Impacts of Climate Change on Post-Fire Forest Recruitment Rates in Colorado Front Range

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Introduction

Forest ecosystems are critical biomes, performing a nearly endless number of important ecosystem services, but in recent years their resiliency to fire disturbance has become increasingly threatened by climate change. Forests are responsible for many different functions like removing and storing carbon from the atmosphere, stabilizing soil, preventing flooding and erosion and they also act as hubs for biodiversity (Aznar-Sánchez et al., 2018; Luyssaert et al., 2008). Additionally, forests provide countless recreational opportunities and often hold a lot of cultural value for residents and visitors alike. Other aspects of a healthy forest are disturbance regimes, and resiliency, which is the ability and speed at which an ecosystem can recover after a major disturbance (e.g., fire). In a healthy and resilient forest, fire disturbances can enhance biodiversity by creating heterogeneity in the age of trees and create more niche spaces for pioneer and early succession plant species that are outcompeted over time. In some areas however, fire disturbance, in combination with changing climate conditions, has decreased the resiliency of forest ecosystems. Together, these two variables are rendering some areas no longer favorable for tree seedling establishment, and as a result, there is a reduction in the resiliency of the forest, leaving it vulnerable to abrupt changes in vegetative composition.

A more specific example of an affected forested area is the Colorado Front Range (CFR), which is located within the Southern Rocky Mountains subregion. After fire suppression management techniques pushed many forest types outside their regular fire regime—most notably the lower elevation montane ponderosa pine (*Pinus ponderosa*) forests—the increased frequency and severity of fires in this area have become progressively more destructive and difficult to recover from (Davis et al., 2019; Schoennagel et al., 2004; Stevens-Rumann et al., 2018). Additionally, climate change has led to drier, and hotter conditions. Tree seedlings are less adaptable than their mature counterparts to these harsher environmental conditions, making them vulnerable to many of the effects of climate change. Reduced seasonal summer precipitation in the CRF region has resulted in reduced seedling establishment because of drought-stress. The potential consequence of this decline in seedling recruitment is a future vegetation shift for forested areas to become a non-forested system, like a grassland, if there is no management intervention. Understanding the potential causes of this trend is important in assessing and effectively managing these areas.

Climate

Over the years, climate change has been measured in many different ways, but the main focus has been on changes in temperature, precipitation, and overall climate seasonality. Across the continuous U.S., the past 30 years has seen measurable changes in the mean temperature and precipitation values (NOAA, 2021). A comparison of trends from 1981-2010 to 1991-2020 shows an increase in mean temperature of +0.5°F. Changes in precipitation do vary across the country, but much of the western U.S. shows a trend of declining average precipitation.

The most common climate variables associated with western U.S., and specifically Colorado, fire activity, are reduced precipitation and increasing summer temperatures (Holden et al., 2018). Increased fire activity will create a bigger need for seedling recruitment to reforest burned areas, but the same climate conditions that increase fire activity also reduce moisture availability. Moisture availability is a critical component for seedling germination in any forest system, and reduced precipitation can leave germinating seedlings in drought stress conditions that they cannot tolerate.

When it comes to the Colorado Front Range, climate change is most notably observed in the form of drought conditions. The snowpack levels for Rocky Mountain National Park, a heavily studied forested area in the CFR, were reported to have small changes in overall winter precipitation over the studied 35-year period (1981-2016), and the summers have had warmer, drier conditions with an overall slight shift in the seasonality of weather patterns (Fassnacht et al., 2018). In the CRF, reduced summer precipitation, between the months of April to September, is associated with more severe fires and reduced seedling establishment (Holden et al., 2018; Rodman et al., 2020).

In addition to these hot and dry trends, the climate conditions of the CRF may be exacerbated by elevation-dependent warming, which is a hypothesis that suggests high elevation areas like mountainous regions could be experiencing accelerated warming (Pepin et al., 2015; Rangwala & Miller, 2012). One of the mechanisms behind elevation-dependent warming include a retreat of the snowline, where areas that were once covered in snow most of the year are no longer covered because of a decrease in snowpack or because of warm temperatures. Because of this, the solar radiation that once was reflected by the snow is now absorbed into the ground, adding more heat than usual into the environment. Another proposed mechanism of elevation-dependent warming is changes in cloud cover. Pepin et al. proposed that a decrease in daytime cloud coverage and an increase in nighttime clouds exposes high elevation areas to higher than usual amounts of solar radiation during the day. There is not a large body of conclusive evidence that supports the claim that this effect is occurring specifically in the Front Range yet, primarily because there is a lack of long-term meteorologic records in higher elevation areas and because the climate of mountain ranges is extremely variable because of differences in geomorphic features. These factors make it difficult to find strong evidence for global patterns of elevation-dependent warming. Despite the challenges, there have been some instances of successful observation, primarily across the Tibetan Plateau in Asia. Some experts are confident that elevation-dependent warming is occurring across the world, but further research and dedicated data-gathering is required to better understand how climate change and warming is affecting mountains in regard to these mechanisms specifically.

Overall, climate is a significant contributor to the health and diversity of an ecosystem. On a very broad and global scale, there are changes occurring in the climate worldwide, but mountainous, higher elevation areas are potentially experiencing an even more significant change. The Front Range continues to face some significant challenges that are caused by drought conditions. This poses a challenge because water availability is such a crucial resource for flora and fauna alike, and many of the natural cycles of forests, like fire, are impacted by changes in climate patterns.

Fire Disturbance

Colorado Front Range forests span a variety of fire regimes, and being able to assess the current conditions of these forests requires a comprehensive understanding of both the historic and current fire regimes. Some research has been able to reconstruct vegetative communities of areas within the CFR dating back more than 2,000 years ago, and two studies found that wildfires have always been a significant driver of vegetative changes but were secondary to the influence that a changing climate has on vegetation which can result in abrupt shifts in vegetation (Calder & Shuman, 2017; Chileen et al., 2020). This is because not only does climate affect vegetative communities directly, but it can also alter the disturbance patterns of an ecosystem as well. Additionally, as long as humans are a part of an ecosystem, they are also a part of that ecosystem’s disturbance regime. Humans have increased the number of wildfires that these forests experience, both purposefully for management, and on accident. One study found that 84% of all fires between 1992-2012 in the continuous U.S. were caused by humans (Balch et al., 2017). But there is also a rich history of different indigenous people groups managing and caring for their land through the practice of fires. Within the last few centuries, the technique of fire suppression, which is the practice of reducing and extinguishing every wildfire, was introduced to this area as the result of Euro-American settlement. This technique has often been blamed for pushing American forests, including the Front Range, outside of their natural fire regimes and is considered to be partially responsible for the observed increase in larger and more severe fires (Schoennagel et al., 2004). While this is partially true, particularly for low elevation ponderosa pine-dominated forests, higher elevation forests like lodgepole pine (*Pinus contorta*) and subalpine fir (*Abies lasiocarpa*) have not been as impacted (Ehle & Baker, 2003). These higher elevation forests have not experienced as significant of a change in their historic fire regime because they typically go through long periods with no burning, up to 500 years. During these long periods without burning, the forests slowly build up fuel through an accumulation of dead sticks and trees. When fires do occur, they are very severe and kill off most of the forest (Sibold et al., 2006). For these forests, both their fire regime and current forest conditions are generally considered to currently be within their historic range of variability. On the other hand, low elevation ponderosa-dominated forests historically burned much more frequently, but less severely. This is partially because the frequent fires will reduce the amount of fuel available for future fires, constantly clearing out any litter or dead tree limbs. In these ecosystems, the suppression of fire increased the amount of fuel which in turn has resulted in more severe fires, that cause more severe damage than the forest would have experienced previously.

Understanding historic fire regimes is a key component of effective management because it helps managers prioritize where intervention action is most needed. Schoennagel et al. (2004) criticized the one-size-fits-all approach that some managers had been taking in the Rocky

Mountain forests by using prescribed fires and mechanical thinning as a preventative measure against large, high-severity stand replacing fires across the region. These techniques, while effective for low-severity fire regimes like ponderosa pine-dominant forests, had no discernible effect on high-severity fire regimes that have severe burns, regardless of intervention methods. Instead, they advocated for management techniques that acknowledge and protect the heterogeneity of the Rocky Mountains while prioritizing areas that need the most remedial resources. Being able to reconstruct and reference historic conditions and regimes has informed researchers and practitioners alike to focus on ponderosa pine forests as a more vulnerable ecosystem.

Seedling Recruitment Rates

In order to study changes in forest health and resiliency after a disturbance, you have to be able to measure it. One commonly used proxy measurement of forest resiliency is the rate of seedling recruitment after a major disturbance like fire (Chambers et al., 2016; Davis et al., 2019; Kemp et al., 2016; Rodman et al., 2020; Rother & Veblen, 2016). Seedling recruitment rate is a comprehensive measurement of resiliency because it is the culmination of climate conditions, soil conditions, terrain, and historic forest composition. As mentioned earlier, disturbance is a natural and important part of forest health. There is always tree mortality occurring in forests from competition, falling over, insects, etc., and all of these factors contribute to a non-catastrophic background rate of tree mortality. Over the last few decades however, the background rate of tree mortality has significantly increased across the continuous U.S. (Allen et al., 2010; Van Mantgem et al., 2009). The rate of seedling recruitment, however, has not matched this increase in tree mortality which suggests a wide-scale change in forest composition, which can be potentially viewed as the cause or the result of vegetative shifts away from forested states in some areas.

What actually causes this mismatched rate of seedling recruitment is a more recent area of research. There are several factors that are considered strong predictors for whether a burn area will have sufficient seedling recruitment rates for recovery, or if the area will need active intervention to restore to pre-burn conditions. One of the major predictors for determining if a burn site will have adequate establishment or recruitment, is the distance from the nearest seed source, with one study finding 95m to be an estimated threshold (Kemp et al., 2016; Rodman et al., 2020; Rother & Veblen, 2016; Stevens-Rumann et al., 2018). This means that if a burned area is further than 95m from a seed source, the probability of adequate seedling establishment in that patch is significantly reduced. This is because coniferous seeds are not well adapted for dispersing large distances, which is why management intervention may be required in large, high severity burn sites that have patch interiors with no seed sources. Another important variable in seedling establishment is the number of drought years that follow the fire disturbance. This is especially notable because many models for predicting the future effects of climate change show that the variability of the climate can be expected to increase (Rodman et al., 2020). This will likely increase the number of consecutive drought-years, which would be unfavorable to forest recovery after a fire.

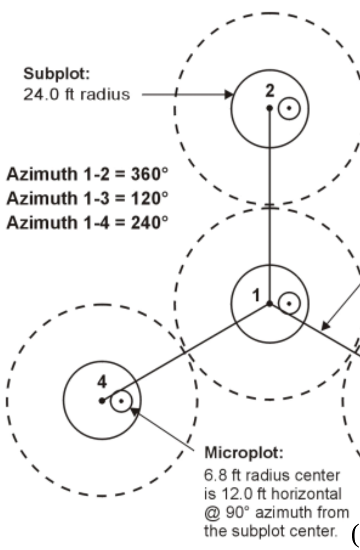
Predictions

A key uncertainty in this field is whether the result of changes in the climatic conditions of the CFR and subsequently a continued decrease in recruitment rates, could be a significant transition away from a forested state into a more grass-dominated biome. This is a special concern in some areas of Colorado but could also occur in forests across the country. Broad shifts in vegetation not only mean that current montane forests could be overrun by grasses, but that the current montane ecosystems may shift to ranges in higher elevations (Batllori et al., 2017). In theory, montane forests could move to a different area that has more fitting environmental conditions that correspond to the environmental conditions of their old range. In that case, it is possible that the function and biodiversity of these unique forests will not be lost due to climate change. Unfortunately, there are some significant barriers to "colonizing" these new areas into montane forests. The velocity of change in these areas is one of these major barriers. Trees are slow to establish, grow, and reproduce, often taking multiple decades. If environmental conditions change too quickly, then they will not be able to get established before the new area is no longer viable. Also, as previously discussed, having a seed source in a viable area is important, but will not likely be overcome without direct intervention. This is particularly true in especially steep sloped areas, where seeds would have to defy gravity in order to reach their desired area, or for areas that have no montane forests near them originally and would require a significant trek from an immobile coniferous cone to reach the new area.

Despite these challenges, many experts agree some kind of biome shift is extremely possible in the future There is a debate, however, on whether this shift is inevitable and worth embracing, and not fighting, or if intervention through management actions could successfully intervene and prevent a large-scale vegetation shift over the next 20-80 years (Batllori et al., 2017; Davis et al., 2019; Rodman et al., 2020). The reason for this debate is because there is often no singular answer for what a healthy ecosystem should look like, which can make ecosystems difficult to manage. Ecosystem health is often measured by its functionality, for instance, whether it can support a diverse collection of organisms. There are several ways to accomplish this however, with several different options for vegetative communities that could exist, that could support several different kinds of animal communities. Because of this, whether a once-forested site should be "allowed" to become a grassland in the future, depends on the goals for the land. For example, a patch of burned, once-forested land that is part of a federally run national park might be worth the time and money to intervene with transplanted seedlings, to ensure that it remains forested, for the sake of preserving its historic conditions for the public to enjoy. Conversely, the owners of private land that has suffered a severe fire might not be able or willing to invest the money or time to return it to its previous vegetative condition. Determining what the goals of the land are, is a helpful way to guide any restoration or management actions.

Original analysis

Methods - Every year, the U.S. Forest Service conducts thousands of surveys on forested plots to record and assess forest health from areas across the U.S. This collected data is publicly accessible, and practitioners and scientists can use this data to make informed decisions about forest management and future research priorities. In order to relate this backbone of scientific literature to real-world data, I looked at seedling establishment data in three Colorado counties that are located in the Front Range: Larimer, Boulder, and Grand counties. I used tree seedling data that was available through a publicly accessible database, the U.S. Forest Service's Forest Inventory and Analysis database (FIA), summarizing it and determining whether it agrees with the wider span of academic literature on this topic. The data I used was collected between 2002 and 2019, on the scale of a circular



(Burrill et al., 2018)

Figure 1: FIA plot design for forest survey data. Each plot is made up of four circular subplots.

subplot with a radius of 24ft (Figure 1). I wanted to see if there were any patterns in the distribution of seedling recruitment across the variables of elevation range, aspect, and tree species.

Results – The three counties had a total number of 281 plots, (Larimer n = 126, Grand n = 125, Boulder n = 30), and total subplot sample count of 1796. Using the latitude and longitudinal coordinates, each plot was graphed onto a map using Google Earth Pro (Figure 2). Next, the distribution of subplots across elevation was studied by making a histogram of the number of subplots in each elevation range (Figure 3). In this figure there is an uneven plot distribution across elevation, with a majority of subplots falling between the elevation range of between 8,000 to 10,000 ft. The next variable was aspect, which is the direction that the slope faces. When looking at aspect alongside the number of tree seedlings, there is an increase in the presence of seedlings in northern facing slopes, and a stark

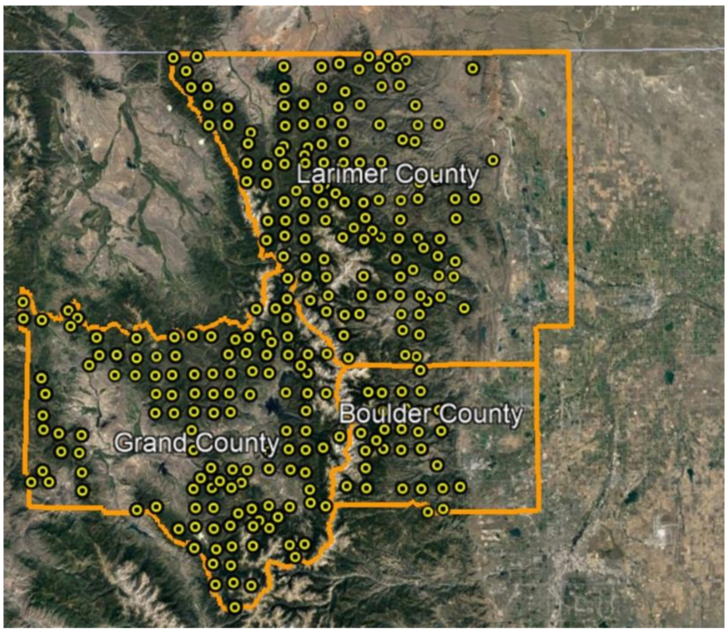


Figure 2: Map of plot distribution. Each yellow dot represents a plot, and the orange lines represent county lines.

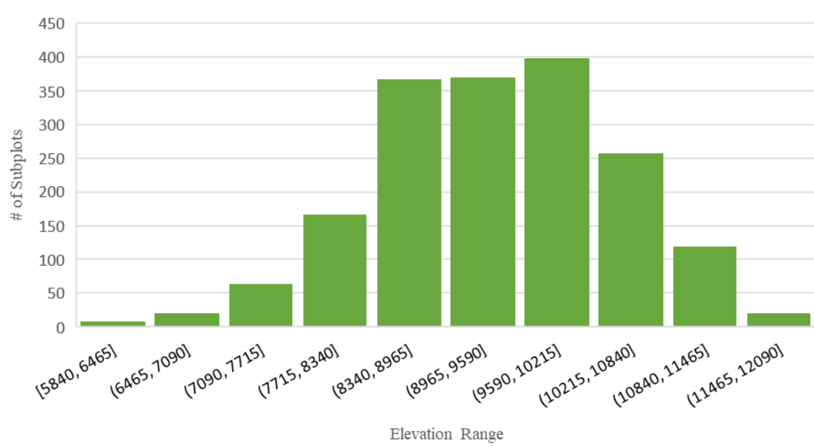


Figure 3: Histogram of elevation distribution for all subplots in dataset. Values range from 5840 ft to 12090 ft, with a majority in the 8,000ft-10,000ft range.

difference arises when the seedling count of northern and southern facing slopes are compared to each other (Figure 4).

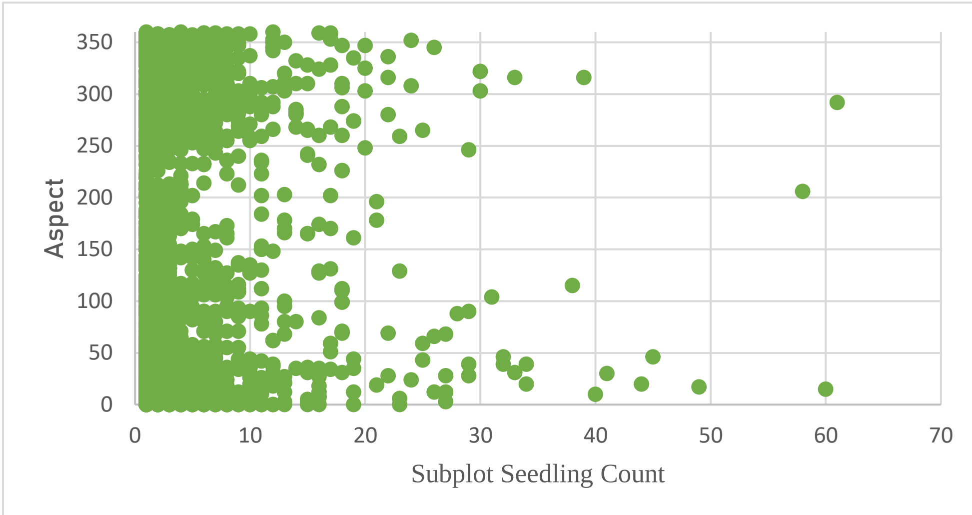


Figure 4: Scatter plot showing distribution of aspect and subplot tree seedling count. The y-axis shows the degree angle of the slope from 0, which represents north. The top and the bottom of the y-axis are northern facing slopes, and the middle values of the y-axis represent southern facing slopes.

Lastly, the total number of seedlings organized by species, shows that certain species, namely subalpine fir, make up most of the seedlings surveyed, and other species, like ponderosa pine and Douglas fir (*Pseudotsuga menziesii*), are not as common in the surveyed plots (Figure 5).

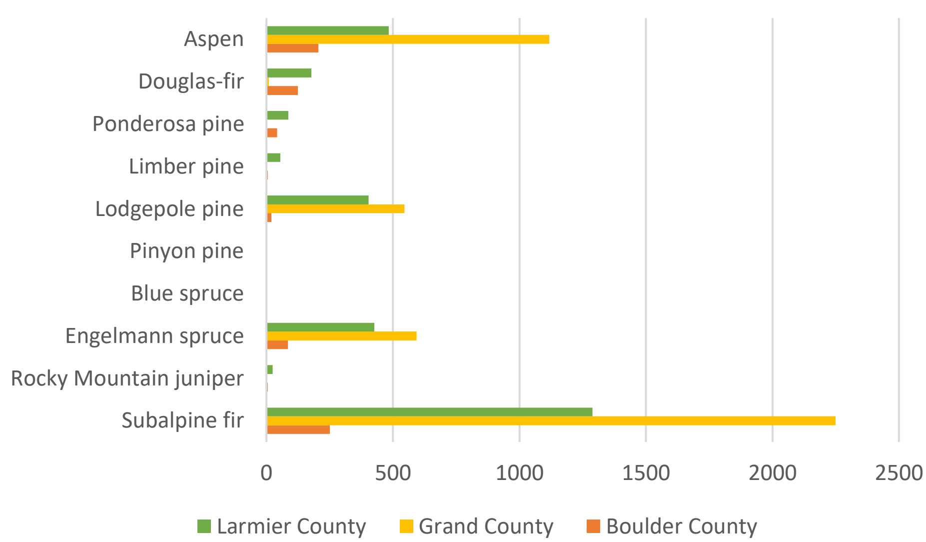


Figure 5: Bar graph distribution of total number of tree seedlings in surveyed plots by species, for each county.

The seedling count varies greatly across all three counties, with Grand County having the greatest number of seedlings, across most species, and Boulder County having the least.

Discussion – The elevation and species distribution from the dataset show that lower elevation, ponderosa pine-dominated forests, are not as well represented in these counties than the mid to high elevation forests. The most prevalent species in the seedling count were not the species that are most vulnerable to the impacts of climate change, ponderosa pine and Douglas fir, both low elevation species. The aspect data shows some of the impacts of dry, hot conditions. Southern facing slopes in the northern hemisphere are subjected to hotter, drier conditions because of the direct sunlight. The decrease in recruitment for southern facing slopes shows that seedlings are not responding well to hot and dry environmental conditions, regardless of species. Overall, this data does not directly address the question of whether tree seedling rates are declining in low elevation forests, but it does show that this is an area that is currently underrepresented by these U.S. Forest Service surveys. This information can then be used to consider adding more low elevation plots to this program, to monitor the health of all types of Colorado Forests.

Conclusion

According to the available research on this topic, Colorado Front Range forests are in fact vulnerable to the effects of climate change. Across the world, the effects of climate change have been observed, particularly in changes of precipitation and temperature patterns. The Front Range specifically has experienced increased drought conditions in recent years, which both exacerbates harmful patterns of increasingly frequent severe fires in low elevation forests, and also make it difficult for seedlings to become established after the initial burn. Although these forests are well acquainted with fire as an important driver of nutrient cycling and biodiversity, a continuation of current environmental conditions may eventually lead to a notable difference in the elevation distribution of certain tree ranges. Future successful research and management of these forested ecosystems requires a comprehensive monitoring program, that surveys a wide variety of sites, across different geomorphic and environmental conditions. Further research, especially research that focuses on low elevation forests, will lead to a to further understanding and appreciation of all of the active variables in this system—the climate, disturbance regimes, and forest growth—and how they all feed into and alter one another. The hope is that a continuous pursuit of deeper understanding will allow for the Front Range to remain forested for as long as possible.

Bibliography:

Allen, C. D., Macalady, A. K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., ... & Cobb, N. (2010). A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest ecology and management*, *259*(4), 660-684.

Aznar-Sánchez, J. A., Belmonte-Ureña, L. J., López-Serrano, M. J., & Velasco-Muñoz, J. F. (2018). Forest ecosystem services: An analysis of worldwide research. In Forests (Vol. 9, Issue 8). https://doi.org/10.3390/f9080453

Balch, J. K., Bradley, B. A., Abatzoglou, J. T., Nagy, R. C., Fusco, E. J., & Mahood, A. L. (2017). Human-started wildfires expand the fire niche across the United States. *Proceedings of the National Academy of Sciences*, *114*(11), 2946-2951.

Batllori, E., Parisien, M. A., Parks, S. A., Moritz, M. A., & Miller, C. (2017). Potential relocation of climatic environments suggests high rates of climate displacement within the North American protection network. *Global Change Biology*, *23*(8), 3219-3230.

Burrill, E., Wilson, A., Turner, J., Pugh, S., Menlove, J., Christensen, G., Conkling, B., & David, W. (2018). *Forest Inventory and Analysis Database Description and User Guide ver. 7.2*. Forest Inventory and Analysis National Program. https://www.fia.fs.usda.gov/library/database-documentation/

Calder, W. J., & Shuman, B. (2017). Extensive wildfires, climate change, and an abrupt state change in subalpine ribbon forests, Colorado. *Ecology*, *98*(10), 2585-2600.

Chambers, M. E., Fornwalt, P. J., Malone, S. L., & Battaglia, M. A. (2016). Patterns of conifer regeneration following high severity wildfire in ponderosa pine–dominated forests of the Colorado Front Range. *Forest Ecology and Management*, *378*, 57-67.

Chileen, B. V., McLauchlan, K. K., Higuera, P. E., Parish, M., & Shuman, B. N. (2020). Vegetation response to wildfire and climate forcing in a Rocky Mountain lodgepole pine forest over the past 2500 years. *The Holocene*, *30*(11), 1493-1503.

Davis, K. T., Dobrowski, S. Z., Higuera, P. E., Holden, Z. A., Veblen, T. T., Rother, M. T., ... & Maneta, M. P. (2019). Wildfires and climate change push low-elevation forests across a critical climate threshold for tree regeneration. *Proceedings of the National Academy of Sciences*, *116*(13), 6193-6198.

Ehle, D. S., & Baker, W. L. (2003). Disturbance and stand dynamics in ponderosa pine forests in Rocky Mountain National Park, USA. *Ecological Monographs*, *73*(4), 543-566.

Fassnacht, S. R., Venable, N. B., McGrath, D., & Patterson, G. G. (2018). Sub-seasonal snowpack trends in the Rocky Mountain National Park area, Colorado, USA. *Water*, *10*(5), 562.

Holden, Z. A., Swanson, A., Luce, C. H., Jolly, W. M., Maneta, M., Oyler, J. W., ... & Affleck, D. (2018). Decreasing fire season precipitation increased recent western US forest wildfire activity. *Proceedings of the National Academy of Sciences*, *115*(36), E8349-E8357.

Kemp, K. B., Higuera, P. E., & Morgan, P. (2016). Fire legacies impact conifer regeneration across environmental gradients in the US northern Rockies. *Landscape Ecology*, *31*, 619-636.

Luyssaert, S., Schulze, E. D., Börner, A., Knohl, A., Hessenmöller, D., Law, B. E., Ciais, P., & Grace, J. (2008). Old-growth forests as global carbon sinks. Nature, 455(7210). https://doi.org/10.1038/nature07276

NOAA. (2021). *NOAA delivers new U.S. Climate Normals*. National Centers for Environmental Information. https://www.ncei.noaa.gov/news/noaa-delivers-new-us-climate-normals

Pepin, N., Bradley, R. S., Diaz, H. F., Baraer, M., Caceres, E. B., Forsythe, N., Fowler, H., Greenwood, G., Hashmi, M. Z., Liu, X. D., Miller, J. R., Ning, L., Ohmura, A., Palazzi, E., Rangwala, I., Schöner, W., Severskiy, I., Shahgedanova, M., Wang, M. B., … Yang, D. Q. (2015). Elevation-dependent warming in mountain regions of the world. In Nature Climate Change (Vol. 5, Issue 5). https://doi.org/10.1038/nclimate2563

Rangwala, I., & Miller, J. R. (2012). Climate change in mountains: a review of elevation-dependent warming and its possible causes. *Climatic change*, *114*, 527-547.

Rodman, K. C., Veblen, T. T., Battaglia, M. A., Chambers, M. E., Fornwalt, P. J., Holden, Z. A., ... & Rother, M. T. (2020). A changing climate is snuffing out post-fire recovery in montane forests. *Global Ecology and Biogeography*, *29*(11), 2039-2051.

Rother, M. T., & Veblen, T. T. (2016). Limited conifer regeneration following wildfires in dry ponderosa pine forests of the Colorado Front Range. *Ecosphere*, *7*(12), e01594.

Schoennagel, T., Veblen, T. T., & Romme, W. H. (2004). The interaction of fire, fuels, and climate across Rocky Mountain forests. *BioScience*, *54*(7), 661-676.

Sibold, J. S., Veblen, T. T., & González, M. E. (2006). Spatial and temporal variation in historic fire regimes in subalpine forests across the Colorado Front Range in Rocky Mountain National Park, Colorado, USA. *Journal of Biogeography*, *33*(4), 631-647.

Stevens-Rumann, C. S., Kemp, K. B., Higuera, P. E., Harvey, B. J., Rother, M. T., Donato, D. C., ... & Veblen, T. T. (2018). Evidence for declining forest resilience to wildfires under climate change. *Ecology letters*, *21*(2), 243-252.

Van Mantgem, P. J., Stephenson, N. L., Byrne, J. C., Daniels, L. D., Franklin, J. F., Fulé, P. Z., ... & Veblen, T. T. (2009). Widespread increase of tree mortality rates in the western United States. *Science*, *323*(5913), 521-524.