PONDEROSA PINE IN THE COLORADO FRONT RANGE: LONG HISTORICAL FIRE AND TREE RECRUITMENT INTERVALS AND A CASE FOR LANDSCAPE HETEROGENEITY

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ABSTRACT

An unlogged forest landscape in the Colorado Front Range provides insight into historical characteristics of ponderosa pine/Douglas-fir landscapes where the past fire regime was mixed severity with mean fire intervals of 50 years or more. Natural fire and tree recruitment patterns resulted in considerable spatial and temporal heterogeneity, whereas nearby forest landscapes impacted by logging, grazing, and fire suppression are much more homoge neous. The historical landscape characteristics serve as a guide for restoration of current landscape conditions to improve ecological sustainability and mitigate wildfire and post-fire erosion risks.

Keywords: fire history, tree recruitment, historical ecology, landscape scale processes

INTRODUCTION

Managing forests for long-term ecological sustainability requires information about historical forests and the processes that regulated their structure and change over time. Without such knowledge, it is difficult to protect or restore forest characteristics that ensure long-term sustainability (Kaufmann et al. 1994, Kaufmann et al. 1998). In ponderosa pine forests, information about stand structure and fire history have come primarily from the Southwestern US, where early studies and historical literature described an open, park-like condition that developed in association with high-frequency surface fires (Cooper 1960, Covington and Moore 1994, Fulé et al. 1997, Pearson 1933, Woolsey, 1911). This stand structure has become a widely accepted management goal throughout the West wherever past management has resulted in ponderosa pine stands that are dense and relatively young. Brown (1995) suggested, however, that management should focus on the ecological objectives for the fire regime relevant to an area, and many ponderosa pine forests are not characterized by a high-frequency surface fire regime.

Recent research in the central Rocky Mountains is beginning to yield a view of forest structure in ponderosa pine forests that differs greatly from the southwestern pine forest system. In an unlogged forest landscape in the South Platte Basin of the Colorado Front Range, the mean fire interval (MFI) for historical ponderosa pine/Douglas-fir forests was much longer than in the Southwest, and the fire behavior pattern included a more prominent crown fire component along with surface fire (Brown 1995, Brown et al. 1999, Swetnam and Baisan 1996). In general, shorter growing seasons, steeper topography, poorer soils, and more erratic summer rainfall make these forests less productive in both the overstory and understory than in the Southwest. The longer fire interval and a more limited fine fuel condition appear to have had dramatically different effects on forest structure across the landscape than observed where fire intervals were short.

We describe characteristics of a 30-km^2 forest landscape in a nearly historical condition, including the fire and tree recruitment histories and their effects on forest structure and other components of the historical landscape mosaic. The historical landscape surrounds Cheesman Lake, a reservoir on the South Platte River about 60 km southwest of Denver, CO. The land is owned by the Denver Water Department. To protect the coarse granitic soils from erosion, the surrounding forest was protected from logging, and grazing has been excluded since 1905, when the dam was completed. Grazing was not intense before that time.

FIRE HISTORY

Fire scar samples were collected from live and dead trees and log remnants throughout the historical ponderosa pine/Douglas-fir landscape and from an adjacent logged area. Fire scars were used to construct spatial as well as temporal descriptions of past fire extent and frequency. Detailed analyses of the fire history, including maps of the spatial extent of fires in individual fire years, are given in Brown et al. (1999). Figure 1 summarizes the spatial distribution of fire scar sampling and the fire history for each sample area.

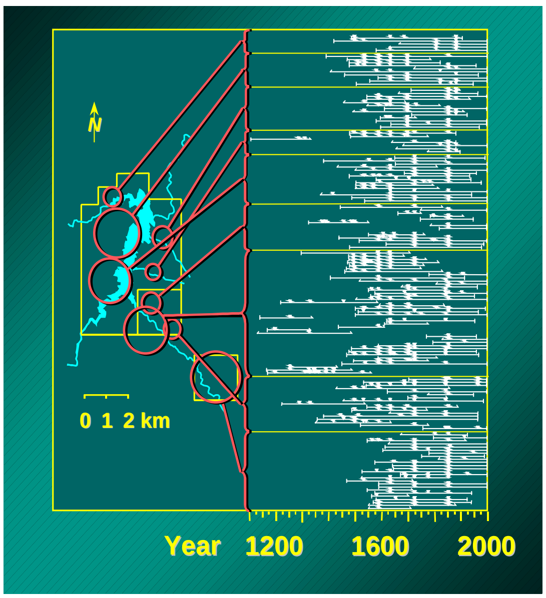

Figure 1. Fire history for the Cheesman Lake landscape (larger portion of insert map) and a portion of the adjacent Turkey Creek landscape (smaller lower right portion of insert map). Circles indicate areas where fire scar groups shown on the right were collected. On the right, individual sample trees or logs are shown as single lines, with inverted triangles representing years in which fire scars were recorded. Vertical bars at the end of each individual tree record indicate pith or bark (death) year. Slanted lines indicate innermost ring with the pith missing or outermost ring with the cambium missing. Vertical alignment of fire scars reflects scarring of multiple trees and locations in a single year. Brown et al. (1999) present complete maps for individual fire years.

The fire scar record included 77 fire years, the earliest in 1197 and the latest in 1963. These studies indicated that during the 1300s to early 1500s, coinciding with the Medieval Warm Period, the MFI in one several-hectare cluster of old trees was 16.8 years (a portion of the samples in the third group from the bottom in Fig. 1). From then until 1902, the MFI increased to 30.1 years. At the landscape scale, the MFI for widespread fires from 1496 to 1851 was 59.2 years (50 years if a light-intensity fire in 1775 is included). The last major fire year in the unlogged landscape was in 1880, presumably because fire suppression limited fire spread during the 20th century. Currently, an average of 10-12 fires per year are suppressed. Long MFIs observed at Cheesman Lake are also found elsewhere. Long fire intervals were observed at the landscape scale in Boulder County northwest of Denver, CO (Goldblum and Veblen 1992) and on drier ponderosa pine sites in western Montana (Arno et al. 1995).

These results contrast with historical fire patterns observed in southwestern ponderosa pine, where MFIs of less than 10 years were normal (Covington and Moore 1994, Swetnam and Baisan 1996). In the Cheesman Lake landscape, widespread fires were widely spaced in time, and there were relatively few small fires that we could detect in intervening intervals. Examples of the areas where trees were scarred by fire in 1723 and 1851 are shown in Fig. 2. Fires in these years were spatially widespread and included a significant stand-replacing component that shaped forest structure. The extent of these fires based on fire scars is nearly identical for these two years except at the northern boundary, where fire scars indicate that the 1851 fire burned areas not burned in 1723. The actual extent of these fires cannot be determined, because trees were scarred to the western, eastern, and southern boundaries of the area sampled. Other large fires appeared to be nearly completely contained in the sample area and burned areas less than 10 km^2, while a fire in 1631 burned in every area sampled and was undoubtedly larger than 30 or 40 km^2. The larger fires observed in Boulder County by Goldblum and Veblen (1992) were of similar size to those observed at Cheesman Lake.

TREE RECRUITMENT HISTORY

Tree recruitment data provide insight into the effects of historical fires on the landscape. If trees in a sample area pre-date or post-date known fires, stand structure indicates whether fire was stand-replacing in that location. Tree recruitment data also can be used to clarify temporal and spatial patterns of reforestation where fire created openings. Tree ages were sampled in 25 0.1-ha plots within a 4-km^2 area in each landscape, shown as squares in the lower right portion of the map insets of Figs. 1 and 2. Cores were collected 30-40 cm above the ground, and pith years at coring height were

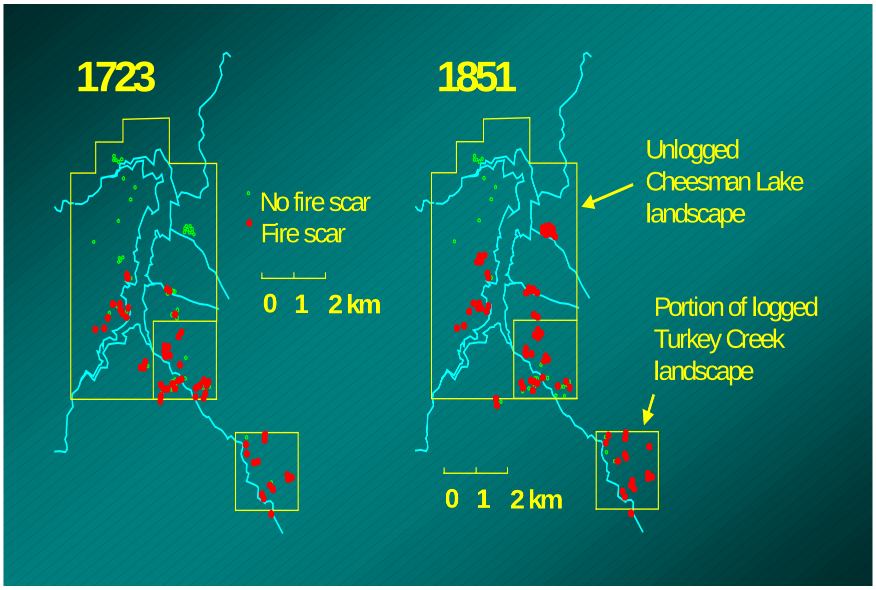

Figure 2. Maps of two large-scale fires in the Cheesman Lake and adjacent Turkey Creek landscapes. Red dots indicate locations of fire-scarred trees. Green dots indicate locations of trees recording growth during the year but not recording a fire scar (additional unscarred trees obscured by red dots). From Brown et al. (1999).

adjusted as a function of early growth rate to estimate germination year. Rates of tree recruitment in the Cheesman Lake landscape and in the adjacent logged landscape were highly variable and occurred largely in pulses about 10 years in duration at mean intervals of about 50 years between the midpoints of pulses. In the unlogged Cheesman Lake landscape, about one-half of the trees were recruited in pulses that amounted to only one-fourth of the time during the last four centuries (Kaufmann et al., in press).

Tree recruitment varied among sites in both timing and intensity (Kaufmann et al. in press). While many sample plots had old trees, other plots had distinct caps on tree ages. The age caps suggest that tree recruitment occurred following a stand-replacing disturbance, most likely fire. In Fig. 3A, the recruitment years for the oldest trees are shown for plots randomly distributed in a 4-km^2 portion of the unlogged Cheesman Lake landscape. The oldest trees in individual plots dated to as early as 1522 and as recently as 1887. Three fire scar sampling areas shown in Fig. 1 provide a fire history for the area shown in Fig. 3. The fire history data indicate that major fires burned across most of the 4 km^2 in 1496, 1587, 1631, 1723, and 1851, with smaller areas burned in 1531, 1534, 1700, 1775, 1841, and 1963 (Fig. 1, and Brown et al. 1999). While additional sampling of tree ages is being done for this study area, data in Figs. 1 and 3A provide a basis for estimating portions of the study area where trees post-date specific fires.

The most recent large fires predating the ages shown in Fig. 3A are given in Fig. 3B. Large portions of the area have trees post-dating the fires in 1723 and 1851, suggesting that in both fire years the fires were of mixed severity with a strong stand-replacement component in this area. Intensively sampled tree ages in a 15-ha area identified two small enclaves of trees dating from the 1600s (after the 1631 fire) within the area where most trees post-date the 1723 fire (see the upper middle portion of the sample area in Fig. 3). In a south-facing portion of this area, tree recruitment was delayed until about 1779, indicating that this slope probably existed as a post-fire opening for over 50 years.

The 1851 fire provides even more evidence of stand replacement and persistent openings following the fire. While a number of sample plots yielded tree ages indicating recruitment within a few decades of the 1851 fire, other south-facing slopes just north of the sample area shown in Fig. 3 are still unforested, 148 years after the fire (Fig. 4, top). Coarse woody debris in these openings indicates they were previously forested; dating of log remnants having intact sapwood indicates the trees died in 1851.

LANDSCAPE COMPONENTS

The structure of the historical Cheesman Lake landscape can be described based on the combined effects of fire and tree recruitment discussed above. Four primary components of the historical landscape have been

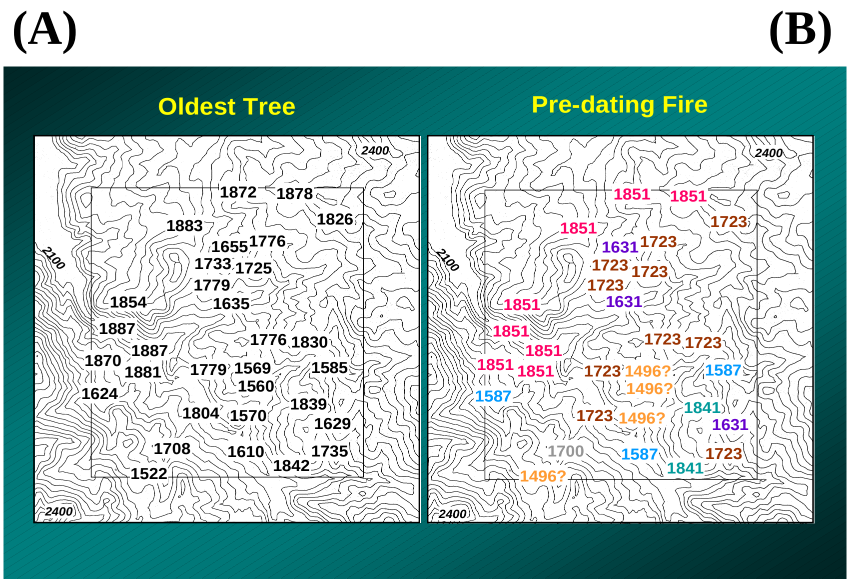

Figure 3. (A) Age of oldest tree at random plot locations in a 4-km² portion of the unlogged Cheesman Lake landscape (see Fig. 2 above). (B) Year of the most recent known large fire pre-dating the oldest tree at each plot location. Two of the fire years are shown in Fig. 2 above. Contour intervals are 15 m (2100 and 2400 m contours shown in Italics, with 2100 m representing the elevation of Cheesman Lake).

identified (Kaufmann et al. in press). First are forested patches that have a distinct age cap. We believe, based on data shown in Fig. 3 and other observations, that extensive areas have age caps related to stand-replacement components of fires in 1723 and 1851, and it is likely that in other portions of the Cheesman Lake landscape similar effects from other fires will be detected. In many patches, ponderosa pine is the predominant species, although in others Douglas-fir trees are common and are occasionally the oldest trees at a site, especially on more protected sites. Many patches with an age cap have a lower density than presently found in surrounding forests, perhaps the result of thinning of understory trees by the surface fire component of the large fires.

The second landscape component includes patches with no evidence of a past stand-replacing fire. In these patches, ponderosa pine and often Douglas-fir trees range widely in ages and states of health and decline, suggesting that mortality occurs from old age or from microscale disturbances such as lightning, very small fires, insect attack, mistletoe, heartrot, windthrow, etc. Four plots shown in Fig. 3A had trees old enough that the pre-dating fire was in 1496. Ponderosa pine trees in the study area rarely reach 500 years of age (Douglas-fir rarely over 300); thus it is unclear if the 1496 fire killed all or any trees in these locations, and in Fig. 3B the 1496 dates are accompanied by a question mark to reflect this uncertainty. We believe, however, that patches without an identifiable age cap are relatively uncommon and probably constitute less than 10 percent of the landscape.

The third landscape component is non-forested openings created by fire (Fig. 4, top). In a recent examination of nearly 50 existing openings varying in size from less than one ha to as large as 20 ha, only one had no coarse woody debris, and all were believed to have resulted from the 1851 fire (Matt Tobler, Colorado State University, pers. comm.). Given that fires have been successfully suppressed most of the 20th century, it seems likely that a century ago openings were much more widespread, and at any date during the 17th-19th centuries they might have constituted 10-20 percent or more of the landscape. Some openings are grassy, but most have a strong shrub component that persists until forest cover is extensive.

The final component of the landscape is the riparian system. Though limited to only a small percentage of the landscape, it supports most of the plant diversity (Kaufmann and Stohlgren, unpublished data). Some riparian areas are openings, whereas others are heavily forested. Plot data shown in Fig. 3 included two forested riparian areas (left middle portion of diagram) where trees dated to 1887, suggesting that the 1851 fire killed any trees that might have existed prior to the fire.

Figure 4. (Top) Current view of historical Cheesman Lake landscape with openings as a feature contributing to landscape heterogeneity. (Bottom) Current landscape in the South Platte basin with few features contributing to landscape heterogeneity.

SPATIAL AND TEMPORAL HETEROGENEITY

Our data and landscape characteristics suggest that the natural landscape mosaic during the 16th-19th centuries was a changing pattern of forest patches (many low in tree density) and openings reflecting the combined effects of fire and tree recruitment. In the absence of fire suppression or any other anthropogenic effect (Native American influences arebelieved to have been small), the natural state of the landscape included some proportion of each of the components described above. After a mixed severity fire that created openings, the landscape probably consisted of the residual forest components that did not burn, those that burned lightly (perhaps with some mortality mainly among smaller trees), and newly created openings. The openings may have been extensive, perhaps hundreds of hectares, but were rarely continuous as indicated by enclaves of old trees that still exist in areas we know were largely consumed by the more recent large fires (e.g. 1723, 1851, 1880).

Forest patches consisted primarily of ponderosa pine and Douglas-fir, with aspen, narrowleaf cottonwood, blue spruce, and Rocky Mountain juniper as minor components, primarily in wetter sites. Surface fires maintained more open forests and controlled the amount of Douglas-fir (and perhaps juniper) that survived to maturity. During the 20th century, a significant amount of Douglas-fir ingrowth has occurred. While it is easy to attribute this to fire suppression, it is also quite possible that similar ingrowth occurred historically because the intervals between fires averaged 50 years or more, and often fires only burned part of the landscape, making the intervals twice that long in many cases (e.g. 1723 to 1851 in Fig. 1). Such ingrowth historically would have contributed to the mixed severity fire behavior pattern by providing ladder fuels.

The historical landscape at Cheesman Lake has many patches where trees are older than 200 years, the age at which old-growth characteristics typically emerge in ponderosa pine (Kaufmann 1996). In 25 sample plots over 4 km^2, 200 year-old trees were found on 12 plots, 300 year-old trees on eight plots, and 400 year-old trees on five plots (Kaufmann et al. in press). Most old trees were ponderosa pine, and only one Douglas-fir tree over 300 years of age was detected. Almost all junipers were less than a century old.

The heterogeneous residual forest structure after fire was augmented by variable regeneration in the openings. Evidence from age structure data indicates that following both the 1723 and 1851 fires, portions of openings created by these fires regenerated within a decade or so after the fire, particularly in more protected environments, whereas more exposed areas remained unforested for 50 to 150 years. This spatial and temporal variability in tree recruitment added heterogeneity to the landscape mosaic for long periods following mixed severity fires. Together, variable fire severity and temporal variability in tree recruitment, both presumably driven by climate, yielded a complex and continuously changing landscape structure, with large numbers of openings and low-density forest patches interspersed with more dense forest patches and some patches where very old trees persisted.

COMPARISON WITH CURRENT CONDITIONS

Many areas surrounding the Cheesman Lake landscape are at similar elevations and have similar soils and climate, yet the forest structure is very different, presumably the result of a long history of human impacts beginning with logging in the 1870s, intensive grazing shortly thereafter, and fire suppression during the 20th century (Baker 1992). Our data indicate that tree recruitment occurred at a high rate for a 40-year period after logging began around 1875 (Kaufmann et al. in press). This appears to be the pattern throughout the lower montane zone of the South Platte Basin, with the overall result being a very homogeneous forest landscape of young ponderosa pine mixed with much more Douglas-fir than anticipated (Fig. 4, bottom) based on the historical Cheesman Lake landscape. While trees older than 200 years are numerous in logged areas, trees older than 300 years are rare (Kaufmann et al. in press).

Openings and patches with low forest density that characterize the historical landscape are absent in much of the South Platte Basin, although US Geological Survey General Land Office field notes from the 1870s and 1880s indicate that openings, areas of low forest density, and areas having evidence of fire were common. It is likely that pre-existing openings were reforested as a result of a combination of factors, including reduced competition by understory vegetation during a half century or more of heavy grazing (until the 1940s), and an active program of fire suppression activities and reforestation during this century. Mast et al. (1997) observed rapid encroachment of openings by trees in areas where fires have been suppressed. The present homogeneous landscape is highly prone to rapidly spreading crown fires and subsequent soil erosion, as evidenced by the Buffalo Creek fire discussed below.

SUMMARY OF HISTORICAL LANDSCAPE CONDITIONS

Our data suggest a series of conclusions regarding the historical Cheesman Lake landscape and management implications for surrounding forests influenced by logging, grazing, and fire suppression.

1. The historical landscape was a much more complex and heterogeneous mosaic than may have been found historically in the Southwest, where MFIs were shorter.

2. Long mean fire intervals (50-60 years) resulted in a mixed severity fire regime with a prominent stand-replacing component.

3. Tree recruitment occurred historically in pulses lasting about 10 years. The pulses generally coincided with periods when landscape-scale fires burned. Possibly the two processes were driven by climate. Periods favorable to tree establishment also may have encouraged the production of fine fuels needed for fire spread.

4. Spatial and temporal variability of tree recruitment into openings created by fire, combined with residual forest structure in unburned areas, resulted in a complex and changing landscape structure that included many openings persisting for decades or even a century or more, interspersed with areas having low to high forest density.

5. In adjacent landscapes where logging and fire suppression occurred, the forest landscape structure has few openings or low-density forests but many more Douglas-fir trees. These forests are highly vulnerable to severe wildfires and post-fire erosion.

MANAGEMENT IMPLICATIONS

The following changes in landscape structure of human-impacted lands in the South Platte Basin would help mitigate the risks of wildfire and soil erosion while restoring landscapes to a condition more likely to be ecologically sustainable.

1. Forest density should be greatly reduced through a combination of mechanical thinning and prescribed fire, resulting in the creation of a large number of openings varying in size from less than one to more than 20 hectares, interspersed with patches of forest having low to moderate tree densities. Some openings should be managed so they persist for decades.

2. A large percentage of Douglas-fir in most diameter classes should be removed, and Rocky Mountain juniper densities should be kept low.

3. Residual old-growth trees should be retained, because they provide an important component of the historical age structure.

4. Prescribed burning should be managed, where possible, to burn hot enough to create openings in the overstory. Surface fire can help maintain low forest density and thin out Douglas-fir.

IMPLEMENTATION IN LANDSCAPE RESTORATION

The Buffalo Creek fire in the South Platte Basin in 1996 (about 10 km north of the Cheesman Lake landscape) illustrated the magnitude of risk associated with the current forest structure in most of the basin. This fire burned about 5,000 ha, creating in one afternoon a single 3,000 ha area of nearly complete overstory mortality. Thunderstorms since the fire (the worst about six weeks after the fire) resulted in massive soil erosion with major impacts on the water supply for the Denver, Colorado metropolitan area. While thunderstorms are common, their effects after the fire are probably well outside historical levels.

The Upper South Platte Watershed Protection and Restoration Project, begun in 1999, is an outgrowth of several converging factors, including the Buffalo Creek fire and available research on the historical landscape in the basin. The South Platte is an important watershed and water supply system, and it contains areas of rapidly expanding urban/wildland interface. These factors led to the development of a partnership of agencies interested in implementing a restoration effort. This partnership includes the USDA Forest Service (both management and research), Colorado State Forest Service, Denver Water, Environmental Protection Agency, US Geological Survey, and others.

Research results from the Cheesman Lake landscape provide a basis for altering existing forest conditions in the South Platte Basin based upon documented characteristics of a historical landscape, which we believe to be ecologically sustainable. Such conditions are likely to mitigate the spread of crown fires and subsequent erosion.

Implementing the changes outlined in the previous section requires several additional research steps that are presently underway. First, a map of the historical landscape is required. We are creating a detailed GIS layer of ecologically significant polygons mapped from 1:6000 color infrared photographs. All forested polygons have been classified according to tree size structure using a template developed from plot data collected in the historical landscape and in the adjacent logged landscape. This template includes six diameter-class distributions and a range of overstory crown closures indicative of tree density. The mapping and classification effort will provide an understanding of patch characteristics and conditions for the entire historical landscape and adjacent areas that were logged and grazed. However, even the historical landscape has been subjected to fire suppression, and in its present condition may not reflect the true natural landscape.

We are analyzing landscape metrics, potential and past fire behavior, and stand growth characteristics for modeling four contrasting landscape scenarios: (1) the historical Cheesman Lake landscape in its present condition, (2) the historical landscape as it might have been about 100 years ago, representing the pre-fire suppression era, (3) the current landscape condition in other portions of the South Platte Basin as affected by logging, grazing, and fire suppression, and (4) a range of scenarios that might be implemented in these logged lands to restore historical conditions.

The analysis scenarios will focus on the effects of landscape structure on fire behavior and on the recreation of a more natural landscape structure. Based on tree recruitment and fire history data from the Cheesman Lake landscape, we believe that conditions were right for two landscape-scale fires that did not happen due to suppression, around 1906 and 1963. We intend to reconstruct landscape conditions prior to 1906, then simulate the effects of fire in about 1906 and another in 1963 (when in fact a small but intense fire was suppressed). This will provide two estimates of a "natural" landscape, one prior to fire suppression and one in the absence of fire suppression. We will model forest development using the Forest Vegetation Simulator (FVS). Temporal changes in overstory structure predicted with FVS will be used to evaluate the long-term value of modest forest treatment over large areas vs. intense treatment over smaller areas for mitigating wildfire risk.

Related studies are being conducted by the Colorado State Forest Service, US Geological Service, and USDA Forest Service to assess the cost effectiveness of mechanical treatments and prescribed burning to accomplish the necessary landscape changes and to assess the consequences of treatment on soil erosion risks. Collectively, the partnership of research and management has the potential for dramatically altering forest structure in the South Platte Basin to reduce the risk of catastrophic wildfires while improving the likelihood of ecological sustainability for the long term.

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