Landscape Patterns of Montane Forest Age Structure Relative to Fire History at Cheesman Lake in the Colorado Front Range

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Abstract—Lack of Euro-American disturbance, except fire suppression, has preserved the patterns of forest structure that resulted from the presettlement disturbance regime in a ponderosa pine/Douglas-fir landscape at Cheesman Lake in the Colorado Front Range. A mixed-severity fire regime and variable timing of tree recruitment created a heterogeneous forest age structure with considerable old growth. Surrounding forests subjected to human alteration since the late 1800s are younger, denser, and more continuous. We present preliminary data from a study of fire history and age structure. We mapped forest patches based on tree size and density using color-infrared aerial photos, then randomly sampled 10 percent of these patches across the 35 km^2 landscape for the ages of the five apparent oldest trees. Trees older than 200 years were found in 70 percent of sampled stands. Trees older than 400 years were found in 30 percent of sampled stands, suggesting that old growth was common and widespread in historical landscapes in the Front Range. We compared the stand ages with locations of known fire dates derived from fire scars. Concentrations of trees that postdate known fires indicate a past stand-replacing fire. Such postfire cohorts are discernible as far back as 1531 A.D. Of 21 fires recorded by scars between 1531 and 1880, 16 appear to have had a stand-replacing component, and seven known fires predate 71 percent of the postfire cohorts. Time between stand-replacing disturbance and tree establishment varied considerably between sites, but generally ranged from 20 to 50 years. Some openings began to regenerate within 10 years after fire, while others remain unforested 150 years later.

Introduction

Most scientists and managers acknowledge that old-growth forest was more common in Western ponderosa pine landscapes before Euro-American settlement than it is now (Regan 1997; Baker 1992; Kaufmann and others 1992; Moir 1992; Veblen and Lorenz 1991). Old-growth ponderosa pine forests with large, open-grown trees generally older than 200 years were more heavily impacted by logging and grazing during and immediately after the settlement period than younger stands (Covington and Moore 1994; Cooper 1960). Managers attempting forest restoration in ponderosa pine landscapes of the West face several questions: what constitutes old-growth forest in their ecosystems? How much old growth existed historically, and how was it distributed? What were the disturbance regimes that regulated landscape structure? How much old growth remains on the present landscape, and how can we recreate a more historical and sustainable forest structure? In many locations, these questions are largely unanswerable. No old growth remains that developed under historical disturbance regimes. Where old growth does exist, it is often small, isolated stands that were preserved by their inaccessibility or lack of productivity, and does not necessarily reflect the historical distribution of old-growth forest on the landscape.

Reconstructing historical disturbance regimes is essential for understanding the processes that regulated forest structure and the distribution of old growth across the landscape (Veblen and others 2000; Mast and others 1999; Fulé and others 1997; Brown and Sieg 1996; Swetnam and Baisan 1996; Brown 1995; Veblen and Lorenz 1986). The spatial and temporal scale of historical disturbances determined the distribution, extent, character, and persistence of old-growth stands. Using the age structure of present forests, particularly in relatively undisturbed stands, is one way to reconstruct historical forests (Mast and others 1999; Arno and others 1995; Duncan and Stewart 1991). However, because remaining old stands are often small and isolated, it is difficult to extrapolate to a larger scale.

We have been fortunate to study a relatively undisturbed ponderosa pine landscape of 35 km^2 in the Colorado Front Range. The land surrounding Cheesman Lake, on the South Platte River, experienced only minimal, localized logging and grazing before 1900, unlike most montane forests in the Front Range. While fire suppression since 1900 has allowed for some ingrowth of trees and increased prevalence of young Douglas-fir, the lack of other anthropogenic disturbance has preserved the distribution of presettlement trees that resulted from the historical disturbance regime. The cool, dry climate has preserved remnant wood, allowing us

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to reconstruct the fire history back to 1197 A.D. (Brown and others 1999). The historical mixed-severity fire regime and variable timing of tree establishment in the ponderosa pine/ Douglas-fir forest created an older and more heterogeneous age structure than that found in surrounding areas that have experienced more human alteration since the mid-19th century (Kaufmann and others 2000a). The size of the protected area has allowed us to study a historical landscape on a scale similar to that at which we believe historical disturbance regimes actually operated, and gives us some sense of the scale of patterning in the landscape. We present preliminary data from a landscape-scale study comparing forest age structure and fire history.

Background and Methods

The Cheesman Lake Landscape

The Cheesman Lake landscape is 3,040 ha of land area, excluding the lake, located in the montane forest zone, about 60 km southwest of Denver. Elevations range from 2,100 m at the water level of the reservoir to 2,400 m on the west side of the lake. The vegetation at Cheesman Lake is dry ponderosa pine/Douglas-fir forest (*Pinus ponderosa*/*Pseudotsuga menziesii*) (Peet 1991). Understories are typically grassy or shrubby or both; denser forests have very sparse understories. Most of the botanical diversity in this landscape is concentrated in the relatively small riparian areas around streams, many of which are intermittent. These forests were historically open, with the Douglas-fir concentrated on northerly slopes (Kaufmann and others 2000b). Aspen (*Populus tremuloides*), blue spruce (*Picea pungens*), Rocky Mountain juniper (*Juniperus scopulorum*), and narrow-leaf cottonwood (*Populus angustifolia*) are typically found in riparian areas, but are more common outside the study area. Soils are gravelly coarse sandy loams derived from weathered Pikes Peak granite (USDA Forest Service 1992). They are very well drained and erosive. Average annual precipitation is around 40 cm (USDA Forest Service 1992), and there is no persistent winter snowpack. Summer precipitation comes mainly in the form of erratic thunderstorms that produce much lightning.

The native inhabitants since at least 1700 were nomadic Utes (Cassells 1983), whose activity was probably confined to the river corridor and other reliable sources of water before 1880 (A. Kane, Pike NF Archaeologist, personal communication; De Lay 1989). Bison may have grazed in the area before 1880 (De Lay 1989). Euro-American settlement began in the Front Range after 1859, but did not become heavy until the 1870s–1890s. Logging and ranching began downstream from the Cheesman property during that period, and reached forests adjacent to Cheesman in the late 1890s. The Cheesman Lake property is presently owned and managed by Denver Water. The dam on the South Platte River that created the reservoir was completed in 1905 (Denver Water archives). At the same time, a six-strand barbed wire fence was erected around the entire property to exclude grazing. The forest on the property was not cut except for logging below the present water line. Grazing has been excluded since 1905, and was probably light before that time. There was little mining in the area, though placer claims did exist along the river where the reservoir now lies (Denver Water archives). Fire has been suppressed on the Cheesman Lake property since the time of dam construction. The only fire that burned significant acreage within the landscape since 1880 occurred in 1963, burning about 25 ha on the south end of the property before it was extinguished (Bill Newberry, Denver Water, personal communication).

Sampling Scheme

We mapped the Cheesman Lake landscape from 1:6000 color-infrared aerial photographs, drawing polygons around visually ecologically distinct areas. We classified polygons based on tree density and size distribution as either forested or nonforested (rocks, water, grass, riparian shrubs, less than 10 percent tree canopy cover), and estimated forest canopy cover by 10 percent classes. We were unable to differentiate between ponderosa pine and Douglas-fir on the color-infrared photographs. We scanned the polygon maps into digital form and georectified them by overlaying them onto the digital orthoquarterquad using ArcInfo.

We randomly selected 10 percent of the mapped forested polygons from our GIS database for sampling. Sampled polygons varied in size, from less than 0.1 ha to 33 ha; the average size of sampled forested polygons was 3.3 ± 2.0 ha. The total area of the sampled polygons, 680 ha, represents 22 percent of the total land area. Within each polygon, we selected the five living trees that appeared to be the oldest, or to represent the oldest cohort, and cored them at approximately 35 cm above the ground. Where trees were rotten, or there appeared to be more than one older cohort, we took more than five cores and included those ages in our analysis. In some stands, all of the trees appeared to be old; in other stands, a few old trees were present among younger trees. Where there were no old trees at all, we selected the dominants. The correlation between size and age on our sites is very poor. Some of the largest trees on favorable sites are only around 150 years old, while some of the oldest trees on dry slopes range from 25 to 35 cm d.b.h.

Ponderosa pine trees begin to take on distinctive characteristics at around 200 years of age (Kaufmann 1996). We used these characteristics to identify the old trees in stands (fig. 1). Old ponderosa pines have smoother, lighter colored bark, smaller live crown ratio, and more flattened crowns than young trees. Dead tops are common, as are fire scars, lightning scars, and other injuries. Old Douglas-fir trees also have distinctive characteristics, including thick, deeply fissured bark and relatively small live crown ratios; crowns tend to be sparser, rounder, and less conical than those of young trees. As with pines, dead tops and injuries become more common over time.

Tree-Ring Dating

We used standard dendrochronological cross-dating techniques to age our sampled trees (Swetnam and others 1985; Stokes and Smiley 1968). Cores were surfaced with progressively finer grits of sandpaper to 400 grit and cross-dated under a stereomicroscope, using the chronology developed

Figure 1—This ponderosa pine germinated around 1447 A.D. It exhibits classic old-growth characteristics. The other trees sampled on this dry, south-facing slope dated to the mid-18th century.

for dating the Cheesman Lake fire history (Brown and others 1999). It extends from 1107 A.D. to 2000 A.D.

We cored trees as close as possible to the pith. We determined the approximate germination date of sampled trees by estimating rings to the pith using the concentric circle method (Applequist 1958), and we estimated the number of years required for a tree to grow to coring height of 35 cm based on aging destructively sampled small trees on good and poor sites (Kaufmann and others 2000a; Mast and others 1998). Growth times to 35 cm ranged from 5 years for ponderosa pines on good sites to 18 years for Douglas-fir on poor sites.

Our fire history was constructed from fire-scarred living trees and remnant material sampled at sites subjectively located across the Cheesman lake landscape, and is reported in Brown and others (1999). Fire scars were sampled by cutting a cross-section or partial cross-section through the fire-scarred face of a tree, snag, or log with a chainsaw. Sections were surfaced and cross-dated using the chronology developed for Cheesman Lake.

Old Growth and Fire History

Historical Fire Regime

We believe that individual historical fire events at Cheesman Lake burned with variable intensity. Under less extreme conditions, surface fires consumed grassy fuels and scarred but did not kill mature trees. Buried fire scars on some samples are evidence of fires light enough to scar but not kill trees 2–5 cm in diameter. Where fuels were heavy or in high winds, fires could be intense enough to kill all of the trees in an area. Stands on south- and west-facing slopes may have been so sparsely forested that fires killed trees only under extreme conditions. Modeling with FARSITE indicates that considerable wind is required to advance a fire in this environment even after decades of fire suppression, and is particularly necessary for crown fire (unpublished data; see Kaufmann and others, this proceedings). Fuel buildups from a series of wet years followed by dry weather probably also contributed to large, intense fires (Veblen and others 2000).

Seasonality of scars from the more widespread fires encompasses the entire growing season (mid-June to early September) and the dormant season, which could be either fall or spring, both usually dry periods (Brown and others 1999). Historically, fires that started early in the season may have burned across the landscape throughout the summer until snowfall put them out. Lightning is very common from April through September and per year ignites 10 to 12 fires, which are presently suppressed (Bill Newberry, Denver Water, personal communication). The Native American influence on historical ignitions is unknown.

The mean fire interval (MFI) at Cheesman Lake depends on the scale at which it is observed. The length of fire-free interval is inversely proportional to the size of area over which the intervals are assessed; larger areas have shorter intervals. Any given location on the Cheesman landscape might historically have gone as much as 128 years between fires. For the full period of analysis (1285 to 1963 A.D.) over the entire landscape, the MFI was 9.2 years ±7 years (Brown and others 1999). However, this includes fires of all intensities and many localized fires. When the fire scar sample area was divided into smaller areas of 0.5 to 2 km^2, the MFI for all individual areas between 1496 A.D. to 1880 A.D. was 50.0 years, ±17.2 years (Kaufmann and others, this proceedings). When we consider only the larger scale fires that burned more than 5 km^2, based on the distribution of fire scars, the MFI between 1496 and 1880 was 42.7 years, ±12.7 years, with a range of 27 to 65 years between fires (Kaufmann and others, this proceedings). Large-scale fires tended to alternate across the landscape; for example, the northern area that burned in 1696 did not burn in 1723. However, many areas that had burned in 1723 also burned in 1851, but not in 1820. Only the fire in 1631 scarred trees at every sampling location.

Figure 2 shows generalized minimum extents of the widespread fires based on locations where fire scars from that year were collected (Brown and others 1999). Many other fire years were recorded as far back as 1197 A.D., but sample depth declines dramatically before 1500 A.D. Note that fire scar sampling did not extend beyond the area mapped for the 1631 fire and was generally confined to

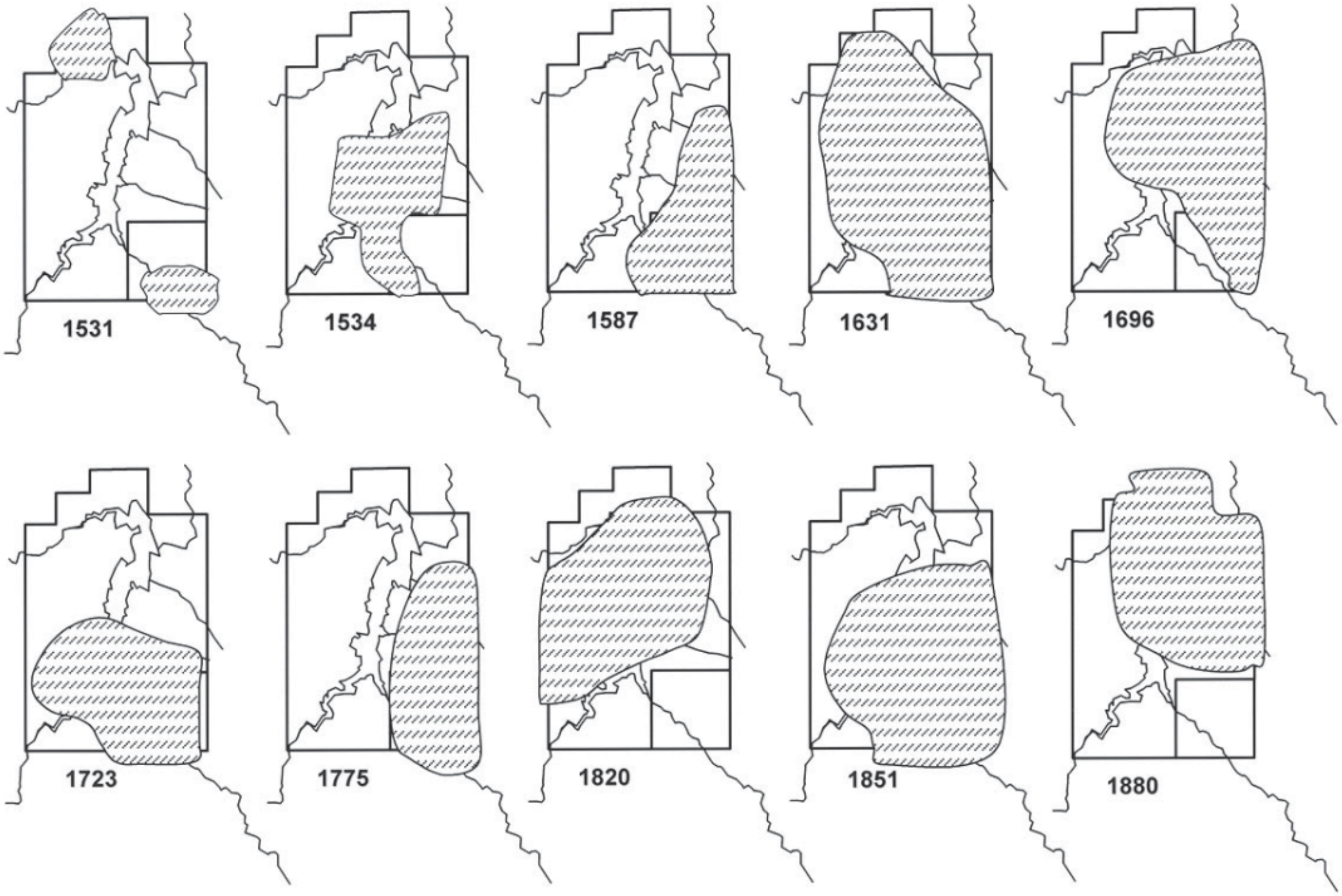

Figure 2—Generalized extents of large fires with stand-replacing components, based on the locations of trees sampled for the fire history. Compare these with polygons postdating these fires in figure 5. Because fire scar sampling was confined to the Cheesman property, the actual areas of the fires may be larger than shown. (Maps are developed from Brown and others 1999.)

the Cheesman property, except for an area southeast of the Cheesman boundary, so actual fire areas were probably larger than those shown. The Cheesman Lake landscape seems to encompass the total area of some historical fires and not of others. The South Platte River does not seem to have been a significant firebreak, as fires predating the reservoir were recorded on both sides of the river. Historical photos and predam survey maps (courtesy of Denver Water archives) show that the valley where Cheesman Lake currently lies was fairly flat and grassy, so fire probably spread rapidly across it. Suppression of spreading fires outside of the property may have had as much effect on the decline in fire frequency in the 20th century as suppression within the property.

Age Distribution and Old Growth

Old growth is a complex ecological concept, based not only on the ages of the oldest trees, but also on stand structural and functional characteristics (Kaufmann and others 1992; Moir 1992). Old-growth stands contribute to biodiversity by providing habitat for wildlife and late successional plant species. Ponderosa pine stands begin to take on old-growth characteristics around 200 years of age. Old stands tend to have more snags and coarse woody debris, large trees for the site conditions, old trees, and a variety of trees of younger ages. Such stands evolved under presettlement disturbance regimes. Even in relatively undisturbed places such as Cheesman Lake, fire suppression has changed the structure of old stands by allowing ingrowth of young trees, especially Douglas-fir. Where logging has occurred, the distribution and prevalence of old-growth stands in presettlement times is difficult to determine (Mast and others 1999; Regan 1997).

Our data indicate that old stands were common and widely distributed in unlogged montane forests around Cheesman Lake. Figure 3 shows the locations of our sampled polygons classified into age categories based on the age of the oldest tree collected. At Cheesman Lake, where the historical age structure persists, 70 percent of the sampled polygons had trees 200 years old or older; 30 percent of sampled polygons had trees more than 400 years of age. In 30 percent of polygons, all trees sampled were less than 200 years old, indicating more recent stand-replacing disturbance in a

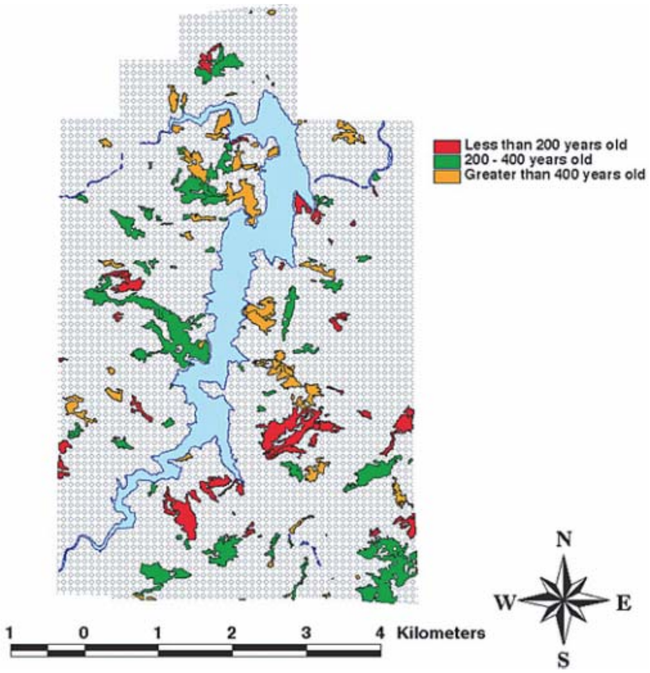

Figure 3—Distribution of old growth among sampled stands, based on the age of the oldest tree cored in the polygon. Thirty percent of sampled stands had all trees younger than 200 years; 40 percent had the oldest trees between 200 and 400 years old, and 30 percent had the oldest trees older than 400 years.

third of the sampled landscape. These younger stands were concentrated in the southeast part of the property where the 1851 fire burned. The oldest stands were concentrated in the northwest quadrant of the property, though stands with old trees were fairly evenly distributed over the landscape.

Though old trees were widespread among our samples, very old trees were relatively uncommon, reflecting the fact that many stands have a few old trees surrounded by trees of younger cohorts. Only 10 percent of the sampled trees were more than 400 years old; 40 percent of trees were 200–400 years old. Trees less than 200 years old constituted 50 percent of the trees sampled as the oldest in the stands. Douglas-fir has always been a component of the landscape, though it is probably more abundant and widespread now than in the past. Of 1,279 cores sampled and dated from the Cheesman Lake landscape, 86 percent (1,108) were ponderosa pine and 13 percent (171) were Douglas-fir. The estimated germination year of the oldest living ponderosa pine collected was 1395 A.D. The estimated germination year of the oldest Douglas-fir collected was 1459 A.D. The oldest trees in most polygons were ponderosa pines, but 25 polygons out of 224 had a Douglas-fir as the oldest tree.

The oldest trees in most stands appear to have an upper age limit postdating a documented fire in the area. These stands with an age cap are the most common stand structure in the landscape (Kaufmann and others, this proceedings). However, some stands seemed to have no identifiable initiating event. The ages of sampled trees in these stands were continuous over a long time, with no concentrations of ages (for example, truly uneven-aged). Some were more than 600 years old. We call these stands persistent old growth (Kaufmann and others, this proceedings; fig. 4). Such stands apparently have not experienced a stand-replacing event in the lifetimes of the trees. Their structure seems to be regulated by microsite events such as heartrot, windthrow, individual tree insect infestation, or mistletoe. Fire scars are usually present in these stands, indicating periodic surface fire, but age distributions do not suggest a stand-initiating event that coincides with any recorded fire in the area. Such stands constituted 16 percent of sampled polygons. Persistent old growth occurs in all parts of the landscape, but is concentrated in the northwestern quadrant. Some stands classified as persistent old growth may in fact postdate early fires for which no scar record exists. Further analysis is required to determine what factors allow the persistence of such stands.

Figure 4—Persistent old growth. These stands have very old trees with no evidence of a stand-initiating event. They are characterized by a continuum of tree ages, including trees more than 400 years of age, old trees dying from microscale disturbances such as mistletoe infestation, windthrow, or lightning strike, and coarse woody debris on the ground. Fire scars are sometimes present, indicating that surface fires have burned in the stands without killing all of the trees.

Age Structure and Fire Regime

Determining the ages of the oldest trees in a stand and comparing them to known fire dates in the area gives us some idea of where stand-replacing fire burned in individual fire years. Age structure has been used to approximate the dates of stand-replacing fires elsewhere (Mast and others 1999; Arno and others 1995; Goldblum and Veblen 1992; Duncan and Stewart 1991). Concentrations of trees that postdate known fires suggest the forest in that location burned in a stand-replacing fire. In an attempt to determine the locations of stand-replacing components of known fires, we compared the estimated germination dates of the oldest trees sampled in the polygons with the dates of fire scar records in the vicinity. Of 21 fires recorded over the entire landscape from 1531 to 1880, 16 appeared to have a crown fire component detectable in the age structure of sampled trees. Seventy-one percent of sampled polygons clearly postdated one of seven major fire events over the last 470 years (1531, 1534, 1587, 1631, 1723, 1851, 1880), suggesting that those events had a significant stand-replacing component (fig. 5).

This approach has limitations that become more restrictive to interpretation the further back in time we go. We can only assess the residual polygons, in other words, those that have survived subsequent fires. For example, a polygon in which the forest appears to postdate the 1851 fire might also have burned as a stand-replacing fire in 1631, but evidence of the stand that initiated after 1631 has been destroyed by more recent stand-replacing fire. Therefore, figure 5 is a conservative estimate of the number of polygons that postdate known historical fires. Only polygons burned in 1851 and 1880 have not been burned over by subsequent fires. Similarly, evidence of surface fire in the form of scarred trees may have been obliterated by subsequent disturbances, so the mapped extents of the fires based on scars is also conservative. It is also certain that the mosaic of forest stands of different age and size structure (which we mapped as polygons) has shifted over time as the result of disturbances. The polygon map of 1630 probably would have looked very different from the one of today.

Locations of sampled polygons that appear to postdate known stand-initiating fires are shown in figure 6. The earliest scar-recorded fire that clearly predated some sampled stands was in 1531 A.D. (figs. 2 and 6). This fire burned in both the far northern and southern parts of the Cheesman Lake landscape. Evidence of this fire in the central portion of the landscape may have been obliterated by subsequent fires. Nine sampled polygons located within the fire boundary (as defined by the locations of fire-scarred samples) postdated this fire, yet initiated before the next known fire in the area. A fire in 1534 A.D. burned the central and south-central two-thirds of the Cheesman Lake landscape. The oldest trees in 22 polygons postdated this fire (fig. 5). A fire in 1587 burned the southeastern part of the Cheesman Lake landscape. Ten polygons clearly postdated this fire.

The fire in 1631 was recorded by scars at all of the sampling locations throughout the landscape, and 36 polygons appear to postdate this fire, mostly in the central and northern part of the landscape (figs. 5 and 6). Scars from a fire in 1696 were widespread over the northern and central

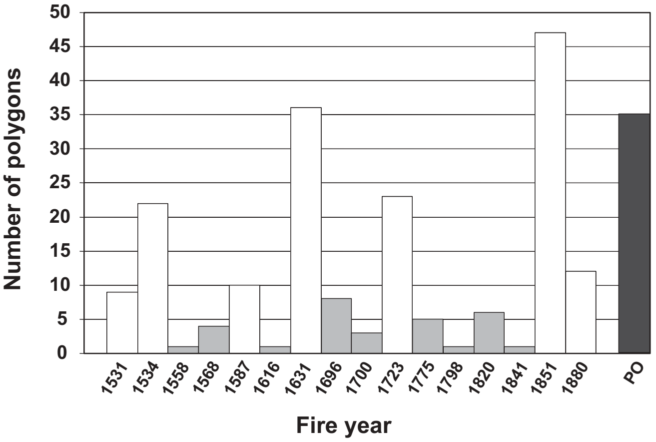

Figure 5—The number of sampled polygons where the oldest tree postdated a known fire in the area, by fire year. Seventy-one percent of sampled polygons clearly postdated one of seven major fires over the last 470 years (1531, 1534, 1587, 1631, 1723, 1851, 1880), indicating that those events had a significant stand-replacing component. A total of 21 fires were recorded by fire scars during that period, of which 16 seem to have had some crown fire component. Fifteen percent of the polygons sampled were classified as persistent old growth, with no clear stand-initiating event evident in the ages of the oldest trees.

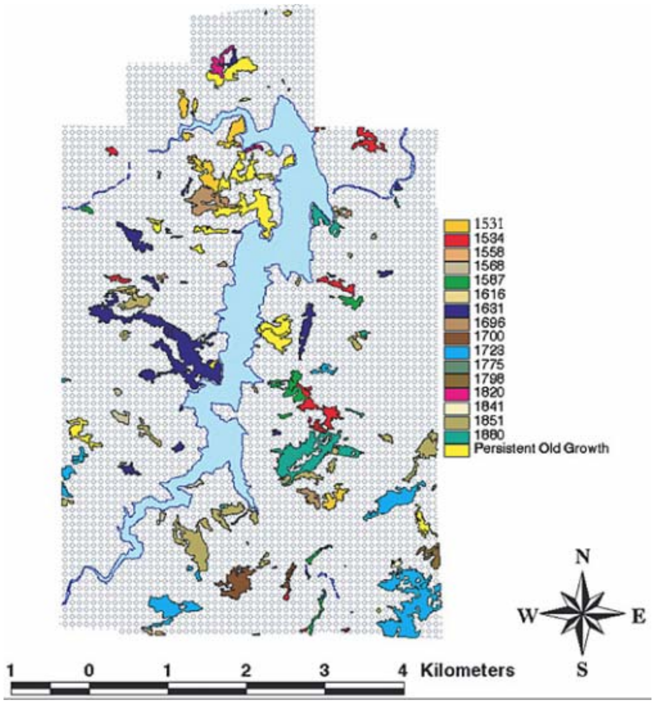

Figure 6—We mapped the distribution of apparent stand-replacing fire events in the sampled polygons. This map shows the recorded fire that probably predated the oldest trees in each sampled polygon. Stands that did not appear to have a clear initiating event are labeled *persistent old growth*.

part of the landscape, but relatively few stands (except for some on the northwest side of the river) postdate this fire. The fire in 1631 may have left large areas unsusceptible to stand-replacing fire 1696. A fire in 1723 burned the southern half of the landscape, on both sides of the river. Much of the evidence of stand initiation after this fire may have been obliterated by the fire in 1851, which burned much of the same area. A fire in 1775 scarred widely distributed trees on the east side of the river, but apparently had only a small stand-replacing component. Similarly, a fire on the north half of the landscape in 1820 scarred widespread trees but initiated few stands. These may have been less intense surface fires in the very open landscape left in the wake of fires in 1631 and 1723. This was also a fairly cool and wet period (P. Brown, personal communication).

Fire-created openings persisted for variable lengths of time, depending on when conditions favored tree establishment in subsequent years (Kaufmann and others 2000a), and whether the location experienced another disturbance before the trees were large enough to survive it. Tobler (2000) sampled vegetation in openings at Cheesman Lake and found coarse woody debris in all but one of them, indicating that they had been forested in the past. Death dates on the down logs indicate that the openings were created by a fire in 1851, and remained unforested 149 years later. Fire scars found nearby suggest that the northern part of the area may have burned again in 1880, slowing tree regeneration.

When we compared the ages of the oldest trees sampled in the polygons with the dates of nearby fire scars, we saw highly variable intervals between fire and tree establishment. Time to regeneration in sampled polygons ranged between 0 and 95 years, but generally occurred within 15 to 30 years, with an overall average of 18 years (table 1). Tree ages collected in other plots in the southeast part of the property were also compared to fire scar dates in the vicinity. Some of them appear to have regenerated immediately, while others seem to have remained unforested for as many as 107 years (Kaufmann and others 2000b). We believe this phenomenon is due to climate and episodic periods of regeneration (Kaufmann and others 2000a). If a fire occurred at the beginning of a period favorable for tree establishment, even south-facing slopes could regenerate quickly, but if the fire occurred at the end of such a period, regeneration would be limited until the next favorable period.

Table 1—Years to tree regeneration following historical stand-replacing fires.

Stand-replacing fire year	Mean years to regeneration	Standard deviation
1531	32.9	21.4
1534	25.6	18.7
1558	16.0	0
1568	16.8	14.7
1587	18.3	10.7
1616	11.0	0
1631	32.5	17.4
1696	24.6	27.3
1700	14.7	8.5
1723	20.4	17.6
1775	25.6	20.8
1798	20.5	2.5
1820	6.2	20.6
1841	0	0
1851	13.6	11.6
1880	10.1	7.3
Average time between fire and regeneration (all stand-replacing years) range: 0 to 33	18.0	9.3

The mean regeneration period after the seven major fires with stand-replacing components was 22 years. Regeneration was slower in the northwest quadrant of the landscape, where the oldest stands were concentrated. Time to regeneration there averaged 30 years after a fire, with a range of 0 to 93 years, while the southeast quadrant averaged only 12 years to tree regeneration, with a range of 0 to 57 years. Interpretation of these data is complicated by how long ago some of the recruitment occurred. Establishment time for both species was highly variable, but where Douglas-fir was among the oldest trees, it established more quickly on average, within 15 years, while ponderosa pine averaged 21 years to establish following fire. However, Douglas-fir was more often found on north- and east-facing slopes where establishment conditions were probably better.

The fire in 1851 burned the southern two-thirds of the landscape. Openings created by this fire still persist on south- and west-facing slopes (fig. 7). Vegetation in these openings is mainly bunchgrass, or bunchgrass and shrubs, primarily mountain mahogany (*Cerocarpus montanus*) and wax currant (*Ribes cereum*). Trees began to invade these openings between 1880 and 1920. The northern part of

Figure 7—These openings were created by the 1851 fire, based on death dates from the coarse woody debris that is scattered throughout. Vegetation in openings may be grassy or a combination of grass and shrubs, primarily *Cerocarpus montanus* and *Ribes cereum*. Parts of these openings also may have burned in the 1880 fire.

these openings may have burned again in 1880, as scars from this fire spatially overlap the ones from 1851. Areas adjacent to the present openings also appear to have burned in stand-replacing fires in 1851, but have now regenerated to young forest on north- and east-facing slopes. Shrubs common in the openings persist in the understories.

Fire, Old Growth, and Restoration Efforts

Our data suggest that old trees and old stands were historically common in the montane zone of the Colorado Front Range. The presettlement fire regime was spatially and temporally a mixture of surface fire and stand-replacing fire, which maintained open stands interspersed with areas that remained treeless for decades at a time. Logging, grazing, and fire suppression have altered this condition in much of the Front Range, creating a forest that is younger, denser, and more continuous than the presettlement norm and converting fire behavior from a mixed severity fire regime to a crown fire regime. Recent rapid growth of the human population has created an extensive urban-wildland interface in the Front Range that is at risk from wildfire, and water sources are also in danger from postfire erosion (Culver and others, this proceedings).

Restoring the landscape to an ecologically sustainable condition by recreating a more historical forest structure may mitigate the risk of intense, large-scale wildfires and subsequent erosion (Kaufmann and others 2000b). Restoration efforts should consider the role and distribution of old growth on the landscape, and its relationship to disturbance regime. It is important to conserve the old trees that still exist on the landscape and to select trees for retention that will grow into an old-growth condition in a reasonable amount of time (Mast and others 1999; Fulé and others 1997; Kaufmann and others 1994). It is also important to restore a disturbance regime that allows the old trees to persist, for example, periodic surface fire that removes ingrowth without killing the old trees. Mechanical thinning may be required to allow for prescribed fires of appropriate intensities, especially in areas with considerable young ingrowth. However, restoring an ecologically sustainable landscape with a historical structure requires creation and maintenance of unforested openings, so treatments including both thinning and prescribed fires must be locally intense enough to replace some stands at longer intervals.

Front Range forests are not as productive, in terms of trees or understory, as those in the Southwest, and their historical fire regime was less frequent and more variable in intensity, so the Southwestern model cannot be correctly applied here (Veblen and others 2000; Brown and Sieg 1996; Swetnam and Baisan 1996; Goldblum and Veblen 1992). Because fire and tree regeneration historically occurred at long, often coincident intervals, the timing of restoration efforts may be important for successful maintenance of openings.

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