risks to communities.

BOX 1.

The Human Costs of Wildfire

Recent increases in western wildfires have exerted their most significant effects on people—especially because more now live in or adjacent to forests and woodlands, where they and their property are vulnerable. Across the nation, 32 percent of all housing sits in the wildland-urban interface, where vulnerability to wildfires is high (Stein et al. 2013).

In the six Rocky Mountain states, some 5.1 million acres—about the size of New Jersey—is in this vulnerable zone. One-eighth of this land area has been developed, with structures including some 253,000 homes (Headwaters Economics 2013). With population in these states projected to rise by 35 percent from 2000 to 2030, risks to humans and property from wildfires will grow (U.S. Census Bureau 2014).

In the Rocky Mountain foothills along Colorado's urbanized Front Range corridor, the number of structures burned and the loss of insured property have set state records in three of the past four seasons. The 2013 Black Forest fire near Colorado Springs—which burned 486 homes and caused $293 million in losses—set the latest record (RMIIA n.d.).

Wildfires take a toll in human lives too. More than 300 firefighters have died battling wildfires in the interior West since 1910, including 19 who lost their lives in Arizona's Yarnell Hill fire in 2013 (Calkin et al. 2014; National Interagency Fire Center n.d.).

Wildfires can also undermine air quality and human health while they are burning, as shown by studies beyond the Rocky Mountain region. Wildfire smoke includes particulate matter—one of the main pollutants causing respiratory problems (Wegesser, Pinterton, and Last 2009). Wildfire smoke can also degrade air quality as far as 500 miles away, putting more people at risk (Sapkota et al. 2005).

© Flickr/Linda_Bisset

Colorado broke state records for number of structures burned (such as this home in Fourmile Canyon) and insured property losses in three of the past four wildfire seasons.

What's more, firefighting drains tax dollars and diverts resources from other missions. The annual wildfire budgets for the U.S. Department of Interior and the U.S. Forest Service rose from an average of $1.39 billion a year in the 1990s to $3.51 billion a year from 2002 to 2012.

And wildfires can severely compromise wildlife habitat, recreational values, and other ecosystem services for many years. The largest recorded fire in the Sierra Nevada's history, the 2013 Rim Fire in and around Yosemite National Park, cost an estimated $100 million to $736 million in such losses (Batker et al. 2013).[4]

© Flickr/arbyreed

Firefighting costs drain tax dollars and divert resources from other missions.

4 For more information, see Cleetus and Mulik 2014.

What Scientists Project Will Happen

Based on climate changes projected for the West (see Chapter 6), scientists expect large, intense, more frequent fires to affect the region's forests (Joyce et al. 2014). Analysts project that a temperature increase of just 1.8°F will lead to several serious effects, compared with 1950–2003 averages (Figure 4, p. 18) (NRC 2011; Littell et al. 2009):[5]

- A 241 percent increase in acreage burned in the northern Rockies
- A 515 percent increase in acreage burned in the central Rockies
- A 656 percent increase in acreage burned in the southern Rockies
- A 470 percent increase in acreage burned in the Arizona and New Mexico foothills of the Rockies and related areas

Other scientists project that, under a medium-high scenario for heat-trapping emissions, fire seasons comparable to 1988 could occur in the Greater Yellowstone Ecosystem one to five times by 2050.[6] By 2075, the area burned *every year* would regularly exceed that from the 1988 event—except that wildfires and other effects of climate change would likely have so transformed the region's forests that modeling based on the historic climate-fire relationship would no longer apply. By then, the types of forests now found at lower elevations and more southern locations, shrublands, or grasslands would probably have replaced the conifer species that have long dominated Yellowstone forests (Westerling et al. 2011). Comparable changes in other forest communities might also make other long-term wildfire projections less reliable (NRC 2011; Flannigan et al. 2009).

[The West had nearly four times as many large wildfires during the period 1987 to 2003 compared with 1970 to 1986.]

© Amy Guth

In the Yellowstone area, 1.2 million acres burned in 1988, including 36 percent of the national park. Comparable fire seasons could occur one to five times by 2050.

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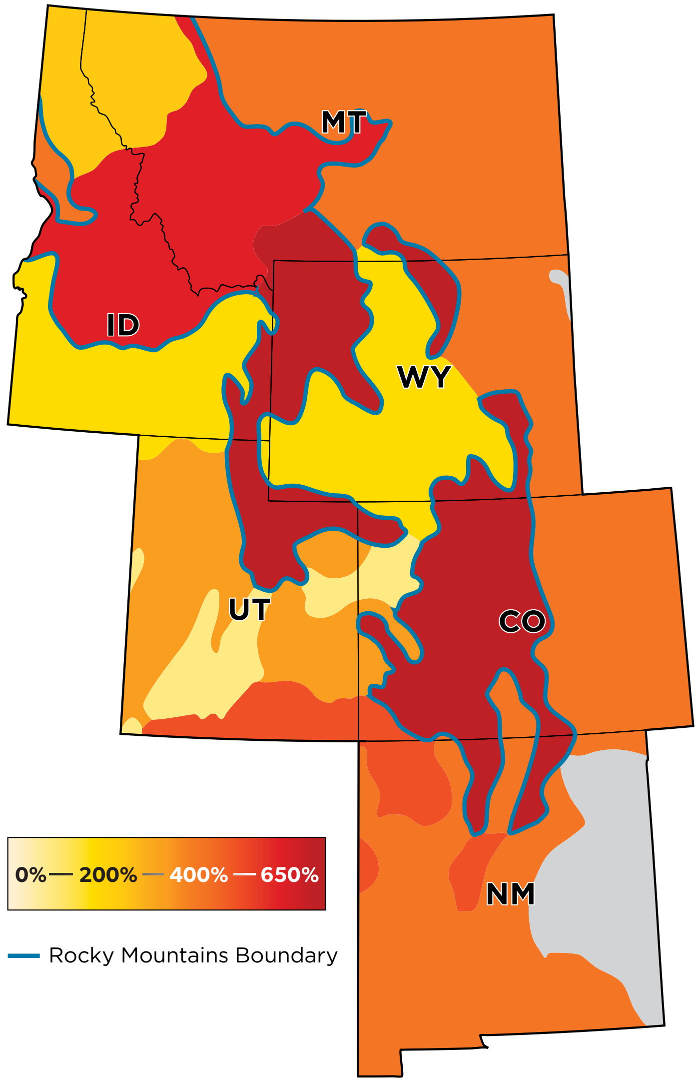
5 The regions described in NRC 2011 and Littell et al. 2009 are defined differently than those defined on p. 7 of this report.
6 This study used the IPCC's A2 medium-high emissions scenario.

FIGURE 4. Projected Changes in Average Area Burned with a 1.8°F Rise in Average Temperature



Scientists project that a temperature increase of just 1.8°F will lead to marked increases in acreage burned by wildfires in the West. The figure shows the projected percentage increase in burned area, compared with the 1950–2003 average, for different ecological regions of the West, including the Rocky Mountains. (Grey indicates areas with insufficient data for making projections.)

SOURCES: ADAPTED FROM NRC 2011 AND LITTELL ET AL. 2009.

[CHAPTER 4]

Impacts of Heat and Dryness on Forests

- Tree die-offs of many species are increasing because of stress from drought.
- Rising temperatures, drier conditions, and more severe droughts owing to climate change are projected to kill more trees and lead to large-scale changes in the extent and types of forests in the region.

[Projections suggest that further climate changes could drive fundamental changes in the extent and nature of Rocky Mountain forests.]

Scientists have documented rising tree mortality in the Rocky Mountains. Factors affecting tree deaths—including drought, water stress, higher temperatures, insects, and

Bureau of Land Management, CA/Bob Wick

Grasslands like these in New Mexico's Continental Divide Wilderness Study Area, along with shrublands and other non-forest ecosystems, could replace some forests, especially in the southernmost Rocky Mountains.

diseases—are often related, so identifying a single cause is difficult. However, scientists have linked higher rates of tree mortality in western forests to both rising temperatures and the trees' greater demand for water. Scientists consider western forests to be more vulnerable than eastern forests to further warming (Joyce et al. 2014).

What Is Already Happening

Tree mortality in relatively undisturbed old-growth forests across the West has risen even when not triggered by wildfires or insect infestations. Long-term monitoring of 76 sites in old-growth, undisturbed forests showed that mortality rates of trees of all types and ages had doubled in recent decades, with no compensating increase in the number of tree seedlings. And more trees have died in more recent years (van Mantgem et al. 2009).

For example, tree mortality in the Southwest has been more extreme and more widespread since 1980 than during any other period in nearly a century of clear documentation—including the 1950s, a time of major drought (Williams et al. 2010). Scientists suggest that hotter and drier conditions across the West are causing these effects (Williams et al. 2010; van Mantgem et al. 2009).

What Scientists Project Will Happen

Projected increases in both average temperatures and extreme events could bring more forest disturbances and tree deaths. In particular, scientists have high confidence that higher temperatures will accompany future droughts—a combination that can trigger more tree mortality than droughts alone (Joyce et al. 2014).

Recent modeling shows that the extent of western forests could change dramatically in response to changing temperature and precipitation patterns if heat-trapping emissions continue unchecked (Rehfeldt et al. 2012). The U.S. Forest Service has projected changes in the distribution of dozens of types of trees in the West, based on the conditions in which they need to survive and how climate change may alter where those conditions occur. Although all such projections have inherent uncertainty, the projections suggest future declines in the ranges of many of the most important and widespread species in the Rocky Mountains, with major declines if climate change continues unchecked (USFS Moscow Lab 2014).[7] For instance, the areas projected to be climatically suitable for lodgepole pines, ponderosa pines, Engelmann spruce, and Douglas fir are much smaller in 2060 than they are today, with projected net declines ranging from 58 percent to 90 percent of the current suitability (Figure 5/Table 1). The pervasive impacts across multiple species suggest that the overall extent of forests in the Rocky Mountains could decline.

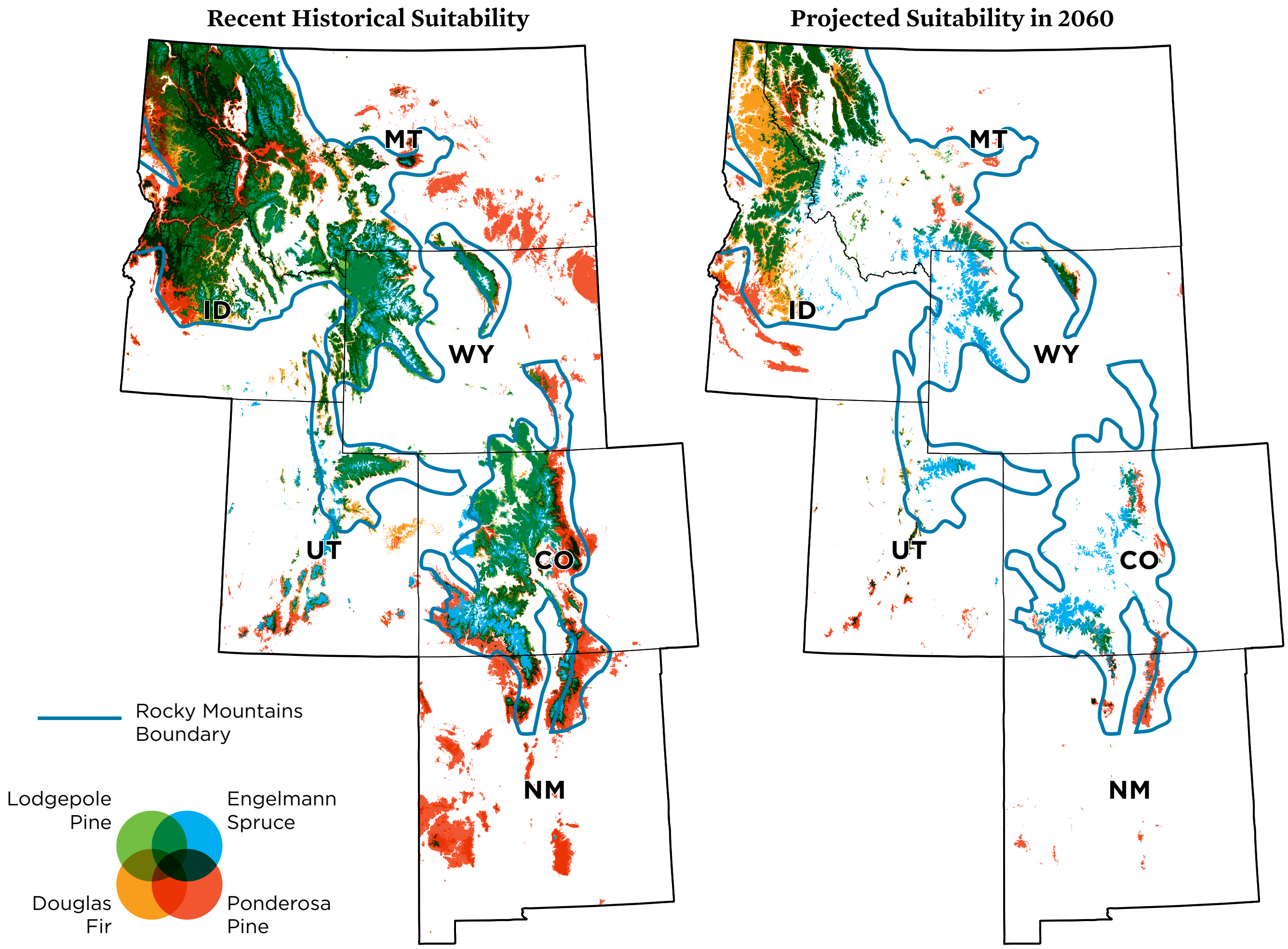
Other scientists have made similar projections. According to one study, also assuming medium-high levels of future emissions, conifer forests are projected to shrink by half, from 24 percent of the West's land cover in 2005 to 11 percent by 2100.[8] The Southwest in particular is projected to lose nearly all its conifer forests. Shrublands and grasslands would largely replace the conifer forests, expanding from 11 percent to 25 percent of land cover in the West. These changes could occur rapidly and should begin to become evident around 2030, when average western temperatures reach about 1.6°F above late-twentieth-century levels—or 0.6°F of further warming (Jiang et al. 2013).

These projections indicate only the possible scale of changes, given the complexity of predicting highly localized climate conditions and trees' response to multiple stresses (Allen et al. 2010).[9] Modeled climate suitability indicates how closely the climate conditions will match the species' requirements, not the actual occurrence of the species.

[Tree mortality in relatively undisturbed old-growth forests across the West has risen even when not triggered by wildfires or insect infestations.]

7 For this report, the authors obtained data from the U.S. Forest Service on these projections for four key species characteristic of the conifer forests that dominate in the Rocky Mountains: lodgepole pines, ponderosa pines, Engelmann spruce, and Douglas fir.
8 This study used the IPCC's A2 medium-high emissions scenario.
9 In another study, for example, 41 percent of the Greater Yellowstone region was identified as climatically suitable for aspens. However, they cover only 1.4 percent of that area, presumably because of competition from other trees and plants, limits on the dispersal of aspen seeds, and other factors (Brown et al. 2006).

FIGURE 5 AND TABLE 1. Projected Changes in Suitable Ranges for Key Rocky Mountain Tree Species

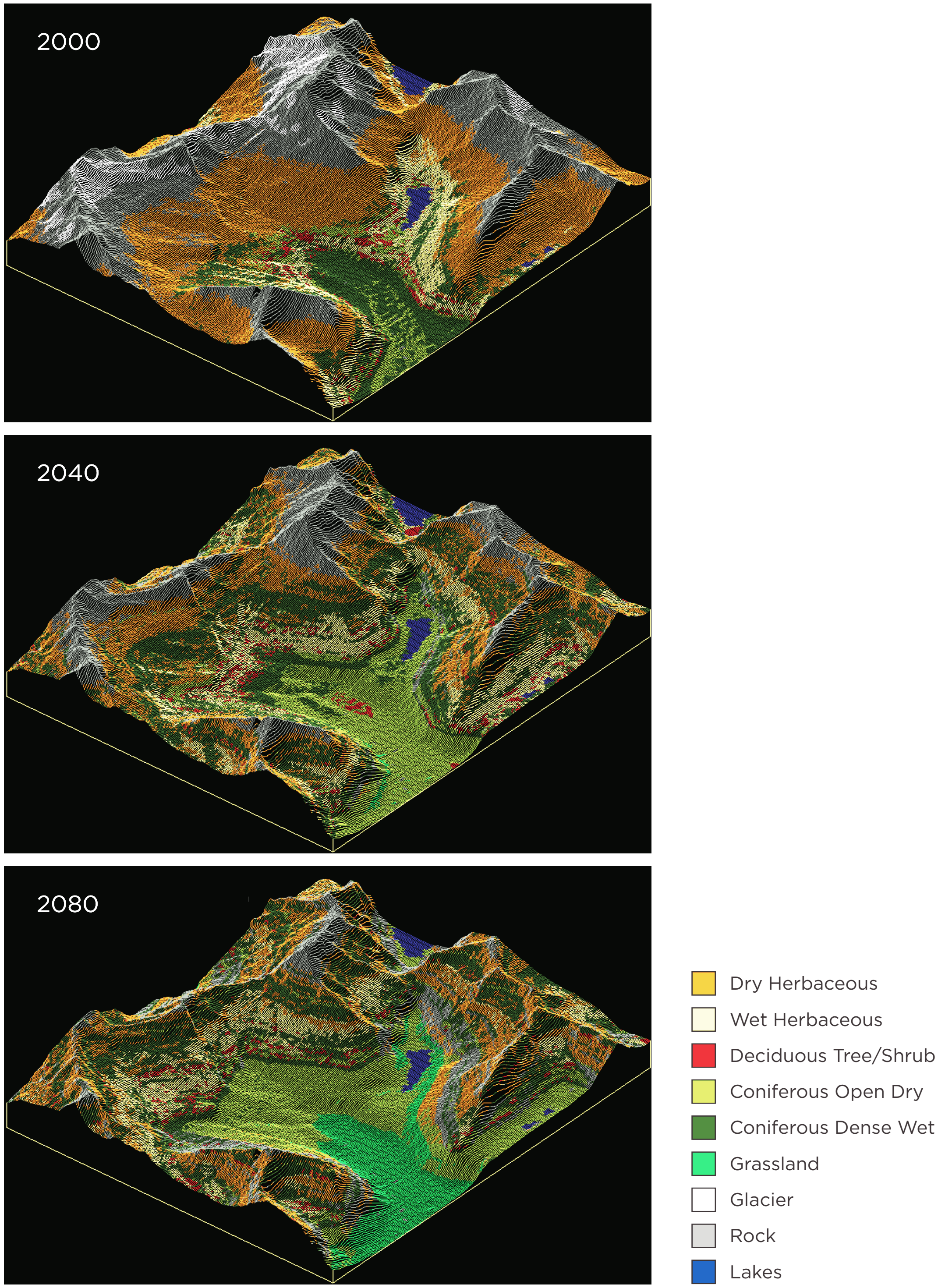


Species	Current	2060		
	Recent Historical Suitability (acres)	Projected Suitability (acres)	Net Change in Suitability (acres)	Percent Net Change
Lodgepole Pine	60,474,000	6,065,000	-54,409,000	-90%
Ponderosa Pine	39,842,000	7,771,000	-32,071,000	-80%
Engelmann Spruce	64,651,000	21,999,000	-42,652,000	-66%
Douglas Fir	53,620,000	22,606,000	-31,014,000	-58%

Much of the current range of these four widespread Rocky Mountain conifer species is projected to become climatically unsuitable for them by 2060 if emissions of heat-trapping gases continue to rise. The map on the left shows areas projected to be climatically suitable for these tree species under the recent historical (1961–1990) climate; the map on the right depicts conditions projected for 2060 given medium-high levels of heat-trapping emissions. Areas in color have at least a 50 percent likelihood of being climatically suitable according to the models, which did not address other factors that affect where species occur (e.g., soil types). Emissions levels reflect the A2 scenario of the Intergovernmental Panel on Climate Change. For more about this methodology, see www.ucsusa.org/forestannex.

SOURCE: UCS ANALYSIS OF PROJECTIONS FROM USFS MOSCOW LAB 2014; MAP BASED ON USFS N.D.

FIGURE 6. Projected Changes in Plant Communities in Blackfoot-Jackson Basin, Glacier National Park, 2000–2080



A combination of climate and vegetation models projects major changes in plant cover in one basin in Glacier National Park over the next several decades if climate change continues unabated. The area now covered by forests of all types is projected to decline after the middle of the century, replaced partly by grasslands, which are not now present.

SOURCE: NORTHERN ROCKY MOUNTAIN SCIENCE CENTER N.D., BASED ON HALL AND FAGRE 2003.

Although modelers have made major efforts to develop and improve their models of the locations of plant communities, further study of the future ranges of tree species and forest ecosystems is needed (Jiang et al. 2013; Anderegg et al. 2012; Rehfeldt et al. 2012; Stephenson et al. 2011; McDowell et al. 2008). Still, these projections suggest that further climate changes could drive fundamental changes in the extent and nature of Rocky Mountain forests.

Scientists also project that earlier snowmelt and less spring snow cover—driven by higher temperatures—will create new water stresses, with earlier snowmelt leading to declining forest health in the northern Rocky Mountains. One study shows that even with a medium level of future heat-trapping emissions, forested sites in Glacier National Park in Montana will experience peak snowpack some 40 days earlier by the end of this century.[10] Late-summer dryness would last six to eight weeks longer, and water stress among forests in Yellowstone National Park and Glacier National Park would become common. Other forests across the Northern Rockies would also face more stress from water shortages, leading to a substantial decline in forest health across the region (Boisvenue and Running 2010).

Forests in and around the southernmost Rocky Mountains—mostly piñon-junipers—will see "substantially reduced growth during this century." With "only two more recurrences of droughts and die-offs similar or worse than the recent events," grasslands, shrublands, and other non-forest ecosystems could replace more than half of the forests (Williams et al. 2010).

Extreme drought-driven forest stress occurred in the Southwest during four of the years from 2000 to 2012, and projections under a medium-high scenario for heat-trapping emissions suggest that these conditions could become much more common (Williams et al. 2013). Extreme drought-driven stress in the Southwest is expected to occur in 59 percent of the years of this century—and 80 percent of those in the second half of the century (Williams et al. 2013). If that does occur, the ability of trees to regenerate after beetle outbreaks and wildfires could be low, leading to long-term reductions in the extent of southwestern forests.

For example, a study modeling changes in one basin in Glacier National Park predicts a dramatic transformation of forests in this iconic park if climate change continues unabated. Scientists project that higher summer temperatures and lower soil moisture will mean that alpine tundra plants will inhabit areas now covered by glaciers, forests will colonize upslope areas, and grasslands will move into the basin (Figure 6). The area now covered by forests of all types will decline after the middle of the century, replaced partly by grasslands, which are not now present (Hall and Fagre 2003).

Projections suggest future declines in the ranges of many of the most important and widespread species in the Rocky Mountains, with major declines if climate change continues unchecked.

10 This study used the IPCC's A1B medium emissions scenario.

Effects on Iconic Tree Species of the Rocky Mountains

- Whitebark pines—a keystone species that provides food and habitat for many other species and reforests harsh, high-elevation areas after fires and avalanches—are declining dramatically because of disease, severe insect outbreaks, and changing fire conditions. Further climate change is projected to greatly reduce the amount of suitable habitat for whitebark pines, and the species could disappear from Rocky Mountain states.
- Extreme drought that peaked in 2002 led to severe and widespread mortality among quaking aspens across much of the Rocky Mountains. Higher temperatures and more drought stress from continued climate change could eliminate this iconic and ecologically important species from much of its current range.
- Piñon pines—which have strong cultural significance and play important roles in local climate and hydrology—have suffered a massive die-off, triggered by the early-twenty-first-century drought and exceptional heat. Scientists project the loss of piñon pines throughout much of their existing range, given continued climate change.

High-elevation pine species in the Rocky Mountains, including whitebark pines, bristlecone pines, and this limber pine in Grand Teton National Park, face threats from climate change.

Climate change already under way in Rocky Mountain forests has exerted widespread effects on three key tree species: whitebark pines in the Northern Rockies, aspens in the Southern Rockies, and piñon pines in the southernmost Rockies and the surrounding areas.

Whitebark Pines

Whitebark pines (*Pinus albicaulis*)—iconic trees of the cold, dry, windswept subalpine slopes of the Northern Rockies—are in catastrophic decline throughout their range in western North America. Whitebark pines are one of a group of five-needled pines—including limber pine (*Pinus flexilis*) and bristlecone pine (*Pinus aristata*)—that grow in high mountain habitats. Majestic and slow-growing, whitebark pines can live for more than 1,000 years.

Whitebark pines are a keystone species: they provide critical support for many other species in high-elevation forest communities (Tomback et al. 2001). For example, the fat-packed, highly nutritious seeds of the whitebark pine are an important food source for wildlife, including grizzly bears (see Box 2) (Mattson, Blanchard, and Knight 1991).

BOX 2.

Young Scientists Help Answer Questions about a Pine Beetle Outbreak

In summer 2013, graduate students Emily Francis and Maxim Grigri hiked the remote, high-elevation whitebark pine forests of the Greater Yellowstone Ecosystem, tracking the mountain pine beetle. The graduate students were following up on a 2009 aerial survey that had uncovered what appeared to be a consistent, counterintuitive pattern of tree deaths occurring first in mid-elevation whitebark forests, rather than progressing from lower elevations upward (Macfarlane, Logan, and Kern 2013).

Remote sensing cannot perform some important measures of forest conditions. So to confirm this observation, researchers Wally Macfarlane and Jesse Logan stratified 150 randomly selected plots across the Beartooth Plateau and West Beartooth (Absaroka) mountains by high, intermediate, and low effects from mountain pine beetles, as revealed by the aerial survey.

Making several multiday forays into extremely remote areas, Francis and Grigri found chronic, sub-outbreak mortality in nearly half the 113 plots they surveyed. Their findings suggest a potentially new disturbance regime: chronic low levels of tree deaths year after year, with a cumulative effect equivalent to that from severe beetle outbreaks in the early 2000s.

© UCS/Adam Markham

In 2013, researchers conducting a ground survey confirmed extensive mortality of whitebark pines across 150 sites within the Greater Yellowstone Ecosystem. Pictured from left to right are Jesse Logan, Wally Macfarlane, Max Grigri, and Emily Francis.

The infestation now seems to be subsiding, Logan says, because "there are simply not enough living trees left to maintain an outbreak population. In many of the hardest-hit areas, it is difficult to find a living cone-bearing tree."

The graduate students also found substantial blister rust infection, particularly among young trees. Logan characterizes this as "an old and sadly repeated story: beetles get the big trees, blister rust the little ones."

The startling state of the forest impressed the students the most. "There were times when we looked around an entire valley from a high point, and would see whole mountainsides covered in gray trees," Grigri recalls. Says Francis, "It's pretty clear that the rate of disturbance cannot be sustained for more than a few decades. What struck me is that, even in a place humans hardly ever see, rapid changes are taking place as a result of human activities occurring all over the world."

© Wally Macfarlane

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

WHAT IS ALREADY HAPPENING

Whitebark pines are in "substantial and pervasive decline throughout almost the entire range of the species," according to the U.S. Fish and Wildlife Service (USFWS 2011). One reason is white pine blister rust, which is caused by a non-native fungus (*Cronartium ribicola*) (Six and Newcombe 2005). Introduced to the Northwest from Asia around 1910, this blister rust has devastated whitebark pines, especially in the Pacific Northwest, southern Canada, and parts of the Northern Rockies, including Glacier National Park. Mortality in some of these forests has reached 90 percent to 100 percent (Tomback et al. 2011). Even if blister rust does not kill the trees, infections in the canopy severely reduce or curtail cone production (Smith et al. 2008).

A severe and widespread outbreak of mountain pine beetles in the last 15 years is the cause of whitebark pine mortality most clearly driven by a changing climate. Such serious outbreaks have occurred before—notably in the 1930s, and again in the 1970s and 1980s (Tomback et al. 2011). The 1930s outbreak was linked to unusually warm temperatures, especially during the winter of 1933–1934—the warmest on record in the Greater Yellowstone Ecosystem. However, those outbreaks died out after temperatures returned to historical ranges (Logan, MacFarlane, and Willcox 2010).

The more recent outbreak has been different. A sustained warming trend has brought winter temperatures mild enough to allow mountain pine beetles to overwinter. Hotter and longer summers are also allowing them to complete an entire life cycle in one year. Those two conditions—both essential for severe beetle outbreaks in whitebark pine forests—have now become common (Six, Biber, and Long 2014; Logan, MacFarlane, and Willcox 2010). Unlike other pines, whitebark pines have not yet evolved a chemical defense against these infestations. Lodgepole pines, for example, produce resin to immobilize or expel beetles, as well as chemicals that are toxic to the insects. However, these defenses are weak and usually ineffective in whitebark pines, so outbreaks can grow quickly (Raffa et al. 2012; Logan, MacFarlane, and Willcox 2010).

Recent infestations are driving beetle damage to whitebark forests well beyond historical levels. Beetles have

U.S. Forest Service/Richard Sniezko

Whitebark pines are iconic trees of the cold, dry, windswept subalpine slopes of the Northern Rockies.

killed many whitebark pines hundreds of years old—some more than 1,000 years old. Milder winters and warmer summers allow beetles to sustain more prolonged attacks on high-elevation whitebark pine forests in the Rockies, and decades of fire suppression and a hotter, drier climate have worsened the threat (USFWS 2011; Raffa 2008). These beetles have even become a major problem in Canada—the northerly range of the whitebark pine (Six, Biber, and Long 2014).

Extreme cold in the winter of 2008–2009 prompted some observers to assume that these outbreaks of mountain pine beetles had finally begun to subside. A record cold snap in early October 2009—when temperatures of -20°F were common across the Greater Yellowstone Ecosystem—may have temporarily slowed progression of the outbreak there (Logan 2011). However, field research revealed that beetle populations persisted through the winter of 2013, and are still at outbreak levels in some areas, and at sub-outbreak levels in others (see Box 3).

If the upward temperature trend continues, the availability of suitable hosts will be the only brake on mountain pine

[Higher temperatures and more drought stress from continued climate change could eliminate whitebark pine—an iconic and ecologically important species—from much of its current range.]

BOX 3.

Why Whitebark Pines Matter

© UCS/Adam Markham

The seeds of whitebark pines are among the largest pine nuts.

For high-country wilderness enthusiasts, whitebark pines define the subalpine forest and ridgelines of the Northern Rockies. They also provide essential ecological services, providing food for wildlife and sustaining water supplies.

Food source for wildlife. Whitebark seeds—among the largest pine nuts—provide a high-energy food for many species. For example, the seeds can be one of the most important foods for grizzly bears in the Greater Yellowstone Ecosystem before they hibernate. In years with abundant cone production, whitebark pine seeds can account for 50 percent to 80 percent of bear scat in the fall (IGBST 2013).

Scientists have linked lower production of whitebark pine nuts to lower birth rates among grizzlies, lower over-winter survival rates, and more conflicts with humans as bears search for other food (IGBST 2013; Gunther et al. 2010; Gunther et al. 2004). The drastic decline in whitebark pine was the primary reason a U.S. Court of Appeals blocked an effort by the U.S. Fish and Wildlife Service to remove Yellowstone-area grizzlies from the endangered species list. A later federal interagency review concluded that the region's grizzly bears can survive the decline of the whitebark, but controversy over that finding continues (IGBST 2013).

Whitebark pines also provide food for Clark's nutcrackers, and depend on them to disperse the seeds (Hutchins and Lanner 1982). A large bird from the crow family, Clark's nutcrackers harvest the seeds and bury them in caches that average three to five seeds each (Tomback et al. 2011). The seeds left over in these caches are the primary source of new trees (Lanner 1996). Although nutcrackers sometimes cache seeds close to a source tree, the birds have been shown to carry the seeds more than 19 miles (Lorenz and Sullivan 2009). This long-distance dispersal enables white-bark pines to recolonize disturbed areas.

Pine squirrels compete with nutcrackers to harvest whitebark cones, storing large quantities in middens beneath the trees. Black bears and grizzly bears then raid the squirrel middens.

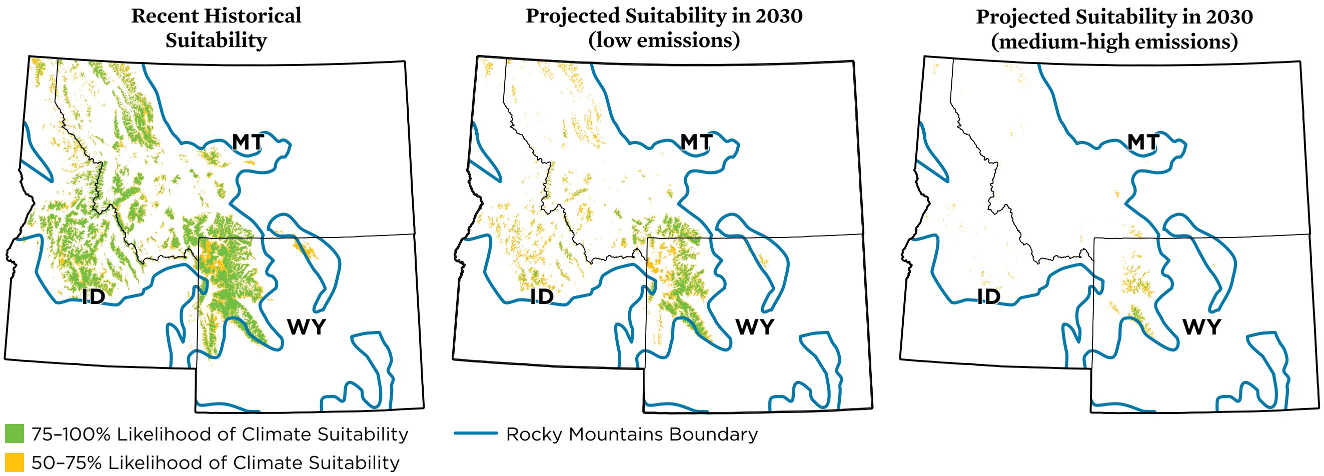
Water regulation. Most water in the major rivers with headwaters in the Rocky Mountains begins as winter snowfall. Whitebark forests on the high ridgelines act as snow fences, protecting the winter accumulation of snow from winds. With their wide-spreading crowns shading the snow, the pines also slow snowmelt in the spring, reducing the risk of flooding, sustaining higher stream levels into early summer, and curbing soil erosion (Tomback, Arno, and Keane 2001). In fact, the very presence of whitebark pines—rooted in rocky, windswept areas with poor soils—plays a significant role in preventing soil loss.

Given the many ecological services whitebark forests provide, the loss of this keystone species would produce cascading effects from the highest mountains to the valleys and rivers below.

© Frank D. Lospalluto

Clark's nutcrackers store the seeds of whitebark pines and help the species spread into new areas.

FIGURE 7. Modeled Suitable Range for Whitebark Pines—Today and under Two Climate Scenarios



Climate change is projected to greatly reduce the amount of western land suitable for whitebark pines. These maps depict areas modeled to be climatically suitable for the tree species under the recent historical (1961–1990) climate (left), conditions projected for 2030 given lower levels of heat-trapping emissions (center), and conditions projected for 2030 given medium-high levels of emissions (right). Areas in yellow have a 50–75 percent likelihood of being climatically suitable according to the models; areas in green have more than a 75 percent likelihood. These models do not address other factors that affect where species occur, such as soil types. (The two future emissions levels are the B1 and A2 scenarios of the Intergovernmental Panel on Climate Change, respectively.)

SOURCES: BASED ON USFS MOSCOW LAB 2014 AND USFS N.D. C.

beetle populations. If insects, disease, and fire suppression continue to build off each other, the keystone species of high-elevation forest ecosystems could disappear from the Rocky Mountains (Tomback et al. 2011; USFWS 2011; Logan et al. 2003; Tomback and Kendall 2001).

WHAT SCIENTISTS PROJECT WILL HAPPEN

Based on the significant decline already under way, and the fact that climate models show that suitable habitat will severely shrink, the U.S. Fish and Wildlife Service has concluded that whitebark pines appear "likely to be in danger of extinction, or likely to become so within the foreseeable future." The agency therefore determined that the trees qualify for listing under the Endangered Species Act (USFWS 2011). The same combination of blister rust, mountain pine beetle infestation, and climate change prompted the Canadian government to list whitebark pine as endangered in 2012 (SARPR 2012).

Because whitebark pines are already found at high elevations and little suitable habitat is available upslope, their ability to move to higher elevations as the climate continues to warm is limited. The whitebark pine's extended reproduction period also limits its adaptive capacity. Slow-growing and long-lived, the pine takes at least 60 years to go from seedling to mature, cone-bearing tree. And the mountain pine beetle epidemic and blister rust have killed so many of the most productive mature trees that a lack of seed severely limits their ability to regenerate—in place or in new habitat.

Scientists from the U.S. Forest Service expect the areas suitable for whitebarks to shrink drastically, especially if heat-trapping emissions continue unchecked (Figure 7) (USFS Moscow Lab 2014).

As noted, even if models show that an area has a suitable climate, a species may or may not occur there.[11] And Forest Service projections do not factor in other potential losses from mountain pine beetles or blister rust, or the species' declining ability to spread their seeds.

Despite all these stresses, remnant populations of whitebark pines will likely remain in mixed-conifer forests for the foreseeable future. However, our grandchildren may no longer experience the mature whitebark pine forests that now help define the charismatic Rocky Mountain landscape.

11 For example, a modeling study showed that 41 percent of the Greater Yellowstone region is now suitable for aspens. However, they cover only 1.4 percent of that area—presumably because of competition from other trees and plants, limits on the dispersal of aspen seeds, and other factors (Brown et al. 2006).

Aspens

Quaking aspens (*Populus tremuloides*) have seen abrupt and extensive mortality across large areas of their range (Guyon and Hoffman 2011; Rehfeldt, Ferguson, and Crookston 2009; Fairweather, Geils, and Manthei 2008; Hogg, Brandt, and Michaelian 2008; Worrall et al. 2008). Some scientists call this severe phenomenon "sudden aspen decline," to distinguish it from normal levels of tree deaths (see Box 4, p. 30).

Scientists have linked this widespread mortality to stress from heat and drought. This suggests that aspen dieback will continue or accelerate if, as expected, the climate becomes even hotter and drier. Scientists are now monitoring the affected areas to determine if aspen populations will recover, or if the stresses mean that this species will play a greatly diminished role in these landscapes.

WHAT IS ALREADY HAPPENING

Localized die-offs of mature aspen stands are not uncommon (Frey et al. 2004). Evidence from tree rings, as well as genetic differences among aspen populations, point to major droughts and die-offs earlier in their ecological history (Callahan et al. 2013; Hogg, Brandt, and Kochtubajda 2001).

In 2002, however, scientists began seeing extreme declines that differed from typical declines in two important ways. First, they rapidly affected entire landscapes (Worrall et al. 2010). Second, the death of mature aspens has not spurred the normal surge in new shoots (Zegler et al. 2012; Worrall et al. 2010).

The sudden onset and rapid progress of aspen die-off occurred during the worst year of the unusually hot and severe drought in the Rocky Mountain region at the turn of this century (see Chapter 6). Scientists first noticed extreme declines in aspen in northern Arizona and Utah, and later in southwestern Colorado (Morelli and Carr 2011). They then documented mortality throughout much of the Rocky Mountain region and western Canada (Michaelian et al. 2011; Hogg, Brandt, and Michaelian 2008).

Aspens were dying at startlingly high rates in these locations. In Coconino National Forest in Arizona, the U.S. Forest Service found sites with aspen mortality as high as 95 percent (Fairweather, Geils, and Manthei 2008). Another study found that 85 percent of aspens in mixed-conifer forests in the same region died from 1997 to 2007 (Ganey and Vojta 2011). In southwestern Colorado, mortality rates of 7 percent to 9 percent in sample sites in 2002 and 2003 had surged to 31 percent to 60 percent by 2006 (Worrall et al. 2008). Multiple lines of evidence link these die-offs to locally severe heat and dryness (Anderegg et al. 2013a; Marchetti et al. 2011; Worrall et al. 2010; Rehfeldt et al. 2009).

In the Southern Rockies—the most affected region—aspens declined throughout 1.3 million acres from 2000 to 2010, with about 92 percent of those acres in Colorado (Worrall

Quaking aspens, like these in Colorado's White River National Forest, have seen abrupt and extensive mortality across large areas of their range.

et al. 2013). The most recent evidence from western Colorado confirms that aspen regeneration rates remain unusually low. In the Grand Mesa and Uncompahgre National Forests, surveys in 2013 revealed that affected stands had even lower rates of new shoots than in 2007 and 2008 (Worrall et al. 2014). Without the normal surge in sprouting after the death of mature trees, the recovery of the affected stands is in question.

CAUSES OF ASPEN DECLINE

Robust evidence shows that the extreme multiyear drought that peaked in 2002 largely drove the aspen die-off in much of the West (Anderegg et al. 2013a; Worrall et al. 2013; Marchetti, Worrall, and Eager 2011; Worrall et al. 2010; Rehfeldt, Ferguson, and Crookston 2009). Although they occur widely, aspens are limited to areas with enough precipitation (Morelli and Carr

BOX 4.

Why Aspens Matter

With shimmering leaves that flutter in the slightest breeze—hence the name quaking aspens—aspens have been called America's liveliest trees. Their light green leaves and white bark provide a strong counterpoint to the dark backdrop of the conifers that are the other large trees in the Rocky Mountain region.

The iconic aspen is also the only deciduous tree that is widespread in the Rockies. It plays a uniquely beneficial role that includes sustaining wildlife, serving as a firebreak, boosting water yield from forests, and drawing tourists to view its autumn foliage (USFS n.d.a). Tourism is the second-largest industry in Colorado—the state with the most aspens—and they are a major annual draw (Worrall et al. 2014). During the recent aspen decline, leaders in the state's mountain communities expressed concern that a loss of aspen could reduce local income and jobs (Worrall et al. 2014).

Aspen stands support some of the richest diversity of plant and animal life in Rocky Mountain forests (Kuhn et al. 2011). Unlike conifers, aspens allow enough sunlight to reach the forest floor to support a vibrant understory of plants, including shrubs, grasses, and wildflowers. These abundant food sources support wildlife populations while also delighting hikers (USFS n.d.a). Litter from the aspens also adds organic matter to soil, prevents erosion, retains moisture, and creates a biologically rich environment (USFS n.d.a; Worrall et al. 2014).

Aspens and associated vegetation also provide grazing for domestic livestock as well as native species, particularly elk (USFS n.d.b). Beaver feed on them and use them to build their dams, expanding local wetlands and reshaping the landscape to the benefit of many species (USFS n.d.b). Birds are more abundant and diverse in aspen stands than in other forests at similar elevations, and many bird species—including woodpeckers, owls, and songbirds—depend on them for nesting habitat (RMBO n.d.; Turchi et al. 1995).

Aspens protect and nourish the surrounding forest by providing natural firebreaks and regulating the supply of water. Their moist, green leaves and thick twigs do not burn as easily as conifers. Crown fires running through coniferous forest are often interrupted and may quickly burn out when they encounter an aspen stand (USFS n.d.b). Aspen stands also accumulate more snowfall and consume less water than conifer stands, so they contribute more to downstream water supplies than other forested lands in the Rockies (Worrall et al. 2014; Morelli and Carr 2011).

Aspens rely on an unusual reproductive strategy: they often grow in a group, with an interconnected root network that distributes water and nutrients among a number of trees (De Byle 1964). An entire aspen stand is often actually a single organism with multiple trunks. When a single mature tree dies, many new shoots usually sprout from its roots (USFS n.d.a). This strategy may buffer the species against local disturbances.

Southern Utah is home to the largest and oldest aspen clone—a collection of genetically identical tree stems from a single network of roots. This incredible organism covers more than 100 acres, weighs 40 times as much as a blue whale (the largest animal ever to live on Earth), and is about 80,000 years old (USFS n.d.a).

Aspens add aesthetic, environmental, and economic value to the Rocky Mountain region.

U.S. Forest Service/Jim Worrall

The sudden onset and rapid progress of aspen die-off in the Rocky Mountain region at the turn of this century coincided with unusually hot and severe drought.

2011). Heat and dryness in summer—especially daily maximum temperatures and the amount of rainfall—appear to be the most important climatic factors affecting where aspens occur (Worrall et al. 2013; Rehfeldt, Ferguson, and Crookston 2009).

Some strategies that help aspens thrive during favorable conditions actually make them more vulnerable to drought. For example, their shallow, interconnected root system absorbs and distributes rain and melting snow. However, this feature makes aspens vulnerable to hot, dry conditions, which quickly dry out the top few inches of soil (Anderegg et al. 2013a). And drought-induced damage to an aspen's circulatory system often impairs its ability to absorb water and nutrients, making it more vulnerable during the next drought (Anderegg et al. 2013b).

In western Colorado—which has high concentrations of both aspens and recent aspen decline—summer 2002 brought the highest average temperature of any summer since 1895 (WRCC n.d.). Abundant evidence shows that the accompanying drought caused sudden and acute mortality among aspens in Colorado and Arizona (Huang and Anderegg 2012; Zegler et al. 2012; Fairweather, Geils, and Manthei 2008; Worrall et al. 2008). The drought extended to much of western North America and damaged many aspen stands, and mortality continued in later years (Hanna and Kulakowski 2012; Hogg, Brandt, and Michaelian 2008). The affected stands were usually in locations most vulnerable to high temperatures, such as lower elevations and south-facing and west-facing slopes in Colorado (Worrall et al. 2008).

Hotter and drier conditions are not the only factors affecting the health and extent of aspens in the Rockies. Diseases, insects, and browsing wildlife also contribute—often in ways that are difficult to separate from the effects of drought. Multiple stressors put pressure on a species, and when one of them worsens, it can push the species into decline. Drought, insects, and diseases also interact, amplifying the effect far beyond that from any single stressor.

The recent aspen decline provides evidence of such effects. For example, heat and drought stress in southwestern Colorado that peaked in 2002 made aspens more susceptible to a combination of insects and diseases and contributed to extensive aspen mortality—even though these agents do not normally kill aspens on their own (Marchetti, Worrall, and Eager 2011; Worrall et al. 2008).

Populations of elk and deer, which eat aspen twigs and shoots, and grazing by cattle and other livestock can greatly reduce aspen regeneration, preventing a stand's recovery (Kulakowski et al. 2013; Fairweather, Geils, and Manthei 2008). Multiple studies suggest that management of such herbivores can influence the extent to which aspens thrive (Rogers and Mittanck 2014; Kulakowski et al. 2013; Endress et al. 2012; Zegler et al. 2012).

Climate change can worsen the damage to aspens caused by browsing elk. In the Greater Yellowstone region and in northern Arizona, smaller snowpacks appear to lengthen the season in which elk browse in high-elevation forests, contributing to a smaller aspen population (Brodie et al. 2012; Martin and Maron 2012). With continued climate change, smaller snowpacks could increase the effects of elk browsing on aspens across the West.

WHAT SCIENTISTS PROJECT WILL HAPPEN

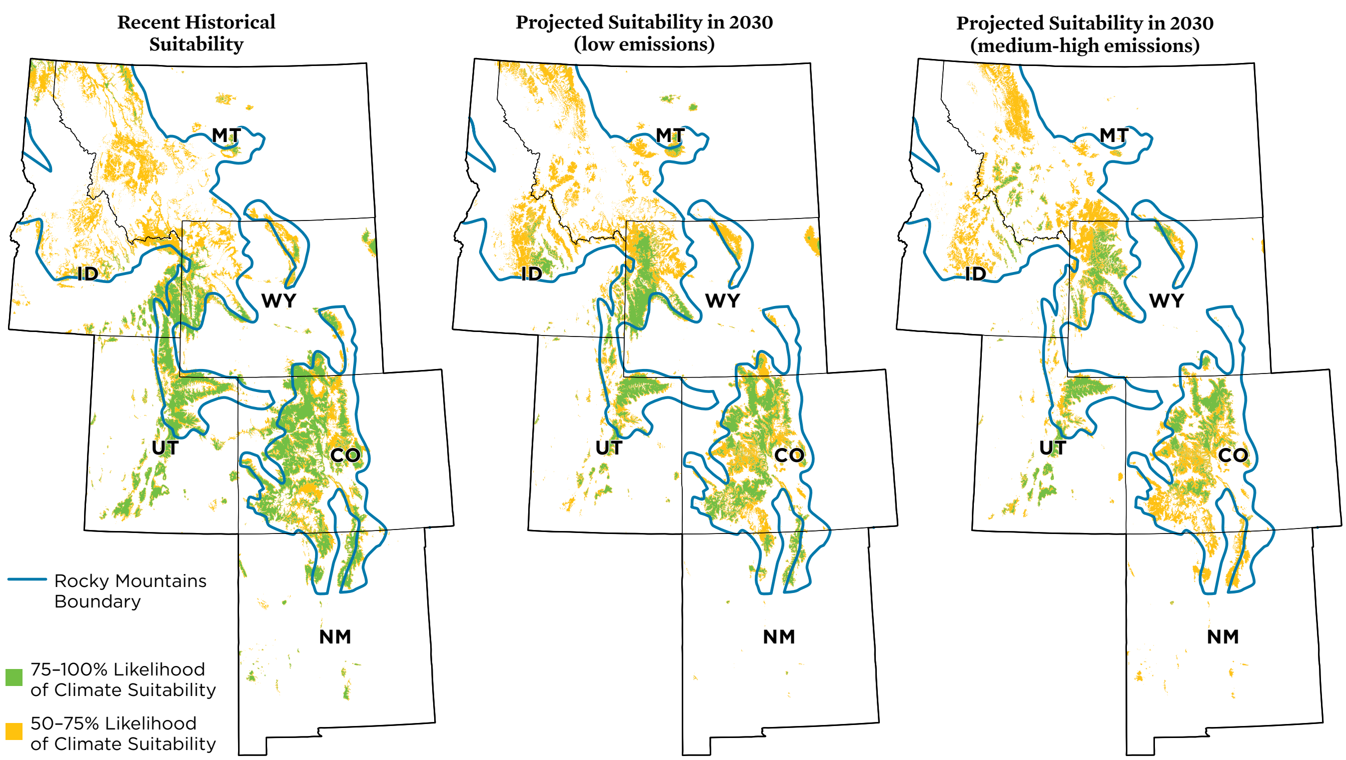
Despite these combined stresses, widespread, long-term aspen decline is not a foregone conclusion. Forest disturbances usually favor aspens, and a changing climate is already bringing more disturbances. Aspens could colonize areas after wildfires and beetle infestations, especially if people manage those areas to reduce other stressors (Pelz and Smith 2013). Still, intense browsing and other stresses may severely limit the ability of aspens to colonize new areas, while heat and drought stress will likely continue to cause mortality in their existing range (Kulakowski et al. 2013).

Links between the recent aspen decline and drought stress suggest that mortality in forests that are already nearly as dry as aspens can tolerate will be substantial as the climate gets hotter and drier. Some aspen subpopulations may be more resistant to drought, particularly in the southwestern portion of the species' range, but any adaptive characteristics might be lost if climate change pushes these subpopulations past their limits (Callahan et al. 2013). Expansion into new areas can compensate somewhat for the loss of existing stands (Worrall et al. 2013; Landhäusser, Deshaies, and Lieffers 2010); however, the overall effect could be a dramatic change in the location of aspen stands, and they could disappear from a significant portion of their existing range (Worrall et al. 2013; Rehfeldt, Ferguson, and Crookston 2009).

The U.S. Forest Service projects significant changes in the areas climatically suitable for aspens by 2030, under two different levels of heat-trapping emissions (Figure 8) (USFS Moscow Lab 2014).[12] A similar modeled projection suggests that by 2060 the U.S. Rocky Mountains could see about a 60 percent drop in land area suitable for aspens if future emissions continue to rise (Table 2) (Worrall et al. 2013). All such projections have inherent uncertainty (see Chapter 4), and there are a number of factors not explicitly addressed in the modeling (e.g., browsing by wildlife and livestock, non-forest land uses, insects, diseases) that could limit the ability of aspens to colonize new areas (Pelz and Smith 2013; Seager, Eisenberg, and St. Clair 2013; Hogg, Brandt, and Kochtubajda 2001). On the other hand, increased disturbances by wildfires and bark beetles could create opportunities for aspens to colonize new areas (Collins et al. 2011).

Another study shows substantial overlap between areas in western Colorado with recent aspen decline and areas that modeling shows have already become less climatically suitable (Worrall et al. 2014). This suggests that recent aspen declines might be the beginning of a climate-induced change in aspen populations, with aspens disappearing from some areas in the West (Figure 9, p. 34) (Worrall et al. 2014).

FIGURE 8. Modeled Suitable Range for Aspens—Today and under Two Climate Scenarios



The degree of climate change will affect the amount of western land suitable for aspens in 2030. These maps depict areas modeled to be climatically suitable for the species under the recent historical (1961–1990) climate (left), conditions projected for 2030 given lower levels of heat-trapping emissions (center), and conditions projected for 2030 given medium-high levels of emissions (right). Areas in yellow have a 50–75 percent likelihood of being climatically suitable according to the models; areas in green have more than a 75 percent likelihood. These models do not address other factors that affect where species occur, such as soil types. (The two future emissions levels are the B1 and A2 scenarios of the Intergovernmental Panel on Climate Change, respectively.)

SOURCES: BASED ON USFS MOSCOW LAB 2014 AND USFS N.D. C.

12 These projections were developed under the same modeling effort on which Figure 7 (whitebark pines) and Figure 10 (piñon pines) are based.

© Colorado Tourism Office/Matt Inden/Miles

In the fall, aspen colors like these near Crested Butte, CO, draw visitors into the Rocky Mountains.

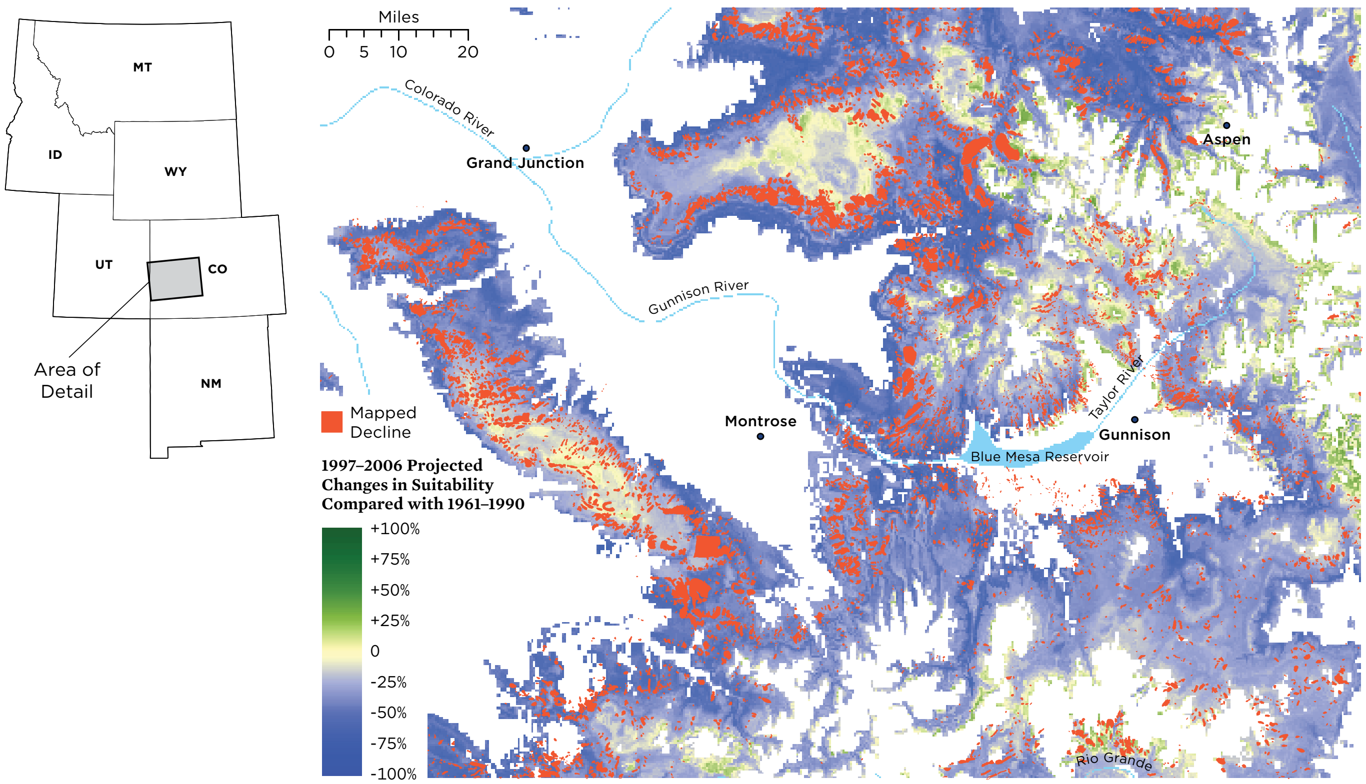
TABLE 2. Projected Changes in Land Area Suitable for Aspens, Rocky Mountain Region

State	1961–1990	2060			
	Recent Historical Suitability (acres)	Projected Suitability (acres)	Area Lost (%)	Area Gained (%)	Net Area Lost (%)
Colorado	18,210,000	10,060,000	-60	16	-45
Idaho	13,090,000	1,972,000	-97	12	-85
Montana	20,670,000	6,039,000	-81	11	-71
New Mexico	3,799,000	975,000	-77	2	-74
Utah	10,130,000	2,815,000	-75	3	-72
Wyoming	9,633,000	7,449,000	-71	48	-23
Total	75,532,000	29,310,000	-77	15	-61

More than 75 percent of the historical range for aspens in the Rocky Mountain region is projected to become unsuitable for them by 2060, given medium-high levels of heat-trapping emissions (the A2 scenario of the Intergovernmental Panel on Climate Change). Other areas—equivalent to 15 percent of the historical area—are projected to become newly suitable. Overall, aspens in the Rocky Mountains face a projected decline of about 60 percent in suitable area. "Projected Suitability" encompasses those areas projected to have a 40 percent or greater likelihood of being climatically suitable for aspens in 2060. These models do not address other factors that affect where species occur, such as soil types. For more about this methodology, see www.ucsusa.org/forestannex.

SOURCE: WORRALL AND MARCHETTI 2014, BASED ON WORRALL ET AL. 2013.

FIGURE 9. Recent Declines in Aspens in Western Colorado, Compared with Projected Reduction in Suitable Range



Recent areas of aspen decline in western Colorado from 2000 to 2010 (in orange) show substantial overlap with areas that climate models projected would become unsuitable from 1997 to 2006. Darker shades of blue indicate stronger projected declines in suitability for aspen compared with 1961 to 1990 (shades of green indicate projected increases in suitability). The overlap between actual decline and modeled loss of suitable range suggests that the recent decline could be climate-driven rather than a singular phenomenon.

SOURCE: WORRALL ET AL. 2014.

[*Aspens play a uniquely beneficial role that includes sustaining wildlife, serving as a firebreak, boosting water yield from forests, and drawing tourists to view their autumn foliage.*]

Piñon Pines

© John Fielder

Piñon pines like these in Colorado's Browns Canyon Wilderness Study Area are a foundation species of forests in the southern Rocky Mountains and much of the interior West.

Piñon pines (*Pinus edulis*)—a foundation species of the piñon-juniper forests that flank the southern Rockies and cover much of the interior West—suffered a mass die-off in 2002–2003, caused by severe drought and exceptional heat as well as bark beetle infestations. Scientists project that piñon pines as well as other tree species across the southern Rocky Mountains and the Southwest are vulnerable to further impacts and higher mortality rates from continued climate change.

WHAT IS ALREADY HAPPENING

The Southwest is home to the continent's most extensive piñon-juniper woodlands, including those around the southernmost Rockies in New Mexico. A severe drought began in this region in 2000, accompanied by exceptional heat. These extreme conditions triggered a mass die-off of piñon pines in 2002 and 2003 over about 4,600 square miles—nearly half the size of New Hampshire (see Box 5, p. 36) (Breshears et al. 2005).

As much as 90 percent of piñons died at some sites in Mesa Verde National Park in Colorado, near Los Alamos in northern New Mexico, and near Flagstaff, AZ. Enormous numbers of piñon pines of reproductive age also died in key areas of the species' range, including 60 percent in Mesa Verde, 74 percent in the San Francisco Peaks in Arizona, and 94 percent in the middle Rio Grande Basin in New Mexico (Floyd et al. 2009). One study estimated that as many as 350 million piñons died across the West, with the greatest mortality occurring in the northern New Mexico foothills of the Southern Rockies (Meddens, Hicke, and Ferguson 2012).

[Enormous numbers of piñon pines of reproductive age died in key areas of the species' range.]

Although dead piñons often revealed infestation by piñon ips beetles, scientists have consistently pointed to stress from the combination of exceptional heat and extreme drought as the likely underlying cause of the die-off (Clifford et al. 2013; Gaylord et al. 2013; Adams et al. 2009; Breshears et al. 2009; McDowell et al. 2008; Breshears et al. 2005).

The Southwest has always known drought. However, the previous major drought, in the 1950s—although drier than the 1999–2003 drought—killed far fewer piñons. Exceptional heat during the more recent drought made the critical difference (WRCC n.d.; Breshears et al. 2005). New Mexico's driest year of the 1950s (1956) was only 0.4°F above the 1971–2000 average, while the driest year during the recent drought (2003) was 2.4°F above average (WRCC n.d.). Scientists have warned that the recent combination of exceptional heat and drought could presage "future global-change type drought" (Breshears et al. 2005).

Tree mortality across Arizona and New Mexico from 1997 to 2008 likely occurred at the fastest rate in 90 years

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Infestation by piñon ips beetles and stress from exceptional heat and drought were the likely causes of a massive die-off of piñon pines in 2002 and 2003.

BOX 5.

Why Piñon Pines Matter

The mass piñon pine die-off of 2002–2003 is "one of the most extensively documented examples of a sudden ecosystem crash in response to climate change" (Breshears et al. 2011). Likely effects include at least a temporary shift from woodlands to shrublands and grasslands, higher temperatures, more evaporation and less soil moisture because of a loss of shade, more erosion, potentially affecting water quality, and a loss of piñon nuts and firewood (Breshears et al. 2011).

Piñon-juniper woodlands are the most extensive type of forest in the United States, covering about 15 percent of all land in Arizona, Colorado, Nevada, New Mexico, and Utah. These trees provide aesthetic beauty that enhances some of the most scenic landscapes in North America (Romme et al. 2009).

The piñon pine—New Mexico's state tree—also has great cultural importance in the Southwest, profoundly valued by Native Americans, Hispanics, and Anglos alike (Breshears et al. 2011). Its importance largely reflects the fact that few other trees can survive in the semi-arid areas where piñons are most common. If piñons were to disappear from portions of this region, many junipers—but perhaps no other tree species—might remain (USFS Moscow Lab 2014; Gaylord et al. 2013; Williams et al. 2010).

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Piñon pines add aesthetic and ecosystem value to some of the most spectacular landscapes in the West, including Canyonlands National Park.

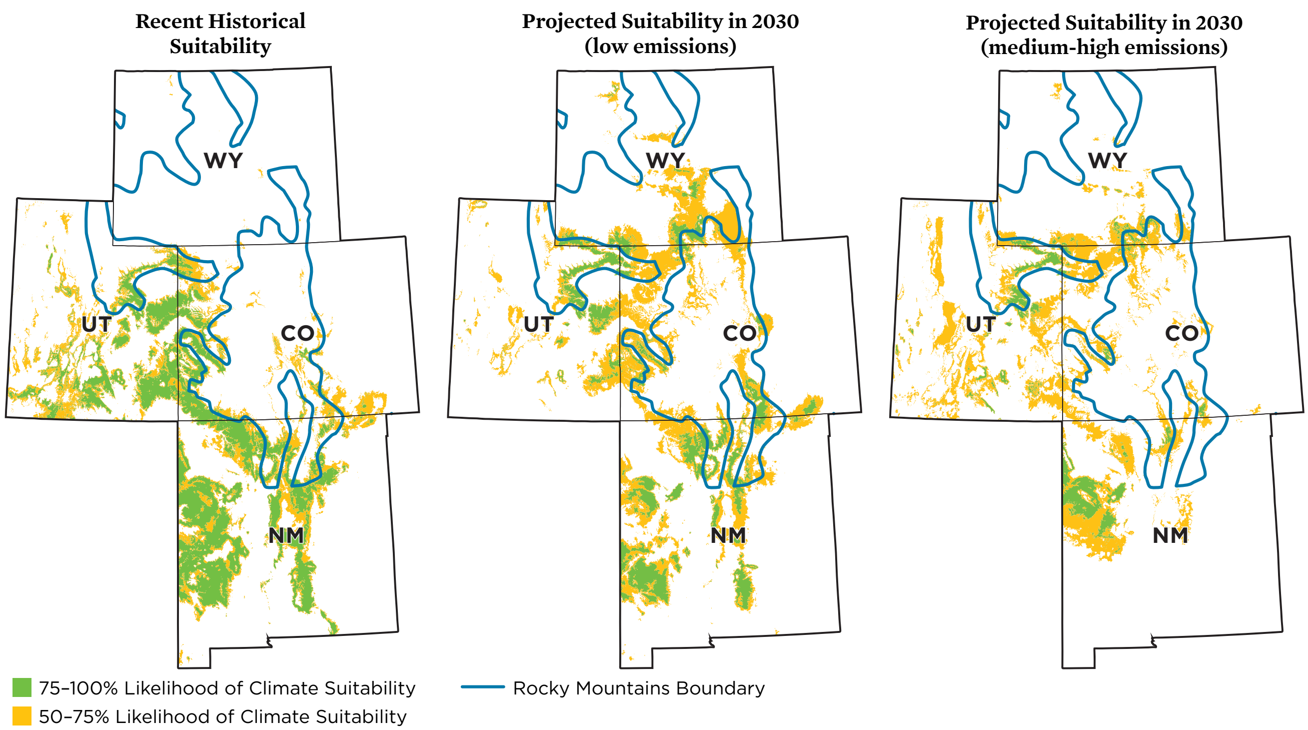
(Williams et al. 2010). Piñon pines died off in 7.6 percent to 11.3 percent of southwestern forest and woodlands, and overall mortality in southwestern forests reached 14 percent to 18 percent. Scientists concluded that the recent drought and high temperatures contributed to increases in both beetle outbreaks and fires (Williams et al. 2010).

Tree die-off in some areas around Flagstaff, AZ, was as high as 100 percent from 2002 to 2004 (Gitlin et al. 2006). With 41 percent mortality, piñon pines had the highest die-off rate among the three most widespread southwestern tree species. Scientists clearly implicated both heat and dryness. In mid-elevation woodlands, only 9 percent of piñons on shaded and cooler north-facing slopes died, while 93 percent on hotter south-facing slopes succumbed. And the region's most drought-tolerant tree—the one-seed juniper—saw only 3 percent mortality.

WHAT SCIENTISTS PROJECT WILL HAPPEN

The U.S. Forest Service projects that piñons could disappear from much of their current range, given current and future climate conditions. Under a scenario of medium-high heat-trapping emissions, a large majority of the areas where piñons now occur would be no longer suitable (Figure 10).[13] Another study projects a fivefold increase in regional piñon mortality solely because of higher temperatures, even if precipitation levels remain unchanged (Adams et al. 2009).

FIGURE 10. Modeled Suitable Range for Piñon Pines—Today and under Two Climate Scenarios



The degree of climate change will affect the amount of western land suitable for piñon pines in 2030. These maps depict areas modeled to be climatically suitable for the tree species under the recent historical (1961–1990) climate (left), conditions projected for 2030 given lower levels of heat-trapping emissions (center), and conditions projected for 2030 given medium-high levels of emissions (right). Areas in yellow have a 50–75 percent likelihood of being climatically suitable according to the models; areas in green have more than a 75 percent likelihood. These models do not address other factors that affect where species occur, such as soil types. (The two future emissions levels are the B1 and A2 scenarios of the Intergovernmental Panel on Climate Change, respectively.)

SOURCES: BASED ON USFS MOSCOW LAB 2014 AND USFS N.D. C.

13 This analysis was based on the IPCC's A2 medium-high emissions scenario.

[CHAPTER 6]

Present and Future Climate Change in the Rocky Mountains

- Temperatures have risen more in the Rocky Mountain region than in the nation as a whole over the past 20 years.
- Exceptional heat and dryness from 1999 to 2003 triggered major impacts on forests.
- Projections show that temperatures will continue to rise, even with significant cuts in heat-trapping emissions. If emissions remain unchecked, temperatures could rise twice as fast.

What Has Already Happened

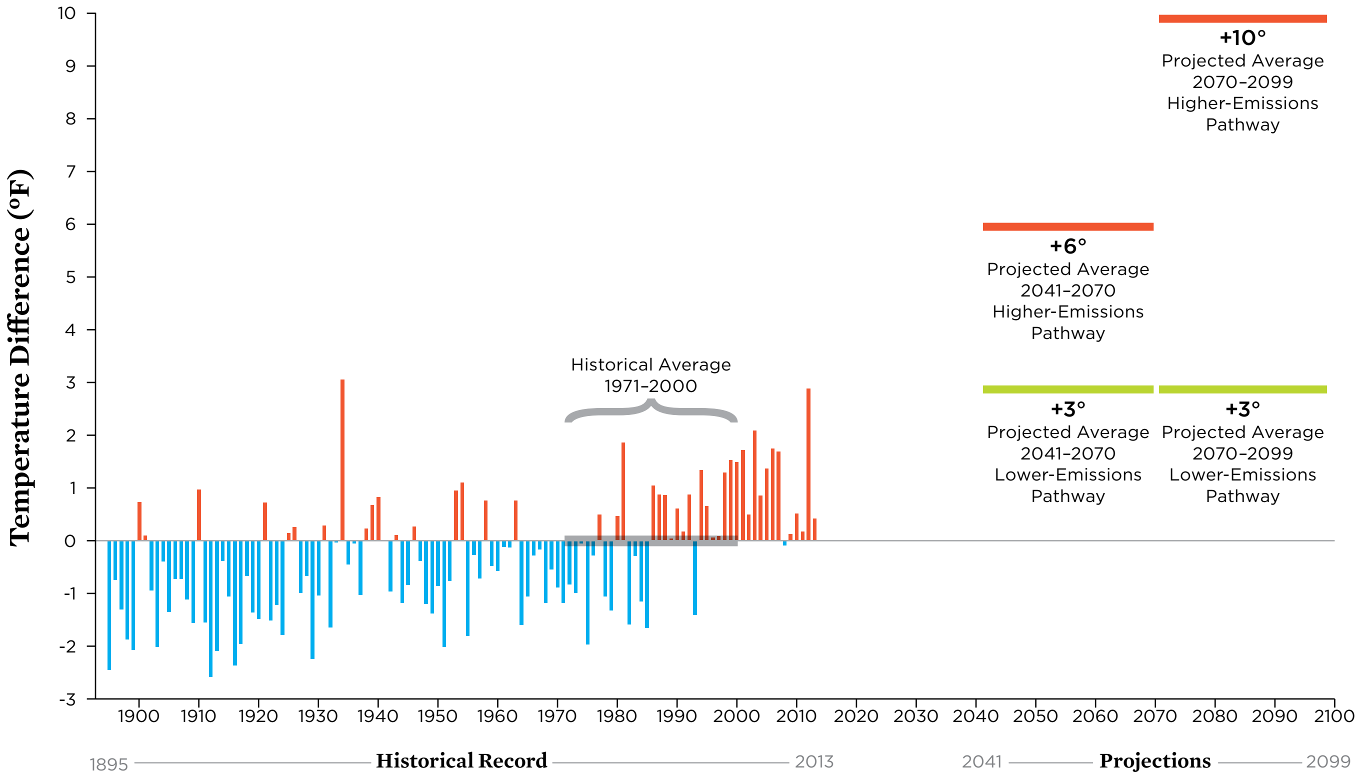
The Rocky Mountain region has been warmer in the past few decades than at any other time since 1895. Average annual temperatures across the six Rocky Mountain states rose by 2.1°F from 1895 to 2013—versus 1.9°F for the entire continental United States (Walsh et al. 2014; WRCC n.d.). Like the rest of the nation, the Rocky Mountain region has been especially hot in recent years (see Figure 11).

Rising temperatures are driving changes in the natural hydrology, or water cycles, of the Rocky Mountain region. These changes are fundamentally important to the region's forests. Especially in the mountains' high-elevation core, winters have historically been cold enough that precipitation falls as snow and remains through the winter season in snowpacks, which serve as natural reservoirs. As snowpacks melt from spring into summer, they account for as much as 90 percent of annual streamflow in some Rocky Mountain

© Flickr/Djof

The water level in Lake Mead on the Colorado River is at a historic low due to prolonged drought.

FIGURE 11. Changes in Average Temperatures in the Rocky Mountain Region—Historical and Projected



Average temperatures in the six Rocky Mountain states have risen and are projected to rise further, with the increase depending on heat-trapping emissions. The left side of the figure shows changes in average temperatures from 1895 to 2013 compared with the 1971–2000 average. The right side of the figure depicts projected changes in average temperatures for 2041–2070 and 2070–2099 compared with the 1971–2000 average. Changes in future averages are projections from multiple climate models, based on lower emissions (representative concentration pathway, or RCP, 2.6) and higher emissions (RCP 8.5). If future emissions are high, average annual temperatures could be far higher than historical levels, with dramatic effects on Rocky Mountain forests.

SOURCES: WRCC N.D.; KUNKEL AND STEVENS 2014, BASED ON WALSH ET AL. 2014.

watersheds, supplementing spring and summer rainfall. Thus the higher-elevation storage of winter snow helps meet the needs of forests as well as other ecosystems and people in hotter times of the year, when those needs are greatest (Stewart, Cayan, and Dettinger 2004).

In recent decades, however, a smaller share of winter precipitation has fallen as snow and a greater share has fallen as rain. The result is reduced spring snowpacks, earlier snowmelt, earlier peak streamflows, and drier summers (Fritze, Stewart, and Pebesma 2011; Pederson et al. 2011; Knowles, Dettinger, and Cayan 2006; Mote et al. 2005; Stewart, Cayan, and Dettinger 2004). As one specific example, peak streamflows in the West occurred a few days to 30 days earlier from 2001 to 2010 than from 1950 to 2000 (Figure 12, p. 40) (Hoerling et al. 2013).

A growing number of studies suggest that some of these changes are outside the range of natural variability for the West, and are largely driven by human-caused climate change. These include higher minimum winter temperatures, higher late winter and early spring temperatures in mountainous regions, and lower volumes of river flows, as well as earlier peak streamflows (Hidalgo et al. 2009; Barnett et al. 2008; Bonfils et al. 2008; Pierce et al. 2008).

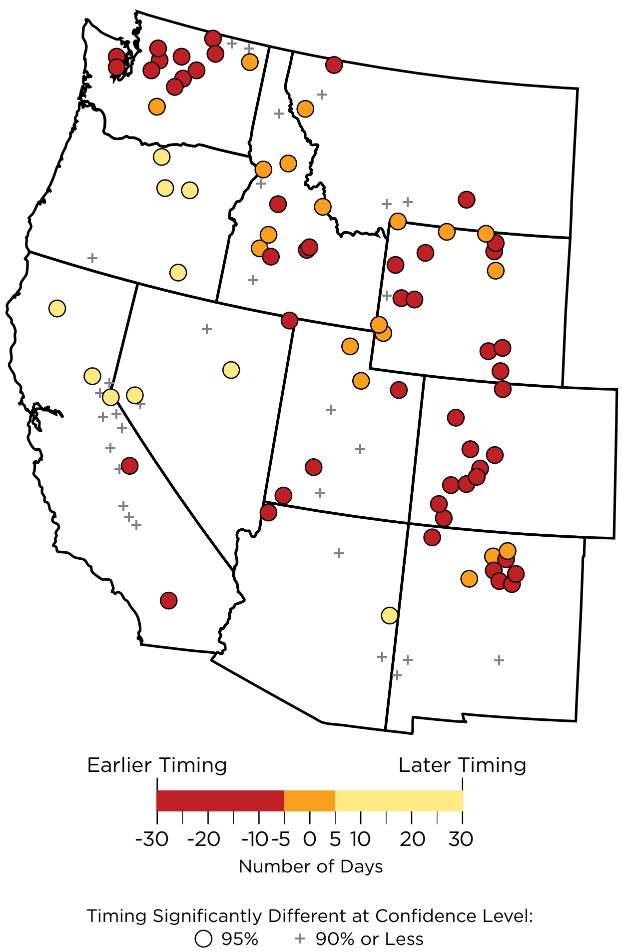
The West has historically faced major droughts—periods that are drier than normal in a given area—once or twice per century. Globally, droughts are more common in arid and semi-arid areas, because precipitation there typically depends on a few storms a year. In the Southwest, including the area around the southern end of the Rocky Mountains, tree rings show previous episodes of drought more severe and persistent than in recent times (Cook et al. 2004). However, drought has become more widespread in that region since 1900 (Hoerling et al. 2013).

As noted, extreme drought and high temperatures came together in the Rocky Mountain region from 1999 to 2003, with major impacts on the region's forests. Across the six states in the region, that period had the fourth-lowest five-year precipitation total—and was the second-hottest five-year stretch—since 1895. In the middle of this stretch, 2002 was the region's driest year since 1895, with precipitation 22 percent below average (WRCC n.d.). The potent combination of extreme heat and dryness also produced the highest five-year rating on a drought severity index in eight centuries (Schwalm et al. 2012).[14] And the most severe effects of drought on forests ever recorded in Arizona, New Mexico, and southernmost Utah and Colorado, and on aspens in Colorado, occurred in 2002 (Williams et al. 2013; Marchetti, Worrall, and Eager 2011; Worrall et al. 2010).

This turn-of-the-century drought has persisted in the southern Rocky Mountain region. Flows of the Colorado River and the Rio Grande—the region's two most important rivers—remain below average (Llewellyn and Vaddey 2013; U.S. Bureau of Reclamation 2012). These drops in river flows stem more from higher temperatures than from less precipitation. The latter has declined only slightly in the Colorado River basin, and has actually increased in the Rio Grande basin (Hoerling et al. 2013).

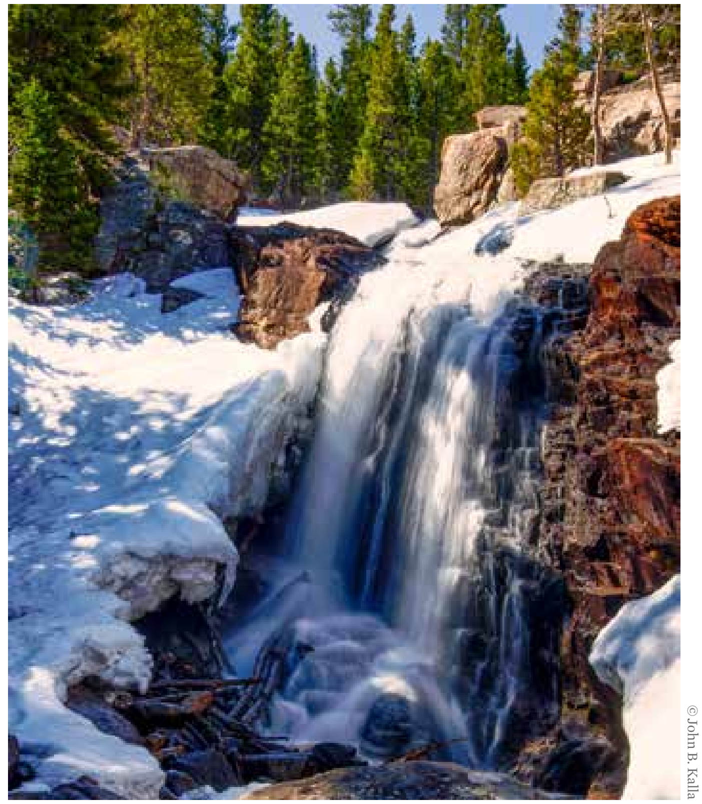
Average annual river flows have generally increased in the Northern Rockies (Alexander et al. 2011). However, with peak flows occurring earlier, August streamflows have declined significantly over the past half-century, especially in recent years, producing drier summers. And August streamflows may have greater ecological effects because they occur during the heat of late summer (Leppi et al. 2012).

FIGURE 12. Changes in Spring Streamflow Timing in the West, 2001–2010 versus 1950–2000



Peak streamflows in the West occurred earlier—from a few days to 30 days—during the 2001–2010 period, compared with the 1950–2000 period.

SOURCE: ADAPTED FROM HOERLING ET AL. 2013.



Higher temperatures in winter and early spring result in lower overall volumes of water in rivers like this one in Rocky Mountain National Park, as well as earlier peak streamflow.

14 This was the Palmer Drought Severity Index.

How Climate Change Interacts with Other Stressors

Other stressors may accelerate the effects of climate change on Rocky Mountain forests (Aber et al. 2001). These stressors include:

- **A legacy of fire suppression.** Fire suppression was the dominant response of the U.S. Forest Service to wildfires through most of the twentieth century, despite growing costs and mounting evidence that this approach was counterproductive (Stephens and Ruth 2005). A legacy of fire suppression is still apparent in the higher-than-normal tree density in some of the region's forests (Joyce et al. 2014) (see Chapter 3). Competition among many small trees actually makes them more vulnerable, because they draw down water and nutrients faster than a less-dense forest (Franklin et al. 2002). Fire can spread rapidly in these dense stands of stressed trees, with devastating results.
- **Encroaching human development.** Human encroachment alters the ecological processes that maintain forests—particularly in riparian areas vital for recovery after fire (Dwire and Kauffman 2003). As noted in Chapter 3, the growing number of homes in forests is a major cause of the rising costs from wildfire. Development also affects the way firefighters respond when a fire breaks out. Rather than controlling and managing the fire—possibly to the benefit of the forest—they often focus on protecting homes and other buildings (OIGWR 2006). Development can help firefighters by improving access to fires and providing supporting infrastructure. However, the presence of people and buildings can also impede the effective use of firefighting resources, increasing the costs of fire suppression (Liang et al. 2008).
- **Changes in wildlife populations.** The elimination of predators from large areas of the West affects forest health. With a lack of predators, surging populations of browsers such as elk and deer prevent young trees from thriving (Beschta and Ripple 2009). The effect is species- and location-specific: some tree species have expanded their range even as elk and cattle have inhibited the growth of others, including aspens (Rogers et al. 2014,

Rocky Mountain forests provide vital habitat for elk and other treasured species of the West.

In recent decades, a smaller share of winter precipitation has fallen as snow on Rocky Mountain peaks such as Colorado's Mount Sneffels, while a greater share has fallen as rain. In addition, spring snowpacks have been reduced, snowmelt and peak streamflows have come earlier, and summers have been drier.

2010; Campbell et al. 1994). Browsing by herbivores can alter the age structure of a forest and hamper its ability to respond to climate and other stressors.

- **More grazing by livestock.** Long-term overgrazing by domestic sheep and cattle can make forests more vulnerable to high-intensity fires (Belsky and Blumenthal 1997). Low-lying vegetation helps keep fire near the ground and curbs its intensity. When grazing removes that vegetation, fire can more easily move into the crowns of trees, where it can become more severe.
- **Invasive species and diseases.** Invasive species and diseases introduced by humans can disrupt forests—as shown by the contribution of white pine blister rust to the pervasive decline of whitebark pines. Cheatgrass—an introduced species that has become widespread in the West—promotes wildfire. It is expected to spread into new areas as the climate changes (Staudt et al. 2012). However, interactions among stressors create a complex story: fire suppression may make forests more vulnerable to fire and pathogens, but it has likely reduced the spread of some invasive plant species (Keeley 2006).
- **Pollution.** Air and water pollution can stress trees, making them more vulnerable to other stresses such as droughts and wildfires (Joyce et al. 2014).

Forest scientists face enormous challenges in understanding the effects of these multiple stresses, given a changing climate. However, scientists do know that they can have detrimental effects on forests in many locations, and that changes in climate may outpace the ability of forest species to recover.

What Scientists Project Will Happen

The extreme conditions of 1999 to 2003 may come to be seen as mild as the climate continues to change. Scientists expect recent temperature and snowpack trends in the Rocky Mountain region to worsen if heat-trapping emissions from human activities—principally the burning of fossil fuels—remain high (Georgakakos et al. 2014; Walsh et al. 2014).

Our new analysis of data used for the 2014 National Climate Assessment shows that even if carbon emissions fall dramatically, average temperatures in the Rocky Mountain states could rise about 3°F above 1971–2000 levels (Figure 11, p. 39).[15] If emissions continue unchecked, average temperatures in these states could increase by about 6°F by mid-century, and by 10°F near the end of the century.[16] Under the latter scenario, temperatures would be far higher than they have been in several thousand years. And even the less severe scenario could bring dramatic effects, given that the region saw significant impacts from a temperature increase of 1°F from 2000 to 2013, compared with temperatures from 1971 to 2000.

Projected changes in future precipitation are less certain than projections for temperature—and more varied across the region. Today's climate models show that much of the Northern Rockies will receive more total precipitation, with the increases concentrated in winter and spring. Summer rainfall will remain about the same or decline (Walsh et al. 2014). The Southern Rockies could see the same seasonal pattern, but with smaller increases in winter and spring precipitation. Across the broader Southwest, in contrast, spring precipitation is projected to decline markedly, and that change may affect the southernmost Rockies (Walsh et al. 2014).

Other projected climate changes would contribute to drier conditions across the Rockies, especially in summer and in the Southern Rockies. For example, climate models project large changes for spring snowpack levels. Given medium-high levels of heat-trapping emissions, spring snowpack would decline about 13 percent in Colorado, about 9 percent in Utah, and about 42 percent in New Mexico by mid-century, compared with the 1971–2000 average (Garfin et al. 2014).

Scientists project that river flows will diminish in the Southern Rockies (Llewellyn and Vaddey 2013; U.S. Bureau of Reclamation 2012). In the Colorado River Basin, drought is projected to become more frequent, intense, and longer-lasting, and hotter conditions will magnify the impacts of drought (Cayan et al. 2013). Together these changes could make the Southern Rockies much drier. These changes also mean that soil will become drier across most of the Rocky Mountains, especially the Southern Rockies, with more moisture loss occurring if heat-trapping emissions are higher (Walsh et al. 2014).

[The extreme conditions of 1999 to 2003 may come to be seen as mild as the climate continues to change. As a result, future impacts on forests could outstrip those seen so far.]

15 This analysis reflects the IPCC emissions scenario known as the representative concentration pathway (RCP) 2.6, which assumes a 70 percent drop in global emissions by mid-century and an even larger drop thereafter.
16 This analysis reflects the IPCC's RCP 8.5, which assumes somewhat higher emissions than the A2 scenario used by other studies cited in this report.

[CHAPTER 7]

What We Can Do

- Protecting Rocky Mountain forests requires immediate action to cope with the impacts of climate change already under way. The federal agencies that manage nearly all forested land in the Rocky Mountains are beginning to take important steps, and need the resources to continue this work. Stakeholder engagement will be essential.
- Swift and deep reductions in heat-trapping emissions are the most important step we can take to protect treasured Rocky Mountain landscapes.

Rocky Mountain forests are already undergoing major changes, and face further severe impacts if we do not act. Everyone with an interest in these forests can make meaningful contributions by both working to improve their resilience and reducing heat-trapping emissions.

Some critical efforts are already under way, and wider engagement and concerted action by stakeholders can prevent further damage to these treasured resources (see Box 6). The knowledge that climate change is the source of the changes suggests that a comprehensive response is essential.

Six sensible, practical steps could guide our nation's response and focus our efforts on the most effective ways to protect Rocky Mountain forests.

Step 1: Assess Risks

More detailed scientific information will be vital in choosing the right priorities for on-the-ground decisions about managing these forests (Baron et al. 2008; Joyce et al. 2008). Better scientific information is especially important because some forest managers are waiting for more local analysis of the impacts of climate change, despite scientists' assertions that we already know enough about the threat to warrant immediate action (Joyce et al. 2008).

The U.S. Forest Service has issued a new climate change response strategy calling for assessing risks as the first of three essential steps (see more on these below). Other agencies have also begun assessing the vulnerabilities of forested lands in the face of climate change, and gaps in our knowledge about those risks.

More information from scientific monitoring and assessments of Rocky Mountain forests will provide some of the best insights into the extent of climate change and its effects on natural resources.

Step 2: Engage Stakeholders

Because the effects of climate change on Rocky Mountain forests are so complex, engaging partners in seeking solutions is critical to managing these impacts. Indeed, the Forest Service posits engaging stakeholders as the second pillar of its climate change response strategy (U.S. Forest Service 2010c).

Early examples of stakeholder engagement are already yielding lessons on which to build:

- In the western United States and Canada, public and private organizations and experts have worked together to develop a range-wide restoration strategy to address threats to whitebark pines (Keane et al. 2012).
- In the Jemez Mountains in northwestern New Mexico, the U.S. Forest Service, the Valles Caldera Trust, the New Mexico Forest and Watershed Restoration Institute, and

BOX 6.

Key Actors in Curbing the Impacts of Climate Change on Rocky Mountain Forests

Numerous entities and individuals are critical to identifying, preparing for, and addressing the effects of climate on Rocky Mountain forests:

- **Federal, state, local, and tribal governments** often have the most direct opportunities to tackle the impacts of climate change on forests. As noted, the federal government owns and manages the vast majority of forested lands in the Rockies. Government agencies also have broad responsibility for assessing and addressing far-reaching effects on communities across the region and even the nation. And government policies and actions play a critical role in curbing further human-caused climate change.
- **Scientists** at government agencies, universities, and other research institutions must continue to analyze the effects of climate change on Rocky Mountain forests. Scientists must also deliver that information in ways that enable land managers and other stakeholders to make informed decisions on how to best protect those resources most at risk.
- **Stakeholders** who use and enjoy these public resources and depend on the services and benefits they provide must ensure that government decision makers hear and consider their views, and those of the full range of national, regional, and local interests. Stakeholders include landowners, foresters, hikers, hunters, anglers, and other users of these forests, to name a few.
- **Everyone** across America and beyond who cares about the forests can support efforts to limit climate change and its impacts—especially by doing their part to reduce climate-changing emissions and holding their elected officials accountable for doing the same.

The federal agencies responsible for managing these lands—the U.S. Forest Service, National Park Service, Bureau of Land Management, and Fish and Wildlife Service—have already emerged as leaders in the important challenge of protecting natural resources threatened by climate change. The three guiding principles of the Forest Service's climate change response strategy—assess risks, engage partners, and manage for resilience—provide a good framework for the actions that these agencies are now taking (U.S. Forest Service 2010c).

The Nature Conservancy are partnering to identify and implement efforts to make forests more resistant to large-scale disturbances such as severe wildfires and insect epidemics.

- In the Nez Perce-Clearwater National Forests in Idaho, one of the first forest planning efforts under the new U.S. Forest Service approach has included more extensive public engagement than with previous forest plans. This work has included a series of community meetings, a three-day stakeholder summit, and a two-day workshop on climate change vulnerability.
- In the Gunnison Basin in southwest Colorado, which ranges from low-elevation shrublands to 14,000-foot mountains in the Gunnison National Forest, The Nature Conservancy has led a collaboration among 14 local, state, and federal agencies, private organizations, academic institutions, and private landowners to identify and address the local effects of climate change.

Step 3: Manage for Resilience

In 2012, the U.S. Forest Service adopted "managing for resilience" as the third principle of its climate change response strategy. The final rule emphasized collaboration in the forest planning process, through public involvement and dialogue, and the use of the best available scientific information to inform decisions on the protection of land, water, and wildlife. The collaborative effort in the Jemez Mountains noted above has already produced consensus on a range of actions to address the effects of intensive logging and grazing, road building, and fire suppression, which have degraded the forest and made it more vulnerable to climate change (U.S. Forest Service 2014). Stakeholders are now beginning to take these actions.

Managing for resilience begins with incorporating information on climate change into decisions on protecting the most important resources and values. The National Park Service has been a leader in using multiple scenarios to identify actions to address a changed future for its lands (National

Park Service 2010). Managing for resilience also includes tackling other stressors that combine with climate change to produce cumulative effects on forests (Baron et al. 2008; Joyce et al. 2008).

In managing for resilience, federal land-management agencies are also working to reduce heat-trapping emissions. More than 270 million people visit U.S. national parks each year, and the National Park Service is beginning to offer these visitors information on climate change, its effects, and how to prevent and address them.

Step 4: Increase the Capacity of Public Agencies

To combat the severe threats to Rocky Mountain forests and other national resources from climate change, federal land managers must launch an extraordinary suite of actions, including firefighting to protect lives, property, and other resources. And that means federal land-management agencies need more resources. Yet Congress has not even provided the relatively limited funds that federal agencies have requested for this work.

For example, Congress did not approve a modest funding request from the National Park Service to address climate change, despite the agency's declaration that climate change represents the greatest threat ever to the parks (National Park Service 2010). Congress should provide the funds that the federal land-management agencies need to fulfill their responsibility to protect our nationally significant natural resources from climate change—in the Rocky Mountains and elsewhere.

Step 5: Address the Vulnerability of Communities

The effects of climate change on forest resources do not end at their edge: they do and will affect communities throughout the region and the nation. Tackling these impacts will require government actions beyond those of land-management agencies.

State and local governments, for example, with assistance from federal agencies, need to assess the impacts already under way and consider those of future climate scenarios, and then work with others to combat them. Some effects, such as the growing risks of wildfires in the wildland-urban interface, will require state and local cooperation to reduce the exposure of people, property, and resources and respond to remaining risks.

Step 6: Reduce Emissions

The future of Rocky Mountain forests ultimately depends on how much and how quickly we can curb heat-trapping emissions. As temperatures have climbed two to three degrees above the recent historic average, the impacts on forests have been severe. If emissions continue unchecked and temperatures reach 10°F above that average, the impacts could be extraordinary. As the Climate Science Panel of the American Association for the Advancement of Science recently stated, "We are at risk of pushing our climate system toward abrupt, unpredictable, and potentially irreversible changes with highly damaging impacts" (AAAS 2014).

The good news is that we have addressed many serious environmental problems before, and we have practical solutions at hand to significantly reduce the heat-trapping emissions we release into the atmosphere. As individuals, we can help by taking action to reduce our personal carbon emissions. But to fully address the threat of global warming, we must demand action from our elected leaders to support and implement a comprehensive set of climate solutions.

The most important actions at the federal level are occurring under the Clean Air Act, which requires the Environmental Protection Agency (EPA) to reduce air pollution that harms public health. That pollution includes global warming emissions, which the EPA has found endanger public health. The EPA is responsible for developing, implementing, and enforcing standards to reduce those emissions. It should act on that responsibility and take all necessary steps to protect public health, including by reducing the heat-trapping emissions that new and existing power plants are allowed to emit.

Reducing emissions can actually strengthen our economy. The EPA's Clean Power Plan, proposed in June 2014, would give states flexibility in choosing how to reduce emissions over 10 to 15 years, while creating public health and climate benefits worth an estimated $55 billion to $93 billion per year in 2030—far outweighing the costs of $7.3 billion to $8.8 billion (EPA 2013). State and local governments also have an essential role to play in reducing emissions, and many are taking action to curb emissions and climate change while promoting economic growth.

Our response to climate change is one test by which future generations will measure our resolve in the face of daunting challenges. For the many Americans who cherish the forested landscapes and snowy peaks of the Rocky Mountains as iconic images of the American West, the choice is stark: unless we want to sit by and watch this majestic landscape and treasured resource degrade irrevocably, we must act now to preserve it.

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Rocky Mountain Forests at Risk

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The Rocky Mountain Climate Organization works to reduce climate disruption and its impacts, to help keep the Interior West the special place that we cherish. 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.

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