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Warming and Warnings: Assessing Climate Change Vulnerability in the Rocky Mountain Region

In the past 200 years, a handful of events have had a major impact on the life and landscape of the Rocky Mountain region. One of these occurred in the 1880s and 1890s, when the region's human population jumped as people moved west for health reasons. Back then, tuberculosis was the leading cause of death in the United States. Entire cities sprung up around treatment facilities for people who moved west for the dry, sunny climate.

Today, more than 130 years later, the U.S. Forest Service's Rocky Mountain Region faces another landscape-changing situation. This time, it's also related to climate. In the Rocky Mountain Region and elsewhere,

Ecosystems in the Rocky Mountain Region are connected by water; future climate in this region is projected to see warming temperatures that are likely to reduce snowpack and affect the timing and amount of water moving from the mountains to the plains (Photo by J. Rice).

SUMMARY

The Rocky Mountain Research Station recently published a general technical report addressing climate change vulnerability in the Rocky Mountain Region. This report, entitled Climate Change Vulnerability Assessment of Aquatic and Terrestrial Ecosystems in the US Forest Service Rocky Mountain Region, focuses on six ecosystems. Scientists evaluated each ecosystem based on several factors, including their current extent, exposure to climate change, sensitivity and adaptability to climate change, the ability of the ecosystem to shift geographically, and non-climate stressors such as recreational use, air pollution and infrastructure development.

Of the six categories, all were seen as vulnerable to climate change, although the level of vulnerability varied. The three aquatic systems evaluated (Great Plains streams and riparian areas; aquatic, riparian and wetland ecosystems in glaciated valleys, and low-gradient mountain stream reaches) were rated as the most vulnerable: "highly vulnerable." One terrestrial ecosystem (alpine turf and dwarf-shrublands) was also rated as having high vulnerability to climate change. Finally, two ecosystems were classified as moderately vulnerable to climate change (ponderosa pine woodlands and savannas and subalpine spruce-fir forests). The report, which is summarized in this companion document, provides detailed insights on vulnerability to climate change along with interactions with non-climate stressors for each ecosystem type.

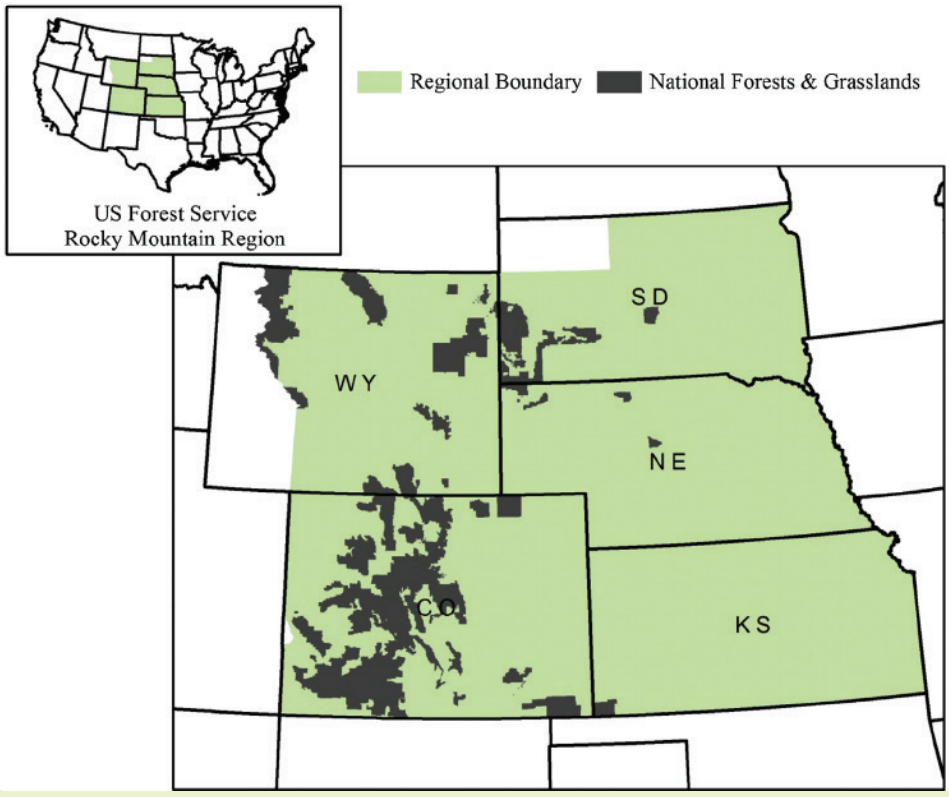
climate change can affect a wide range of environmental conditions, including precipitation levels, drought and flooding frequency, soil moisture, invasive species, beetle and disease infestations and other factors. The Intergovernmental Panel on Climate Change has estimated that up to 30 percent of known plants and animals worldwide could be at risk of extinction if average global temperatures reach projected levels by the year 2100. In the Rocky Mountain Region, which includes Colorado, Nebraska, Kansas and most of South Dakota and Wyoming, many species are vulnerable, especially in aquatic ecosystems.

COLLABORATING FOR CLIMATE CHANGE ADAPTATION

To help evaluate ecosystem vulnerability across the Rocky Mountain Region, a team of scientists with the U.S. Forest Service Rocky Mountain Research Station compiled extensive research over the past few years, collaborating on a general technical report entitled Climate Change Vulnerability Assessment of Aquatic and Terrestrial Ecosystems in the US Forest Service Rocky Mountain Region. This report, published in July 2018, can be found at https://www.fs.usda.gov/treesearch/pubs/56392.

Trey Schillie, a policy analyst for climate change and ecosystem services, describes the report this way: "National forests and grasslands are important to people living in the West, but they're under threat from insects and disease, uncharacteristic wildfire, drought and invasive species. The report provides a consistent tool that Rocky Mountain Region land managers can use to identify climate-related stressors to services provided by key ecosystems." This publication will help managers with national forest planning and compliance with the Forest Service's *National Roadmap for Responding to Climate Change*, Schillie says, adding, "The assessments in the report can also be used to inform forest planning at the landscape scale and to set the stage for a broader discussion with resource professionals about management options to facilitate climate change adaptation."

The general technical report covers six ecosystems that represent a large part of the Rocky Mountain Region's 17 national forests and 7 grasslands from the semi-arid climate of the short-grass prairie to the cold and windy climate of the alpine tundra. Scientists evaluated each ecosystem in terms of several factors, including their current extent, exposure to climate change, sensitivity and adaptability to climate change, the ability of the



Researchers compiled climate change data and expectations for the Forest Service Rocky Mountain Region, which encompasses Colorado, Kansas, Nebraska and most of Wyoming and South Dakota. Elevations in this region range from about 2500 feet on the central mixed grass prairie to over 14000 feet in the alpine tundra of the Rocky Mountains (image courtesy of U.S. Forest Service).

MANAGEMENT IMPLICATIONS

- Looking forward through the 21st century, all five states in the Rocky Mountain Region are expected to experience a continued warming trend.
- Recently compiled research results indicate different levels of climate vulnerability among six ecosystem types found in the Rocky Mountain Region.
- Aquatic ecosystems in the Rocky Mountain region were considered to be the most vulnerable to climate stressors relative to the terrestrial ecosystems evaluated.
- Climate change should be considered in context with non-climate stressors such as recreational use, air pollution and infrastructure development, all of which can be exacerbated by climate change.
- This report can be used to help land managers to identify sensitive areas, prioritize management efforts, facilitate conversation with stakeholders, and comply with the Forest Service's National Roadmap for Responding to Climate Change.

ecosystem to shift geographically, and non-climate stressors such as recreational use, air pollution and infrastructure development. Here's how each ecosystem was rated in terms of climate vulnerability:

- Ponderosa pine woodlands and savannahs: **Moderate**
- Subalpine spruce-fir forests: **Moderate**
- Alpine turf and dwarf-shrubland: **High**
- Great Plains streams and riparian areas: **Very high**
- Aquatic, riparian and wetland ecosystems in glaciated valleys: **Very high**
- Low-gradient mountain stream reaches: **Very high**

HOW IS THE ROCKY MOUNTAIN REGION'S CLIMATE CHANGING?

The Rocky Mountain Region encompasses a wide range of climates, from the semiarid short-grass prairies to the cold and windy alpine tundra. The regional climate is influenced by moist air masses from the Pacific Ocean and the Gulf of Mexico, as well as by cold, dry air masses from Canada. These climate forces interact with the Rocky Mountains, forcing the westerly movement of moist air upslope and causing higher precipitation levels on the west side of these mountains. The eastern side of the Rockies lies in a rain shadow where annual precipitation can be less than 14 inches along the Front Range of Colorado. Across the Great Plains area of the Region, precipitation levels gradually increase from this rain shadow area to the eastern edges of Kansas and Nebraska.

Warming trends were seen in this Region in the late 20th century, with the mean annual temperature in all five Rocky Mountain Region states rising between 1 and 2 °F. The greatest warming was during winter, with Colorado, Nebraska and Kansas also warming in spring. In Wyoming, the frequency of very hot days (maximum temperature above 95 °F) has increased since 2000. South Dakota has experienced a below-average number of very cold nights (minimum temperature below 0 °F) since 2000.

The recent trends and future projections identify increasing temperatures, suggesting that the historic long-term average may be an underestimate of what is likely, even in the near term.

Climate models allow scientists to explore how climate might respond to changes in atmospheric chemistry, land use and other disturbances. Based on these projections, all five Rocky Mountain Region states are expected to experience historically unprecedented warming during the 21st century. By midcentury, winter temperatures in the Region could increase by as much as 6 °F. In some places, average winter temperatures could rise above a biologically meaningful threshold, above freezing in some areas. For spring temperatures, the projected average increase is 3 to 4 °F above the historical record.

With warming, new environments for some species may open up, as

has been seen in areas of glacial melt, where midges and other species have colonized newly exposed surfaces. Warming winter and spring temperatures have already led to earlier snowmelt and earlier spring flowering of some alpine/subalpine plants, which can be damaged by spring freezing events. Warming temperatures, even without changes in rain and snow levels, are expected to increase moisture stress, particularly in late summer.

Within the Rocky Mountain Region, climate is highly variable. Averages over time can be used to guide expectations about factors such as the likelihood of frozen soil, the likely timing of spring greening, peak runoff levels and other climate characteristics used in planning management actions. The recent trends and future projections identify increasing temperatures, suggesting that the historic long-term average may be an underestimate of what is likely, even in the near term. Climate projections and implications to terrestrial and aquatic ecosystems can be used to guide management of lands in the Rocky Mountain Region.

Because ponderosa pine regeneration is highly sensitive to moisture availability and the trees' seed dispersal ability is limited, ponderosa pine forest recovery can be delayed following a disturbance. Drier and hotter conditions may reduce ponderosa pine regeneration and lead to changes in grassland ecosystems (Photo by R. Addington, TNC).

PONDEROSA PINE WOODLANDS AND SAVANNAS

The Black Hills of South Dakota and Wyoming have been described as an island of trees in a sea of grass. From a distance, more than a million acres of ponderosa pine trees in the Black Hills and nearby forests can make the area appear black. This led the Lakota Sioux tribe to call the area *Pahá Sápa*, which was translated by English-speaking Americans into Black Hills. These ecologically diverse mountains are blanketed by meadows, ponderosa pines and more than a dozen other tree species, including white spruce and quaking aspen.

In the Black Hills' lower elevations, dense forests often transition into "woodlands," which are defined as wooded areas with less than 80% canopy closure, and which then often transition into "savannahs," which are grassy plains with scattered trees. While the lower tree density generally helps these areas adapt to changing conditions, these areas still face challenges. According to Mike Battaglia, a research forester with the Rocky Mountain Research Station, "In the lower elevations of the Black Hills, there's high tree density and a lot of fuel, mostly due to past fire exclusion management practices. Because of this, in recent decades the fires have been unusually

PONDEROSA PINE WOODLANDS AND SAVANNAS

CLIMATE VULNERABILITY: MODERATE

FACTORS:

- **Exposure.** While these ecosystems are somewhat adaptable to variations in precipitation, temperatures and growing season length, warming and more variable precipitation may hinder seedling establishment and seed/cone production of ponderosa pine as well as regeneration of understory plants. Insect outbreaks and large, severe wildfires may reduce habitat for species such as northern goshawks and squirrels that depend on mature forest structure.
- **Shift capacity.** Upslope expansion is possible in parts of Colorado and Wyoming but less likely in lower-elevation areas.
- **Non-climate stressors.** Past and ongoing natural and human-caused disturbances include logging, roads, fire, beetle outbreaks, fire suppression, grazing, recreational use, invasive species and urbanization.

Vegetation treatments that promote a mix of individual trees, groups and clumps like the one picture above near Red Feather Lakes, Colorado on the Roosevelt National Forest promote conditions more typical of Front Range forest structure in the mid-1800s. Such treatments can increase resilience to future climate and non-climate stressors (Credit P. Brown).

severe, causing the overstory and the ponderosa pine seeds to die. These more severe fires are making it very difficult for the ponderosa pine trees to regenerate." Battaglia says the outlook is for more of the same. "Since the projections are that it's going to get hotter and possibly drier, this will definitely influence ponderosa pine susceptibility to beetles by stressing the trees," Battaglia says, adding, "You're also looking at an increased probability of fire, including in some areas that already have a really high fuel load."

When Linda Joyce, a supervisory research rangeland scientist with the Rocky Mountain Research Station and a 40-year Colorado resident, is asked to name a species of personal concern to her, she quickly comes back with ponderosa pine, which is considered by many to be the signature tree of the mountain West. "Climate change calls into question the capacity of some of the major tree species to survive," Joyce says, adding, "It's not clear that other trees would replace ponderosa pines to the extent that they exist in the area today."

In the Rocky Mountain Region, these ecosystems received a climate vulnerability rating of "moderate" from the research team, which cited the likelihood of warmer temperatures, more variable precipitation, severe wildfires and insect outbreaks — all of which could reduce habitat for species such as northern goshawks and squirrels that depend on a mature forest structure. Fortunately, these ecosystems are relatively common: Ponderosa pine woodlands can be found on about 4.8 million acres of the Rocky Mountain Region, while ponderosa pine savannas occur on approximately 1.6 million acres on Colorado's Front Range and in southwestern Colorado.

SUBALPINE SPRUCE-FIR FORESTS

The Rocky Mountain Region can lay claim to many natural wonders, and one of them is the world's largest agricultural alpine valley. Located in southwestern Colorado, the San Luis Valley is also one of the world's largest high deserts that is located near mountains. Much of this valley can be found within the Rio Grande National Forest and its four wilderness areas. Covering nearly 1.9 million acres, the Rio Grande National Forest is known for its fall colors, panoramic views, a National Scenic Byway, a ski area and more than half a million acres of spruce-fir forests.

Also found to the north in Colorado and Wyoming, spruce-fir forests

Spruce-fir ecosystems are sensitive to warmer temperatures and drought and to disturbances such as insect outbreaks and fire that could be exacerbated by warming and drying.

SUBALPINE SPRUCE-FIR FORESTS

CLIMATE VULNERABILITY: MODERATE

FACTORS:

- **Exposure.** Warming temperatures in winter and spring are expected to contribute to early snowpack melt and a longer growing season, both of which could cause moisture stress during the late growing season.
- **Sensitivity and adaptability.** Spruce-fir ecosystems are sensitive to warmer temperatures and drought, and to disturbances such as insect outbreaks and fire that can be made worse by warming and drying.
- **Shift capacity.** Where moisture availability and site conditions allow, spruce and fir trees may spread north or into higher elevations. However, less space is available at higher elevations.
- **Non-climate stressors.** Harvesting, road development and mining have affected forest structure and composition, as well as landscape patterns. Future trends in recreation, atmospheric nitrogen deposition and dust-on-snow may impact ecosystem processes and species composition.

Future climate conditions may lead to increased insect outbreaks and drought in subalpine Spruce-fir forests such as those in Glacier Lakes Ecosystem Experiments Sites in Wyoming. High summer temperatures can allow spruce beetles to complete a generation in a single year rather than in two years, translating to significant beetle population growth (Photo B. Cooke).

ecosystems have a cold climate year-round, with frost possible at any time. Year-round wildlife can include red squirrels, chipmunks, snowshoe hares, American martens and, in Colorado, reintroduced Canada lynx. Larger mammals such as elk, bighorn sheep, black bear and moose can be found during the summer, while bird species include white-tailed ptarmigans and migratory flycatchers and hummingbirds.

In recent years, the Rio Grande National Forest and its subalpine spruce-fir ecosystems have experienced drought, major fires and a spruce beetle epidemic. Non-climate stressors are relatively limited, but include roads, localized mining impacts, atmospheric nitrogen deposition and historical fire suppression. According to Jose Negron, a research entomologist for the Rocky Mountain Research Station in Fort Collins, "We're studying the interactions between fire and spruce beetles — mainly changes in the frequency and severity of outbreaks, and the role of drought in triggering these outbreaks. The second thing we're looking at is recovery and revegetation patterns following an outbreak. Climate change can play a role in the intensity and frequency of drought, which can stress the trees."

This ecosystem type, which can be found across about 4.5 million acres in Colorado and Wyoming, was given a climate vulnerability rating of "moderate" by the research team, which cited moisture stress from a longer growing season, as well as continued sensitivity to fire and insect outbreaks. Spruce and fir trees are expected to spread north or onto higher elevations

Since these ecosystems are often found in unconnected mountaintop locations, plant and animal migration potential is often limited.

with warming temperatures, but challenging conditions may follow them. As Negron explains, "There's a lot we still don't know. We're expecting some of these trees to retract in distribution, but the question is whether the insects will adjust in distribution as well. It's likely that they will, because insects tend to adapt quickly because of their short life cycle. Overall, we need to be able to adjust to a changing environment."

ALPINE TURF AND DWARF-SHRUBLANDS

Tucked away in the Medicine Bow Mountains west of Laramie, Wyoming, lies a Forest Service research site with high-elevation lakes, wetlands, meadows and forest. Called the Glacier Lakes Ecosystem Experiments Site — or GLEES — it's beautiful, remote and often exceptionally windy. It's also relatively untouched by human impact, which makes it highly valuable for scientists looking to compare its relatively undisturbed conditions to other high-elevation areas in the Rocky Mountain region. Located on the edge of timberline, GLEES includes areas with alpine turf and dwarf-shrubland.

In this Rocky Mountain Region ecosystem, the year-round temperatures are cold, the growing season is short, and high winds can dry out the soil and plants. Temperatures and moisture levels can change significantly over short distances. Despite these conditions — and also because of them — these ecosystems have a rich mixture of plant and animal diversity: Low perennial grasses and sedges give way to mat-forming forbs, which exist alongside voles, pikas and marmots, along with elk, big horn sheep, hummingbirds and butterflies during the short summer season.

Covering less than 1 percent of the entire Rocky Mountain Region, this is an ecosystem type that researchers have classified as highly vulnerable to disruption from climate change. It's seen as vulnerable to warming temperatures year-round, potential early snowmelt, and higher variability in terms of spring and fall freezes.

According to Kate Dwire, scientist in charge at GLEES, "We're definitely seeing a long-term

Alpine turf and dwarf shrubland ecosystems such as those found at Glacier Lakes Ecosystem Experiments Sites are considered vulnerable to warming temperatures, potential early snowmelt, and more erratic spring and fall freezes (photo J. King, University of Wyoming).

Dust on snow can further enhance the melting of snow in addition to already expected increased rates of snowmelt as a consequence of warmer spring conditions. Snowpits, like the one pictured above in Senator Beck Basin on the San Juan National Forest, enable scientists to track distinct dust on snow events. This work is part of ongoing study by the Center for Snow and Avalanche Studies (CSAS) and the Colorado Dust-on-Snow program, an applied science effort on behalf of Colorado and regional water management agencies (Photo courtesy of the Center for Snow and Avalanche Studies).

warming trend through our studies -- specifically how warm the summers are. We're starting to see a little bit of woody encroachment by conifers, which is being seen in other alpine situations around the world, including the Alps in Europe and Glacier National Park in Montana."

These areas have high plant diversity and variety in terms of community structure. However, these areas are slow to recover from disturbances such as road and trail building, water and wind erosion, fire, and trampling from recreation. Pikas, birds and animals that moult, and plant communities in these ecosystems are considered highly vulnerable to disturbance and climate change. And since they are often found in unconnected mountaintop locations, plant and animal migration potential is limited. In the meantime, these ecosystems may be subject to tree encroachment from lower elevations. According to Dwire, "As a result of these changes, alpine areas could be restricted in area. Plant and animal species composition could also change as a result of different season lengths."

ALPINE TURF AND DWARF-SHRUBLANDS

CLIMATE VULNERABILITY: HIGH

FACTORS:

- **Exposure.** These ecosystems are seen as vulnerable to warming temperatures year-round, potential early snowpack decline, and higher variability in timing of spring-fall freezing events.
- **Current extent.** These ecosystems cover less than 1 percent of the entire Rocky Mountain Region.
- **Sensitivity and adaptability.** These ecosystems are very slow to recover from disturbances. Warmer temperatures and loss of winter snowpack cover are expected to stress plants and animals, while interference with plant and pollination could lower successful plant reproduction.
- **Shift capacity.** Since these ecosystems are often found in unconnected mountaintop locations, plant and animal migration potential is often limited. These ecosystems may also be subject to tree encroachment from lower elevations.
- **Non-climate stressors.** Past and current uses include livestock grazing, mining, roads and recreation, although impacts are often limited due to remote locations. These areas are also subject to air quality issues such as nitrogen deposition and dust-on-snow.

GREAT PLAINS STREAMS AND RIPARIAN AREAS

The Purgatoire River in southeastern Colorado is one example of a Great Plains river that, along with its many tributaries, faces possible disruption from climate change. This river runs through the Comanche National Grassland, with its canyons, steppes, shortgrass prairie and privately owned tracts of ranchland mixed in with government-

Climate change is expected to reduce patches of perennial habitat along stream networks in Rocky Mountain Region national grasslands, making it difficult for Great Plains plants and animals such as plains topminnows to move along riparian corridors (photo by Lindsay Vivian, U.S. Fish and Wildlife Service).

managed land. Cottonwoods and willows can be found near streams, with a variety of plant and animal life in the canyons. Wildlife ranges from pronghorns to prairie dogs, and more than 325 bird species have been recorded here.

Lindsay Reynolds, who works with the U.S. Forest Service's National Stream and Aquatic Ecology Center, describes the area this way: "The Purgatoire has an upstream dam that collects snowmelt but it also has unregulated tributary inputs that help maintain flood flows in the summer and late fall. It also has a long history of human impacts from ranching, grazing and military use of the land by the Department of Defense at Fort Carson's Piñon Canyon Maneuver Site."

Reynolds says the main climate-related issue here is water flow levels. She explains, "There's a concern that a changing climate could result in reduced snowmelt and runoff and also increased water flows from quick, intense storms. This can cause riparian plants to become scoured out. Scouring can be good in the short term because it provides an opportunity for more trees to establish, but it can be bad in the long run because fewer trees will grow to reach maturity and provide the shade needed for the

Increasing water temperatures and declining flow are expected to fragment aquatic habitat and reduce plants' and animals' ability to move along riparian corridors.

Higher water temperatures and lower flows are expected to fragment aquatic habitat in southeastern Colorado's Purgatoire River on the Comanche National Grassland and other Great Plains waterways. Great Plains streams that are considered very highly vulnerable to climate change and highly fragmented land ownership, continued non-climate stressors such as grazing and agriculture (photo D. Merritt).

GREAT PLAINS STREAMS AND RIPARIAN AREAS

CLIMATE VULNERABILITY: VERY HIGH

Factors:

- **Exposure.** Warming temperatures, reduced flows in streams and stream flow changes could interfere with existing natural processes.
- **Current extent.** Perennial and intermittent streams and rivers on national forests and grasslands lands within the Great Plains area of the Rocky Mountain Region include more than 13,000 miles — a relatively small portion of the Rocky Mountain Region.
- **Sensitivity and adaptability.** Increasing water temperatures and declining flow are expected to fragment aquatic habitat and reduce plants' and animals' ability to move along riparian corridors.
- **Shift capacity.** Opportunities for shifts to cooler northward latitudes are limited.
- **Non-climate stressors.** Livestock grazing, row-crop agriculture, planted pasture, urban areas, roads, dams and reservoir development, and energy development have reduced riparian areas, compacted soils, altered biotic communities, destabilized channels and introduced undesirable plants.

At the highest elevations, plants and animals in these ecosystems have nowhere to go, with most having no connection to higher landscapes.

current riparian ecosystem to survive."

Across the eastern part of the Rocky Mountain Region, this ecosystem type covers more than 13,000 stream miles. Because their hydrology is mainly influenced by local precipitation and groundwater availability, these riparian areas can have water flows that range from seasonal flooding to periodic or seasonal drought. In some cases, this variability can create harsh conditions that are already near some species' tolerance limits. In many cases, these areas already face human-caused disruptors such as livestock grazing, agriculture, roads, dams, pollution, drilling, groundwater pumping and invasion by tamarisk, cheatgrass, Asian carp and American bullfrogs.

Many of the plants and animals inhabiting these environments have evolved strategies to successfully survive and reproduce. However, the risk of reduced water flow and higher temperatures — and the resulting impact to native plants and animals — caused the Forest Service research team to give these ecosystems a climate vulnerability rating of "very high."

According to Reynolds, "These areas are important as water-rich places for riparian trees and shrubs and as places that provide habitat for mammals, birds, fish and other creatures. In the Great Plains region in particular there's a risk that some riparian areas may dry up partly or completely, which obviously would affect the riparian ecosystem. In addition, with climate change you run the risk that human-caused ecological impacts that are already affecting these areas will be made even worse."

AQUATIC, RIPARIAN AND WETLAND ECOSYSTEMS IN GLACIATED VALLEYS

Located in Shoshone National Forest, the Fitzpatrick Wilderness boasts Wyoming's highest peak and 44 active glaciers. It contains alpine meadows, rocky plateaus and virgin timber stands. Steep canyon walls and granitic cirques tower over rocky streams and more than 60 crystalline lakes. This is one of the most remote backpacking destinations in the conterminous states, with some spots as much as 20 miles from the nearest trailhead. This wilderness area also includes many "glaciated valleys" — U-shaped troughs that are formed by the glaciation process.

Wyoming's Shoshone National Forest is home to the Fitzpatrick Wilderness and dozens of glaciated valleys. These ecosystems were rated as very highly vulnerable to climate change based on expected glacial retreat, reduced annual snowpack and earlier snowmelt as a result of warming temperatures (photo U.S. Forest Service).

AQUATIC, RIPARIAN AND WETLAND ECOSYSTEMS IN GLACIATED VALLEYS

CLIMATE VULNERABILITY: VERY HIGH

FACTORS:

- **Exposure.** Warming temperatures, particularly in winter and spring, are expected to cause glacial retreat, reduced annual snowpack and potential early snowmelt, especially at lower elevations.
- **Current extent.** These areas account for a small fraction of area in the high-elevation mountain valleys of Colorado and Wyoming.
- **Sensitivity and adaptability.** These ecosystems are highly dependent on snow levels. Lower stream flows, drying ponds and lower water tables will stress aquatic and wetland plants and animals.
- **Shift capacity.** At the highest elevations, plants and animals in these ecosystems have nowhere to go.
- **Non-climate stressors.** Mining, livestock grazing, and road, trail and infrastructure development affect water quality, as well as water flow patterns in these broad valleys. Atmospheric nitrogen deposition and dust-on-snow also affect snowpack and water chemistry.

Rocky Mountain Research Station researchers collect environmental DNA samples to identify fi sh and other species of interest in glaciated valleys, which are considered highly vulnerable to rising stream temperatures and other stressors (Photo D. Isaak).

Aquatic, riparian and wetland ecosystems in glaciated valleys like those in the Fitzpatrick Wilderness cover only a small fraction of the Rocky Mountain region. The climate in these valleys is harsh, with a short growing season, high snowfall, cold temperatures and high winds that can cause drying. Yet these valleys provide important and unique habitats for cold-adapted plants and animals such as cutthroat trout and the boreal toad.

These relatively fragile and usually unconnected ecosystems received a very high vulnerability rating from climate researchers, for several reasons. Warming temperatures are expected to cause glacial retreat, reduced annual snowpack, lower water tables and earlier snowmelt, especially at lower elevations. And although many of these valleys are remote and seldom visited by humans, they are also vulnerable to increasing recreational use and air pollution.

According to Dan Isaak, a fisheries scientist for the Rocky Mountain Research Station in Boise, Idaho, “Stream temperatures strongly affect the distribution and abundance of fish, amphibians, mussels and macroinvertebrates throughout all aquatic landscapes in the Rocky Mountains. As stream temperatures increase for the foreseeable future this century, species will be forced to shift upstream as they track thermally suitable habitats. This may place some populations in peril of continued existence.”

LOW-GRADIENT MOUNTAIN STREAM REACHES

Located in north-central Colorado, the Cache la Poudre River Canyon — or "Poudre Canyon," for short — has been described as a hidden treasure, with rugged cliffs and rock formations surrounded by ponderosa and lodgepole pines, sagebrush and aspen. The canyon runs through the Roosevelt and Arapaho National Forests on its way to the communities of Colorado's northern Front Range. The canyon also includes part of a National Scenic Byway, numerous hiking trails and the Poudre River itself — Colorado's only nationally designated Wild and Scenic River. As such streams and rivers run from alpine areas to the plains, the terrain can be steep, with water cascading rapidly down narrow, V-shaped valleys. In other areas, the terrain can be relatively flat, with streams and rivers running through wider, U-shaped valleys and sometimes meandering across the landscape. Streams in these relatively flat valleys are called low-gradient streams. These wider valleys support a variety of plants, animals and fish.

Just a few years ago, the Poudre Canyon gained fame for another reason: The High Park fire. This wildfire, which burned more than 87,000 acres during the summer of 2012, was the second-largest fire in Colorado history by area burned. It destroyed around 300 homes and caused the river to run black with soot. When this kind of event occurs, erosion from the upper watershed rapidly moves through the steep areas but can settle in the low-gradient valleys.

Warmer, drier conditions are expected to increase the frequency and extent of high-intensity fires like the 2013 High Park Fire in Roosevelt National Forest. Such fires can damage downstream ecosystems in low-gradient streams (Photo: B. Wudtke, CFRI).

LOW-GRADIENT MOUNTAIN STREAM REACHES

CLIMATE VULNERABILITY: VERY HIGH

FACTORS:

- **Exposure.** Earlier local snow melting and more frequent fire and flooding could increase debris flow. At lower elevations, warming temperatures may reduce aquatic species diversity.
- **Current extent.** Only 11 percent of all stream lengths on national forest lands in the Rocky Mountain Region are classified as low-gradient mountain streams.
- **Shift capacity.** Low-gradient stream reaches and their floodplains have a constrained capacity for network range shifts. Higher temperatures and reduced flows may fragment individual stream reaches and restrict fish movement.
- **Non-climate stressors.** Many stream reaches have yet to recover from past human activities such as beaver trapping, placer mining, logging, road and railroad development, domestic livestock grazing, and water development and diversion. Ongoing stressors include recreation, wildlife and agricultural grazing, and roads and land use development.

According to Jill Oropeza, water quality services manager for the nearby City of Fort Collins, "The

High Park fire resulted in literally tons of ash and sediment being deposited into the river channel. In the upper reaches of the Poudre River watershed, the fire sediments caused severe impairment of water quality and a temporary loss of a key drinking water supply. However, it was the downstream reaches, where lower flows prevail, that the most significant deposition of fire sediments occurred. Had it not been for the 2013 flood which effectively scoured the river channel, these sediment banks would likely have become established with vegetation, a process that can lead to a constricted river channel with a diminished ability to convey flood waters."

Vulnerability to fire-related sediment is one of many climate-related risk factors faced by low-gradient mountain stream reaches in the Rocky Mountain Region. Other risk factors include an increased likelihood of flooding and drought, as well as non-climate stressors such as land development, grazing, invasive species, recreational use and water development and diversion.

These are among the reasons why Rocky Mountain Region specialists

Many Rocky Mountain Region stream reaches have yet to recover from human activities from the mid-1800s to the early 1900s.

Increasingly frequent fires and floods can destabilize streambanks and cause debris flows like the ones that occurred along the Cache la Poudre River in 2013, following the High Park Fire. These events can damage aquatic habitat and water quality (photo L. Mouttet, City of Fort Collins).

rated this ecosystem category's vulnerability to climate change as "very high."

Oropeza explained that the Poudre River and other rivers along Colorado's Front Range already experience the pressures of regional urban development and a growing demand for water. Climate change may complicate matters even further. As Oropeza says, "Climate changes present yet another layer of potential stressors that can limit a river's ability to rebound from future disturbances."

KEY FINDINGS

- During the 20th century, the mean annual temperature in all five Rocky Mountain Region states rose between 1 and 2 degrees Fahrenheit; all five states are expected to experience historically unprecedented warming during the 21st century.
- Ponderosa pine woodlands and savannahs were rated as moderately vulnerable to climate change. While ponderosa pine ecosystems are widespread, ponderosa seed and seedling production is highly dependent on temperature and precipitation conditions. Non-climate stressors include beetle epidemics and severe fire.
- Subalpine spruce-fir forests were rated as moderately vulnerable, based on factors such as expected late-season moisture and insect outbreaks and fire that can be made worse by warmer, dryer conditions.
- Alpine turf and dwarf-shrublands were rated as highly vulnerable, based on factors such as limited shift capacity and extent, potential early snowpack decline, and sensitivity to variations in spring/fall freeze timing.
- Great Plains streams and riparian areas were rated as very highly vulnerable, based on factors such as limited shift capacity and extent, potential reduced water flows and increasing levels of human use.
- Aquatic, riparian and wetland ecosystems in glaciated valleys were rated as very highly vulnerable, because of limited shift capacity and extent, glacial retreat, and potential reduced stream flows.
- Low-gradient mountain stream reaches were rated as very highly vulnerable, with expectations of debris flow increases from more frequent fires and flooding, along with often extensive human use and development.

Photo by J. Rice

FURTHER READING

Halofsky, Jessica E.; Peterson, David L.; Ho, Joanne J.; Little, Natalie, J.; Joyce, Linda A., eds. 2018. Climate change vulnerability and adaptation in the Intermountain Region [Part 1 and Part 2]. Gen. Tech. Rep. RMRS-GTR-375. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 1-197.
https://www.fs.fed.us/rmrs/publications/climate-change-vulnerability-and-adaptation-intermountain-region-part-1
https://www.fs.fed.us/rmrs/publications/climate-change-vulnerability-and-adaptation-intermountain-region-part-2

Halofsky, Jessica E.; Peterson, David L.; Dante-Wood, S. Karen; Hoang, Linh; Ho, Joanne J.; Joyce, Linda A., eds. 2018. Climate change vulnerability and adaptation in the Northern Rocky Mountains [Part 1 and Part 2]. Gen. Tech. Rep. RMRS-GTR-374. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 1-273.
https://www.fs.fed.us/rmrs/publications/climate-change-vulnerability-and-adaptation-northern-rocky-mountains-part-1
https://www.fs.fed.us/rmrs/publications/climate-change-vulnerability-and-adaptation-northern-rocky-mountains-part-2

Rice, Janine; Tredennick, Andrew; Joyce, Linda A. 2012. Climate change on the Shoshone National Forest, Wyoming: a synthesis of past climate, climate projections, and ecosystem implications. Gen. Tech. Rep. RMRS-GTR-264. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 60 p. https://www.fs.fed.us/rmrs/publications/climate-change-shoshone-national-forest-wyoming-synthesis-past-climate-climate

Rice, Janine R.; Joyce, Linda A.; Regan, Claudia; Winters, David; Truex, Rick. 2018. Climate change vulnerability assessment of aquatic and terrestrial ecosystems in the U.S. Forest Service Rocky Mountain Region. Gen. Tech. Rep. RMRS-GTR-376. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 216 p. https://www.fs.usda.gov/treesearch/pubs/56392

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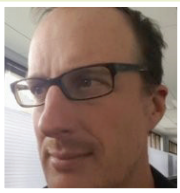

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SYCU

SCIENCE YOU CAN USE BULLETIN

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The purpose of the Science You Can Use Bulletin: To provide scientific information to people who make and influence decisions about managing land.

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