Scope, Setting, and Purpose of the Colorado Front Range Climate Change Vulnerability Assessment for National Forests

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Scope

The Rocky Mountain Region of the U.S. Department of Agriculture, Forest Service requested a climate change vulnerability assessment from Rocky Mountain Research Station in support of future forest plan revision for the Pike-San Isabel National Forests (PSI) and Arapaho-Roosevelt National Forests (AR) in the Rocky Mountain Region. Iterative conversations among the Rocky Mountain Research Station, the PSI and AR National Forests, and the Rocky Mountain Region identified management concerns for high-priority resources that were used to frame a scientist-manager workshop and this climate change vulnerability assessment. A workshop held during November 13–14, 2019, was structured around these priority resource areas and participants included PSI and AR specialists, Rocky Mountain Regional Office program managers, and Rocky Mountain Research Station staff. Workshop presentations included climate change scenarios, discussion of consequences of changes for priority natural and socioeconomic resource areas, and development of corresponding adaptation strategies (Timberlake et al. 2024). Results from the workshop and this climate change vulnerability assessment will help inform upcoming land management plan revisions, as well as project-level work being completed on the PSI and AR National Forests.

This climate change vulnerability assessment summarizes effects of climate change on the PSI and AR and surrounding extent of the Front Range in the southern Rocky Mountains. Here, for this introductory chapter and background for this publication, we provide context for the Front Range region and the role of vulnerability assessments in supporting climate change adaptation. The following overview chapter integrates general issues addressed in all the chapters (Hanberry 2024). Chapters encompass climate and climate change (Rangwala 2024), water resources and fisheries (Smith 2024), trees (Fornwalt et al. 2024), birds (White 2024), citizen involvement in monitoring (Fairchild and Hanberry 2024), insects and disease (Negrón 2024), fire risk (Karau et al. 2024), infrastructure and flooding (Hanberry et al. 2024), ecosystem services (Warziniack et al. 2024), recreation (Sánchez et al. 2024), and a summary of the applications for this assessment (Timberlake et al. 2024).

As subsequent chapters describe, climate change effects on hydrology, ecology, and wildland fire contribute to a complex and rapidly changing management environment. Climate change also will interact with social and environmental drivers, causing either compounding or conflicting changes to the ecosystems and communities of the Front Range (Mora et al. 2018). These interacting influences will shape how climate change impacts manifest and what adaptation activities can be implemented (Peterson et al. 2011). In some instances, long-standing and management practices that maintain or restore resources will help sustain species and ecosystems in the face of climate change (Keane et al. 2018). Other situations will require new or modified management and monitoring strategies to ensure success and improved resilience of ecosystems and communities (Fairchild and Hanberry 2024; Keane et al. 2018). Adoption of new technologies such as low-carbon energy and energy efficiency for Forest Service infrastructure, such as rooftop solar, electric vehicles, and heat pumps help mitigate climate change (Hanberry et al. 2024).

Setting

The Front Range region is located in central Colorado, where the Great Plains, at 5,000 feet (1,550 m) in elevation, meet the Rocky Mountains, rising over 14,000 feet (4,300 m) in elevation (fig. 1). As elevation increases, ecosystems transition from grasslands and shrublands associated with the Great Plains to montane and subalpine forests, with alpine tundra occupying areas above tree line. Prevailing winds originating from the west release the majority of Colorado's precipitation on the mountains and western-facing slopes during winter months (Veblen and Donnegan 2005). Moisture from the Gulf of Mexico can produce heavy precipitation events on the eastern slope of the Continental Divide, especially during the growing season (Veblen and Donnegan 2005). Much of the State's population, and water demand for municipal purposes, resides east of the Continental Divide in an urban corridor of flat land along the Front Range of the Rocky Mountains (Smith 2024).

For the purposes of this assessment, the Colorado Front Range encompasses the entire extent of our focus area, the AR and PSI, including the area west of the Continental Divide where most of Colorado's water flows. The PSI covers approximately 2.2 million acres (890,000 ha) and the AR another 1.3 million acres (525,000 ha). The PSI and AR span key watersheds that provide water for eastern Colorado's communities and agricultural producers (Smith 2024; Warziniack et al. 2024). The PSI and AR also are highly valued for the recreational opportunities that they provide to a rapidly growing Colorado Front Range population and out-of-state and international visitors (Sánchez et al. 2024; Warziniack et al. 2024). The forests generally are adjacent to other public lands and protected areas, including the Rocky Mountain National Park, and privately owned land. Overall, dry climate and shallow, undeveloped montane soils produce low site quality and vegetation growing conditions (Addington et al. 2018). More detailed descriptions are available in land and resource management plans (Arapaho-Roosevelt National Forests and Pawnee Grasslands 1997; Pike-San Isabel National Forests and Cimarron and Comanche National Grasslands 1984).

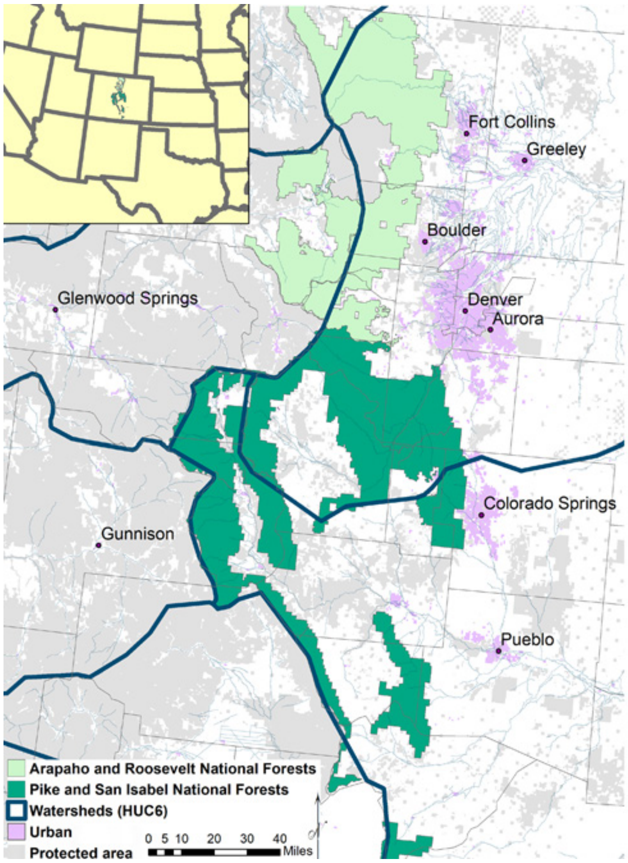

Figure 1—The setting for the Front Range region in central Colorado, including the Arapaho and Roosevelt National Forests and Pike and San Isabel National Forests; watersheds (at the scale of small river basins, HUC6); protected areas; and urban population densities.

The national forests of the Front Range have a complex history of past land-use patterns. Native Americans managed forests with fire as a tool, which controls tree densities, resulting in largely timberless landscapes with limited forests on the eastern side of the Continental Divide comprised predominantly of ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) at lower elevations and Engelmann spruce (*Picea engelmannii*) at higher elevations, according to the first published assessment (Jack 1900). Benefits of this structure include reduced risk of extensive high-severity fires and support of biodiversity of open forest ecosystems, such as herbaceous plants and pollinators (Hanberry and Dumroese 2020; Keane et al. 2018). Euro-American colonization of the Front Range during the second half of the 19th century resulted in logging and grazing, followed by fire exclusion in the 20th century (Veblen and Donnegan 2005). Fire suppression is no longer the exclusive fire management strategy and there is growing recognition of the role of fire, including prescribed burning and management of natural ignitions by managers and communities (Karau et al. 2024; Urza et al. 2023). These forests, however, continue to face challenges associated with the increasing amount of fire along the Front Range, like elsewhere in the West, due to the large human population and high intermix of homes within and close to national forests (Addington et al. 2018; Schultz et al. 2019).

In the drier forest types found at lower elevations in the Front Range, the product of these legacy effects is substantially denser stands than those that occurred before Euro-American influence, altering fire behavior and increasing risk of fire severity (Addington et al. 2018; Battaglia et al. 2018; Keane et al. 2002). The mountain pine beetle outbreak that occurred during the 2000s also affected the forests of Colorado (Abrams et al. 2017; Negrón 2024; Negrón and Cain 2019). Among the drivers contributing to this epidemic were greater basal area, as well as the effects of climate change, including drought that weakened trees' defenses and warmer winters that enabled rapid beetle reproduction (Abrams et al. 2017). Many areas impacted by pine beetle mortality have since burned in recent fires, and ecologists have highlighted complex interactions between beetle mortality and fire behavior and also postfire and postbeetle recovery (Jenkins et al. 2014).

During the past few decades, fires have increased in residential areas, which also have expanded to intermix with wildlands (Karau et al. 2024). In 1989, the Black Tiger Fire burned 44 homes and other structures in Boulder County; this fire was one of the first fires in the State to occur in the wildland-urban interface (Mockrin et al. 2015). In the Upper South Platte River watershed on the PSI, the Buffalo Creek Fire in 1996, the Hayman Fire in 2002, and the rainstorms following both of these events collectively highlighted the challenges that postfire erosion presents for the delivery of clean water to the downstream city of Denver (Huber-Stearns et al. 2019). Long-term ecosystem and watershed impacts from these fires are related to the vast areas that burned at high severities as well as warmer and drier climatic conditions unconducive to forest regeneration and reestablishment (Chambers et al. 2016; Rhoades et al. 2019; Stevens-Rumann et al. 2018). In June of 2012, lightning sparked the High Park Fire, which eventually would burn nearly 90,000 acres and over 250 buildings in areas on and around the AR west of Fort Collins (Miller et al. 2017). As the High Park Fire burned to the north, the Waldo Canyon Fire started a few miles outside of Colorado Springs, eventually burning into the city and destroying over 300 homes (Stratton 2012). The following year, 2013, brought record rainfall in northern Colorado, including in areas recently burned by the High Park Fire. All told, flooding in September 2013 accounted for over $2 billion of damages in Colorado (Gochis et al. 2015). The 2020 fire season further highlighted the stark challenges of managing forests in light of climate change and its effects on fire. In late summer and well into the fall, concurrent fires burned in northern Colorado on the AR, including the Cameron Peak and East Troublesome Fires. These two fires, along with the Calwood Fire in Boulder County, resulted in evacuation of residents, destroyed homes, and reduced air quality (Abbe et al. 2022). Population growth contributes to increasing development in the wildland-urban interface, which increases risks associated with fire and complicates efforts to mitigate these risks and manage fire (Hammer et al. 2009; Karau et al. 2024).

Colorado has experienced substantial population growth during recent decades, especially in urban communities along the Front Range, which is expected to continue (fig. 2; Warziniack et al. 2024). Population growth increases demand for water originating on national forests. A growing population likely will increase demand for recreational opportunities on public lands, which can lead to resource damage from overuse and can increase risks of wildfires ignited by humans (Karau et al. 2024; Sánchez et al. 2024). Land-use patterns, both historic and contemporary, also influence social vulnerability to natural disturbances and effects of climate change (Warziniack et al. 2024). The wildland-urban interface along the Front Range occurs both along the boundaries of National Forest System land and private land inholdings; many of these inholdings were historic mining claims (Calkin et al. 2014; Riebsame et al. 1996). Land use in more distant areas, including the urban corridor and agricultural lands farther east, also influence national forest management through their interactions with demands for water, recreation, air quality, and other ecosystem services offered by the Front Range national forests (Sánchez et al. 2024; Smith et al. 2024; Warziniack et al. 2024).

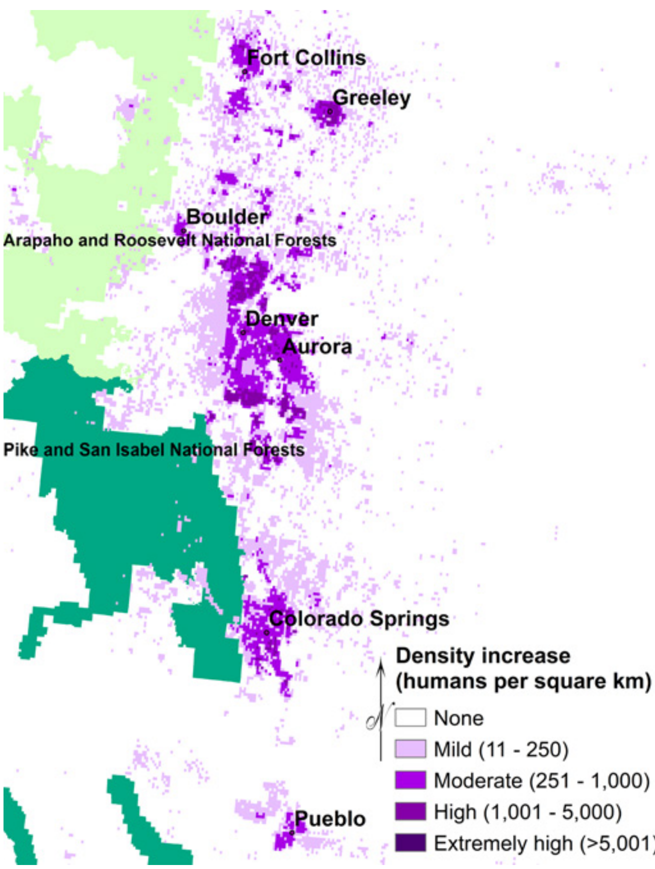

Figure 2—Location of population changes between years 2000 and 2020 (Data from WorldPop 2020).

Purpose of Climate Change Vulnerability Assessments

Climate is the long-term average of atmospheric conditions as opposed to short-term weather. Climate change is the departure of average climate conditions, such as mean temperature or average annual precipitation, that is statistically distinguishable from past climate (Keane et al. 2018). Climate change, as driven by anthropogenic greenhouse gas emissions, is already observable, and general circulation models (GCMs) are used to estimate future change (Keane et al. 2018; Schwalm et al. 2020). The GCMs project continued warming, but precipitation trends are more uncertain in magnitude and direction (increase, decrease, stable) of change (Foote 1856; IPCC 2021; Rangwala 2024). GCMs and downscaled climate data and models generate different spatial and temporal estimates, such as the number and location of extreme rainfall events (Rangwala 2024). Projected climate change also depends upon future socioeconomic changes and, thus, greenhouse gas emissions (Rangwala 2024). Uncertainty in projected climate change, similar to uncertainty in short-term weather forecasts, is not equivalent to a lack of knowledge but represents the best available science. Projections from different GCMs and emissions scenarios offer a way to evaluate and plan for multiple potential futures.

Vulnerability assessments, such as this one, document recent climate and projected climate change and help inform how changes might affect natural resources, and thus serve as the basis for designing strategies for adapting to climate change. Vulnerability, or a version of risk, is a function of exposure to change in climatic conditions, sensitivity to that change, and adaptive capacity (Glick et al. 2011). There are a variety of vulnerability assessment approaches, which can include confidence assignments based on qualitative synthesis of the literature and expert opinion, for example, ranging from high (trends seem clear, evidence supports conclusions), through medium (some evidence supports conclusions), to low (trends are unclear, evidence is lacking) confidence (Colorado Natural Heritage Program 2015).

Vulnerabilities for resources result from direct exposure to climate change or altered timing of annual events and indirect sensitivities to changed interactions or disturbances (Fornwalt et al. 2024; Smith 2024; White 2024). Increased vulnerability occurs in species at the edge of their climatic range in latitude or elevation (Fornwalt et al. 2024; Keane et al. 2018). Altered timing of cyclical biological events, such as spring bud burst, overwintering emergence, and annual migration, may result in a mismatch between needs of species and available resources; for example, food sources may not be abundant during annual migration (White 2024). Changed conditions may favor competitors, damaging insects, or diseases while reducing water, forage, cover, and breeding opportunities (Fornwalt et al. 2024; Keane et al. 2018; White 2024). In addition, climate change amplifies effects from natural disturbances of fire, insects, and other stressors such as extreme weather events and land and water use, which may increase species and ecosystem vulnerabilities to climate change (Fornwalt et al. 2024; Keane et al. 2018; Negrón 2024; Rangwala 2024; Smith 2024; White 2024). Specific sensitivities may include poor dispersal ability or barriers to dispersal, such as low connectivity of suitable habitat (Fornwalt et al. 2024; Smith 2024; White 2024). Climate change may allow expansion of generalist and nonnative species, with traits of strong dispersal ability, rapid growth rates with short generation times, and great capacity to tolerate broad and changing environmental conditions (Glick et al. 2011; Keane et al. 2018). Species may respond to habitat changes by shifting with climate space or adapting within their current range, with some change in abundance, or by decreasing in isolated and increasingly contracting refugia, such as alpine meadows (Fornwalt et al. 2024; Hanberry and Fraser 2019; Smith 2024; White 2024). Over longer time periods, vegetation shifts may disrupt current ecosystems as species respond uniquely in distribution and abundance (fig. 3; Davis and Shaw 2001).

Figure 3—Floral resources may be reduced or not available at the correct time due to climate change (Courtesy photo by P. Hanberry).

Vulnerability assessment and adaptation workshops are useful for exploring implications of climate change to determine climate-informed management actions. During our Colorado Front Range workshop, scientists presented climate futures and participants described the potential implications for resources based on contemporary science and subject-matter expertise, focusing on management concerns in different resource disciplines (e.g., vegetation, wildlife, water) or ecosystem types. Later, managers and scientists discussed potential adaptation options to meet management goals, objectives, and planning needs under these climate-resource scenarios. In general, intentional integration of climate change considerations into management strategies is more likely to be successful compared to assuming an unchanging climate at achieving desired outcomes and meeting management goals (Keane et al. 2018; Timberlake et al. 2024).

Climate change adaptation strategies can be integrated into management and planning, and following an adaptive management process, be updated as needed based on monitoring or advances in science and practice. Adaptation is the adjustment of systems in response to climate change and means adapting to today's changed climate conditions and predicted future conditions, rather than relying on past experience (Keane et al. 2018). Nonetheless, continuing to manage resources and mitigate non-climate stressors will support natural resources under climate change (Keane et al. 2018). Adaptation resources are available to help land managers integrate climate change information into land management planning and decisionmaking, including, for example, the Climate Change Resource Center (USDA FS 2022), Climate Change Response Framework (Swanston et al. 2016), and climate change vulnerability and adaptation assessments (for example, Halofsky et al. 2018).

Land management plan revisions are a key venue for addressing climate change, but climate change considerations are also relevant to other types of strategic planning and project-level planning and implementation (Timberlake and Schultz 2019). The 2012 Planning Rule requires planning teams to consider climate change as a system stressor and driver when developing plan components for ecological integrity and for providing multiple uses (USDA FS 2012). Climate change vulnerability assessments synthesize best available science that can directly inform the assessment phase and other phases of planning of planning and provide useful information for project planning. Managers can use information about climate vulnerability of key resources to assess how planned management actions may help or hinder resource adaptation to climate change. Vulnerability information and subsequent adaptation strategies also can help managers plan activities to better support resources, species, and ecosystems in the face of climate stress.

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